Advanced Simulation Model of Shipyard Production Logistics to Optimize Material Flow and Energy Efficiency

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Advanced Simulation Model of Shipyard Production Logistics to Optimize Material Flow and Energy Efficiency

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
AGVs	Automated Guided Vehicles
AHP	Analytic Hierarchy Process
DES	Discrete Event Simulation
DMAIC	Define, Measure, Analyse, Improve, and Control
dMFA	Dynamic Material Flow Analysis
GSCM	Green Supply Chain Management
JIT	Just-In-Time
MILP	Mixed Integer Linear Programming
MRP	Material Requirements Planning
NVA	Non-Value-Added
PDCA	Plan-Do-Check-Act
ROI	Return on Investment
SLP	Systematic Layout Planning
SM	Simulation Modelling
SOAPS	Simulation Optimization Applied to Production Scheduling
SPC	Statistical Process Control
SPMTs	Self-Propelled Modular Transporters
STS	Simulation Toolkit Shipbuilding
SST	Ship Section Transporter
TOC	Theory of Constraints
TSM	Tailored Simulation Model
VSM	Value Stream Mapping
WIP	Work-In-Progress

ABSTRACT

In this era of industrial digitalization, the shipbuilding industry is adopting digital manufacturing and production planning systems. At shipyards, there is a significant potential to utilize modern tools for simulating production processes to enhance productivity and reduce energy consumption. The primary challenge is to simulate the material flow using modern production simulation tools to perform the testing of realistic operational scenarios for optimizing the material flow for higher productivity, energy-efficient operations, and accurate resource allocation in complex shipbuilding processes. The ongoing research is focused on production planning and transport management for existing shipyards, but there is a necessity to provide simulation-based decision support for engineers that would help in enhancing operational productivity without compromising environmental sustainability. In this thesis, the SimPlan initial simulation model is enhanced into an advanced simulation model using SIEMENS Plant Simulation Software. For this, the initial model of SimPlan's fictional shipyard was evaluated to identify layout inefficiencies for improved systematic layout. Based on the operational requirements, the production logistics were planned in a simulation model. Later, the Eco-Meter was integrated for energy consumption measurements that were analysed by STS Eco-Monitor Tool. Practically, it is difficult to maintain a balance between economically efficient and environmentally sustainable material flow processes. The economic efficiency focuses on minimizing operational costs and maximizing productivity, while the environmental sustainability emphasizes on minimizing energy consumption. So, this thesis provides a novel solution by proposing a methodology for a techno-ecological optimization process for production logistics in shipyards. This advanced simulation model provides a methodology for engineers and managers to perform a multi-objective optimization to optimize the material flow for energy-efficient production logistics in a real shipyard by simulating the dynamic material flow for efficient transporter scheduling, energy monitoring, and accurate resource allocation. The advanced simulation model was tested based on empirical and fictional input values to validate its accurate working by calculating the transportation distance, travel time, energy consumption, estimating operational cost, and estimating CO_2 emissions caused by production logistics. By using the real input data from an existing real shipyard, it would enhance the ability of engineers to understand and evaluate the interdependencies between material transport, energy efficiency, and production scheduling. So, this thesis provides a fundamental and strong foundation for industrial digitalization in shipbuilding, such as predictive optimization in digital twin technology, with a promising future potential to achieve sustainable operational excellence in shipyards.

1. INTRODUCTION

Shipbuilding is a complex manufacturing process to produce a complex product because a ship consists of many components, assemblies, and large structures. It involves complex coordination between material flow, production processes, production logistics, and production planning. It requires efficient planning of large-scale industrial operations with multiple interdependent processes, such as material supply, manufacturing process, material storage at respective production stations, and transportation of semi-finished material to the next production station. The delays and process inefficiencies during the production process led to bottlenecks in terms of material flow, which reduces overall productivity. A digital shipyard layout is required to resolve these complex challenges by eliminating these bottlenecks through simulating production workflows, manufacturing processes, and shipyard production logistics. So, the simulation model would be used to enhance the productivity of production processes at shipyards through performance metrics to evaluate the practical scenarios for efficient material flow in a real shipyard. In Germany, SimPlan AG has been contributing to simulation-based solutions for complex problems regarding efficient and sustainable production planning in shipbuilding using SIEMENS Plant Simulation Software. For this, SimPlan AG provided an initial model of a fictional shipyard. This initial fictional shipyard was modelled for a fictional production data of a ship provided by SIEMENS. The Simulation Toolkit Shipbuilding (STS) library was used to model this fictional shipyard in SIEMENS Plant Simulation Software. In this thesis, the primary objective is to upgrade the fictional shipyard based on operational requirements and provide a methodology to optimize production logistics for energy-efficient material flow in a real shipyard. So, a detailed methodology is proposed for engineers and managers to perform the techno-ecological optimization using this simulation model as a simulation-based decision support. In this study, the shipyard production logistics are analysed in terms of the operational dependencies to ensure the just-in-time (JIT) material delivery and minimize the delays in the shipyards. In terms of environmentally sustainable shipyard logistic operations, the simulation model is integrated with the eco-meter and eco-monitor. The eco-meter is used to calculate electric energy consumption. While eco-monitor is used to analyse electric energy consumption for cost estimation of electric energy and CO_2 emissions caused by each transporter. The performance metrics are proposed to implement the optimization strategies for the production logistics in shipbuilding using this simulation model. The future developments are described as the potential of this study for predictive optimization, advanced energy modelling, and return on investment (ROI) analysis of shipyards' digital twins using artificial intelligence and virtual reality.

1.1. Research Process

The following steps are followed during the research process to complete this master's thesis:

1. Detailed literature review
2. Identify the research gap
3. Develop the research problem
4. Formulate a problem statement
5. Extensive training on the SIEMENS Plant Simulation Model
6. Investigate the shipyard layout for development gaps for efficient material flow
7. Modelling the Shipyard Simulation to address development gaps
8. Integrate Eco-Monitor for energy calculations
9. Collect data from the simulated model
10. Interpret the collected data to validate the utilization of the fictional shipyard simulation model in a real shipyard
11. Prepare the report for the master's thesis

Based on these steps, the chapters of this report for the master's thesis are outlined in the next section of this chapter. The Gantt chart is shown appendix (Figure **63**).

1.2. Thesis Chapter

In the chapter *Introduction*, the background of the problem is explained, including all key objectives and outcomes. The chapter *Literature Review* includes a detailed study of production processes, logistics, simulation models, optimization processes in shipyards, and the research gap in this field. In the chapter Problem Statement, the key objectives are defined based on research gaps. The chapter *Methodology* covers the explanation of the initial simulation model of the fictional shipyard to evaluate it for modelling gaps. Then, a detailed explanation is provided for the steps to upgrade it based on identified modelling gaps for achieving operational requirements. Later, the method is explained to integrate the Eco-Monitor with the Advanced Simulation Model. In the end, the optimization steps are described for efficient material flow and an energy-efficient process. In the chapters *Results* and *Discussions*, the key results from the simulation model are discussed data for its utilization to solve complex engineering problems in shipbuilding. In the chapter *Future Developments*, the remaining gaps in terms of effective utilization of this advanced simulation model are explained. The chapter *Conclusion* presents the concluding remarks of this master's thesis.

2. LITERATURE REVIEW

In this chapter, a comprehensive review of existing literature is presented regarding the production processes at shipyards, methods to achieve the energy-efficient material flow, and simulation models in shipbuilding.

2.1. Shipyard Production Processes

Shipbuilding is a complex production process as it contains complicated production operations, long-term projects, and higher capital costs. Efficient coordination is mandatory between all sub-production systems for productive outcomes. In shipyards, the basic production process from raw material reception to delivery of the ship is explained in the following flowchart, as shown in the figure (Figure **1**) below:

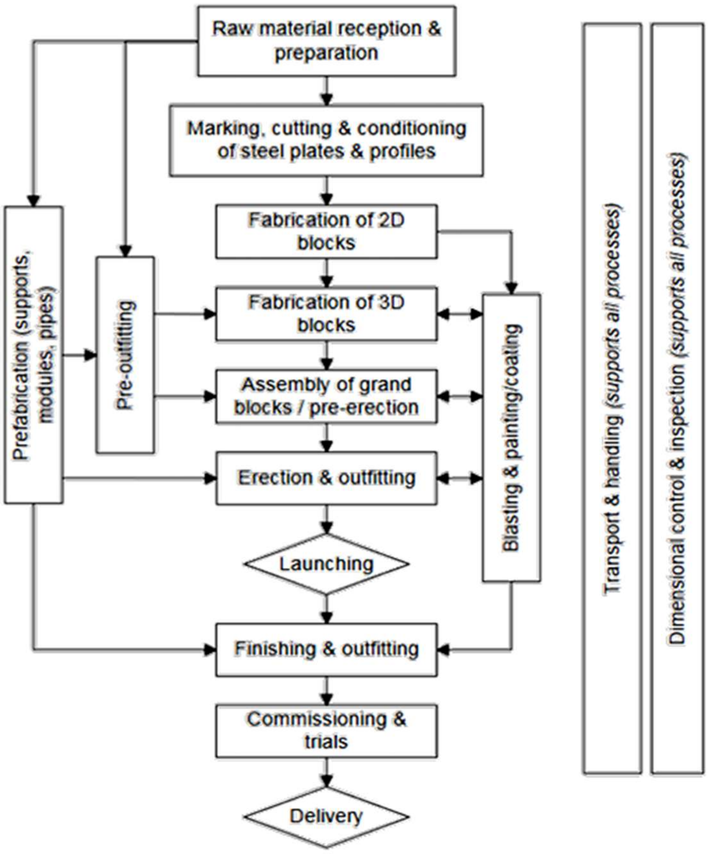
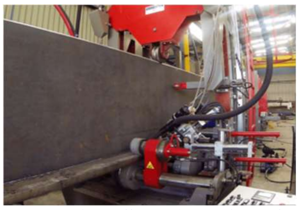


Figure 1. Basic Production Process in Shipbuilding (Florian Sprenger, URO Lectures 2024)

The production processes are based on different manufacturing processes, which are planned for higher production efficiency, waste reduction, and compliance with regulations for lower environmental pollution. The table (Table **1**) shows shipbuilding processes in production sequence and mentions challenges that impact efficiency, productivity, and production quality.

Table 1. Production Process in Shipbuilding - Detailed Review

Sr. No.	Process	Description	Materials	Challenges	Application
1	Plate Fabrication	Shaping	Raw steel plates	Material waste and manual methods (Yushak, Boustead et al. 2018)	 Source: https://schleifstein.de/
2	Profile Fabrication	Welding	Beams, angles, and bars into frames or bulkheads	Lack of standardized practices (Wahidi, Oterkus et al. 2024)	 Source: https://www.inrotech.com/
3	Sub-assembly Production	Cutting and welding	Plates into stiffeners and profiles	Limited automation (Bock, Linner et al. 2011)	 Source: https://www.hazegray.org/
4	Girder Production	Welding	Longitudinal and cross-deck girders	Structural alignment during assembly (Mun, Nam et al. 2015)	 Source: https://www.inrotech.com/
5	Section Production	Welding	Panels, girders, and profiles into 3D sections	Complex interdependencies between components (Kocak 2024)	 Source: https://www.inrotech.com/
6	Block Assembly	Welding	Sections into large blocks	Limited crane capacity and complex interdependencies (Seo, Sheen et al. 2007)	 Source: https://rndv.eu/
7	Painting Process	Coating	Coating of ship components	High energy consumption and Hazardous materials (Purnama Sari, Ilasabilirrosyad et al. 2023)	 Source: https://ulstein.com/

8	Outfitting after Coating	Equipement Installation	HVAC, electrical systems, and machinery	Coordination delays, design changes rising demand for rework (Liu, Cao et al. 2024)	 Source: https://www.marineinsight.com/
9	Hull Erection	Lifting and Welding	Positioning and Welding of Blocks	Safety risks and alignment errors (Yongquan, Xu et al. 2011)	 Source: https://shippingwatch.com/
10	Repair and Maintenance	Inspections	Coating all ship components	High costs, lack of implementation of predictive technologies (Dharmavaram 2025)	 Source: https://www.cowaymarine.com/
11	Final Outfitting & Ship Lift	Interior finishing and lifting	Finishing and launching for sea trials	Higher cost for meeting the quality requirement (Rubesa, Hadjina et al. 2022)	 Source: https://www.imarinenews.com/

The complexity of these production processes introduces the challenges in the shipbuilding process, driving the researchers to solve these complex problems to meet the requirements of the modern market in terms of efficient and sustainable shipbuilding. Here, the production logistics plays an important role in ensuring the efficient material flow, lower energy consumption, and reducing production cost and emissions caused by the production logistics.

2.2. Material Flow in Shipyards

In shipbuilding, scheduling and production planning are important mechanisms to manage the complex shipbuilding processes. The production planning strategies, such as Lean Six Sigma, are used to identify material delay, idle stations, and free workers at the shipyards. This helps in designing the production workflows in a shipyard to eliminate process delays. The optimization models in shipbuilding use multiple constraints to optimize the production planning to ensure that an efficient production plan is achieved according to the real-world working conditions (Hong, Zhang et al. 2023). The management of production planning and scheduling is important to develop an efficient shipyard simulation model. The main requirement of this coordination is the difficulty in the execution of planned production strategies because the production plans may be affected by sudden changes in the schedule. So, the simulation model must provide the opportunity to implement the real-time decision-making frameworks to facilitate these sudden changes in actual shipbuilding processes (Cai, Kutanoglu et al. 2011).

There are Customized Simulation Models, such as the Tailored Simulation Model (TSM), which is used to develop the environment for shipyards to ensure accurate resource allocation for improved production planning in shipbuilding (Kim, Lee et al. 2005). The TSM is based on constraints such as availability of material flow, machinery, workforce skills, and shipyard layouts. In this way, TSM simulates various production scenarios, which helps in identifying the delays and then integrating these delays with the production planning to reduce the downtime and improve the resource allocation at the shipyard. After simulating the production process in a shipyard, these models can be used to locate the critical bottlenecks in streamlining the production workflows, which improves the productivity of the simulation model and efficiency in terms of resource allocations (Hovanec, Korba et al. 2023). For dynamic production planning in a shipyard, genetic algorithms may also integrate with the production simulation through the adaptive-feedback processes and hierarchical data structures. This provides efficient handling of complex production tasks to ensure productive scheduling in case of fluctuating production demands (Niemeyer and Shiroma 1996). In this way, these simulation models are used to model the material flow sufficiently so that they should involve logistical constraints for efficient and accurate production simulations (Krenczyk, Kempa et al. 2017). In case of material flow optimization, the production efficiency can be enhanced by using an accurate allocation of resources and reducing waste through the following strategies:

1. **Integration of Sustainable Modern Tools:** This strategy is considered an emerging tool for optimization of material flow in traditional shipyards, which ensures continuous improvement in production plans by regular monitoring. It also helps in evaluating the production plans based on economic and environmental parameters (Fitriadi and Ahmad Faisal Mohamad 2024). In this way, the unwanted movement of material is avoided to increase the productivity of production processes by reducing waste through accurate inventory management.

2. **Utilization of Expert Approaches:** The Expert Approaches include different methods such as Systematic Planning for Layout (SLP) and Analytic Hierarchical Process (AHP). SLP is used to analyse the material flow, activity relationships, and process requirements. This helps to design efficient facility layouts and production plans by arranging the equipment, workstations, and storage areas in a systematic order. In this way, SLP ensures optimized movement of material and reduction in bottlenecks to enhance the workflow at a production facility. While AHP is utilized as a decision-making tool based on multi-criteria such as cost, safety, and efficiency. These criteria are used to prioritize in a hierarchical order to evaluate alternative factory layouts for higher productivity (Matulja 2016).

3. **Green Production:** This type of method focuses on the ecological factors in the production process and their integration with the principles of sustainable production to optimize the energy-efficient material flow. For example, PT XYZ, an Indonesian Shipyard which has experimented with this Green Manufacturing Method to reduce the idle time during the production process and minimize the waste of inventory in the fabrication workshop (Agustin 2024).

According to the literature, (**Table 2**) shows the key methods for production logistics management in shipyards based on maximum transporter utilization:

Table 2. Key Methods of Material Flow Management in Shipyards

Methods	Application for Production Logistics Management
Flat Transporter Utilization	It is utilized based on the loading constraints and the shape of the ship component. It is feasible for ship components with a flat bottom, such as flat sections and blocks (Liu, Yin et al. 2022).
Energy-Logistics Integration	This method reduces the production costs by 3.27% through planning the production logistics based on eco-friendly approaches instead of the traditional planning methods (Mo, Zhang et al. 2024).
Green Vehicle Scheduling	It minimizes the transport time and energy consumption, which leads to reduced carbon emissions for logistic vehicles (Guo, Wang et al. 2024).
Real-Time Path Planning	It reduces transportation distance for transporters and congestion during material transportation between production stations (Wang, Wang et al. 2020).

2.3. Energy Efficient Processes in Shipyards

Due to global warming, the shipbuilding industries need to reduce their carbon footprints during production operations at shipyards for productive and efficient production operations. So, at shipyards, the energy efficient optimization can be done by implementing the following sustainable practices to reduce emissions as below:

1. **Green Vehicle Routing and Scheduling:** In this method, the routes of transporting vehicles and their schedules are optimized based on monitoring the energy consumption and reducing the carbon emissions during material flow. These models are implemented by the Mixed Integer Linear Programming (MILP) to simulate the simultaneous crane operations to lift the blocks, performing the parallel deliveries within the time constraints (Guo, Wang et al. 2024). MILP is a mathematical-based model which is used to combine the linear constraints (energy consumption and time) with integer variables (transporter's routes, crane movements for lifting ship blocks). In this way, this strategy covers efficient resource allocation integrated with different factors like the self-loading constraints, environmental impact, and time windows.

1. **Green Supply Chain Management:** This method is used to enhance the sustainability performance of shipyards through implementing the green supply chain management (GSCM) in shipbuilding. The GSCM practices are integrated with shipyard operations so that the material flow is optimized in terms of energy consumption, eliminating the carbon footprint in the shipbuilding (Vakili, Schönborn et al. 2023). In this approach, different shipbuilding steps are addressed, such as green ship design, green procurement, green material supply, and green production plans in the shipbuilding. (Tantan and Akdağ 2023).

2. **Low-Carbon Technologies:** In this method, the fundamental objective is to select and implement a suitable technological method for lower emissions (CO_2). This is practiced at the South Chinese shipyard, where a set of eleven key lower-emission (CO_2) technological methods was implemented for the improved material flow and production processes, which concludes that the main affecting factor in low-carbon technologies is the dynamically changing grid, which leads to emissions. It states that there is a need to assess long-term impacts of grid emission factors, ensuring the carbon peak is achievable in 2026 with low-carbon technologies (Liu, Liao et al. 2024).

2.4. Simulation Based Decision Methods in Shipyards

2.4.1. Basics of Simulation Model

The simulation is a tool that is used to imitate the real-world operations, processes, and systems over a time duration. The simulation models provide a visualization of different behaviours of the simulated system under realistic conditions. In the case of shipbuilding, the simulation models need to simulate the complex processes to provide a virtual environment for the evaluation of these complex processes. It includes the key aspects such as the development of a simulation model, performing analysis based on real scenarios, and validation of outcomes by the simulation model according to the real world (Sokolov and Antonova 2024). The model development consists of digital layout development of the shipyard based on discrete elements. The discrete elements include production stations, production logistics, and material storage spaces. The developed model was used to analyse the simulated shipbuilding processes for evaluating the production performance and identifying bottlenecks. So, measures can be taken to solve these complex challenges. It is not possible to make fast and large changes in the real shipyard layout and physical complex production processes, as it requires a large-scale, capital-intensive process. In this way, the simulation model is used as a risk-free and cost-effective tool to evaluate the production processes without any risk of productivity losses (Varga, Mariasiu et al. 2015). To validate the simulated process, it is necessary to model the simulation based on realistic operational requirements. So, it ensures the utilization of simulation results in real shipbuilding production processes.

2.4.2. Discrete Event Simulation

The Discrete Event Simulation (DES) Models are used to simulate the complex shipbuilding operations in terms of a discrete sequence of events to perform a detailed analysis of the production process for efficient scheduling and resource allocation (Caprace, Freire et al. 2011). In this way, DES Models are used to replace the traditional and manual techniques to eliminate operational inefficiencies through enhanced scheduling and accurate resource allocation at shipyards (Caprace, Freire et al. 2011). Using DES Models, it is possible to attain significant productivity through efficient production planning in shipbuilding (Wang, Mao et al. 2015). The DES Models are used to simulate cutting and welding processes at shipyards to improve the throughput and minimize the operational costs (Rouco-Couzo, Crespo-Pereira et al. 2016). According to the literature, there is a need to simulate the production logistics at shipyards to enhance productivity through optimizing the material flow using an advanced simulation model based on discrete event simulation (Wang, Mao et al. 2015).

2.4.3. Optimization Techniques for Production Logistics

The future of the shipbuilding industry is based on the utilization of the emerging Industry 4.0 technologies to facilitate digital transformations in shipbuilding, such as the development of simulation models to implement the modern management principles (Stanic, Hadjina et al. 2018). Currently, the shipyards are working on sustainable production planning, which will help traditional shipyards to compete in the growing market in terms of cost-effective, environment-friendly, and efficient production processes. The optimization techniques in shipyard production systems are the key tool for efficient shipbuilding. The modern optimization methods are used to indicate, eliminate, and analyze the production bottlenecks in the shipyard. It is difficult to implement these optimization methods in the real-time production plans due to complex operational coordination between the production stations and production logistics in a shipyard. The following are the major optimization strategies that are proposed in the literature for reducing the energy consumption and enhancing the overall productivity of production systems:

3. **Manufacturing Cycle Efficiency (MCE) Method:** It is a modern manufacturing tool that is used to identify and fix the Non-Value-Added (NVA) processes, such as process delays, material handling, and the rework process. For traditional shipyards, this method ensures 67.08% of the productivity improvement of the shipyard production processes by identifying bottlenecks such as crane idle time and material waiting in line at a station (Jebbor, Benmamoun et al. 2023). It can be integrated with Simulation-Based Methods by using the Value Stream Mapping (VSM). VSM is used to simulate the overall production workflows as a digital map through visualization of material flow and energy consumption, and the interdependencies between workflows. This helps to identify the NVAs. Later, these NVAs are eliminated to enhance overall production efficiencies (Fitriadi and Ayob 2023).

4. **Integration of Lean-Manufacturing:** In this method, LEAN Tools are used to integrate with the production operations, which are used to eliminate the non-value-added activities to reduce the waiting time for performing a production process at a specific workstation (Fitriadi and Ayob 2023).

5. **Simulation-Based Optimization:** A simulation-based method can be used to perform the optimization of production scheduling. In this case, the ship block assemblies highlight the challenges in terms of complex multi-stage production processes. So, the practical operational constraints may be considered for enhancing the production productivity at shipyards (Lee, SuHeon et al. 2020). The optimized model can be used for material distribution and its scheduling to enhance the productivity at different workstations and accuracy in terms of material distribution. It will help to identify critical paths in terms of

unnecessary movement of material, which leads to excess utilization of energy resources, causing carbon emissions in the shipyard (Zhang, Qu et al. 2023).

In shipyards, the production logistics are based on parameters such as the flow of material, workers, and coordination between material flow based on production processes. Due to dependency on these complex parameters, delays and blockages generally occur during the production processes. So, the LEAN Manufacturing methodologies are used in shipbuilding to counter the challenges as mentioned in the table (Table **1**). The implementation of LEAN methodologies provides efficient material flow, real-time decision making, and sustainability in terms of logistics operations. In addition to these conventional methodologies, modern management technologies are being utilized in production logistics for optimizing the production process, such as Material Requirements Planning (MRP) and Theory of Constraints (Yue, Wang et al. 2012). MRP is designed for production scheduling, which helps to plan the availability of material for production without excess stocking of material, reducing the inventory costs. To forecast this material requirement, MRP uses the master production schedule, inventory data, and bill of materials (BOM). In this way, MRP schedules the production logistics based on material demand and quantity to improve the coordination between procurement, production, and delivery. So, MRP ensures the material availability just-in-time, but there is a need to consider the operational bottlenecks to ensure the smooth workflow. Theory of Constraints (TOC) is used to identify and eliminate the constraints that affect production efficiency, such as operational bottlenecks in terms of time delays. TOC is based on the five steps as mentioned in the figure (Figure **2**) below:

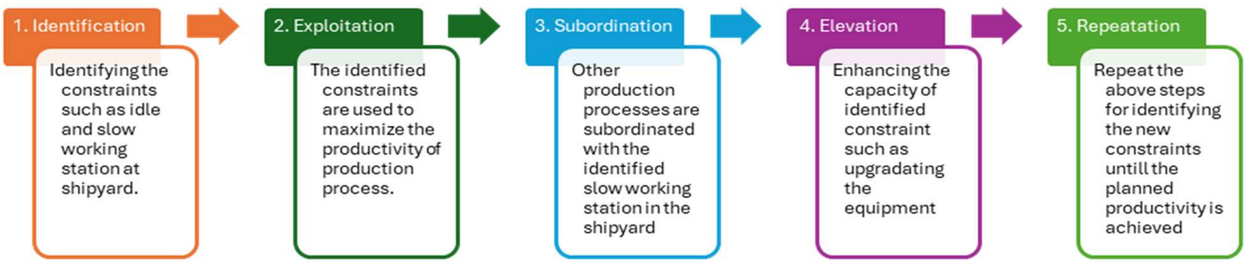


Figure 2. Theory of Constraints (Generated in MS PowerPoint)

In this way, the MRP focuses on logistical planning, and TOC focuses on optimization of the process efficiency. So, the MRP and TOC are combined to achieve higher efficiency in terms of reduction of time, lower production cost, and higher productivity. The Modern MRP systems are capable of dynamic schedule adjustments of material to integrate with TOC-driven process changes in production planning. This dual approach is an example of modern management technologies for efficient optimization of production logistics. The following table (Table **3**) possible utilization of LEAN Tools to choose a suitable optimization tool for using a simulation model of a shipyard for production optimization in terms of efficient material flow and energy consumption. So, the suitable optimization techniques for shipyard production logistics are proposed according to the literature as described in table (Table **3**) below:

Table 3. Optimization Techniques in Shipyard Production Systems (Walentynowicz 2023)

LEAN Tools	Possible Applications in Shipyards
5S Workplace Organization	Organizing tool storage to decrease search time (5S), which ensures efficient production operations.
Kanban Systems	JIT delivery of steel plates (Kanban) and ensuring accurate material inventory to ensure the availability of material when it is required in the shipyard.
Kaizen Events	Cross-functional teams work on continuous improvement in the shipbuilding process (Kaizen) and contribute to enhancing production productivity by re-planning the production in a shipyard.
Poka-Yoke (Error-Proofing)	Designing jigs to prevent faulty aligned block assembly during the hull erection process (Poka-Yoke) and reducing rework in the shipyard via LEAN Six Sigma DMAIC.

The figure (Figure **3**) shows a summary of optimization techniques for shipyard production logistics as described in the table (Table **3**):

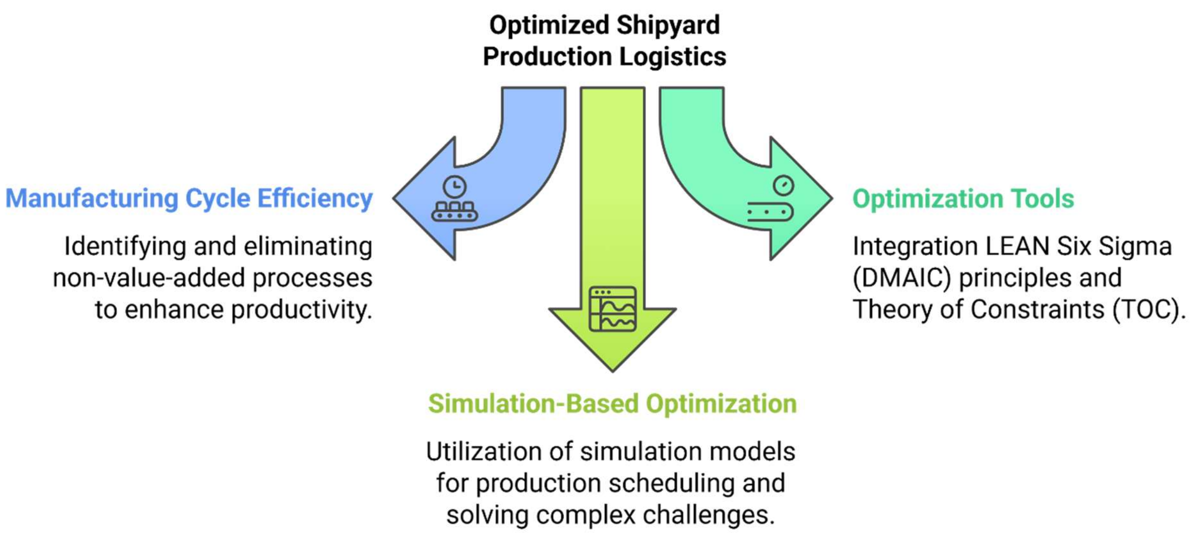


Figure 3. Optimization Techniques for Production Logistics (Generated by Napkin.AI)

Hence, the optimization process of shipyard production logistics is based on the utilization of simulation models using management tools for providing a simulation-based optimization model to maximize productivity and minimize emissions during material slow at shipyards.

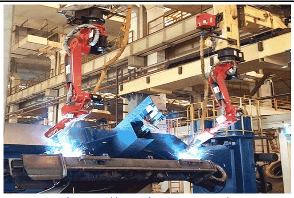
2.5. Shipyard Production Logistics

At shipyards, the production logistics consist of different equipment which are used to move lighter, massive, and heavy produced materials. So, the shipyards use heavy-duty machinery for logistics operations, which are designed based on lifting/loading capacity and operational adaptability. The transport equipment for production logistics in the shipyard is described in the table (Table **4**):

Table 4. Transport Equipment for Production Logistics in a Shipyard

Logistic Transporter	Description	Sub-Systems	Transported Material	Power Source	Figures for Application in Real Shipyards
Self-Propelled Modular Transporters (SPMTs)	It has hydraulic lifting systems integrated into the multi-axle platform vehicles.	Hydraulic lift, drive units, steering, power interface, control system	Ship blocks, engines, and large structures	Diesel or electric motor	 https://www.cometto.com/products/
Gantry Crane	It has overhead rails on both sides, an electric hoist, and a trolley mechanism.	Hoist, bridge structure, trolley, rail system, control cabin	Hull segments, blocks, engines	Diesel or electric motor	 https://www.sinokocrane.com/
Automated Guided Vehicles (AGVs)	It consists of flat-bed vehicles, sensors, motors, and guidance software.	Chassis, drive motors, control unit, sensors	Steel plates, panels, outfitting parts, blocks	Battery-powered electric motors	 https://www.appliedintegration.co.uk/
Forklifts	Mobile lifting machines are suitable for indoor and outdoor operations.	Hydraulic mast, counter weight, drive system, steering wheel	Pipes, crates, tools, pallets	Diesel or electric motor	 https://www.shipyardmarinafreeport.com/
Manual Steel Plate Trollies	It uses a manual or hydraulic trolley having rollers.	Steel frame, rollers, push handles, (optional) lift jack	Steel plates, flat panels	Manual (human-powered)	 https://www.mohn-gmbh.com/
Manual Modular Skates	Roller platforms are manually operated for heavy machinery in constrained areas.	Rollers, guide rails, platform, manual pull handles	Engines, machinery, heavy blocks	Manual (human-powered)	 https://toolwell.com/machine-skates/

Tow Tractors (Tug Units)	Compact tractors that pull multiple trailers; ideal for internal logistics	Two-hitch, motor drive, braking system, cabin	Material trollies, crates, panels	Diesel or electric motor	 https://rotortug.com/
Hydraulic Lift Trucks (Pallet Trucks)	Used to transport stacked materials indoors or short distances.	Hydraulic pump, forks, wheels, and handle.	Palletized materials, cables, fittings	Manual (human-powered)	 https://impa-catalogue.shipserv.com/
Truck-Mounted Cranes	Mobile crane with hydraulic boom for lifting materials at the shipyard.	Hydraulic boom, outriggers, truck chassis.	Machinery, crates, heavy tools	Diesel engine	 https://uper-above-machine.en.made-in-china.com/
Electric Platform Trucks	Flatbed electric carts for moving lighter materials indoors.	Flatbed platform, electric drive, battery.	Electrical units, fittings, and small packages	Battery-powered electric	 https://miag.de/
Rail-Mounted Transfer Carts	Flatbed carts running on rails, used to transport parts between stations.	Steel chassis, rail wheels, electric cable reel, or battery pack.	Hull segments, large panels	Electric (cable or battery)	 https://www.newld-transfercar.com/
Overhead Bridge Crane	Mounted inside buildings. Used for indoor lifting and transport in fabrication halls.	Runways, hoist, end trucks, bridge beam, control system	Machinery, blocks, components	Electric motor	 https://www.maritime.dot.gov/
Crawler Cranes	Heavy-duty track-based crane for lifting large modules in assembly yards.	Tracks, counterweight, lattice boom, hydraulic system	Ship blocks, machinery, and prefabricated modules	Diesel engine	 https://ulstein.com/
Telescopic Handlers	Use an extendable arm to lift pallets at various heights and angles.	Telescopic boom, lifting forks, hydraulic system	Pallets, containers, equipment	Diesel or hybrid	 https://www.gruma.de/
Boom Lifts	Elevating platforms for personnel access during outfitting or inspection tasks.	Hydraulic lift arm, safety platform, control panel	Workers, tools, and light equipment	Electric or diesel	 https://www.sinoboom.au/

Conveyor Systems	Used to move bulk materials within fabrication areas.	Conveyor belts, rollers, electric drive motors, sensors	Steel sheets, components, and scrap material	Electric	 https://www.westphalec.com/
Articulated Arm Robots	Robotic arms with programmed motion paths are used for welding or part transfer.	Servo motors, joints, end effectors, and control software	Panels, small components, and welding tasks	Electric	 https://en.siasun.com/
Skid Systems	Frames on which the equipment is mounted and moved.	Steel frame, roller beds or slide rails, hydraulic jack (optional)	Engines, tanks, and electrical rooms	Manual or Electric	 https://www.enerpac.com/

In modern shipbuilding, the transportation of production logistics and material handling is required to be efficient in terms of productivity, safety, and operational requirements. The shipyard production transporters are utilized to achieve these requirements with the help of specialized carriers such as pallets, racks, and containers. These logistic carriers are used to secure, organize, and protect materials for a smooth logistics flow during transportation of materials between production stations such as storage, fabrication, assembly, painting, and dock stations. The following table (Table **5**) shows details about these logistic carriers in the shipyard:

Table 5. Carriers in Shipyard Production Logistics

Logistic Carrier	**Description**	**Transported Material**	**Transporter**	**Application Figures**
Steel Pallets	It consists of flat structures with open or solid decks.	Steel plates, small machinery, and tools are between the production stations.	Forklifts, AGVs, and cranes	 https://simply-logistic.com/
Wooden Pallets	It is made up of flat wooden platforms.	Medium-weight electrical parts and cables in indoor areas.	Forklifts	 https://www.gebhardt-inc.com/
Pipe Racks	It is made of metal frames.	Long pipes, tubes, and rods are used during the fabrication and outfitting.	Cranes and forklifts	 https://www.made-in-china.com/
Modular Storage Racks	It consists of adjustable and stackable racks	It is used to transport panels, fittings, HVAC ducts, and sub-assemblies in the outfitting zones and warehouse storage.	Forklifts and AGVs	 https://www.topregal.com/

Plastic Boxes	These are lightweight boxes having lids.	It is used to store the fasteners, electrical components, and small tools in the outfitting and assembly lines.	Manual handling, forklifts, and cranes	 https://eurobox-logistics.com/
Wire Mesh Containers	It consists of open steel wire containers.	It is used to handle miscellaneous hardware and other consumables across the shipyard.	Forklifts	 https://net-railing.cn/
Trolleys	It has wheeled platforms with tailored mounts for specific parts.	It is used to handle the prefabricated panels, curved structures, windows, and piping.	Manual push/pull, and AGVs	 https://syncrolift.com/
Transportation Racks	It is made up of metal frames.	It is used to put the sections or blocks where the crane is not accessible, such as at buffer locations.	Manual Push or Pulls	 https://www.logisticsplus.com/

The transportation racks are the carriers in the shipyard that are used to handle the movement and storage of produced sections and assembled blocks (Tao, Cui et al. 2012). The types of transportation racks are shown in the figures (Figure **4**, Figure **5**, and Figure **6**) below:

Figure 4. Fixed Racks (Source: https://marineprojects.pl/activities/hull-blocks/)

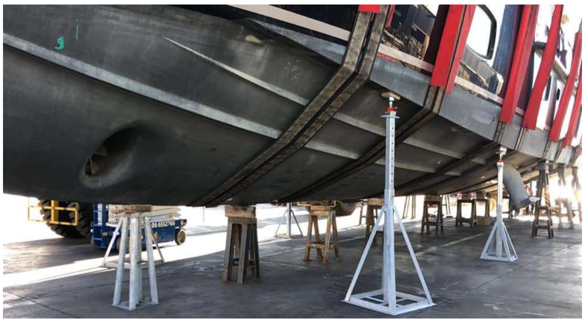


Figure 5. Flexible Rack (Source: https://www.navaltecnosud.it/)

Figure 6. Movable Rack on Ship Section Transporter (https://syncrolift.com/)

The type of rack depends on the required logistics operation for each production station, as described in the table (Table **6**) below:

Table 6. Logistic Handling – Types of Racks

Process Stage	Material	Fixed Racks	Movable Racks	Flexible Racks
Section Production	Produced Sections	Common for standardized flat panels	For flexible transfer of irregular or custom sections	Used for the non-flat sections, such as the bent, L-Shape, and Bilge Panels.
Block Assembly	Assembled Blocks	For standard-size blocks, waiting for the next stage	For varying-sized blocks waiting for the next stage	It has adjustable dimensions to store and transport the irregular and custom-sized blocks.
Painting	Painted Blocks (after coating)	For curing to avoid paint damage	For transport after painting	It has adjustable dimensions to store the irregular-shaped assembled-painted blocks.
Final Assembly	Large Assembled Blocks (painted)	Used as a buffer space	Essential for transporting heavy blocks from the store to the dock (hull) erection area	It is required for safe handling of large and non-flat blocks to store them in buffer space before the final assembly process in the dock (hull) erection area.

The reasons to choose a specific type of rack at a buffer station are described in the table (Table **7**) below:

Table 7. Practical Reasons - Specific Type of Racks at Different Production Stations

Process Stage	Rack Type	Reason for Rack Type
Section Production	Fixed and Flexible Racks	Fixed racks provide static drop points, which provide consistent storage and easy material handling in case of STS Ship Section Transporter. Flexible racks also reduce the complexities in terms of STS Ship Section Transporter negotiations, which enhances the efficiency in terms of operations (Schmitz and Stenzel 2024)

Block Assembly	Movable Racks	For the transportation of assembled blocks, movable racks are flexible in terms of loading and batch movement, which enhances the adaptability during operations (Yao, Alkan et al. 2020).
Painting Process	Movable Racks	For the painting station, the movable rack is used because it avoids unwanted movements during the coating and drying process while maintaining the orientation of the loaded assembled block on it (Negemiya 2023).
Final Assembly	Fixed, Flexible, and Moveable Racks	In final assembly, the movable racks are used for transporting painted blocks, while the fixed and flexible racks are used for buffer space setup for large ship structures, providing a hybrid approach for easy relocation of these big structures. This hybrid approach reduces the transportation time in a flexible manner (Antunović, Ljubenkov et al. 2022).

The shipyard production logistics rely on many factors such as planning schedules, origin of coordination, and material flows (Strandhagen, Jeong et al. 2020). Based on these factors, the figure (Figure 7) shows the flowchart summarizing the shipyard production logistics:

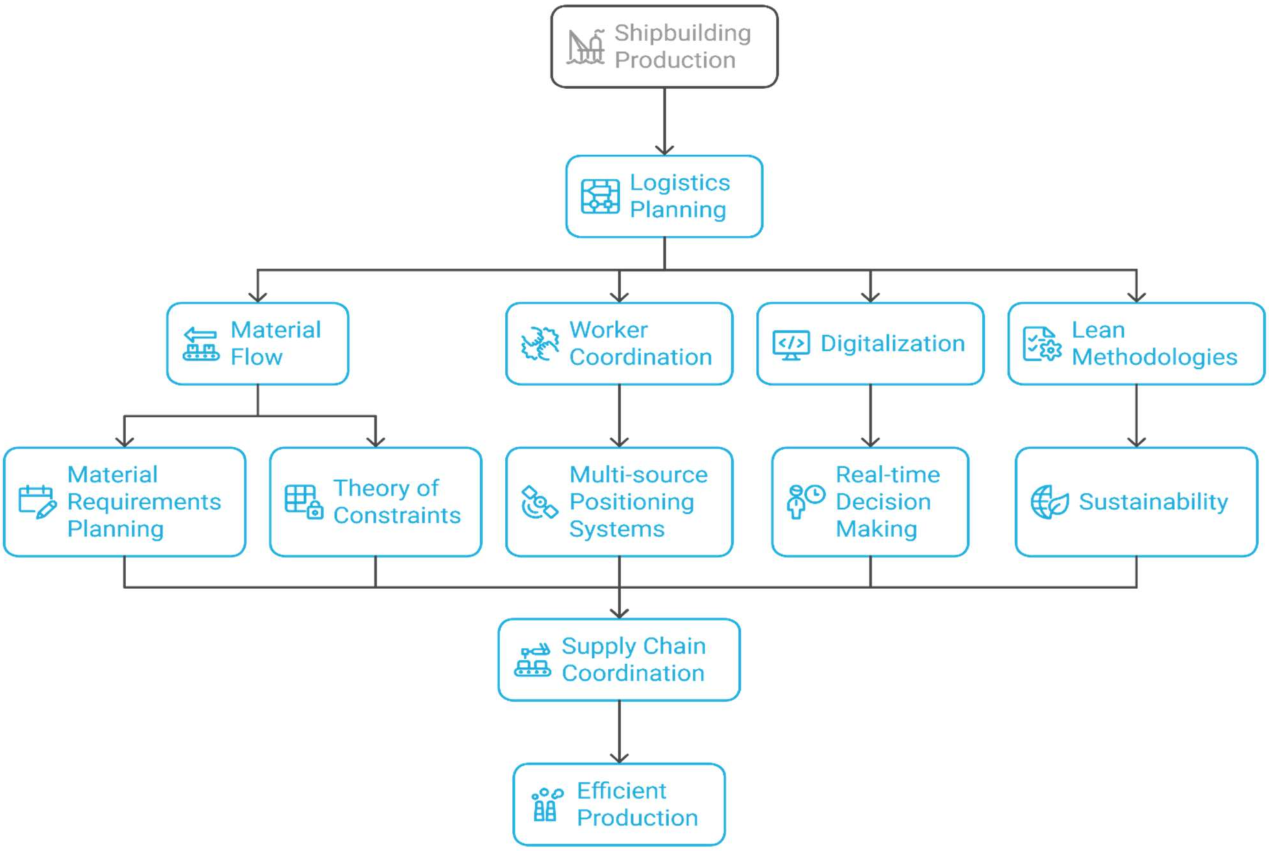


Figure 7. Shipyard Production Logistics Flowchart (Generated by Napkin.AI)

So, in shipbuilding, efficient production logistics operations are based on the material supply, material flow, worker coordination, digitalization, and lean methodologies. In the next section, the research gap is discussed in detail based on this detailed literature review.

2.6. Research Gap

This chapter presents a comprehensive review of the research gap in previous studies related to optimized material flow, energy-efficient processes, and simulation-based decision support for shipyards. Based on these research gaps, the objectives of this master's thesis are outlined in the problem statement provided in the next chapter.

2.6.1. Efficient Material Flow

There is a need to model a shipyard layout through Systematic Layout Planning (SLP) for efficient material flow to enhance production productivity in the shipyards (Tamer, Barlas et al. 2023). The Dynamic Material Flow Analysis (dMFA) is required to identify and analyse the bottlenecks to optimize the material flow (Deng, Zhang et al. 2023). It is required to describe the performance metrics to estimate the overall productivity of production planning, such as material flow, considering practical scenarios by integrating the simulation model with multiple production strategies (Ballou 2013). So, there is a strong demand for developing an advanced simulation model to test and optimize material flow at shipyards (Okubo and Mitsuyuki 2023).

2.6.2. Methods for Energy-Efficient Process

It is required to consider energy efficiencies to ensure an application-oriented and flexible simulation model, as currently there is a lack of standardized energy calculation models and tools (Köberlein, Bank et al. 2022). There is limited data available to calculate and analyse energy consumption during logistic production processes at the shipyards (Wang, Liu et al. 2024). A simulation-based testing model is required to develop a conceptual framework for energy-efficient improvements (Schmitt, Mattsson et al. 2025). The practical implementation of energy methods is required for decision-making in energy-efficient production processes, so there is a need to develop a framework for energy-efficient methods in shipbuilding (Mohamed and Al-Jaroodi 2024). So, there should be a simulation model for production logistics to evaluate and analyse eco-friendly management strategies (Giboulot, Lemelin et al. 2024).

2.6.3. Simulation-Based Optimized Decision Support

There is a lack of availability of practical optimization frameworks and methodologies for production simulation in shipbuilding, where engineers can implement the Industry 4.0 concepts for the Simulation-Based Optimization Applicable to Production Scheduling (SOAPS) to optimize the material flow for energy-efficient processes (Ghasemi, Farajzadeh et al. 2024).

3. PROBLEM STATEMENT

In this study, the following key problems are addressed:

3.1. Efficient Material Flow

Updating the initial shipyard simulation model provided by SimPlan AG to perform dynamic material flow analysis (dMFA) of production logistics for efficient material flow management through evaluating the interdependencies between material flow, energy consumption, production schedules, and resource allocation in the fictional shipyard.

3.2. Energy Efficiency

Evaluating the dynamic energy consumption of production logistics through integrating Eco-Monitor and Eco-Meter into the advanced simulation model to monitor, analyse, and calculate the energy consumption during the material transportation within a shipyard.

3.3. STS Simulation-Based Optimized Decision Support

Proposing a methodology to perform techno-economic optimization in terms of energy-efficient material flow, higher productivity, and accurate resource utilization. So, the simulation model can be utilized as a decision-making support for engineers at real shipyards.

The objectives of this thesis are summarized as shown in the figure (Figure **8**) below:

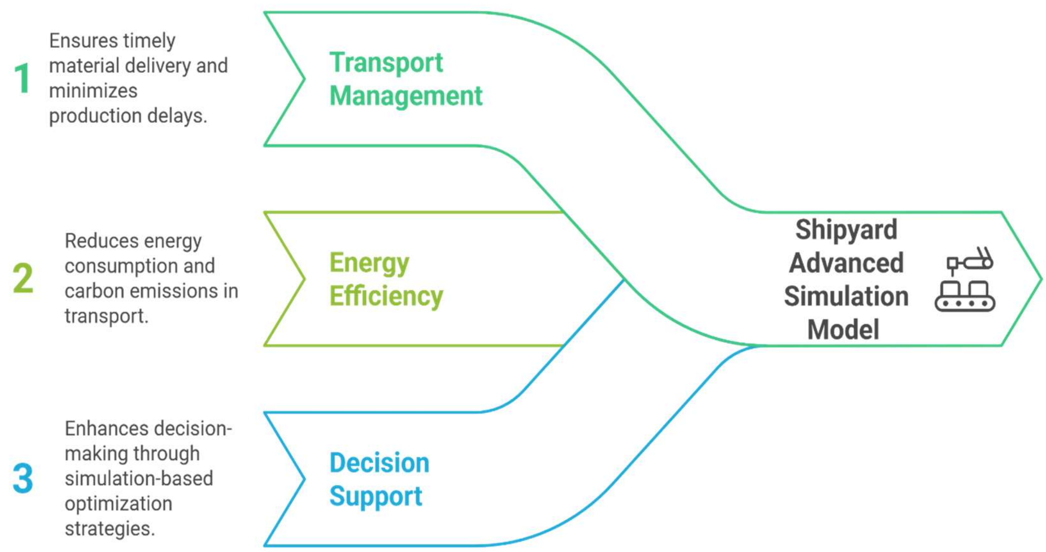


Figure 8. Key Objectives for Shipyard Simulation Demonstrator (Generated by Napkin.AI)

4. METHODOLOGY

The steps for methodology followed to solve the problem statement are: defining the input data in initial simulation model, shipyard layout evaluation for modelling new constructions to eliminate layout inefficiencies in initial simulation model, implementation of complete production logistics and modelling for racks management in upgraded simulation model, utilization of Eco-Meter and Eco-Monitor for energy consumption measurements, selection of optimization tool, and translation of problem statement into optimization components. These methodology steps are summarized in the flowchart, as shown in the figure (Figure **9**) below:

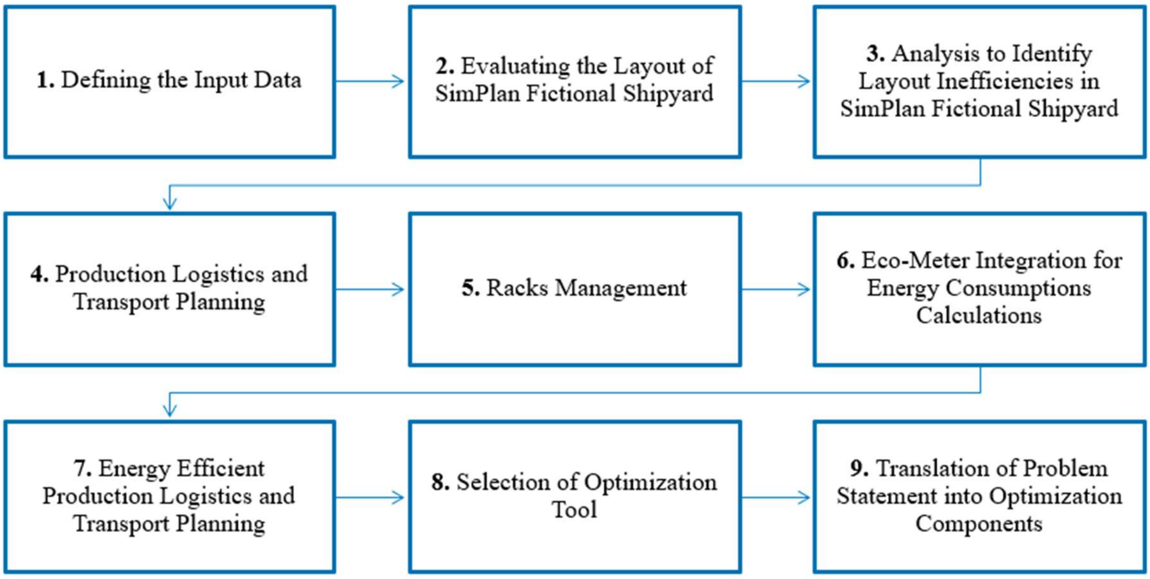


Figure 9. Flowchart – Methodology Steps (Generated in MS PowerPoint)

The initial simulation model of a SimPlan fictional shipyard is simulated in the STS Library of Plant Simulation Software with the production process as listed in the table (Table **8**) below:

Table 8. List of Shipyard Production Processes

Production Process	Process Description
Plate Part Fabrication	Shaping raw metal plates into structural components
Sub-assembly	Welding Plates and Profiles
Profile Part Assembly	Assembling beams and angles into frames/supports
Girder Assembly	Producing keel and deck girders
Panel Production	Welding plates and stiffeners into walls and decks
Section Production	Assembling panels, girders, and profiles into 3D segments
Block Assembly	Welding sections into large blocks
Painting Process	Applying anti-corrosion and anti-fouling coatings
Hull Erection	Lifting and welding the blocks into the hull

The initial layout of the SimPlan fictional shipyard with initial material flow between different stations is shown in the figure (Figure **10**) below:

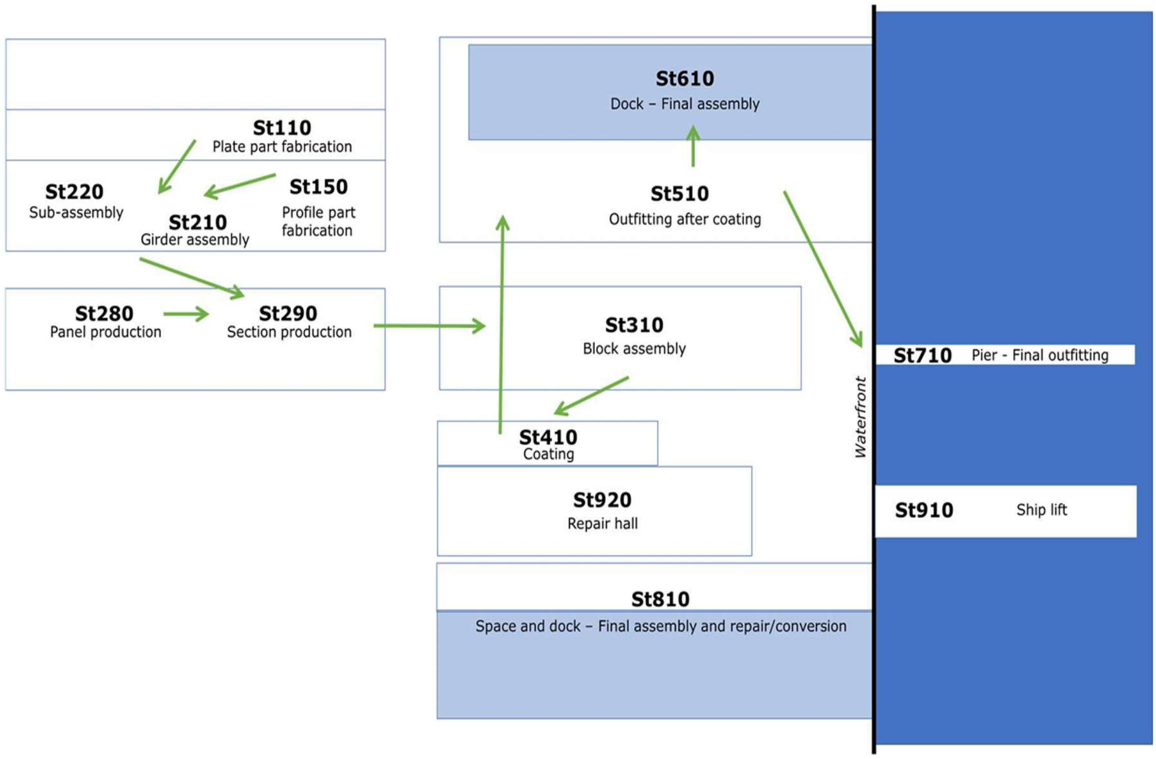


Figure 10. Initial Layout of Fictional Shipyard - Basic Material Flow (SimPlan AG)

4.1. Input Data

For this simulation model, the input data of a Naval Ship is provided by SIEMENS, which is defined in a fictional model through the STS_DataManagement Tool by Dirk Steinhauer (Manager, SimPlan AG) based on his empirical approaches and industrial experience. The STS_DataManagement feature is used to import the data tables, which contain input data related to blocks, sections, and the low-level structure of the detailed sections. The details about these data tables are listed below:

1. **Product Data:** SIEMENS provided the input data for the sections including the Parent ID (Shipbuilding project number), Element ID (ID of ship component), Type (Ship component), dimensions (Length, width, and height), positions (axis coordinates with respect to coordinates of simulation model), and weight (weight of ship component). The example data (for the ship section) is shown in the table (Table **9**) with

2. **Process Data:** This input data is completely based on the empirical approach and experience. It can be updated based on type of ship and production process constraints.

Table 9. Example of SIEMENS Input Data for Sections

Parent ID	Element ID	Type	Length (mm)	Width (mm)	Height (mm)	PosX (mm)	PosY (mm)	PosZ (mm)	Weight (kg)
P001	S01011	Section	15800	16000	3000	7900	-7000	1500	100000
P001	S01012	Section	15800	14000	3000	7900	8000	1500	100000
P001	S01021	Section	15800	16000	3000	7900	-7000	4500	100000
P001	S01022	Section	15800	14000	3000	7900	8000	4500	100000
P001	S02011	Section	15800	16000	3000	23700	-7000	1500	100000
P001	S02012	Section	15800	14000	3000	23700	8000	1500	100000

The figure (Figure **11**) below shows the working principle of the STS_DataManagement Tool to import these data tables:

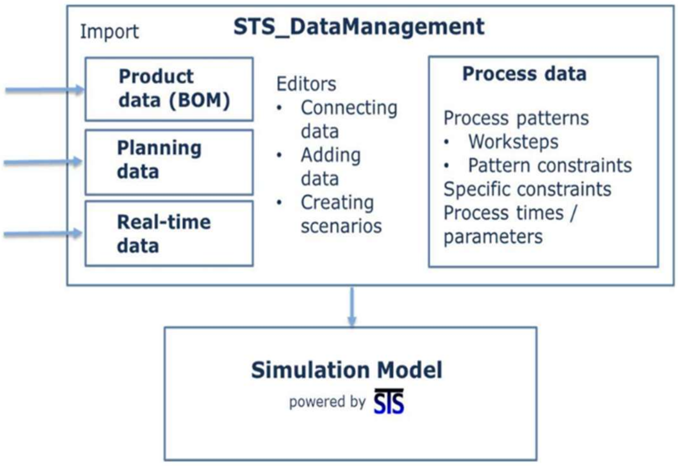


Figure 11. STS DataManagement Working Scheme to Import Data Tables (SimPlan AG)

At STS_DataManagement Tool, the following block and section division was defined by SimPlan AG based on the empirical approach for the SIEMENS Fictional Naval Ship, as defined in the figures (Figure **12**, Figure **13**, and Figure **14**) as shown below:

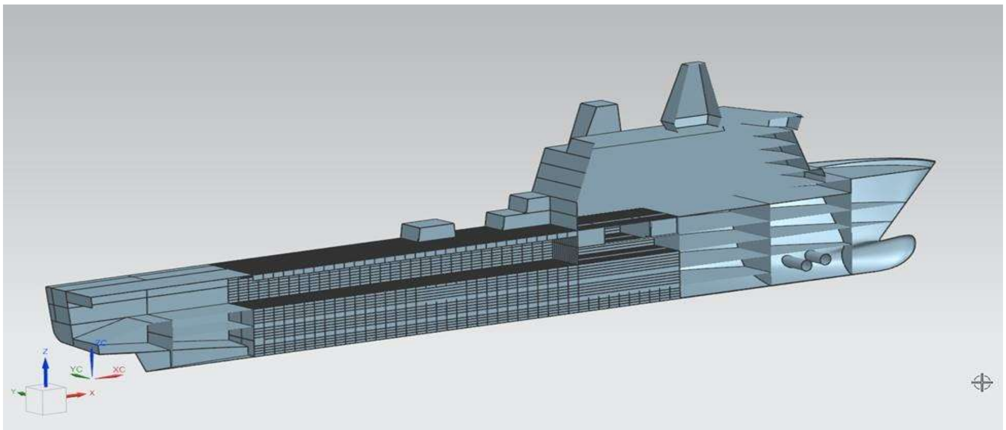


Figure 12. 3D Model of SimPlan Ship (SimPlan AG)

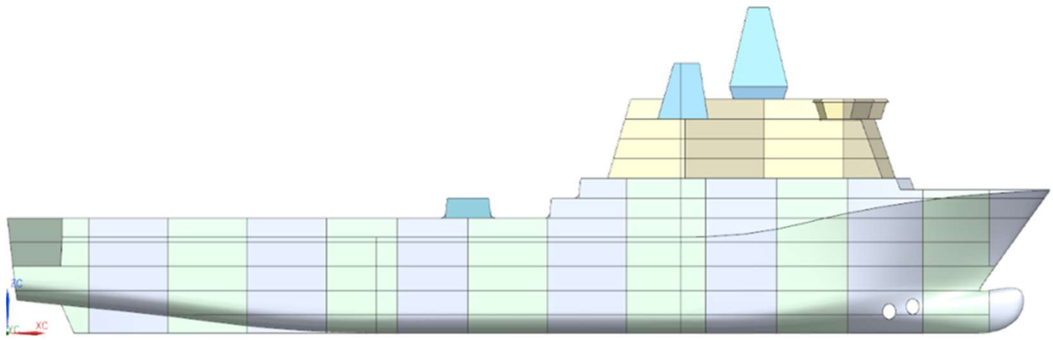


Figure 13. SimPlan Ship – Block and Section Divisions (SimPlan AG)

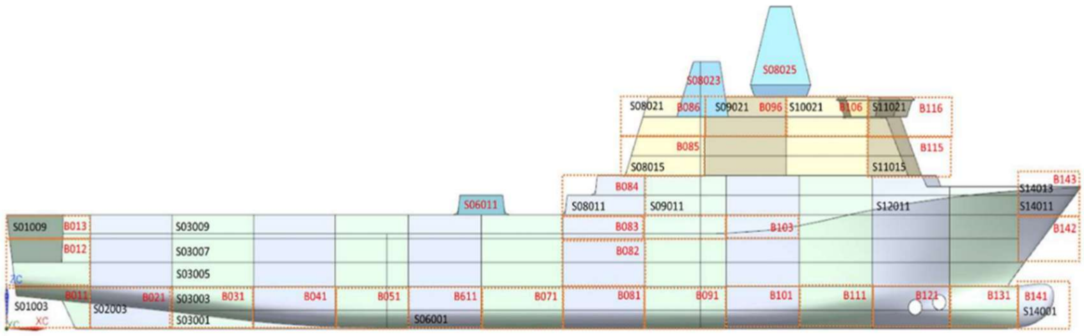


Figure 14. SimPlan Ship – Labels of Block and Section Divisions (SimPlan AG)

Using the feature of nesting in STS_DataManagement Tool, the nesting of plates and profiles is organized in terms of activities at the section level, as shown in the figure (Figure **15**) below:

Plan - Activities (Filter project)

Project	Activity	Description	Station	Start	State	Finish	State	Duration	Progress	Sequence	Mar
P001	P001-S02009-St100	Part manufacturing S02009		18.01.2025		25.01.2025				0	☑
P001	P001-S02009-St200	Part manufacturing S02009		18.01.2025		25.01.2025				0	☑
P001	P001-S02010-St100	Part manufacturing S02010		18.01.2025		25.01.2025				0	☑
P001	P001-S02010-St200	Part manufacturing S02010		18.01.2025		25.01.2025				0	☑
P001	P001-200	Pre-production		19.01.2025		30.06.2025				0	☑
P001	P001-S03009-St100	Part manufacturing S03009		19.01.2025		22.01.2025				0	☑
P001	P001-S03009-St200	Part manufacturing S03009		19.01.2025		22.01.2025				0	☑
P001	P001-S03010-St100	Part manufacturing S03010		19.01.2025		22.01.2025				0	☑
P001	P001-S03010-St200	Part manufacturing S03010		19.01.2025		22.01.2025				0	☑
P001	P001-280	Section production		20.01.2025		30.06.2025				0	☑
P001	P001-S04009-St100	Part manufacturing S04009		20.01.2025		25.01.2025				0	☑
P001	P001-S04009-St200	Part manufacturing S04009		20.01.2025		25.01.2025				0	☑
P001	P001-S04010-St100	Part manufacturing S04010		20.01.2025		25.01.2025				0	☑
P001	P001-S04010-St200	Part manufacturing S04010		20.01.2025		25.01.2025				0	☑

Figure 15. Example of Planned Activities for Part Fabrication (SimPlan AG)

4.1.1. Production Schedule

The initial simulation model consists of two planned shipbuilding projects, P001 (Project-1: SIEMENS Fictional Naval Ship) and P002 (Project-2: SIEMENS Fictional Container Ship). In this thesis, Project-1 is focused because it ensures evaluation of intermediate material flow based on real shipbuilding conditions, such as when the current project is finishing and the next project is starting at the shipyard. So, the production schedule for P001 (Project-1: SIEMENS

Fictional Naval Ship) follows a 24-hour working duration (shift), as mentioned in the table (Table **10**) below:

Table 10. Production Schedule (24-Hour Shift)

Production Process	Date Start	Date End
Raw Material Supply	18.01.2025	30.01.2025
Equipment Supply	20.01.2025	20.01.2025
Plate Fabrication	18.01.2025	30.01.2025
Profile Fabrication	18.01.2025	30.01.2025
Girder Fabrication	22.02.2025	25.03.2025
Sub-Assemblies Production	01.03.2025	25.03.2025
Section Production	25.03.2025	28.04.2025
Block Assembly Process	15.05.2025	25.06.2025
Painting Process	20.05.2025	15.07.2025
Hull Erection Process	10.06.2025	17.07.2025

4.1.2. Transporter Data

The fictional transporter data is defined in simulation model, based on the required operational criteria for different production processes, are described in the table (Table **11**) below:

Table 11. Transporter Data – Input for Transport Control Tool

Sr. No	Transporter	Speed Empty	Speed Loaded	Max. Weight	Powered
1	AGV Warehouse	0.5 m/s	0.5 m/s	100000 kg	Electric
2	Equipment Forklift	1.0 m/s	0.5 m/s	20000 kg	Electric
3	AGV	0.5 m/s	0.5 m/s	100000 kg	Electric
4	Ship Section Transporter	0.5 m/s	0.2 m/s	400000 kg	Diesel/Electric

4.2. Initial Simulation Model (SimPlan Fictional Shipyard)

In this section, a detailed evaluation is performed of the Initial Simulation Model provided by SimPlan for the Fictional Shipyard. It provided a comprehensive analysis for identifying the required improvements in the simulation model to ensure the modelling of shipyard layout and implementation of production logistics according to real-world conditions. Each production station modelled in the initial simulation model is evaluated individually to evaluate layout inefficiencies for through efficient layout mapping in terms of roads, crossings, and buffer spaces. So, all required production logistics can be implemented in the updated simulation model for an efficient material flow based on the operational requirements at the shipyard.

4.2.1. Station Layout – Plate Fabrication Station

The initial model for the plate fabrication station is shown in the figure (Figure **16**) given below:

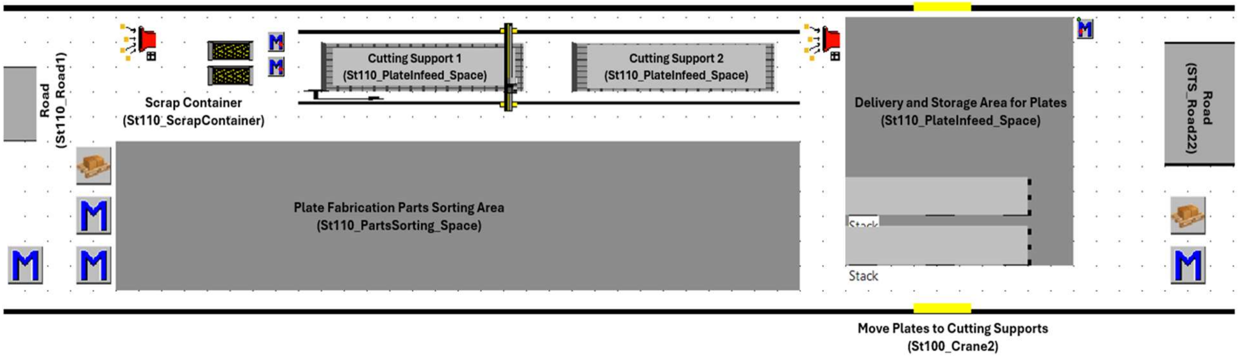


Figure 16. Shipyard Simulation Model for Plate Fabrication Station

The material flow at plate fabrication is planned according to steps defined in table (Table **12**):

Table 12. Material Flow - Plate Fabrication Station

Step	Process Description	Operation	STS Tool
1	Delivery & Storage	Raw material for plates is delivered and stored	St110_PlateInfeed_Space
2	Cutting Support Request	Request cutting support via a demand management system	St110_CuttingSupport_DemandManager
3	Move the Plate to the Cutting Support	Transport the semi-finished plate to the cutting support using a crane.	St100_Crane2
4	Cutting Process	Request a cutting machine to cut the plate into the required dimensions	St110_CuttingMachine
5	Container Request	Request a container for sorting the cut parts	St110_PartsSorting_Packaging
6	Move Cut Plates to Container	Storing cut plates in a container using a crane	St100_Crane2

The 3D view of the profile fabrication station is shown in the figure (Figure **17**) below:

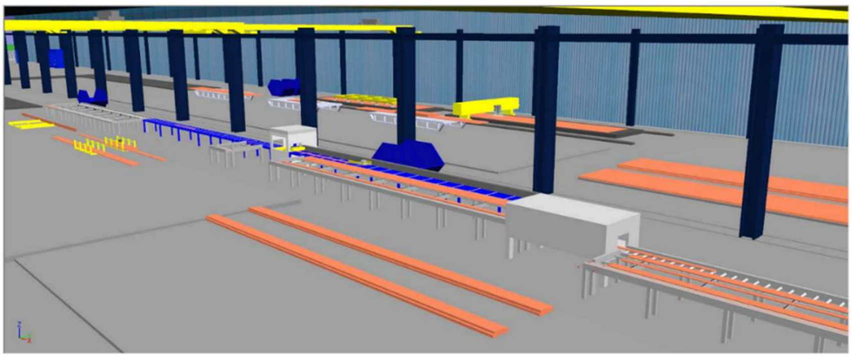


Figure 17. 3D View of Plate Fabrication Station

4.2.2. Station Layout – Profile Fabrication Station

Profile fabrication station in initial model contains material flow as shown in table (Table **13**):

Table 13. Material Flow - Profile Fabrication Station

Step	Process Description	Operation	STS Tool
1	Delivery & Storage	Raw profiles delivered and stored	St150_ProfileInfeed_Space
2	Conveyor Request	Request a profile infeed conveyor for material handling	St150_ProfileInfeed_Conveyor
3	Move the Profile to Conveyor using crane	Transport semi-finished profiles to the infeed conveyor	St100_Crane3
4	Milling Process	Mill profiles to precise dimensions/shapes	St150_ProfileMillingMachine
5	Cutting Process	Request the cutting line to cut profiles to the final length.	St150_ProfileCuttingLine
6	Container Request	Request a container for sorted cut profiles	St150_PartsSorting_Packaging

The initial simulation model for the profile fabrication station is shown in figure (Figure **18**):

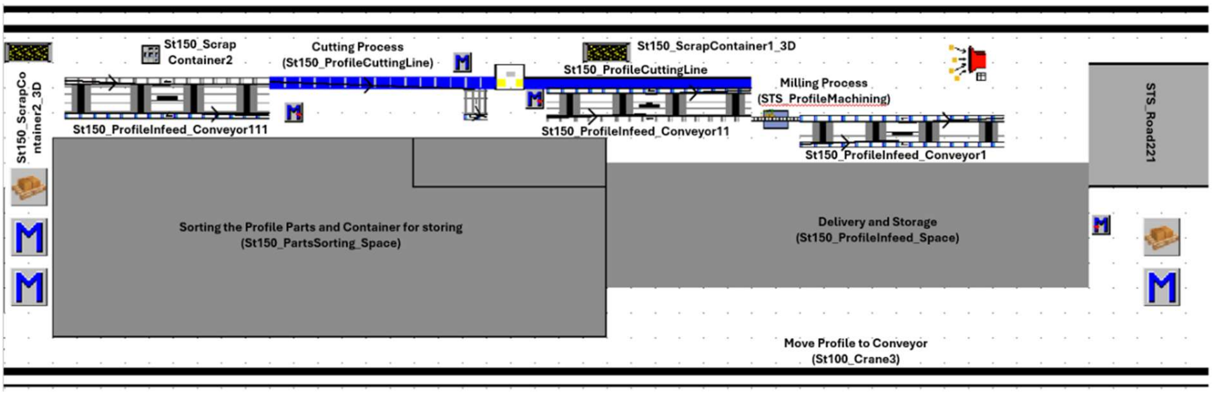


Figure 18. Shipyard Simulation Model for Profile Fabrication Station

The 3D view of the profile fabrication station is shown in the figure (Figure **19**) as shown below:

Figure 19. 3D View of Profile Fabrication Station

4.2.3. Station Layout – Girder Production Station

Material flow during the production of the girder is planned as described in the table (Table **14**):

Table 14. Material Flow – Girders Production Station

Step	Process Description	Operation	STS Tool
1	Delivery & Storage	Plates and profiles delivered	S210_Space
2	Order Generation & Conveyor Request	The order was created, and Conveyor requested the assembly line.	STS_Conveyor: St210_AssemblyConveyor
3	Material Assembly	Manages assembly via process pattern 231 using Mounting with crane group 150_3	St100_Crane3
4	Welding Process	The assembled girder was moved to the welding station	St210_Welding_GirderMachining
5	Post-Welding Transport & Packaging Request	The welded girder was moved to the outfeed conveyor, and a container is requested for sorting	St210_OutfeedConveyor St210_Packaging
6	Final Transfer to Container	Finished girder moved to the assigned container using the crane	St100_Crane3

To produce girders, the initial layout of the production station is given in the figure (Figure **20**):

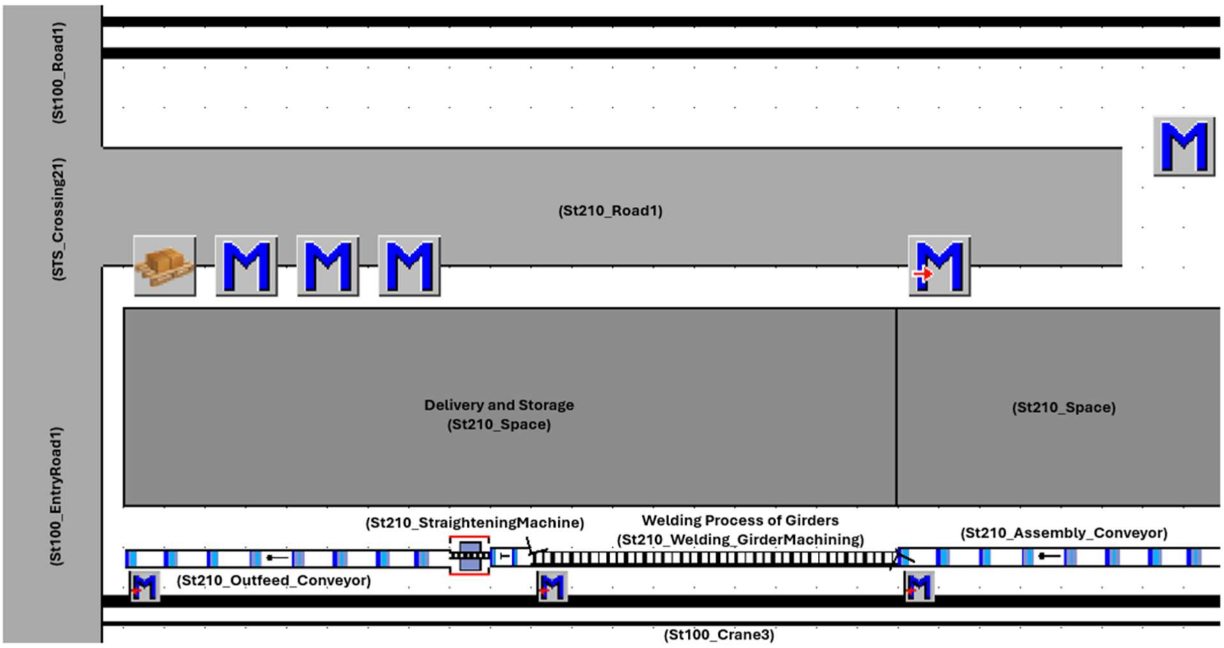


Figure 20. Shipyard Simulation Model for Girders Production Station

The 3D view of the Griders Production station is shown in the figure (Figure **21**) below:

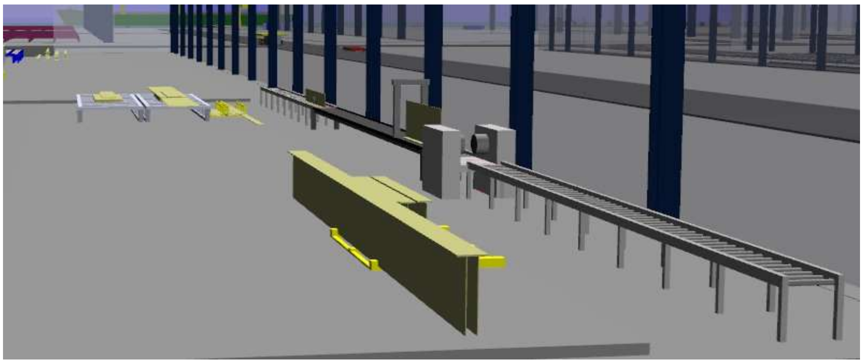


Figure 21. 3D View of Girder Production Station

4.2.4. Station Layout – Sub-Assemblies Production

Material flow to produce sub-assemblies is planned as described in the table (Table **15**):

Table 15. Material Flow - Production of Sub-Assemblies

Step	Process Description	Operation	STS Tool
1	Material Delivery & Storage	Required raw materials for sub-assemblies are delivered to the storage site	St220_Space
2	Order Generation & Assembly Space Allocation	Orders for sub-assemblies are created, and assembly space is requested	STS_OrderGenerator St220_Space
3	Sub-Assembly Production	Assembly managed by process pattern 251 while mounting with crane group 150_4	STS_ProcessControl St100_Crane3
4	Post-Assembly Storage Request	Finished sub-assemblies request storage space at the delivery site	St220_Space

To produce sub-assemblies, the layout of the sub-assembly's production station is given in the figure (Figure **22**) below:

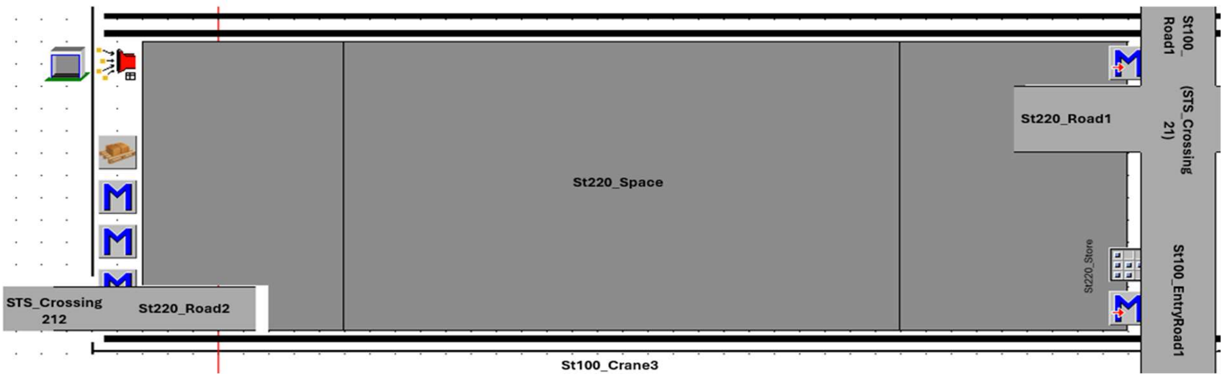


Figure 22. Shipyard Simulation Model for Sub-Assemblies Production Station

The 3D view of the Sub-Assemblies Production station is shown in the figure (Figure **23**) below:

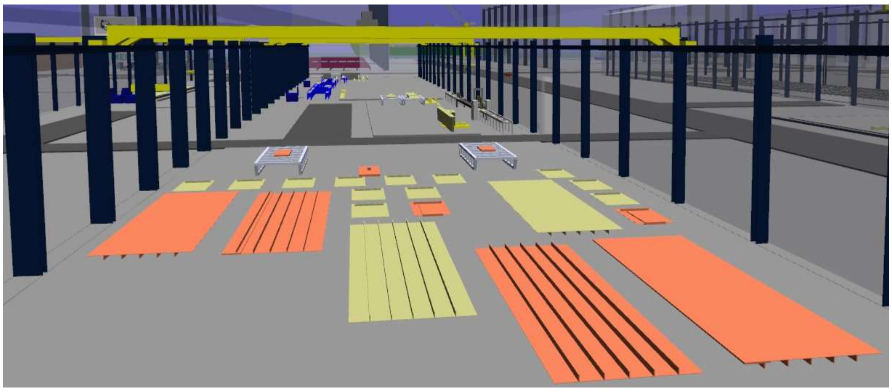


Figure 23. 3D View of Sub-Assemblies Production Station

4.2.5. Station Layout – Section Production Station

The following production processes are defined in the initial simulation model to produce the sections as shown in the table (Table **16**) below:

Table 16. Shipyard Production Process for Sections

Process Name	Process Description	Key Production Activities
Plate Field Assembly and Welding	Assembling panels into larger flat structures	Aligning and welding panels to ensure dimensional accuracy
Plate Field Cutting, Marking, Signing	Preparing plates for assembly	Cutting plates to required size and marking parts for identification and positioning
Profile Erection Station	Erect vertical/horizontal profiles onto steel plates	Positioning profiles (stiffeners, beams) on plates for the temporary tack welding
Assembly Station for Sub-Assemblies	Integrating pre-fabricated sub-assemblies into the section	Mounting girders, walls, or bulkheads
Welding Station (Open Sections)	Finalizing structural joints through welding	Robot welding for high-precision joints and manual welding for complex areas

Material flow during the production of sections is planned as described in the table (Table **17**):

Table 17. Material Flow - Sections Production Station

Step	Process Description	Operation	STS Tool
1	Material Delivery	Raw plates and profiles are delivered to an external location, while Sub-assemblies are delivered inside the hall	STS_Space St290_Assembly_Space
2	Plate Transport	Plates moved on the conveyor inside the hall	St280_PlateStore_Conveyor
3	Plate Field Assembly & Cutting	Plates are welded into a plate field and cut to size on a cutting machine.	St280_ButtWeldingStatio St280_PanelCuttingMachine

4	Profile Erection	Profiles are erected and positioned	St280_ProfileErectionStation
5	Sub-Assembly Integration	Sub-assemblies are mounted on a conveyor and managed by the Assembly control following the process pattern 291	Assembly_Control St280_AssemblyConveyor
6	Automated Welding	Section welded by robotic system (STS_PortalWorkingMachine)	St290_WeldingRobot1
7	Manual Welding	Welding is performed on the conveyor, and workers are required at the workplace	St290_WeldingConveyor3 STS_PersonnelControl

For section production station, the initial layout is shown in figure (Figure **24** and Figure **25**):

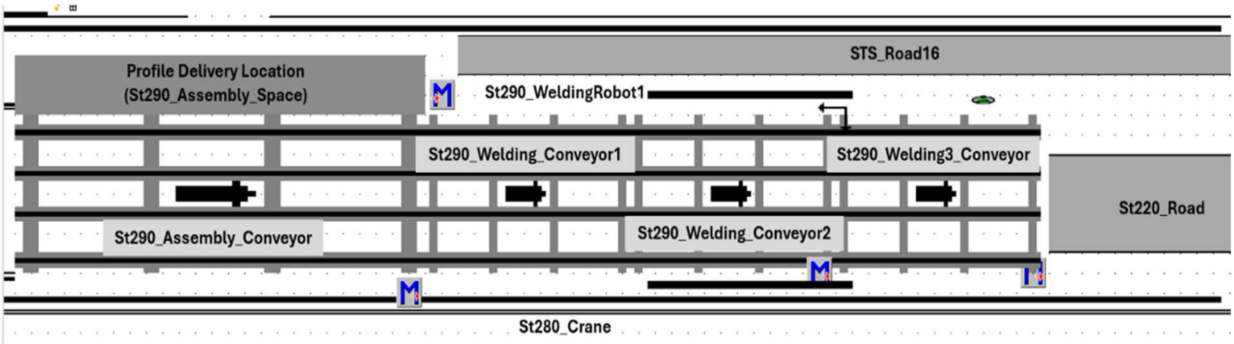


Figure 24. Shipyard Simulation Model for Sections Production Station (Left Side)

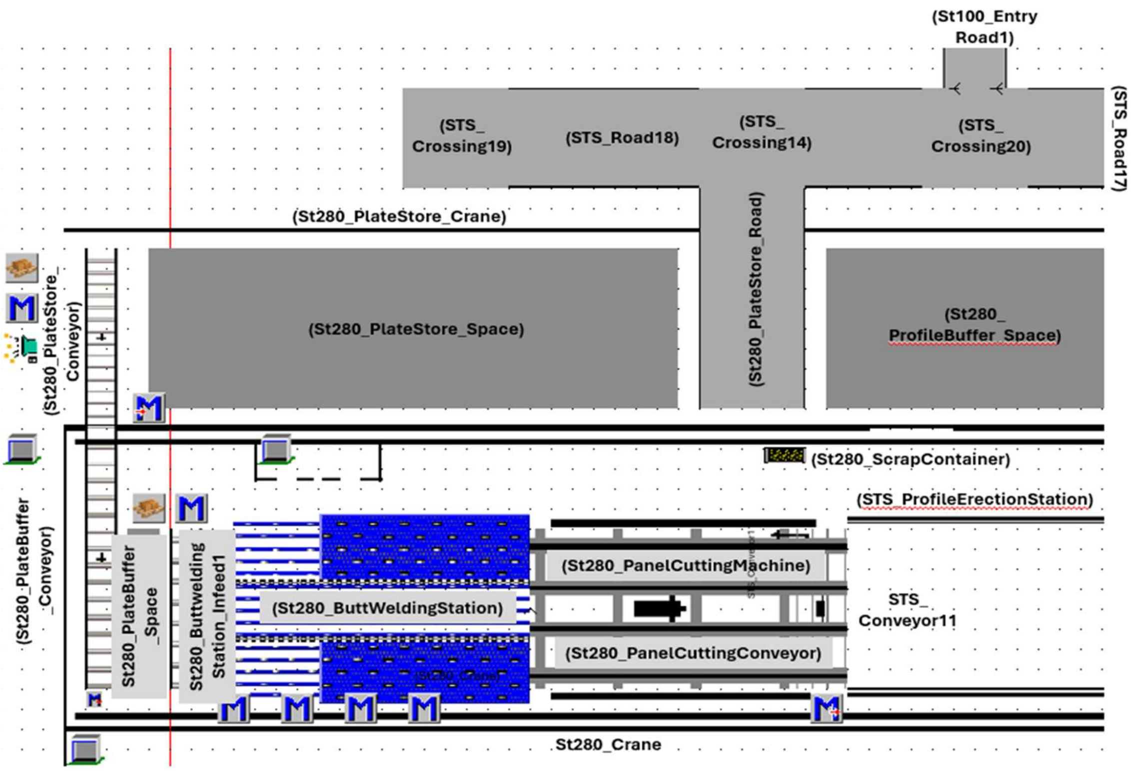


Figure 25. Shipyard Simulation Model for Sections Production Station (Right Side)

The 3D view of the Sections Production station is shown in the figure (Figure **26**) below:

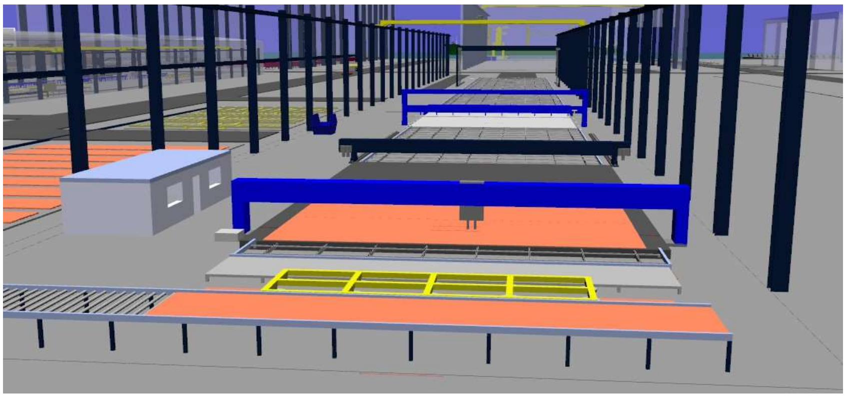


Figure 26. 3D View of Section Production Station

4.2.6. Station Layout – Block Assembly Station

In the initial simulation model, the block assembly process is defined based on the sizes of blocks, such as the small blocks for the covered dock and the large blocks for the dry dock (St810 space in the model). The material flow for assembly of blocks is planned as described in the table (Table **18**):

Table 18. Material Flow – Block Assembly Station

Step	Process Description	Operation	STS Tool
1	Order Generation & Space Allocation	Orders for blocks are created, and assembly space is requested	STS_OrderGenerator, St310_Space
2	Block Assembly Process	Managed by Assembly Control and mounted using the crane	AssemblyControl, STS_TransportControl St310_Crane

The assembly process of blocks is modelled in the initial shipyard model according to the following production pattern, as shown in the table (Table **19**):

Table 19. Shipyard Block Assembly Process

Process Name	Process Description	Production Activities
Plate Field Assembly and Welding	Assembling panels into larger flat structures	Aligning and welding panels to ensure dimensional accuracy
Plate Field Cutting, Marking, Signing	Preparing plates for assembly	Cutting plates to the required size and marking parts for identification and positioning
Profile Erection Station	Erect vertical/horizontal profiles onto steel plates	Positioning profiles (stiffeners, beams) on plates for the temporary tack welding

Assembly Station for Sub-Assemblies	Integrating pre-fabricated sub-assemblies into the section	Mounting girders, walls, or bulkheads
Welding Station (Open Sections)	Finalising structural joints through welding	Robot welding for high-precision joints and manual welding for complex areas

The layout for block assembly in initial model is modelled as shown in the figure (Figure **27**):

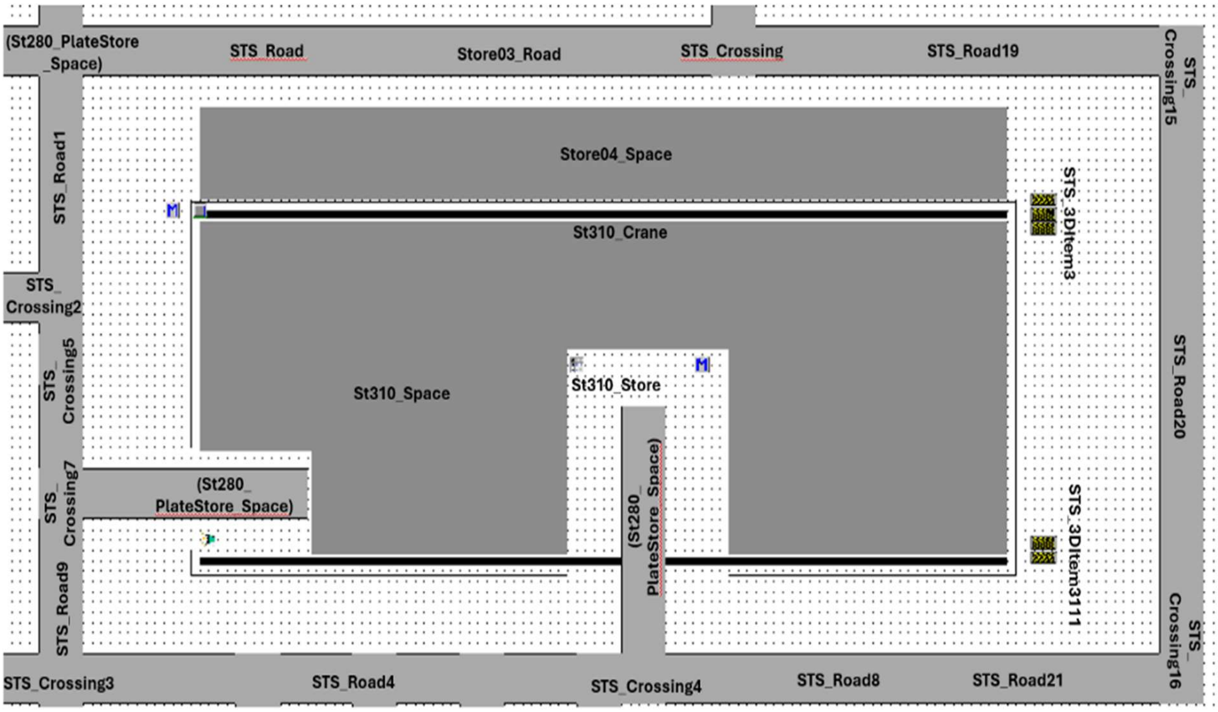


Figure 27. Shipyard Simulation Model for Block Assembly Station

3D view of the simulation model for block assembly is shown in the figure (**Figure 28**) below:

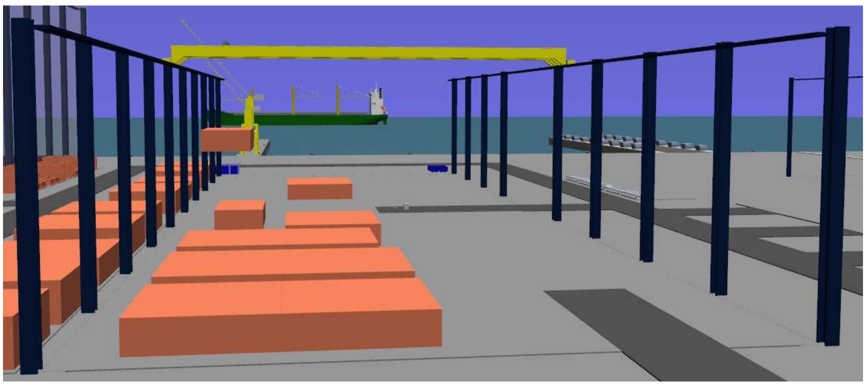


Figure 28. Shipyard Simulation Model for Block Assembly (3D View)

4.2.7. Station Layout – Painting Process Station

Material flow for painting process of assembled blocks is described in table (Table **20**) below:

Table 20. Material Flow – Painting Process Station

Step	Process Description	Operation	STS Tool
1	Post-Assembly Painting Preparation	Finished blocks requested space for the painting process	St410_Space
2	Workplan Management	Process coordinated by Workplan Management Tool, while data for blocks is imported from the STS Data Management Tool	STS Workplan Management, STS Data Management

Initial layout for the painting process station is shown in the figure (Figure **29**) below:

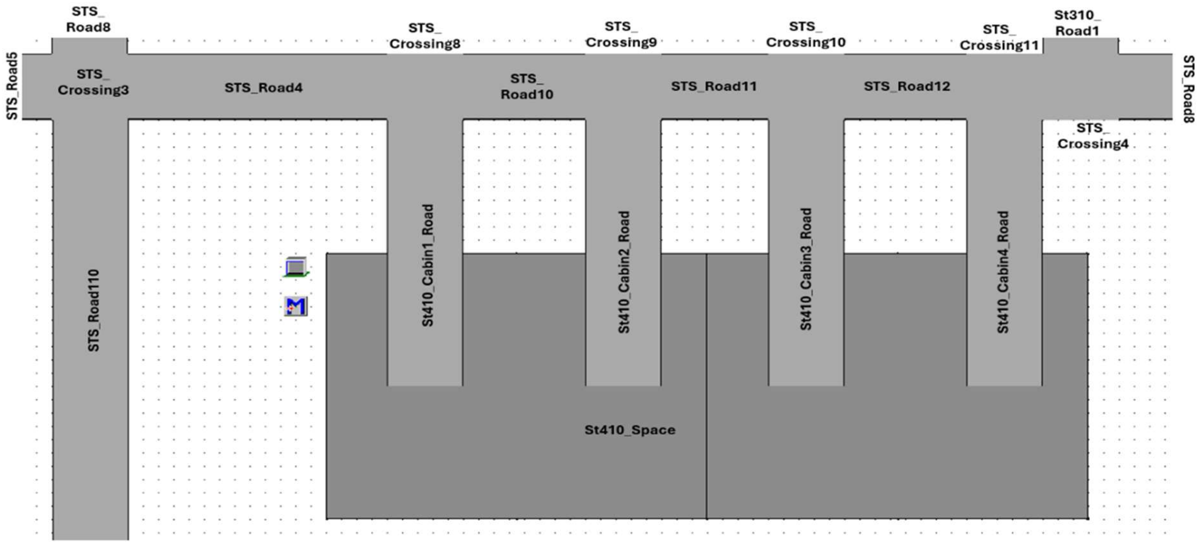


Figure 29. Shipyard Simulation Model for Painting Process Station

3D view of simulation model for the Painting Process Station is shown in figure (Figure **30**):

Figure 30. Shipyard Simulation Model for Painting Process Station (3D View)

4.2.8. Station Layout – Final Assembly Station and Hull Erection Dock

In initial simulation model, the St610 dry dock station is used for hull erection in the shipyard. There is a crane available for mounting the blocks to the hull structure at each dry dock station. The Store02_Space and Store03_Space are used as buffer stores for produced sections before moving to the block assembly area for further production processes. The material flow for hull erection process in this initial model is planned as described in table (Table **21**):

Table 21. Material Flow - Hull Erection Process

Step	Process Description	Operation	STS Tool
1	Order Generation & Dock Allocation	Ship production is requested by the Order Generator and dock space.	STS Order Generator, St610 Dock Space
2	Hull Assembly Process	Assembly is managed by Assembly Control, and blocks are mounted using a crane	STS Assembly Control and St610 Crane

Shipyard layout for hull erection and final assembly station is shown in figure (Figure **31**).

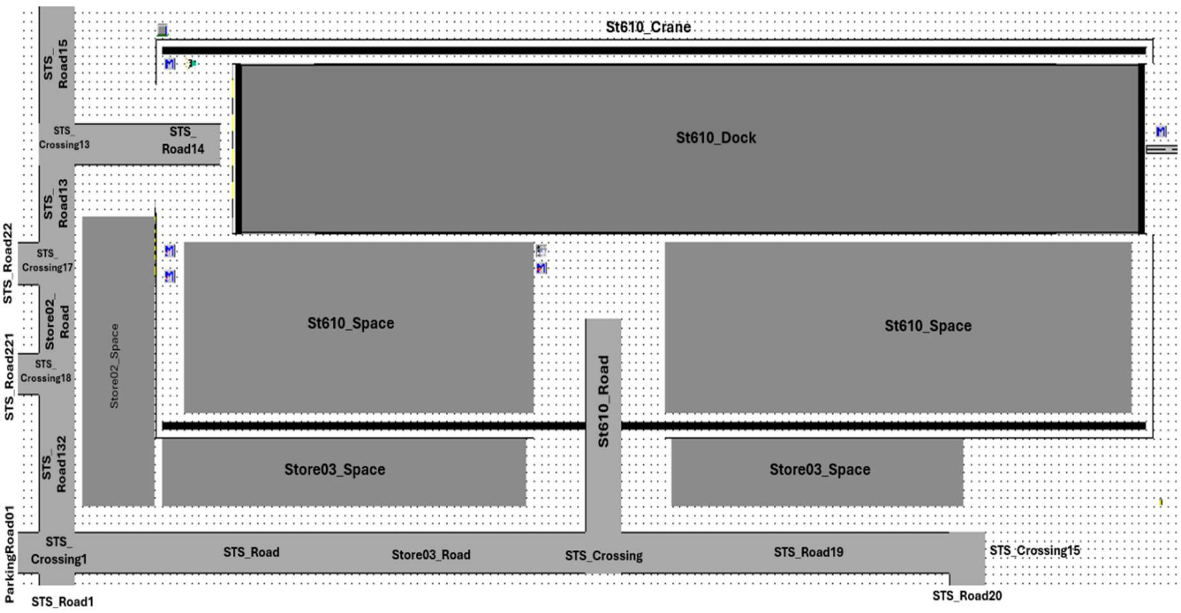


Figure 31. Shipyard Simulation Model for Final Assembly Station and Hull Erection Dock

Figure (Figure **32**) shows a 3D view of the simulation model for Final Assembly Station and Hull Erection Dock.

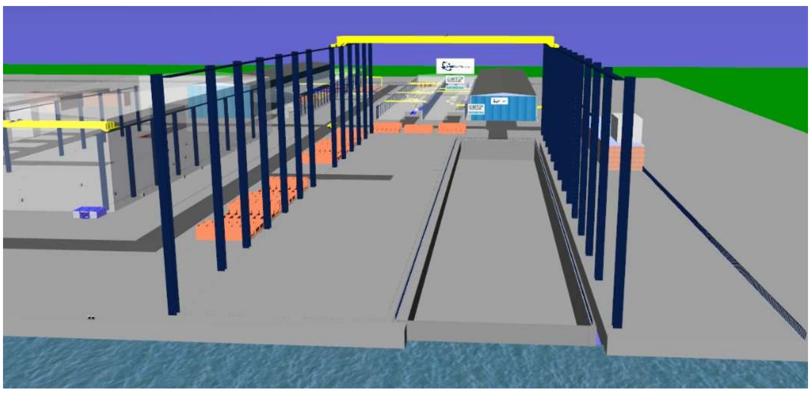


Figure 32. Shipyard Simulation Model for Final Assembly and Hull Erection (3D View)

4.3. Analysis to Identify Layout Inefficiencies in Initial Shipyard Layout

The overall and initial layout of this fictional shipyard is planned based on the sequence of production processes as marked and labelled in the figure (Figure **33**) below:

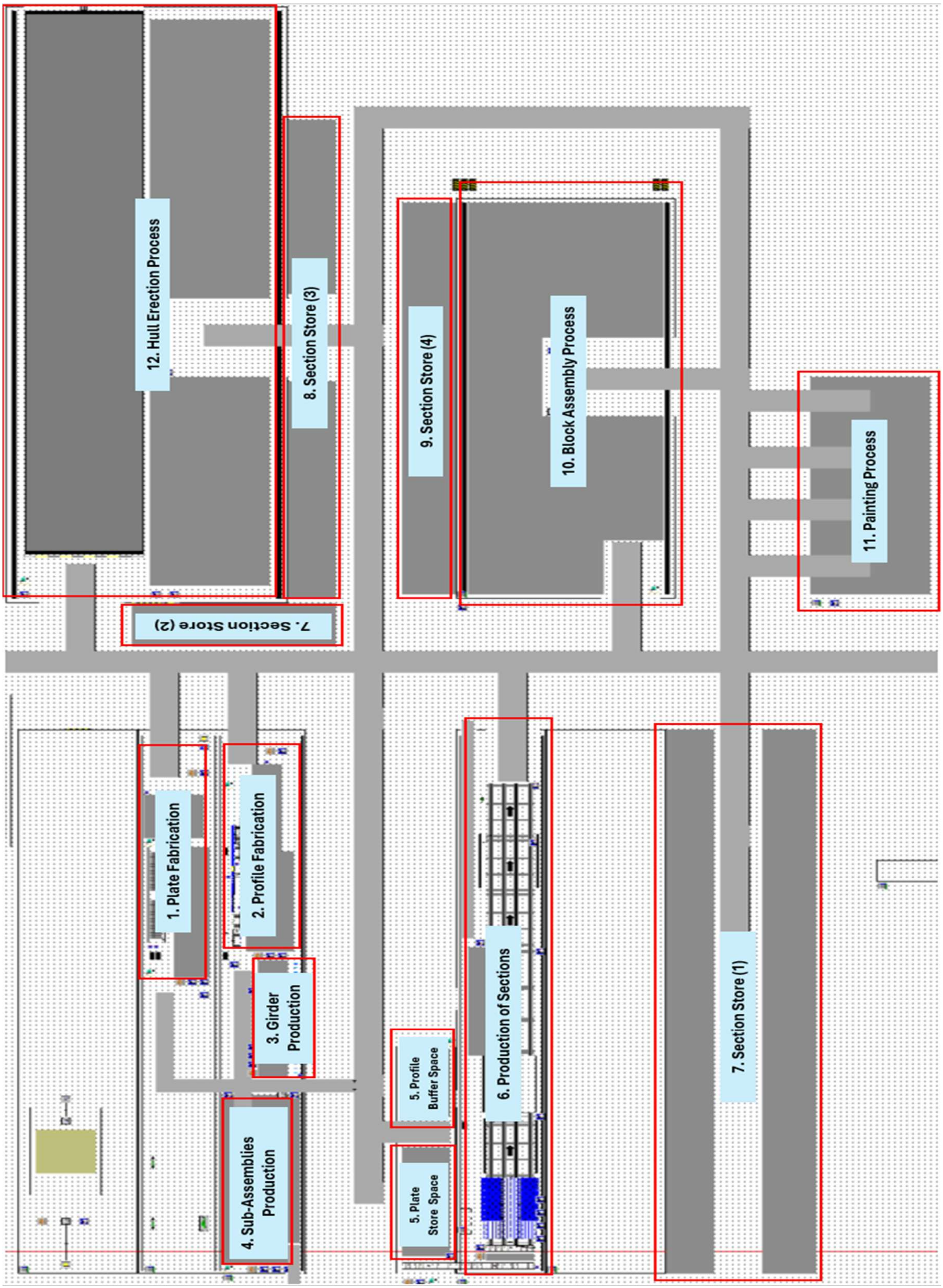


Figure 33. Initial Shipyard Layout – Map of Construction

The following figure (Figure **34**) shows initial route mapping of production logistics planned for the material flow in this initial simulation model of the fictional shipyard:

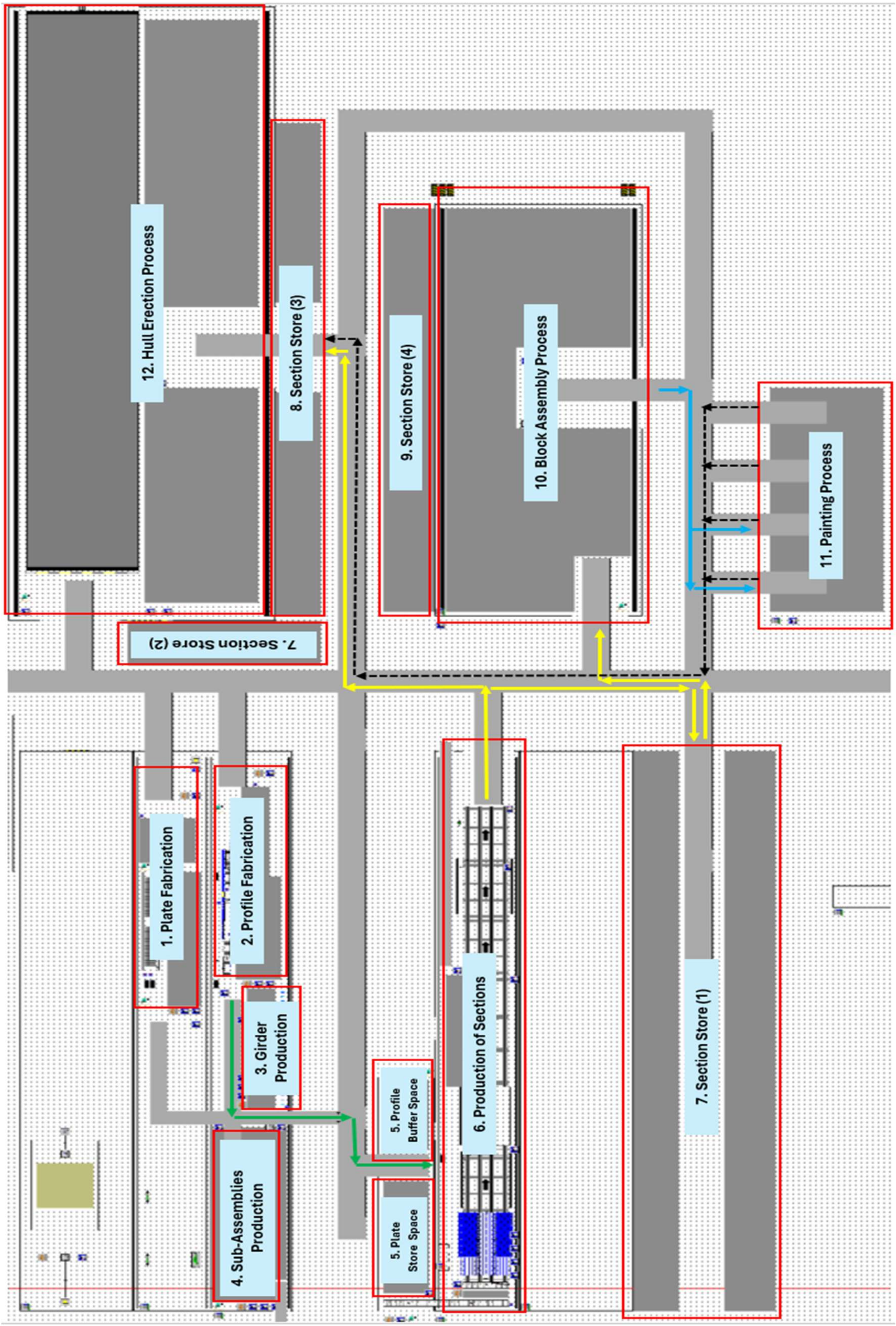
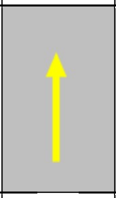


Figure 34. Initial Shipyard Layout – Routes of Production Logistics Transporters

The implemented transportation for the initial simulation model of SimPlan's fictional shipyard is shown in the table (Table 22) below:

Table 22. Assessment of Available Logistics Transporters for Material Flow Planning

Sr. No	Symbol	Operation	Transport From	Transport To	Transporter	STS Tool
1		Fabricated Profile Store Space for Production of Sub-Assemblies and Sections	Profile/Plate Fabrication	Profile/Plate Buffer Space at Section Store	Automated Guided Vehicles	STS AGV
2		Produced Sections for the Hull Erection Process and for waiting, storing in the store, and then moving to the block assembly area	Production of Sections	Hull Erection, Section Store, Block Assembly	Ship Section Transporter	STS Ship Section Transporter
3		Assembled Blocks for the Painting Process	Block Assembly Process	Painting Process	Ship Section Transporter	STS Ship Section Transporter
4		Painted Blocks for Hull Erection Process	Painting Process	Hull Erection Process	Ship Section Transporter	STS Ship Section Transporter

The evaluation of the initial simulation model of SimPlan's fictional shipyard helped to identify the technical gaps in shipyard layout and initial mapping of production logistics. So, in the next steps, the required improvements are described based on operational conditions for efficient material flow in the fictional shipyard.

The required revisions for construction and logistic transporters in the initial simulation model with usable STS tools are shown in the tables (Table **23** and Table **24**) below:

Table 23. Required Layout Improvements for Advanced Simulation Model

Sr. No.	Process Description	Operation	STS Tools
1	Store for Raw Materials & Equipment	It is required to store raw materials and equipment for the production process.	STS Space, STS Racks
2	Roads and Crossings	It is required to provide transportation means for the produced brackets and the sub-assemblies to the Section Production Station.	STS_Road, STS_Crossing
3	Buffer Store at Section Production Station	It is required to model a buffer store for produced Sub-Assemblies and Girders.	STS Space
4	Racks Store	The store for racks parking/storage is required to model in initial simulation model.	STS Space
5	Racks at Final Assembly Station	Fixed Racks are needed as carriers to put the assembled blocks in the painting station.	STS Racks

Table 24. Required Logistic Transporters for Advanced Simulation Model

Sr. No	Logistic Operation	Transport From	Transport To	Transporter	STS Tools
1	Movement of Shipments to Warehouse Store	Outside	Warehouse Store	Trucks, Forklifts	STS Truck, STS Forklift
2	Movement of Raw material from the store to Plate Fabrication, Profile Fabrication, Girder Production, and Sub-Assemblies Production	Warehouse Store	Plate Fabrication, Profile Fabrication, Girder Production, and Sub-Assemblies Production	Forklifts, Pallet Truck, STS AGVs	STS Forklift, STS Pallet Truck, STS AVGs
3	Fabricated Plates to Plate Store Space for Production of Sub-Assemblies and Sections	Plate Fabrication	Plate Store Space and Sub-Assemblies Production	Automated Guided Vehicles	STS AGV
4	Fabricated Girders transportation to produce Sections	Girders Fabrication	Section Production	Automated Guided Vehicles	STS AGV
5	Produced Brackets to Produce Sub-Assemblies	Bracket Production Station	Sub-Assemblies Production	Automated Guided Vehicles	STS AGV
6	Produced Sub-Assemblies for Production of Sections	Sub-Assemblies Production	Production of Sections	Automated Guided Vehicle	STS AVG
7	Initial outfitting Process (Brackets and Long Profiles are considered as outfitting material because they are supplied)	Raw Material Store	Sections Production Station	Forklifts, Trolley, AGVs	STS Forklift, STS Trollies, STS AGVs

For the advanced simulation model, the logistics transportation is planned according to 5S visual management for logistics, as explained below and in the figure (Figure **35**):

1. **Sort Out:** Eliminate unnecessary stations in the shipyard model which is not needed.

2. **Set in Order:** Arranged and labeled all stations in a production sequence so they are easy to locate in the shipyard model. Everything has a place, and everything is in its place. The standard locations are defined by the fixed, clearly marked locations for: stores, stations, buffer spaces, transporter routes with loading/unloading locations.

3. **Shine:** The logistic routes are mapped clearly and neatly, which would help to identify the logistic problems earlier and prevent transportation blockage in the shipyard.

4. **Standardize:** The marking of route identification is standardized for the mapping to keep consistency in logistic planning for the shipyard layout. It would help to dedicate the upcoming optimized routes for transporters, avoiding route overlaps, so the collision risk and delays can be reduced.

5. **Sustain:** Keep standardized labelling and route colours throughout material flow planning.

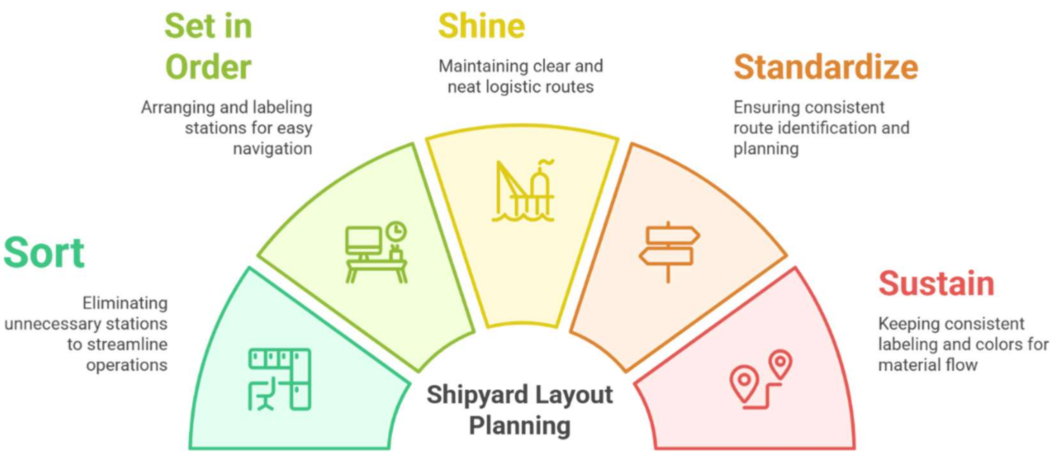


Figure 35. 5S Visual Management for Production Logistics (Generated by Napkin.AI)

4.4. Efficient Material Flow – Production Logistics & Transport Planning

In advanced simulation model of this fictional shipyard, the following STS tools in SIEMENS Plant Simulation software are used to model required updates in initial simulation model:

1. **STS Site Management Tool:** It is used to manage all production sites. This tool uses input data as provided earlier through the STS Data Management tool.

2. **STS Root Finding Tool:** This tool is used to determine a suitable route for a production logistics transporter within roads and crossings. It evaluates these routes for transportation viability because there may be real-time conditions where assigned transporters are unable to move due to the narrow width of STS Road or STS Crossing.

4.4.1. Construction – Warehouse and Equipment Store

According to required improvements for efficient material flow shipyard, warehouse operations are planned to unload the raw material from trucks as described in the table (Table **25**):

Table 25. Material Flow for Raw Material Warehouse

Step	Process Description	Operation
1	Raw Material Arrival	Plates and Panels are supplied by the Supplier using trucks
2	Unloading Process	Raw material is unloaded from trucks using a crane operation
3	Return of Empty Trucks	Empty trucks are moved back to the supplier using a U-turn at the Road

Similarly for the advanced simulation model, the material flow for the equipment store to unload and store the fabricated large profiles and brackets is described in the table (Table **26**) below:

Table 26. Material Flow for Equipment Store

Step	Process Description	Operation
1	Equipement Arrival	Fabricated large profiles and brackets are supplied by the Supplier using trucks
2	Unloading Process	Fabricated large profiles and brackets are unloaded from trucks using a crane operation
3	Return of Empty Trucks	Empty trucks are moved back to the supplier using a U-turn at the Road

Using the STS Space Tool, the St290 Assembly Space is created in the shipyard layout, which is being used as a buffer store for the produced girders and sub-assemblies.

4.4.2. Construction – Roads and Crossings

For efficient material flow, the new roads and road crossings are modelled in the advanced simulation model. These new constructions are used to ensure logistics movements, as explained in the table (Table **27**) below:

Table 27. New Roads and Crossings for Material Flow

Step	Description	STS Tool
1	Road for transportation of Raw Material from the supplier to the warehouse.	STS Road16 and STS Road28
2	Crossings for roads to connect different roads.	STS Crossing22 and STS Crossing23
3	Road for transportation of Store Equipment from the supplier to the storage store.	St100 Road2 and STS Road24
5	Road for transportation of produced sub-assemblies, griders, and brackets from the respective stations to the section production station.	St290 Road1 and STS Road7

The settings are defined for respective roads linked with warehouse and equipment store to return the trucks (after unloading) towards respective suppliers as shown in figure (Figure **36**).

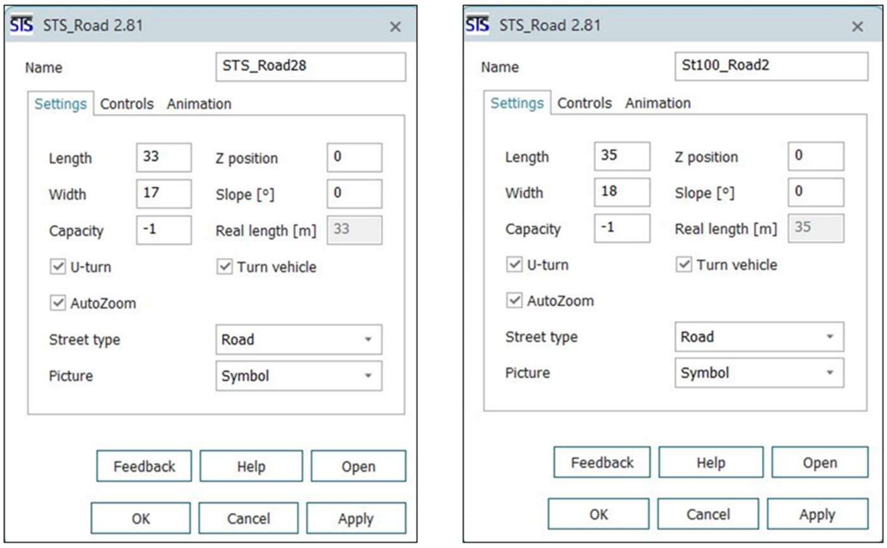


Figure 36. Road Settings – Warehouse (STS_Road28) and Equipment Store (St100_Road2)

4.4.3. Production Logistic Planning – Raw Materials and Equipment

For the advanced simulation model, the table (Table **28**) shows material flow using logistic transporters in the case of transportation of raw materials (plates and profiles) and equipment (brackets and large profiles) from STS Supplier to the warehouse and equipment store, respectively, as described below:

Table 28. Transportation – STS Suppliers to Raw Material Warehouse and Equipment Store

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Movement of Plates in the form of stacks	STS Supplier Warehouse	Warehouse Store	Trucks	STS Truck
2	Movement of Profiles in the form of Bundles	STS Supplier Warehouse	Warehouse Store	Trucks	STS Truck
2	Movement of Brackets and Long Profiles	STS Supplier Store Equipment	Store Equipment	Trucks	STS Truck
3	Unloading of Steel Plates and Panels	STS_Road28 and St100_Road2	Warehouse and Store Storage Area	Gantry Crane	STS Crane
4	Empty Trucks Returning	STS_Road28 and St100_Road2	STS Supplier Warehouse and Store Equipment	Trucks	STS Truck

The stored plates and profiles from the warehouse are transported using AGV and gantry cranes to their respective infeeds at the production stations to ensure just-in-time (JIT) delivery of the material to avoid the waiting time and delay as described in the table (Table **29**) below:

Table 29. Transportation – Raw Materials from Warehouse to Production Stations

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Loading of Plates from Warehouse	Warehouse Stacks	AGV Warehouse1	Gantry Crane	STS Crane
2	Movement of Plates for the fabrication process	Warehouse Raw Material	STS_Road22	AGV Warehouse	STS AGV
3	Unloading of Steel Plates	AVG	Plate Infeed Station	Gantry Crane	STS Crane
4	Loading of Profiles from Warehouse	Warehouse Stacks	AGV Warehouse1	Gantry Crane	STS Crane
5	Movement of Profiles for the fabrication process	Warehouse Raw Material	STS_Road221	AGV Warehouse	STS AGV
6	Unloading of Profiles	AVG	Profile Infeed Station	Gantry Crane	STS Crane

Similarly, the stored brackets and long profiles from equipment are transported using forklifts and gantry cranes to section production stations to ensure just-in-time (JIT) delivery of the material to avoid the waiting time and delay in the advanced simulation model of this fictional shipyard, as described in the table (Table **30**) below:

Table 30. Transportation – Equipment Store to Section Production Stations

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Loading of brackets and long profiles from the Equipment Store	Store Panels	Equipment Forklift	Gantry Crane	STS Crane
2	Movement of brackets and long profiles for the section production	Equipment Store	St290 Assembly Store	Equipment Forklift	STS Forklift
3	Unloading brackets and long profiles	Equipment Forklift	St290 Assembly Store	Gantry Crane	STS Crane
4	Movement of Profiles for the fabrication process	Warehouse Raw Material	STS_Road221	Gantry Crane	STS Crane

4.4.4. Production Logistic Planning – Produced Girders and Sub-Assemblies

In the advanced simulation model, the produced girder and sub-assemblies are modelled to be transported from the girder and sub-assemblies production stations to the St290 assembly store at the section production stations using AGV as described in the table (Table **31**) below:

Table 31. Transportation – Girder and Sub-Assembly to Section Production Station

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Loading of fabricated Girders	Girder Production Station	AGV	Gantry Crane	STS Crane
2	Movement of fabricated Girders for the section production process	Girder Production Station	St290 Assembly Store	AGV	STS AGV
3	Unloading of fabricated Girders	AVG	St290 Assembly Store	Gantry Crane	STS Crane
4	Loading of produced Sub-Assemblies	Sub-Assemblies Production Station	AGV	Gantry Crane	STS Crane
5	Movement of produced Sub-Assemblies for the section production process	Sub-Assemblies Production Station	St290 Assembly Store	AGV	STS AGV
6	Unloading of produced Sub-Assemblies	AVG	St290 Assembly Store	Gantry Crane	STS Crane

4.4.5. Efficient Material Flow – Racks Management

In the initial simulation model of SimPlan AG, the racks were not modelled for the production logistics transportation. In the advanced simulation model, the racks management is implemented according to real scenarios. Practically, the produced sections, assembled blocks, and painted-assembled blocks are stored and moved on racks using a logistic transporter. So, this mandatory improvement is made for the fictional shipyard to ensure realistic results in terms of efficient material flow with a complete logistics transporters fleet.

4.4.6. Approach for Racks Utilization

The table (Table **32**) below describes the concept to model the advanced simulation model in terms of the application of racks at respective production stations based on their operational requirements:

Table 32. Application of Racks at Different Production Stations

Sr. No	Production Station	Material and Rack	Application
1	Section Production Station	Produced Sections on Flexible Racks	Using an STS Ship Section Transporter, the produced sections are transported to the respective section stores at different production stations. The STS Ship Section Transporter will drop the produced sections at the Flexible Racks by using its hydraulic system.

2	Block Assembly Station	Assembled Blocks on Movable Racks	The movable racks are called at the block assembly station, and the assembled blocks are placed on the movable racks using a crane. The loaded movable racks are towed by a ship section transporter and moved to the painting process station.
3	Painting Process Station	Painted Blocks (after coating) on Movable Racks	After the painting process, the movable rack is transported within the painting station for drying, so that multiple painting layers can be coated on the assembled blocks as required, according to the manufacturing process.
4	Final Assembly Station	Large Assembled Blocks (painted) on Fixed Racks, Flexible Racks, and Moveable Racks	After the painting process, the movable racks are transported using a ship section transporter to the hull erection station. The crane will unload the painted station from movable racks and load it onto the fixed racks (used for flat assembled-painted blocks) or flexible racks (used for non-flat assembled-painted blocks) available at the hull erection station. Then, based on the requirement, the painted-assembled blocks are transported to the dock at the hull erection station for the final assembly process.

The summary of logistics operations for racks management in the advanced simulation model of this fictional shipyard is summarized in the figure (Figure **37**) below:

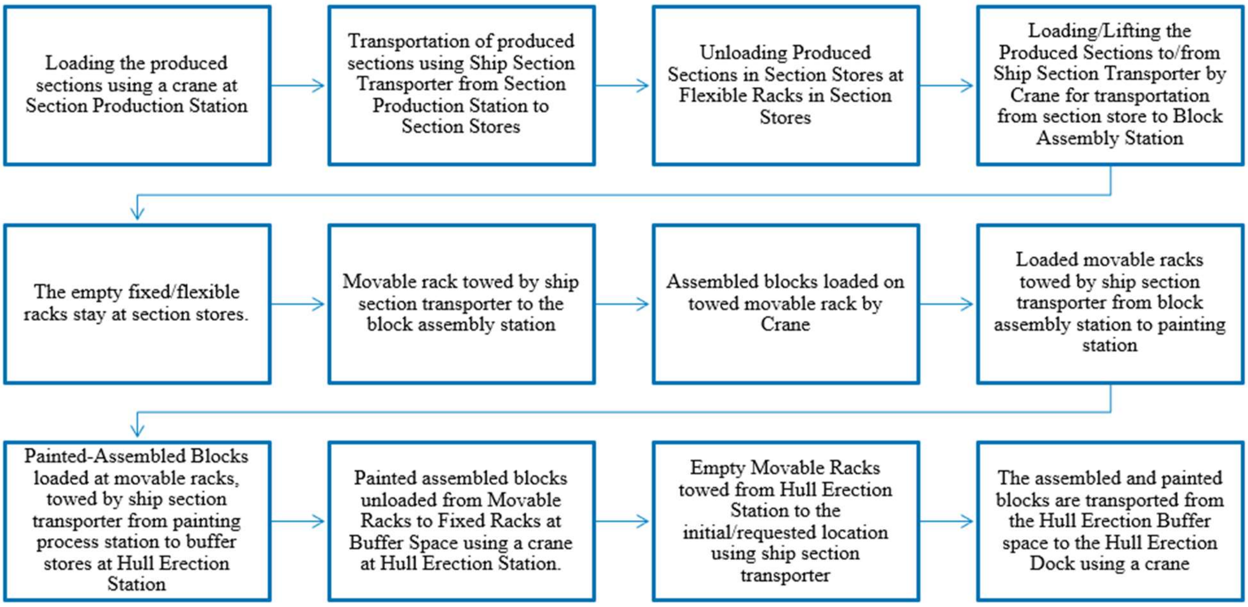


Figure 37. Summary - Racks Management Methodology (Generated in MS PowerPoint)

In the next sections of this chapter, the detailed method is explained to implement racks management for modelling the complete logistics transporters in advanced simulation model.

4.4.7. STS Packaging Control Tool

The STS Packaging Control Tool is used to assign all kinds of transport equipment, such as containers and carriers, to the produced structure for storage based on sorting criteria such as the capacity of the transporter and stacking of MUs (transported material). For example, the criterion "Activity" is used to determine the MU's attribute, which is placed on the same transporter only if it has the same value as the assigned attribute. Additionally, the maximum weight of the transported material (MU) is specified as an attribute of the transporter for transporting material between different production stations. For implementation in the simulation model, the request is made by implementing the request method to request and return the transported material (MU) of a specific type between the respective production stations by defining the STS ID of the MU or defining the name of the STS Transport Equipment (TE) class. Later, a new method is introduced to load the material (MU) on transport equipment (TE).

For example, the current setting for rack management at the block assembly station is defined for the STS Packaging Tool as shown in the figure (Figure **38**) below:

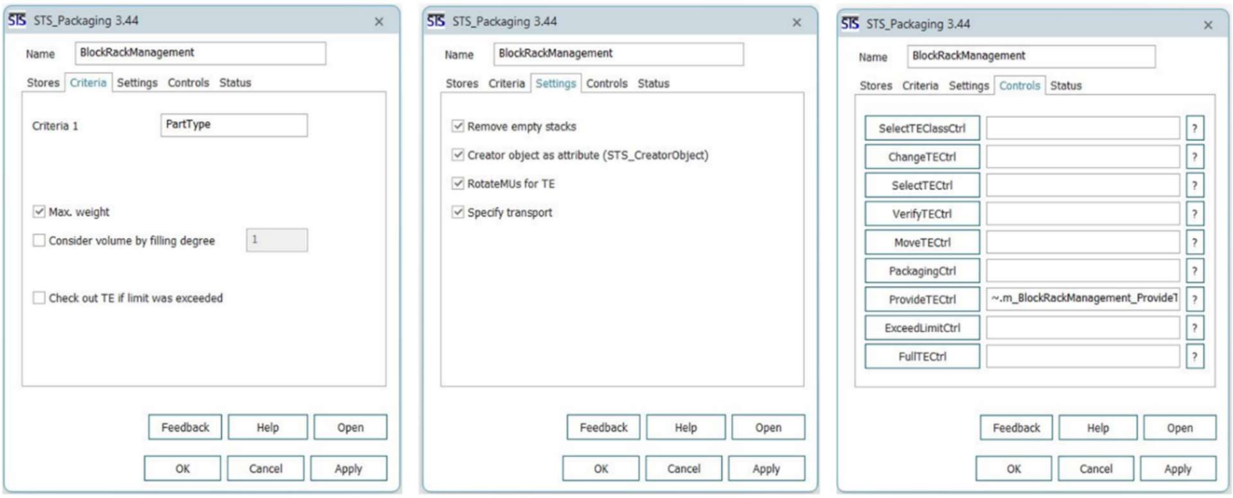


Figure 38. Racks Management for Block Assembly Station (STS Packaging Tool)

4.4.8. Racks Allocation and Logistics Planning at Section Stores

In the advanced simulation model, the produced sections from the section production station are transported using the STS ship section transporter and gantry cranes to stores at the section store. For this, the STS ship section transporter is called when the section is produced at the section production station. Sections are picked by the STS ship section transporter and transported to the predefined fixed rack at the relative section stores, such as Store_01 Space, Store_02 Space, Store_03 Space, and Store_04 Space. For this, the STS ship section transporter is defined in the STS transporter control and method St290_Welding3_Conveyor_Exit so that the STS ship section transporter can reach the St290 Welding3 Conveyor at the section production station and load the produced section. Later, this STS ship section transporter is moved to the respective stores, such as Store_01 Space, Store_02 Space, Store_03 Space, and Store_04 Space. After this, the STS ship section transporter will unload the loaded-produced section. The updated logistics operation is described in the table (Table **33**).

Table 33. Logistic Operation - Racks at Section Stores

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Loading the produced sections	Section Production Station	Ship Section Transporter	Crane	St280 Crane
2	Movement of produced sections	Section Production Station	Store01 Space, Store02 Space, Store03 Space and Store04 Space	Ship Section Transporter	STS Ship Section Transporter
3	Unloading/Lifting produced sections	Ship Section Transporter	Flexible Racks	Ship Section Transporter	STS Ship Section Transporter

The approach used to implement racks utilization at section stores in the advanced simulation model is described in the table (Table **34**) below:

Table 34. Implementation - Racks Utilization at Section Stores

Sr. No	Operation	Implementation Approach
1	Loading the produced sections	The produced sections are already being loaded on the STS Ship Section Transporter at St220 Road using the St280 Crane.
2	Movement of produced sections	STS Ship Section Transporter is already loaded with produced sections and moves from St220 Road to STS Road 5, St610 Road, and St310 Road 2.
3	Flexible Racks	It is required to simulate Flexible Racks at the section stores.
4	Unloading Produced Sections	It is required to command the STS Ship Section Transporter to unload the produced sections onto the Flexible Racks.
5	Lifting Produced Sections	It is required to command the STS Ship Section Transporter so that it loads the produced sections from the Flexible Racks when needed.

The STS tools and methods used in advanced simulation model to implement the racks management at section stores in the fictional shipyard is explained in the table (Table **35**) below:

Table 35. STS Tool for Required Rack Utilization at Section Stores

Sr. No	STS Tool	Description
1	Method Generate Geometry 3D	This method is used to generate the 3D model of fixed racks using the data from the assembly table (which needs to be updated). Later, this method needs to be called Method St290_Welding3_Conveyor_Exit. The geometric dimensions of the 3D model of the racks are based on the type of section that will be stored on them. The bottom frame is made up of beams providing a flat surface. Irregular and Non-Flat Shapes: The flexible racks with adjustable dimensions are required to model, which are used to store the non-flat produced sections, such as Bilge Panels, L sections, in the upper superstructure. The flexible rack must have adjustable dimensions concerning the dimensions of the produced section.
2	Method St290 Welding3 Conveyor Exit	This method is used to register the sections for direct ordering to the block assembly station or section stores.
3	Method Order Part	This method is used to execute the demand manager in the STS Assembly Control Tool to request the Material (sections) at the Block Assembly station for further transportation. The section is registered at the Material Administration, which calls the transporter, and removes the empty racks at the rack store.
4	STS Site Management Tool	This tool is used to perform transportation operations as requested, based on the availability of space at stores. This tool provides space allocation flexibility to provide the possibility to replace fixed and flat racks with flexible racks. So, in this way, the site management tool is used to reserve space for the transportation of flexible rack elements.
5	STS Transport Control Tool	The STS Transport Control Tool is used to assign the place of birth, parking, and destination for the STS Ship Section Transporter, which is set as STS Road. For the flexible racks, additional transport is required, such as a forklift at section stores, which can be done with a packaging tool.
6	Method destination Ctrl	Utilized to discharge the object (sections) from the vehicle (transporter) at the discharge location (St310 Road 2 and St610 Road) after calling the vehicle (STS Ship Section Transporter) at the pickup location (St220 Road).
7	STS Packaging Tool	This tool is used to create and register the carriers (Flexible Racks), which are used to store the produced sections. This tool is used to assign the location where the created transport equipment (carriers) will be hosted in a space (section store). The space allocation of racks at stores can be done by assigning the rack element (produced sections), which is registered at the packaging tool, and the forklift picks and drops it within the section store.
8	Method Packaging Change TE Ctrl	The method m_Packaging_ChangeTECtrl is used to call the carrier (fixed racks), so STS Ship Section Transporter locates the available assigned carrier (fixed racks) in the store to put the produced section on it.

4.4.9. Racks Allocation and Logistics Planning at Block Assembly Stations

In the advanced simulation model, the produced sections from the section store (Store01_Space) are transported using the ship section transporter to the block assembly station (St310_Space). For this, the ship section transporter is moved to the parking location of movable racks. The movable rack is towed by a ship section transporter to the block assembly station (St310_Space). STS Crane (St310_Crane) is used to place the assembled blocks at the movable racks. When the rack is loaded, the ship section transporter is requested to tow the loaded movable racks from St310_Road1 to the painting station at respective cabin roads, such as St410_Cabin1_Road, St410_Cabin2_Road, St410_Cabin3_Road, and St410_Cabin4_Road. The logistics operation at the block assembly station to ensure just-in-time (JIT) delivery is described in the table (Table **36**) below:

Table 36. Logistic Operation – Racks at Block Assembly Station

Sr. No	Operation	Transport From	Transport To	Transporter
1	Availability of Moveable Racks at Block Assembly Station	Designated Parking Location	Block Assembly Station (St310_Space)	Moveable Racks
2	Loading the assembled blocks at the Block Assembly Station	Block Assembly Station (St310_Space)	Moveable Racks	St310_Crane
3	Transportation of assembled blocks	Block Assembly Station (St310_Space)	Painting Station (St410_Space)	Ship Section Transporter

This approach is implemented in advanced simulation model as described in table (Table **37**):

Table 37. Implementation - Racks Utilization at Block Assembly Station

Sr. No	Operation	Implementation
1	Availability of Moveable Racks at Block Assembly Station	It is required to define the movable racks in the STS Tool and update respective method so that when assembly process is done then movable rack is towed by ship section transporter to block assembly station
2	Loading the assembled blocks at Block Assembly Station	The STS Methods need to be updated so that the assembled blocks are loaded on the towed movable rack by the STS Crane.
3	Transportation of assembled blocks	In the current simulation model, the ship section transporter is loaded with assembled sections and transported from the block assembly station to the painting station. The only requirement is to define the STS Tools and Methods so that the loaded movable racks are towed by the ship section transporter from the block assembly station to painting station.

The STS tools and methods used to implement the rack management at block assembly station in advanced simulation model are explained in table (Table **38**):

Table 38. STS Tool for Required Rack Utilization at Block Assembly Station

Sr. No	STS Tool	Application in Shipyard Simulation Model
1	Method St310 Space Generate Sites 3D	This method is used to generate the 3D model of movable racks using the data from the assembly table (which needs to be updated). Later, this method needs to be called Method m_St310_Crane_Load_Ctrl.
2	STS Packaging Tool	This tool is used to create and register carriers (movable racks) at Block Assembly Station, which are used to store assembled blocks. This tool is used to assign a location where transport equipment (carriers) will load material.
3	Method Packaging Change TE Ctrl	The method m_Packaging_ChangeTECtrl is used to call the carrier (movable racks), so the transporter (STS Ship Section Transporter) locates the available assigned carrier (movable racks) to tow it.
4	STS Transport Control Tool	The STS Transport Control Tool is used to assign the place of birth, parking, and destination for the carrier (movable racks), which need to be updated.
5	Method destination Ctrl	This method is utilized to discharge the object (assembled blocks) from the vehicle (STS Ship Section Transporter) at the discharge location (Painting Station Cabins) after calling the vehicle (STS Ship Section Transporter) at the pickup location (St310 Road1), which is towing the loaded movable racks.
6	Method Order Part	This method is used to execute the demand manager in the STS Assembly Control Tool to request the transporter (STS Ship Section Transporter) to move the movable racks from St310 Road 2 to the Painting Station. The blocks are registered at the Material administration, which calls the transporter.

4.4.10. Racks Allocation and Logistics Planning at Painting Process Stations

In the advanced simulation model, the assembled blocks from the block assembly station (St310_Space) are transported using the ship section transporter and the gantry cranes to St410_Space (Painting Station). After painting the assembled blocks at the painting station, the loaded movable racks (with painted-assembled blocks) are moved to the final assembly station (St610_Space) as described in the table (Table **39**):

Table 39. Logistic Operation – Racks at Painting Stations

Sr. No	Operation	Transport From	Transport To	Transporter
1	Painting process on assembled blocks	Painting Zone (St410_Space)	Painting Zone (St410_Space)	Moveable Racks
2	Transporting the painted assembled blocks to the buffer stores at Hull Erection Station	Painting Zone (St410_Space)	Hull Erection Station (St610_Space)	Ship Section Transporter

The table (Table **40**), explains the approach implemented in the advanced simulation model for racks management at painting process stations:

Table 40. Approach - Racks Utilization at Painting Process Station

Sr. No	Operation	Approach
1	Painting process on assembled blocks	It is already implemented in the current simulation model that the assembled blocks are painted at the Painting Process Station.
2	Transporting the painted assembled blocks to the buffer stores at Hull Erection Station	In the current simulation model, the ship section transporter is loaded with painted assembled blocks and transported from the painting process station to the buffer stores at Hull Erection Station. STS Tools and Methods are defined so that the loaded movable racks are towed by the ship section transporter from the painting process station to the buffer stores at Hull Erection Station.

The following STS Tools and Methods are used as explained in the table (Table **41**) below:

Table 41. Application of STS Tool for Rack Utilization at Painting Process Station

Sr. No	STS Tool	Application in Shipyard Simulation Model
1	Method St410 Space Entry	This method is used to call the m_ExecuteWorkplanWorkstep and m_ContinueWorkplan, so after the painting process, the loaded movable racks are towed by the ship section transporter from the painting process station to the buffer stores at Hull Erection Station.
2	Method Execute Workplan Workstep	This method is used to request resources, such as transporters, providing the functionality to manage the defined order processing (production schedule) in the work plan (activity).
3	Method Continue Workplan	This method is used to continue the work plan based on the work step information according to the work plan table. The workplan table consists of Workplan ID, Sequence Number, and Workstation.

4.4.11. Racks Allocation and Logistics Planning at Hull Erection Station

In the advanced simulation model, the painted blocks from the St410_Space (painting station) are transported using movable racks to the final assembly station (St610_Space). The loaded movable racks (with painted-assembled blocks) are towed by a ship section transporter from the painting process station (St410_Space) to the final assembly station (St640_Space). The STS Crane (St640_Crane) is used to unload the painted-assembled blocks from movable racks and load them on the fixed racks available at final assembly station (St640_Space). The empty movable racks are towed by the Ship section transporter and returned to their parking location.

Based on the operational requirement, the painted-assembled blocks are transported by using the STS Crane (St640_Crane) to the Hull Erection Dock Space (St610_Dock) as described in table (Table **42**):

Table 42. Logistic Operation – Racks for Final Assembly Station

Sr. No	Operation	Transport From	Transport To	Transporter	STS Tool
1	Unloading/Lifting the painted assembled blocks	Hull Erection Station (St610_Space)	Fixed Racks at Hull Erection Station (St610_Space)	St610_Crane	STS Crane
2	Empty Movable Racks returning from Hull Erection Station to the initial/requested location	Hull Erection Station (St610_Space)	Initial or Requested location	Ship Section Transporter	STS Ship Section Transporter
3	Putting the assembled and painted blocks on the Hull Erection Dock	Fixed Racks at Hull Erection Station (St610_Space)	Hull Erection Dock (St610_Dock)	St610_Crane	STS Crane

The approach implemented for racks management at final assembly station as explained in the table (Table **43**) below:

Table 43. Implementation - Racks Utilization at Final Assembly Station

Sr. No	Operation	Implementation
1	Unloading the painted assembled blocks	In current simulation model, the painted assembled blocks are placed in space, while it is required to provide fixed racks for placing these painted assembled blocks in buffer space before final assembly process by using STS Crane.
2	Empty Movable Racks from Hull Erection Station	Once the movable racks get emptied by crane, then they are required to be towed back to their initial and requested location.
3	Transportation of assembled and painted blocks at Hull Erection Dock	In the current simulation model, it has already been simulated that the crane is transporting the assembled and painted blocks to the Hull Erection Dock. The empty fixed racks are used for upcoming utilizations if required.

The STS tools and methods used to implement the racks management at the final assembly station in advanced simulation model are explained in the table (Table **44**) below:

Table 44. STS Tool for Required Rack Utilization at Final Assembly Station

Sr. No	STS Tool	Description
1	Method St310 Space Generate Site 3D	This method is used to generate the 3D model of fixed racks using the data from the assembly table (which needs to be updated). Later, this method needs to be called Method m_St610_Space_Entry. The geometric dimensions of the 3D model of the racks are based on the type of assembled-painted blocks that will be stored on them. The bottom frame is made up of beams providing a flat surface.

2	STS Packaging Tool	This tool is used to create and register the carriers (fixed racks) at the Final Assembly Store, which are used to store the assembled and painted blocks on them. This tool is used to assign the location where the created transport equipment (carriers) will load the material. The space allocation of racks at stores can be done by assigning the rack element (assembled-painted blocks), which is registered at the packaging tool.
3	Method Packaging Change TE Ctrl	The method m_Packaging_ChangeTECtrl is used to call the carrier (fixed racks and flexible racks), so the transporter (STS Crane) locates the available assigned carrier (fixed racks and flexible racks) to place the assembled and painted blocks on them.
6	Method St610 Crane Load Ctrl	This method is used to execute the operation in which the assembled and painted blocks are unloaded from movable racks and placed on the fixed/flexible racks and transported from these fixed/flexible racks to the Final Assembly Dock St610 Station using the STS Crane.
7	STS Transport Control Tool	STS Transport Control Tool is used to assign place of birth, parking, and destination for STS Ship Section Transporter, which is set as STS Road. For the flexible racks, additional transport is implemented by using this tool, such as a crane operation at buffer space for assembled-painted blocks.

4.5. Energy Efficient Production Logistics Transport Management

In this section, the dynamic energy consumptions are measured and analysed as follows:

4.5.1. Defining – Evaluation Objectives

The Eco-Meter and Eco-Monitor is integrated with the STS Tools in Plant Simulation Software. So, the energy consumption is monitored, calculated, and optimized in terms of energy-efficient material flow between the production stations using the advanced simulation model.

4.5.2. Defining – Evaluation Parameters

The table (Table **45**) below explains the defined evaluation parameters for the shipyard:

Table 45. Defining – Evaluation Parameters

Sr. No	Parameters	Description
1	Type of Energy	Electrical and Fuel (Diesel)
2	Logistic Operation	Material Lifting and Transportation
3	Timeframe	Weekly
4	Detail Level	Sub-Systems
5	Transporters	Cranes, Forklifts, AGVs, Ship Section Transporters

4.5.3. Defining – Framework for Eco-Meter Implementation

The framework to implement the Eco-Meter in the shipyard simulation model is explained in the table (Table **46**) below:

Table 46. Defining – Framework for Energy Meter Implementation

Sr. No	Framework	Description
1	Identifying the System	The energy consumers are defined for the system: Cranes, Forklifts, AGV, AGV Warehouse, and Ship Section Transporters. Grouping the systems as: • **Crane Systems** All Cranes that are used to load and unload the logistic transporters. • **Logistic Transporters** Forklifts, AGV, AGV Warehouse, and Ship Section Transporters.
2	Identifying the Sub-System	• **Cranes** a) Subsystems are Gantry Drive, Trolley Drive, and Lifting Mechanism. b) The functional constraints for the crane are Weight of load, Lifting Height, and Transportation Speed. • **Forklifts** a) Subsystems are the Propulsion System and Hydraulic Lift System. b) The functional constraints for the crane are Weight of load, Lifting Height, Transportation Speed, and Terrain Type. • **Automated Guided Vehicles** a) Subsystems are Traction Motors, Navigation and Control Systems, and Battery Charging Stations. b) The functional constraints for the crane are Weight of load, Transportation Speed, and Battery Capacity. • **Ship Section Transporters** a) Subsystems are the Propulsion System and Hydraulic Lift System. b) The functional constraints for the crane are Weight of load, Transportation Speed, and Terrain Type.
2	Installing the Eco-Meter at the Local Level in the Simulation Model	Apply the Eco-Meter locally at each sub-system group (Crane Systems and Logistic Transporters) in terms of: • Tracking the Active, Idle, and ON/OFF States • Energy Consumption calculation based on the pre-defined parameters • Recording the Statistical Data in the Energy Monitor
3	Developing the Eco-Meter (Central)	The central Eco-Meter is developed based on the following attributes: • Collecting the Energy Consumption Data from all Local Energy Meters • Dynamic Evaluation for Energy Monitoring of all sub-systems
4	State-Based Consumption Eco-Tracking	The energy states are defined based on the operational conditions, such as: • Active State • Idle State • ON/OFF State Using the method m_ChangeEnergyState to trigger the energy meter based on the changes in energy state. These changes depend on the simulated logistic operations.

4.5.4. Collecting – Monitored Energy Consumption Data Structure

The formal tables are used for collecting the monitored energy consumption data in terms of time series data collection for all sub-systems are described in the table (Table **47**) below:

Table 47. Collecting Energy Consumption Data

Sr. No	Formal Table	Reason for Implementation Method
1	Subsystems	This table contains the list of all monitored components of subsystems.
2	Energy systems	Parent-Child relationship between all sub-systems
3	Filter table	Customized grouping of all sub-systems

This data structure is validated by executing the STS Methods. The method m_getSubSystems is executed to ensure an accurate link between the local Eco-Meter of all sub-systems. While the method m_CheckSubSystems is used to ensure that there is no duplicate data collection and to validate the applied Parent-Child relationship in the Central Eco-Meter.

4.5.5. Implementation of Eco-Meter

The Eco-meter is implemented in STS Transport Control Tool and the sub-systems are defined for tool/plant/machine/system in the STS Eco-Monitor Tool. The STS Eco-Monitor Tool is used to define working states for all sub-systems. Then, the eco-values are defined for sub-systems and states based on the energy consumptions. Then the STS Eco-Monitor Tool track the changes in working states of all sub-systems by accumulating defined eco-values. The figure (Figure **39**) below shows the implement the Eco-Meter in the shipyard simulation model:

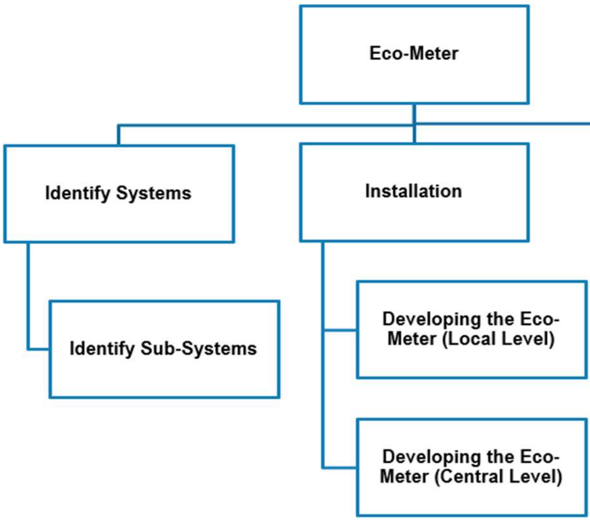


Figure 39. Implementation of Eco-Meter (Generated in MS PowerPoint)

4.5.6. Energy Cost Calculation and CO_2 Emission Estimation

Using the advanced simulation model, the energy cost is estimated based on calculated energy consumptions through Eco-Meter according to electricity price statistics as defined by the European Union, such as 0.1899 Euros/kWh (Christodoulou and Cullinane 2022). Similarly, the CO_2 emissions are also estimated according to CO_2 emissions defined by European

Environment Agency such as 150 gCO_2/kWh and 2.68 kg CO_2/liter for both electrical energy and diesel fuel which is utilized by respective logistics transporters in the advanced simulation model (dos Santos, da Silva et al. 2024).

4.6. STS Simulation-Based Optimized Decision Support

In this section, optimization methods are proposed to identify bottlenecks for the just-in-time delivery of materials to the respective production stations in the fictional shipyard with maximum productivity and minimum energy consumption.

4.6.1. Optimization Tool – Theory of Constraints (TOC)

In this section, the Theory of Constraints (TOC) is proposed to optimize material flow and minimize energy consumption due to highly mixed and low-volume production processes taking place in this fictional shipyard. The bottlenecks in shipyard layout are identified by using while using this advanced simulation model through identifying constraints at production stations regarding logistic transporters, which leads the delays in material delivery, piling up, resulting in congestion points. In this way, TOC helps to provide support in decision-making for productive shipyard productions as described in the figure (Figure **40**) below:

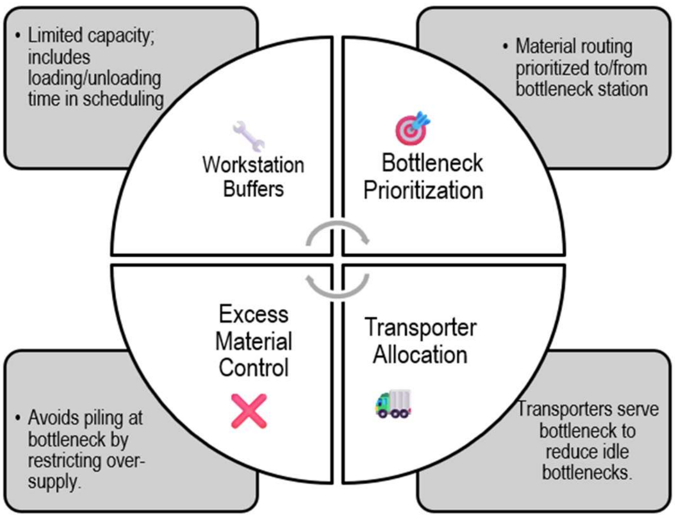


Figure 40. Theory of Constraints (Generated in MS PowerPoint)

4.6.2. Optimization Tool – LEAN Six Sigma (DMAIC)

LEAN Six Sigma (DMAIC) is also proposed to be implemented as an optimization tool in this advanced simulation model. First, it is required to identify the least utilized transporter, which is evaluated based on transporter utilization data generated by the STS Statistics Tool. Then, the transportation distance and time for each transporter by the STS Transport Control Tool. The energy consumption is reduced by implementing the Eco-Monitor in the shipyard model. After these calculations, the Root-Cause Analysis is required to perform to find the logistic bottleneck through transporter utilization data. It will help in effective resource allocation to eliminate the identified bottlenecks. In the end, it is required to test and implement the results of the analysis for the reallocation of transporters and the workflows. It provides various benefits, such as enhancing the quality and consistency of material flow through the use of statistical analysis tools. The method followed to apply LEAN Six Sigma (DMAIC) as an optimization tool is described in the figure (Figure **41**) below:

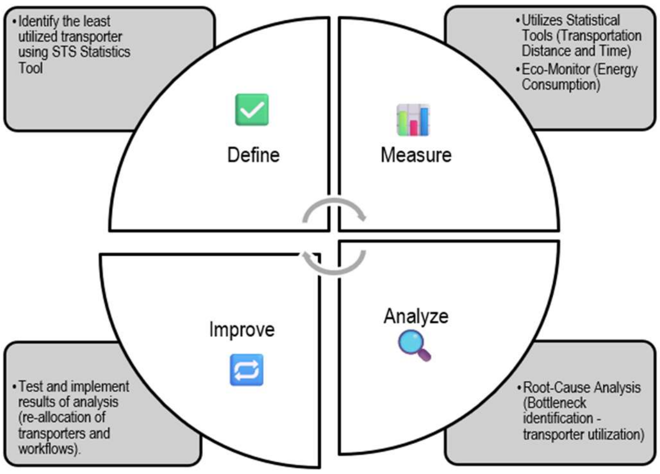


Figure 41. LEAN Six Sigma (Generated in MS PowerPoint)

The information flow chart for the STS simulation-based optimized decision support is described in the figure (Figure **42**) below:

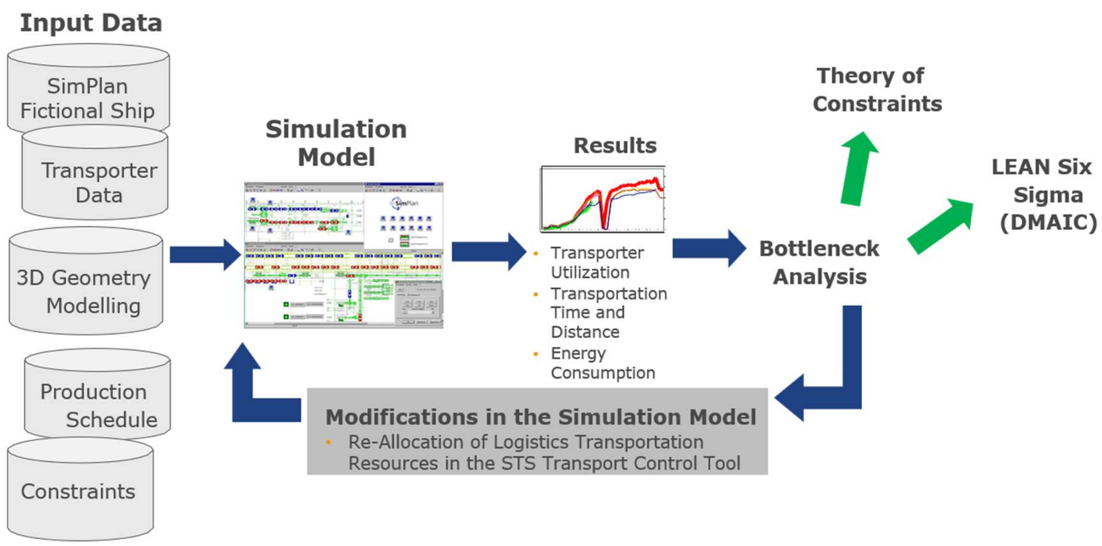


Figure 42. Flowchart – Simulation-Based Optimization (Generated in MS PowerPoint)

5. RESULTS AND DISCUSSIONS

In this chapter, the results are explained related to updating the initial simulation model into an advanced simulation model through implementation of complete production logistics. Example results are also explained which are calculated by using STS Transport Control, STS Model Statistics, Eco-Meter, and STS Eco-Monitor. These example results are used to estimate the operational cost and CO_2 emissions. The resulting optimization components are explained using proposed optimization tool for the advanced simulation model as a simulation-based optimized decision support.

5.1. Efficient Material Flow – Advanced Simulation Model

In this section, the updates made to the initial input shipyard simulation model and its results are discussed in terms of new constructions and transport management for advanced simulation model. The new roads and road crossings are modelled in advanced simulation model as shown in the figure (Figure **43**) below:

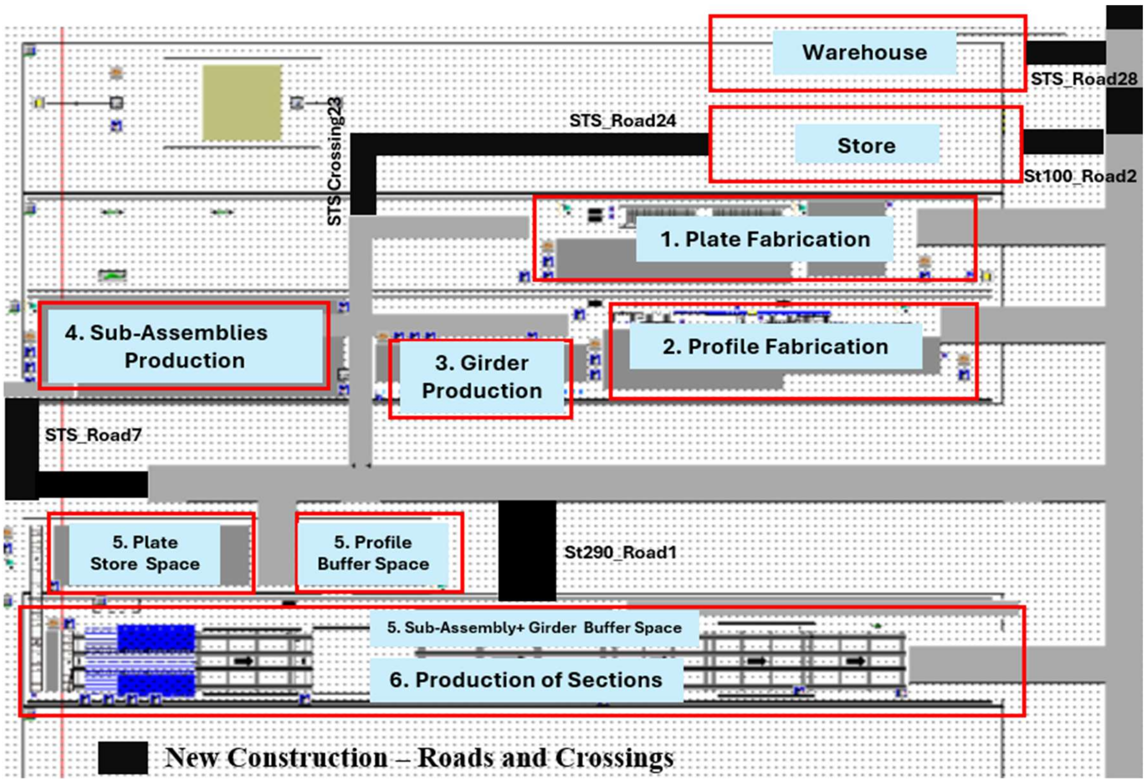


Figure 43. Shipyard Simulation Model - New Construction for Roads and Crossings

The front road of the warehouse (STS Road 28) has a U-Turn and turn-vehicle controls so the supplier trucks can return to STS Supplier Raw Material after delivery of material at the Warehouse Raw Material and Store Equipment. The Warehouse for raw materials such as steel plates and panels is modelled in advanced simulation model as shown in the figure (Figure **44**). This warehouse site, which is used to store the material, has dimensions of 70m in length and 20m in width. It has a gantry crane which is capable of 0.5m/s trolley speed with a length of 80m, a width of 22m, with three height levels: 6m, 9m, and 10m. The logistic transportation of raw materials from the supplier to the warehouse is shown in the figure (Figure **44**) below:

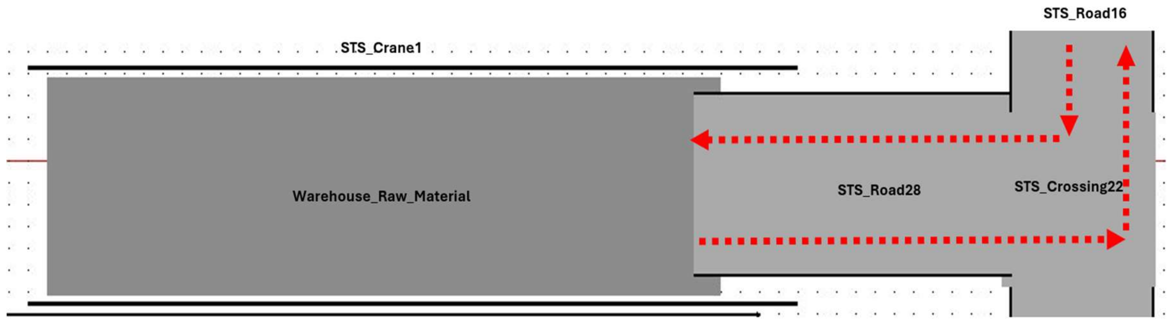


Figure 44. Transportation Route – Raw Materials from Supplier to Warehouse

The Equipment Store (For Brackets) is modelled in advanced simulation model with a storage site of a length of 65m and a width of 30m. The front road of the store for equipment (St100 Road 2) has a U-Turn and turn-vehicle controls so the supplier trucks can return to STS Supplier Equipment after delivery of material at the Store Equipment. The logistic transportation of equipment from the supplier to the store is shown in the figure (Figure **45**) below:

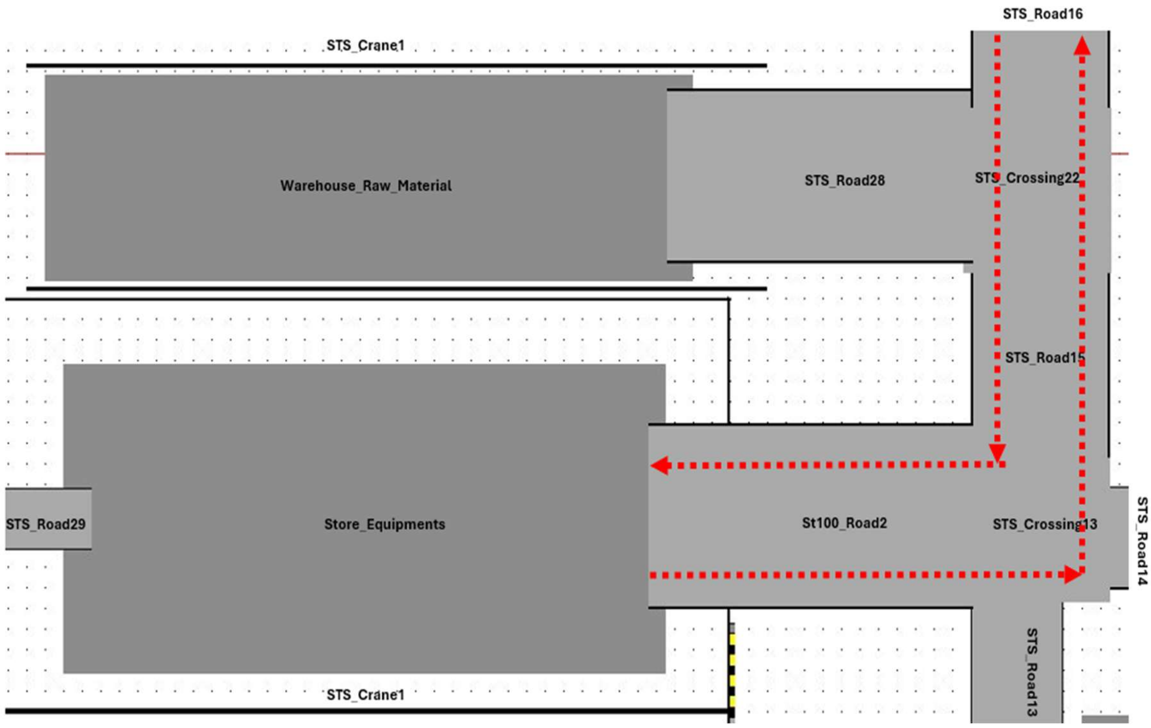


Figure 45. Transportation Route – Equipment from Supplier to Store for Equipment

In advanced simulation model, the logistic transportation of plates and profiles from the warehouse to the Plate Infeed Station and Profile Infeed Station using the AGV (Warehouse) is shown in the figure (Figure **46**). The U-Turn and turn-vehicle controls are provided at material delivery locations (STS Road 22 and STS Road 221) so the AGV (Warehouse) can return to its parking location or next destination as required by STS Assembly Control.

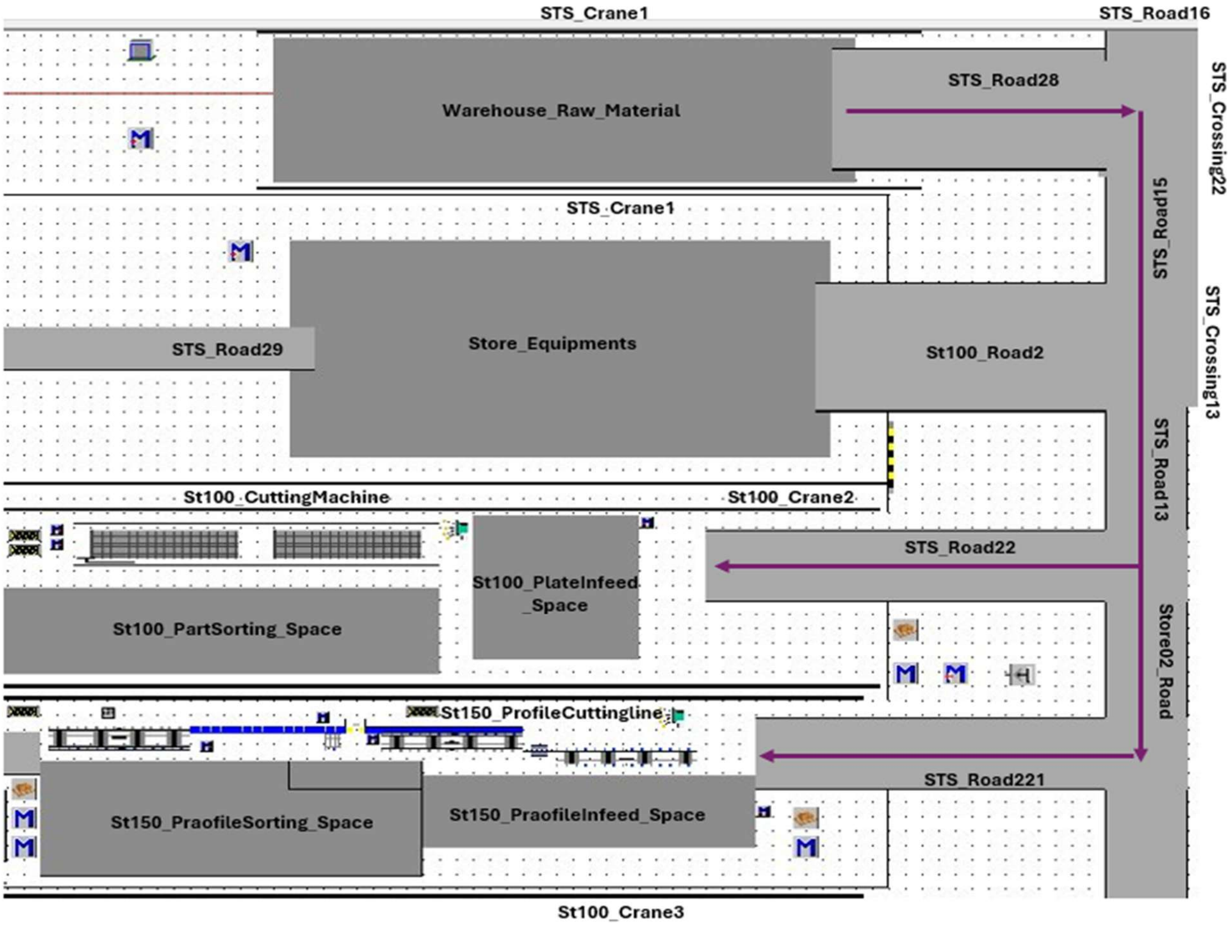


Figure 46. Transportation Route – Raw Material from Warehouse to Production Station

The buffer store for produced girders and sub-assemblies was not modelled in the initial simulation model. In advanced simulation model, the buffer space is modelled for girders and sub-assemblies at section production station. So, the St290 Assembly Space is created in the shipyard layout, which is used for the storage of produced girders and sub-assemblies, as shown in the figure (Figure **47**). The buffer space has a length of 50m and a width of 6m. The AGV (Main) is allocated here to drop the produced subassemblies and griders at St290 Assembly Space. Later, the Crane St280 is used to unload the material from the AGV and transport the material from St290 Assembly Space to St290 Assembly Conveyor. The logistic transportation of produced girder and sub-assemblies from the girder and sub-assemblies' production stations to the section production station is shown in the figure below (Figure **47**):

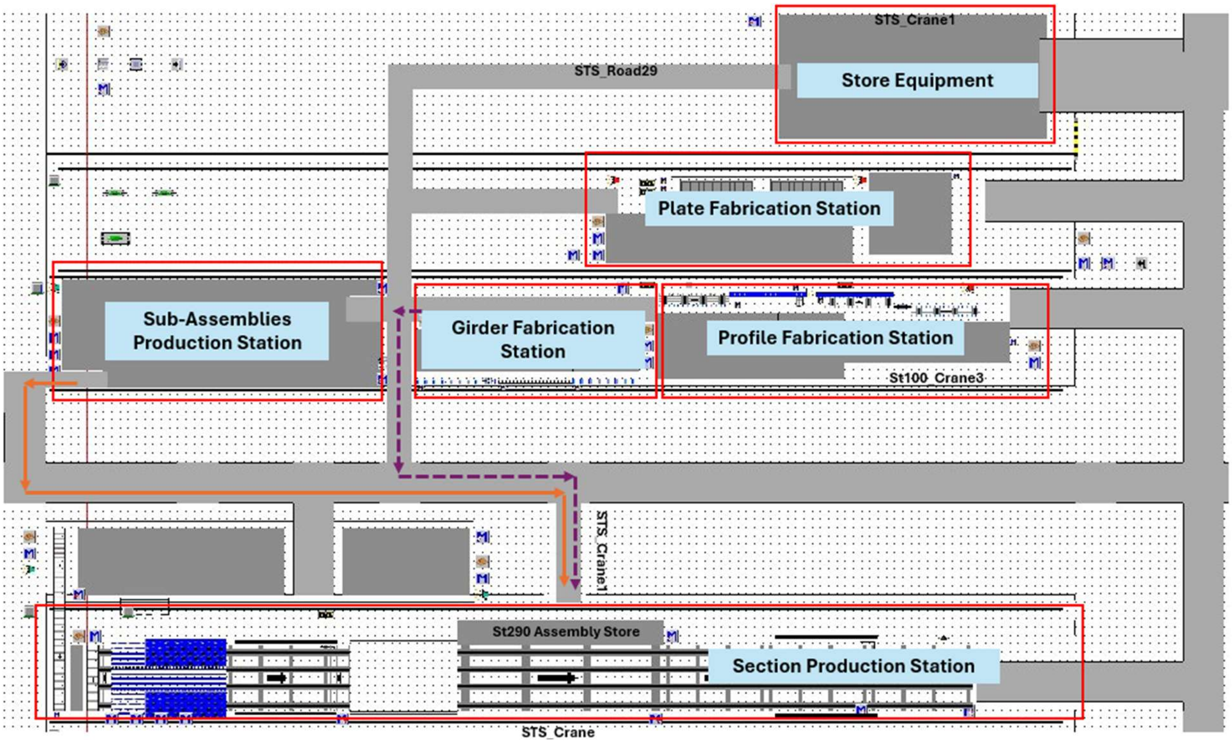


Figure 47. Transportation Route – Girder and Sub-Assembly to Section Production Station

In advanced simulation model, logistic transportation of brackets and long profiles from equipment store to section production station by using equipment forklift as shown in figure (Figure **48**):

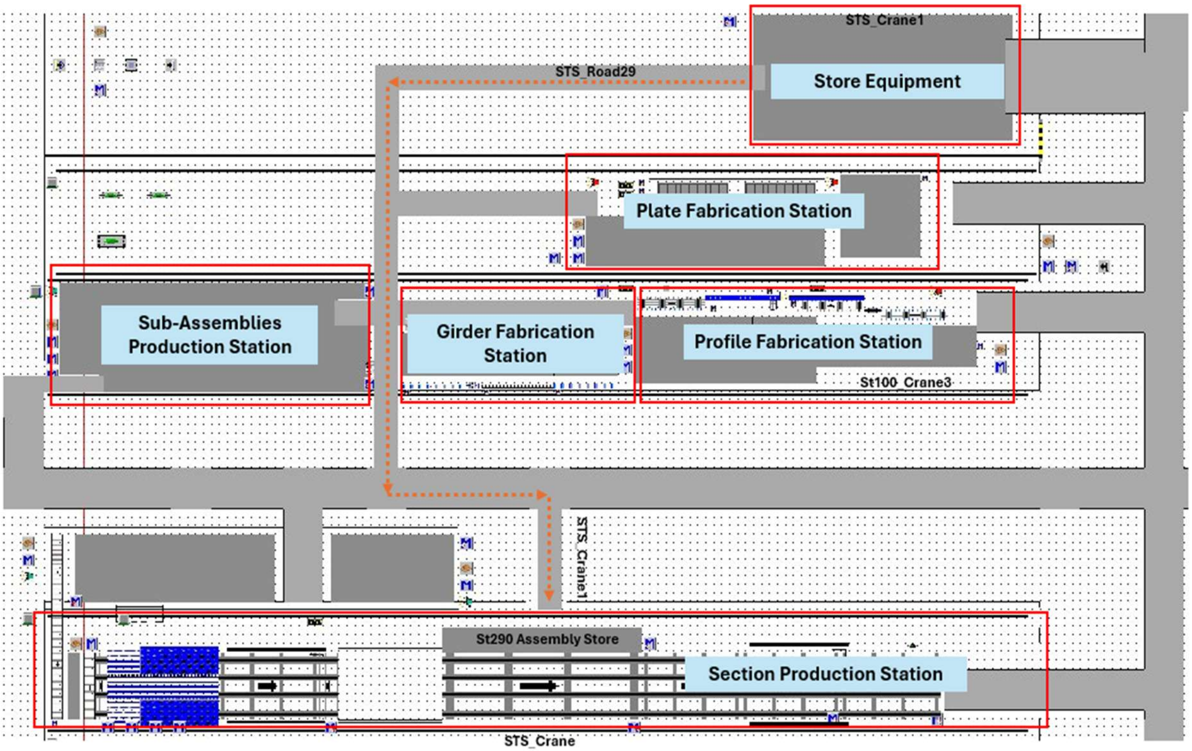


Figure 48. Transportation Route – Equipment Store to Section Production Station

The flexible racks are modelled in advanced simulation model at the Store_01 Space, Store_02 Space, Store_03 Space, and Store_04 Space to place the produced sections using a Ship Section Transporter. The movable racks are modelled to transport the assembled blocks from the Block Assembly Station (St310 Hall) to the Painting station (St410 Hall) and painted-assembled blocks from to Painting station (St410 Hall) to the Hull Erection Station (St610 Space), which are towed by the Ship Section Transporter. The resulting geometry of the movable racks is shown in the figure (Figure **49**):

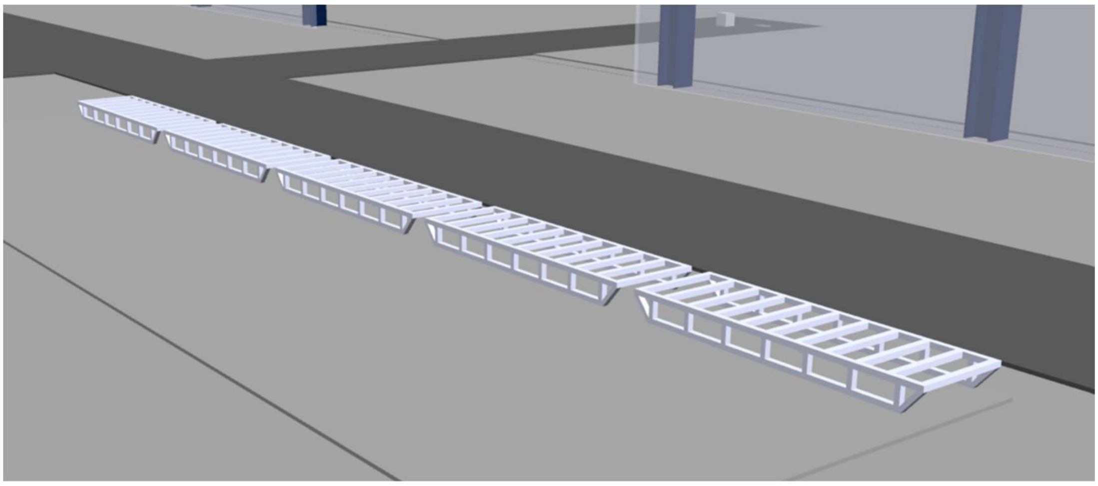


Figure 49. Results – Geometry of Movable Racks in Advanced Simulation Model

The fixed racks are modelled in advanced simulation model at the Hull Erection Buffer Space (St610 Space) to place the painted and assembled blocks from the movable rack (towed by the Ship Section Transporter) using a crane. The resulting geometry of the fixed racks is shown in the figure (Figure **50**) below:

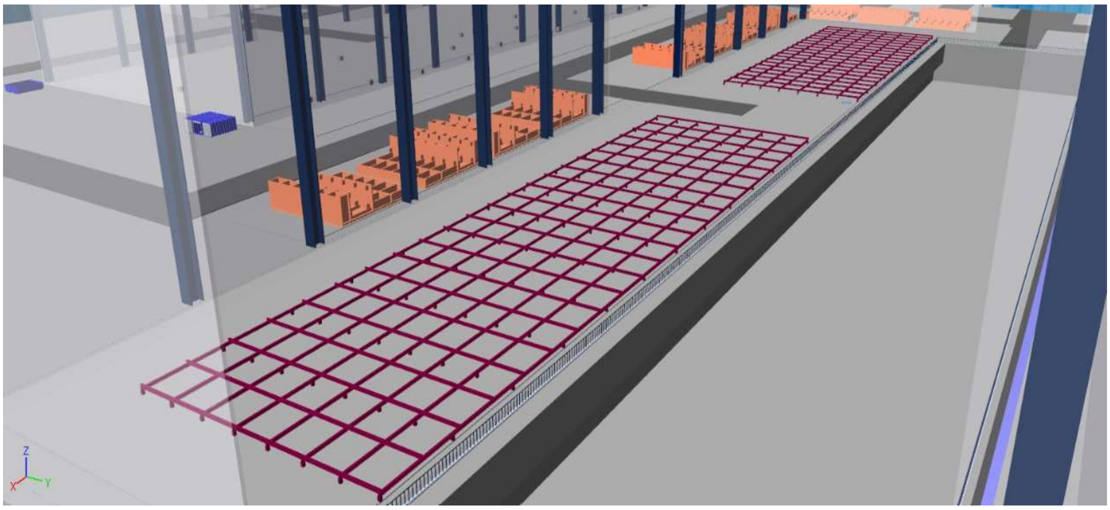


Figure 50. Results – Geometry of Fixed Racks in Advanced Simulation Model

The following table (Table **48**) explains the material flow in the Advanced Simulation Model with the notations categorizing material type based on the respective production process:

Table 48. Material Flow – Advanced Simulation Model

Sr. No	Symbol	Operation	Transport From	Transport To	STS Tool
1		Movement of Shipments to Warehouse Store	STS Supplier	Warehouse Store	STS Truck
2		Movement of Raw material from the store to Plate Fabrication, Profile Fabrication, and Sub-Assemblies Production	Warehouse Store	Plate, Profile, and Sub-Assemblies Production Station	STS Forklift, STS AGV
3		Fabricated Plates to Plate Store Space for Production of Sub-Assemblies and Sections	Plate Fabrication Station	Plate Store Space and Sub-Assemblies Production	STS AGV
4		Fabricated Profile Store Space for Production of Sub-Assemblies and Sections	Profile Fabrication Station	Profile Buffer Store	STS AGV
5		Fabricated Girders transportation to produce Sub-Assemblies and Sections	Girders Fabrication Station	Sections Production Station	STS AGV
6		Produced Sub-Assemblies for Production of Sections	Sub-Assemblies Production Station	Sections Production Station	STS AGV
7		Outfitting Process (Brackets and Long Profiles supply at Sections Production Station)	Raw Material Store (Brackets and Long Profiles)	Sections Production Station	STS Forklift
8		Produced Sections for Hull Erection Process and for waiting, storing in store, and then moving to block assembly area	Production of Sections	Hull Erection, Section Store, and Block Assembly	STS Ship Section Transporter
9		Assembled Blocks for the Painting Process	Block Assembly Station	Painting Process Station	STS Ship Section Transporter
10		Painted Blocks for Hull Erection Process	Painting Process Station	Final Assembly Station (Hull Erection)	STS Ship Section Transporter
11		Transporting Empty Movable Racks to Rack Store	Final Assembly Station (Hull Erection)	Rack Store	STS Ship Section Transporter

The finalised shipyard layout of the advanced simulation model is shown in figure (Figure **51**):

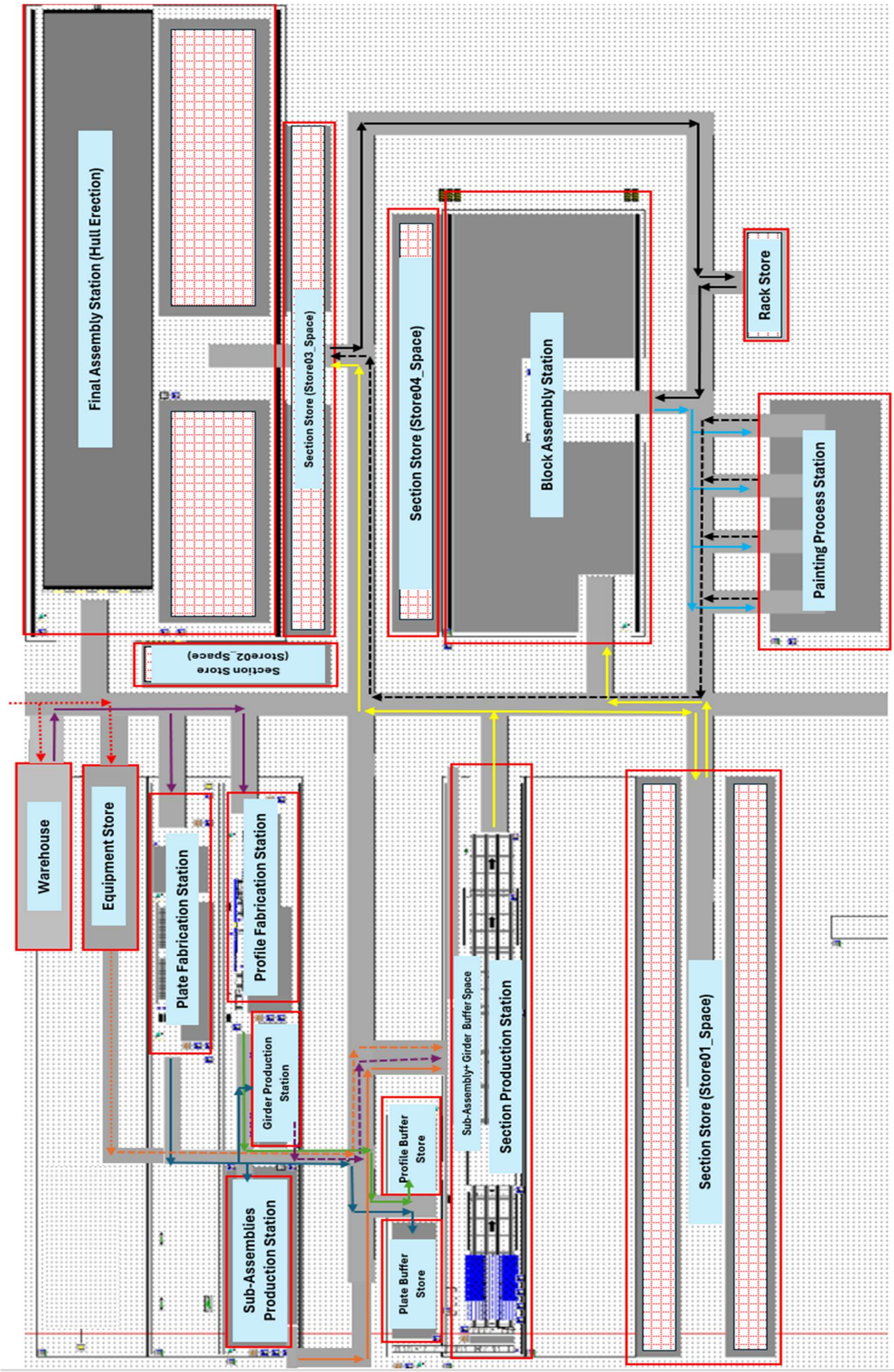


Figure 51. Shipyard Layout – Advanced Simulation Model

5.2. Efficient Material Flow – Transport Statistics & Utilisation

5.2.1. STS Transport Control Tool

The STS Transport Control Tool provides the starting date, ending date, travel distance (km), travel duration (Hours), and percentage utilisation for each transporter. The detailed results of STS Transport Control Tool are shown in table (Table **61**). The results collected for the Automated Guided Vehicle for transportation of raw material are described in table (Table **49**):

Table 49. AGV (Warehouse) – Results by Advanced Simulation Model

Transporter	Start Date	End Date	Distance Travelled (km)	Duration (Hours)
AGV (Warehouse)	18.01.2025	22.01.2025	9.05	2.6
	25.01.2025	30.01.2025	18.91	3.31
	Total =		**27.96**	**5.99**

The results of the Automated Guided Vehicle (Main) used to transport the girders, fabricated plates, fabricated profiles, and produced sub-assemblies are described in the table (Table **50**):

Table 50. AGV - Results by Advanced Simulation Model

Transporter	Start Date	End Date	Distance Travelled (km)	Duration (Hours)
AGV	18.01.2025	01.02.2025	51.14	8.67
	Total =		**51.14**	**8.67**

The collected results of the Equipment Forklift for the transportation of brackets are described in the table (Table **51**):

Table 51. Forklift - Results by Advanced Simulation Model

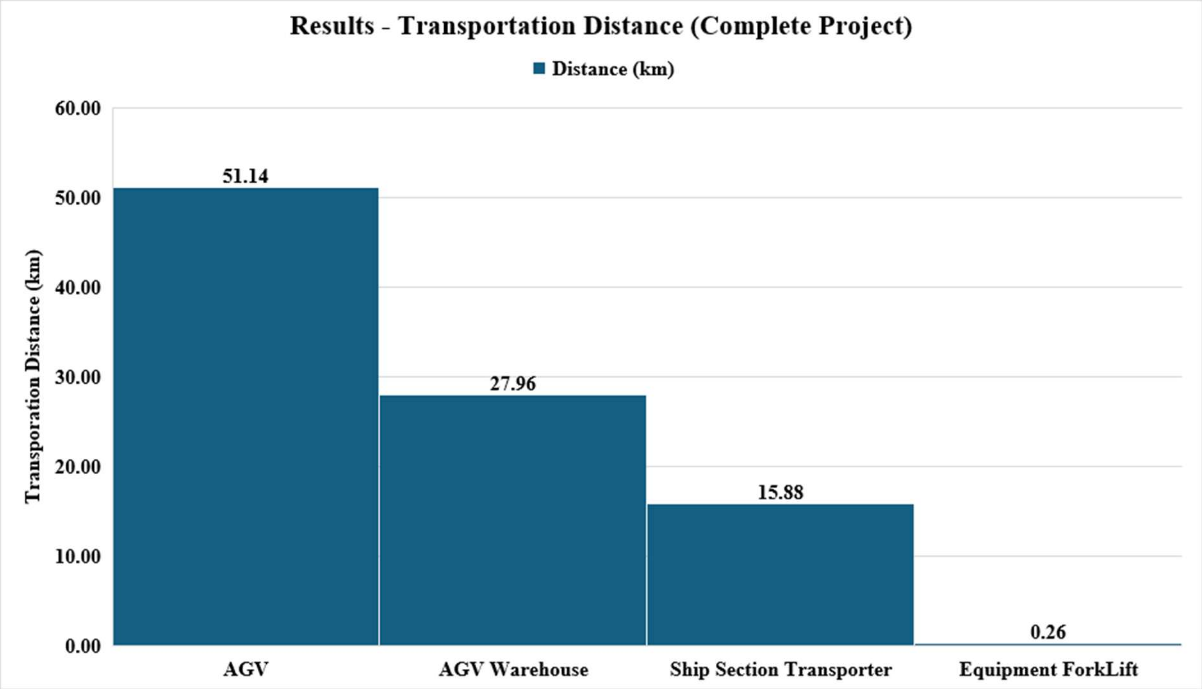
Transporter	Start Date	End Date	Distance Travelled (km)	Duration (Hours)
Equipment Forklift	20.01.2025	20.01.2025	0.26	0.14
	Total =		**0.26**	**0.14**

The collected results of the Ship Section Transporter for the transportation of produced sections, assembled blocks, and painted-assembled blocks are described in the table (Table **52**) below:

Table 52. Ship Section Transporter - Results by Advanced Simulation Model

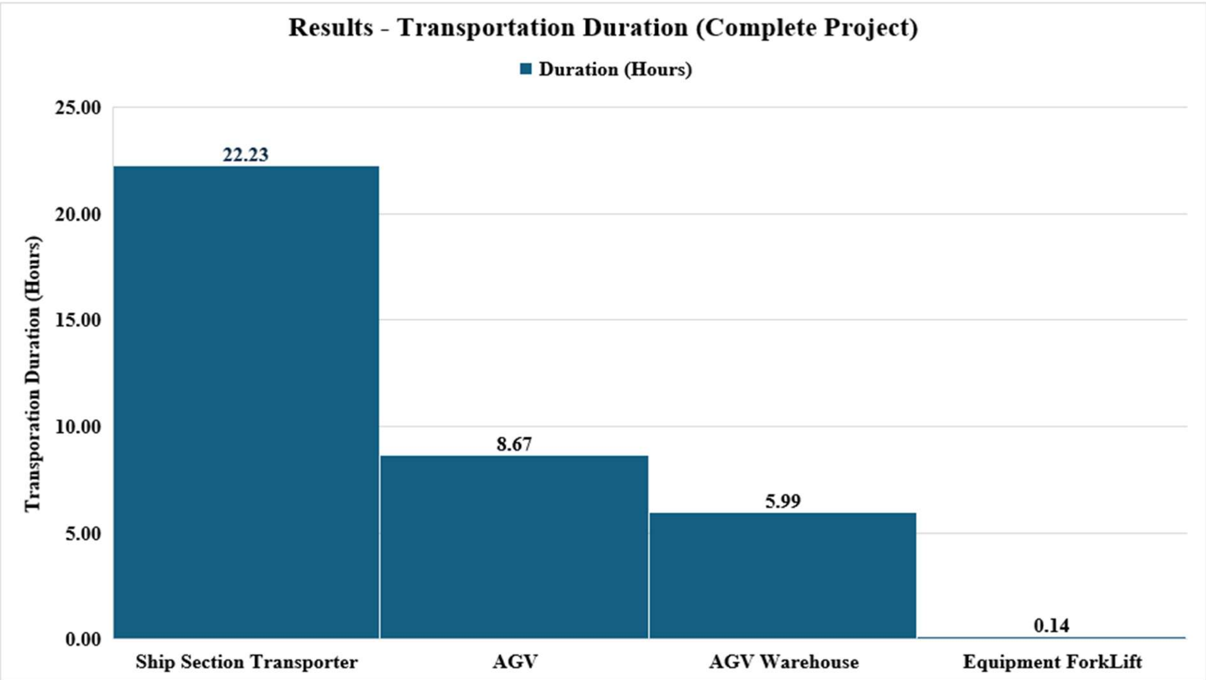
Transporter	Start Date	End Date	Distance Travelled (m)	Duration (Hours)
Ship Section Transporter	21.01.2025	25.01.2025	2.16	3.26
	27.01.2025	02.02.2025	3.99	5.53
	23.02.2025	29.03.2025	9.91	13.44
	Total =		**16.06**	**22.23**

The graphical representation of transportation distance (km) by each transporter is shown in plot (Graph **1**) below:



Graph 1. Results – Transportation Distance (km)

The graphical representation of transportation time (hours) by each transporter is shown in plot (Graph **2**) below:



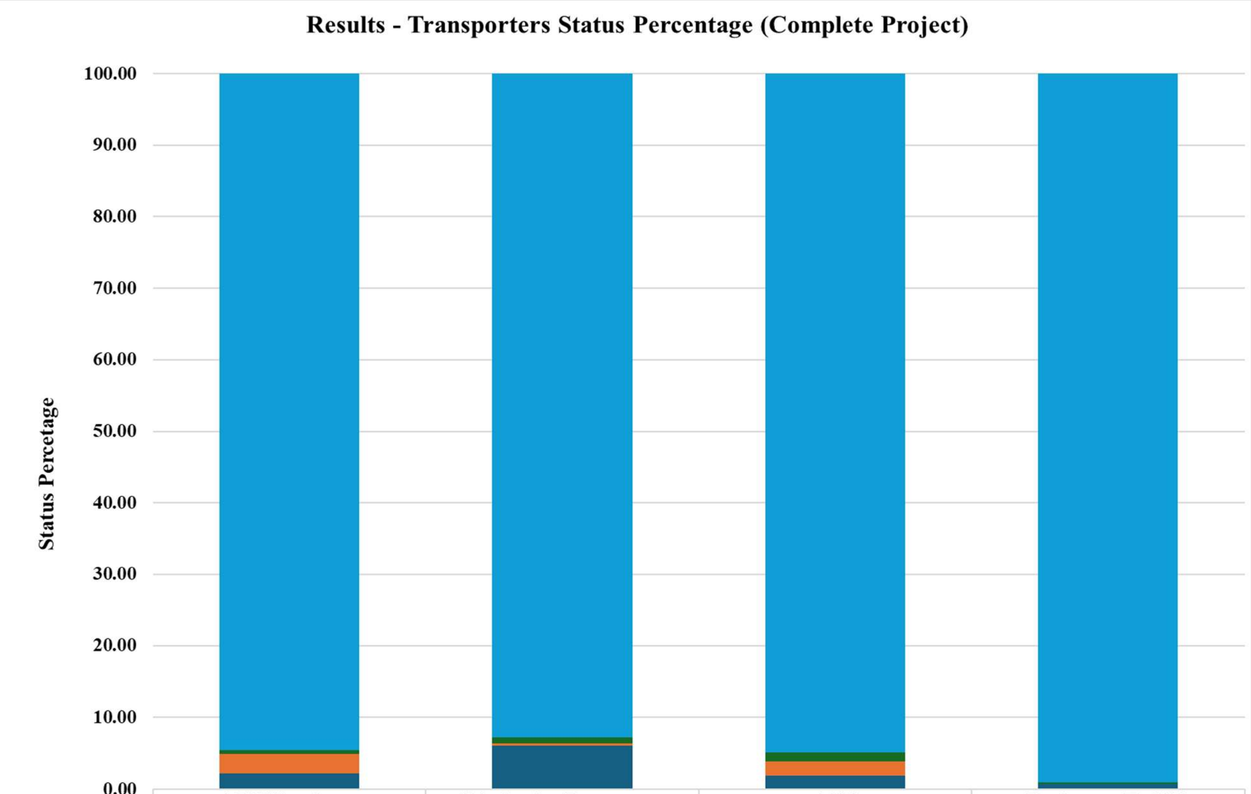
Graph 2. Results – Transportation Duration (Hours)

Using the STS Transport Control Tool, the calculated percentage status for each transporter after a complete simulation run is shown in the table (Table **53**) below:

Table 53. Results - Transporters Percentage Status

Sr. No.	Operational Status	AGV (Warehouse)	Ship Section Transporter	AGV	Equipment Forklift
1	Delivering	2.16	6.09	1.88	0.70
2	Fetching	2.74	0.33	2.00	0.00
3	Moving Empty	0.52	0.79	1.28	0.20
4	Waiting	94.57	92.79	94.84	99.10

Based on percentage status calculated by STS Transport Control Tool, the resulting chart from these example results for each transporter is given in plot (Graph **3**):



	AGV Warehouse	Ship Section Transporter	AGV	Equipment Forklift
Waiting	94.57	92.79	94.84	99.10
Moving Empty	0.52	0.79	1.28	0.20
Fetching	2.74	0.33	2.00	0.00
Delivering	2.16	6.09	1.88	0.70

Graph 3. Results – Transporters Status Percentage (Complete Project)

5.2.2. STS Model Statistics Tool

The STS Model Statistics provides transporters' utilisation of each transporter, based on throughput of each production station. The throughput statistics provide starting date of full production and ending date of full production. These dates are the range in which the transporters that are 100% utilised are shown in the table (Table **54**) below:

Table 54. STS Model Statistics Tool - Throughput Statistics

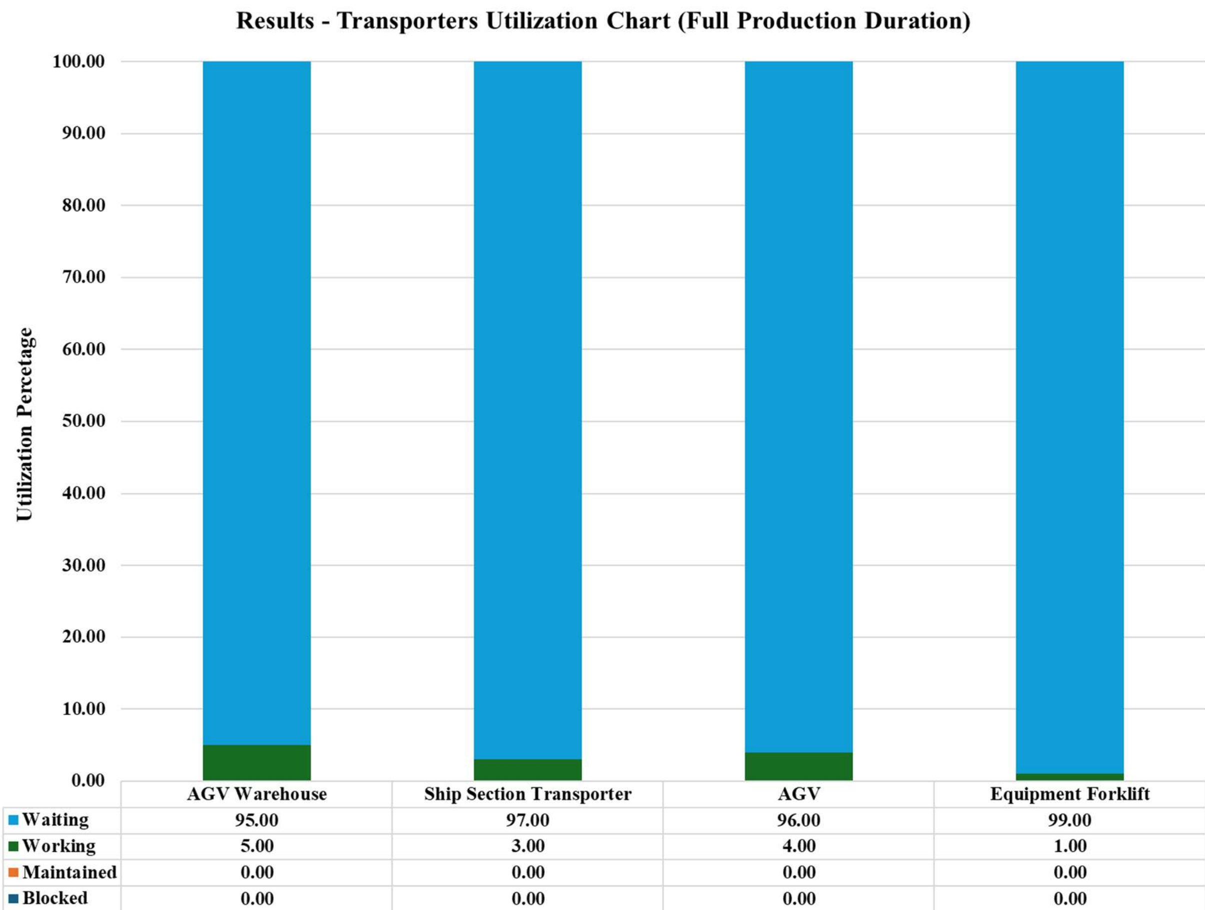
Conditition	Description	Date
Starting Date: Full Production	Plate Cutting Ends at Plate Fabrication Station	20.01.2025
Ending Date: Full Production	Section Production Start	30.01.2025

The table (Table **55**) describes percentage utilisation of each transporter for a complete project.

Table 55. Results - Transporters Utilisation Percentage Data

Operational Status	AGV (Warehouse)	Ship Section Transporter	AGV	Forklift
Blocked	0.00	0.00	0.00	0.00
Maintained	0.00	0.00	0.00	0.00
Working	5.00	3.00	4.00	1.00
Waiting	95.00	97.00	96.00	99.00

Plot (Graph **4**) shows the utilisation chart based on percentage utilisation of transporters:



Graph 4. Results – Transporters Utilisation Chart (Complete Project)

5.3. Energy Efficient Production Logistics Transport Management

5.3.1. Eco-Meter - Transporter Technical Data and Energy Parameters

Using the steps in the methodology, the Eco-Meter is integrated with the STS Transport Control Tool in the simulation model. In Eco-meter, the ValueFix and ValueVariable are estimated. The ValueFix is the fuel or electrical energy which is utilized during the transition states in operations. ValueFix is categorized to occur one time in each state change, independent of the complete duration of transportation, and provided by manufacturers in the form of the transporter technical data sheets. The ValueVariable is the rate of continuous fuel or electrical energy consumption during the transportation time unit during the operational states such as idle, busy, and pause state. ValueVariable is usually depends on the operational duty cycles of the transporter. According to the available transporters in the advanced simulation model, the AGVs and equipment forklifts are electric powered, while the Ship Section Transporter has hybrid power (diesel/electric). The fuel and electric energy consumption by each transporter can be very small but not zero during the idle and pause conditions.

The input data for Eco-Meter is assumed in the advanced simulation model based on details provided in the table (Table **56**):

Table 56. Eco-Monitor - Transporter Technical Data

Transporter	Value Variable	Value Fix	Fuel Variable	Fuel Fixed	Technical Data Validation
Automated Guided Vehicles	7 kW	0.25 kWh	0 liter/hr.	0 liter/hr.	• The typical electric motor output of mid-sized AGVs consumes 3kW to 10 kW in shipyards (Savvidis, Ramasamy et al. 2024). • AGVs consume around 1% to 5% of total hourly usage based on the energy spike during motor startup, and acceleration (Liangou and Dentsoras 2021). • No Fuel powered.
Equipment Forklift	4.5 kW	0.15 kWh	0 liter/hr.	0 liter/hr.	• For the 2.5–3.5ton capacity forklifts consumes 2.5–4.5kW during normal load handling and 3kW for transportation operations. The ON/OFF switching during the lifting system forklift consumes around 3% to 5% of the hourly operating energy (Lun, Wang et al. 2021). • No Fuel powered.

Ship Section Transporter (SPMT)	8–20 kW	0.3 kWh	0.02 liter/hr.	0.01 liter/hr.	• SPMT (diesel-hybrid) supplied by Goldhofer, Scheuerle) can deliver 390 kW power, but based on real operational conditions, 5% to 10% of this power capacity is used for slow/controlled controls. Initially, high torque requires more energy spikes, which require fixed fuel for startup and hydraulic systems (Ren, Zhang et al. 2022). • During hybrid operation, SPMT (diesel-hybrid) is capable of 150 kW pack using 15% duty cycle. So, under transport loads ~20 kW (Yuan, Chen et al. 2022).

Based on the transporter technical data described in the table (Table **56**). The resulting energy parameters were defined in the Eco-Meter, which are shown in the appendix table (Table **62**).

5.3.2. Eco-Monitor Results – Total Electric Energy and Fuel Consumption

The total electric energy consumption and fuel consumption calculated by Eco-Monitor are shown in the table (Table **57**) below:

Table 57. Eco-Monitor Results – Total Electric Energy and Fuel Consumption

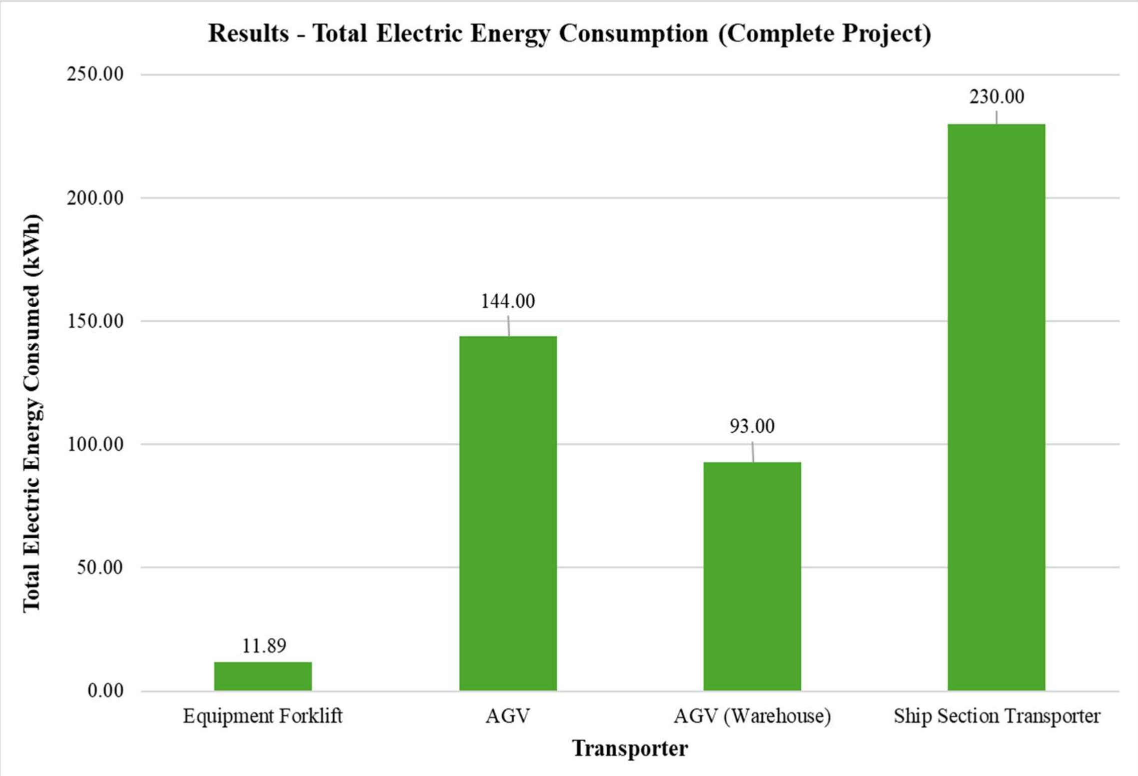
Transporter	Energy Electric Consumed	Fuel Consumed
Equipment Forklift	11.89 kWh	0
AGV	144.00 kWh	0
AGV (Warehouse)	93.00 kWh	0
Ship Section Transporter	230.00 kWh	64.00 Liters
Total Consumption=	**479.89 kWh**	**64.00 Liters**

Table (Table **58**) shows calculated electric energy consumption based on time series (monthly):

Table 58. Eco-Monitor Results – Time Series Vs Electric Energy Consumption

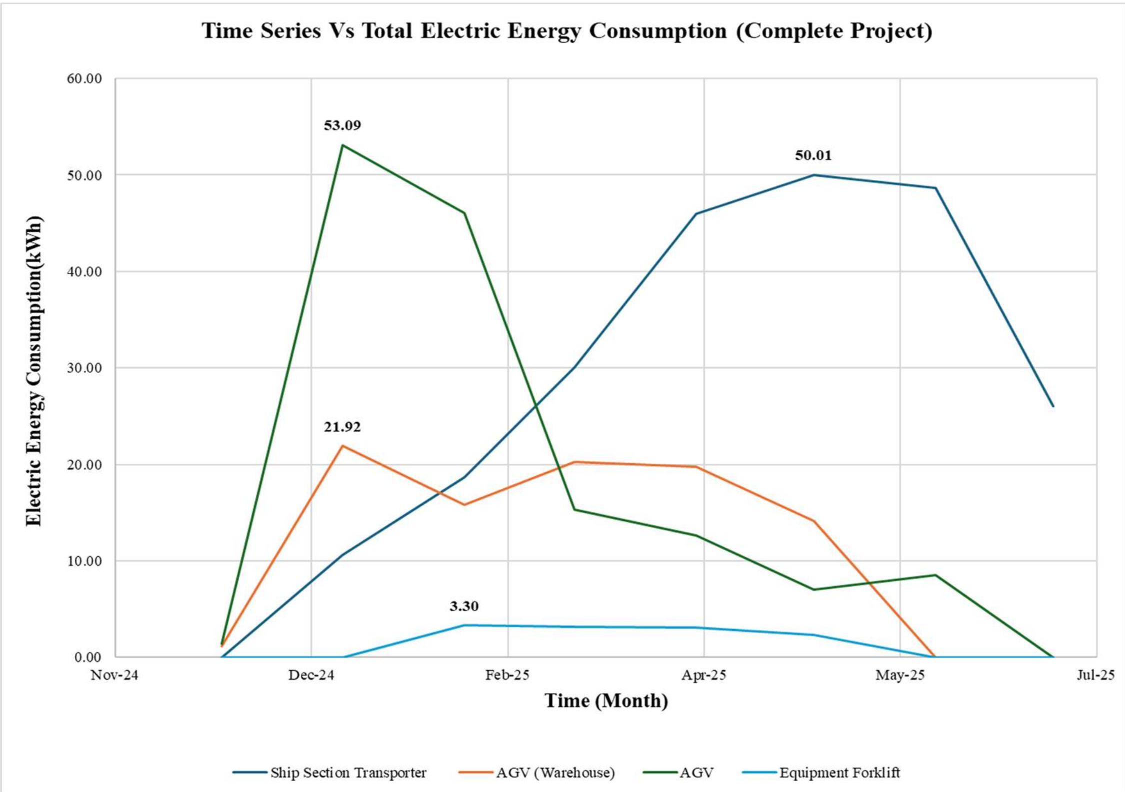
Month	Ship Section Transporter	AGV (Warehouse)	AGV	Equipment Forklift
Dec-24	0.00 kWh	1.12 kWh	1.39 kWh	0.00 kWh
Jan-25	10.63 kWh	21.92 kWh	53.09 kWh	0.00 kWh
Feb-25	18.70 kWh	15.79 kWh	46.04 kWh	3.30 kWh
Mar-25	30.07 kWh	20.29 kWh	15.28 kWh	3.14 kWh
Apr-25	45.95 kWh	19.73 kWh	12.65 kWh	3.10 kWh
May-25	50.01 kWh	14.15 kWh	7.01 kWh	2.36 kWh
Jun-25	48.66 kWh	0.00 kWh	8.54 kWh	0.00 kWh
Jul-25	26.00 kWh	0.00 kWh	0.00 kWh	0.00 kWh
Total =	**230.00 kWh**	**93.00 kWh**	**144.00 kWh**	**11.89 kWh**

The electric energy consumption chart is shown in the plot (Graph **5**) below:



Graph 5. Results – Total Electric Energy Consumption (Complete Project)

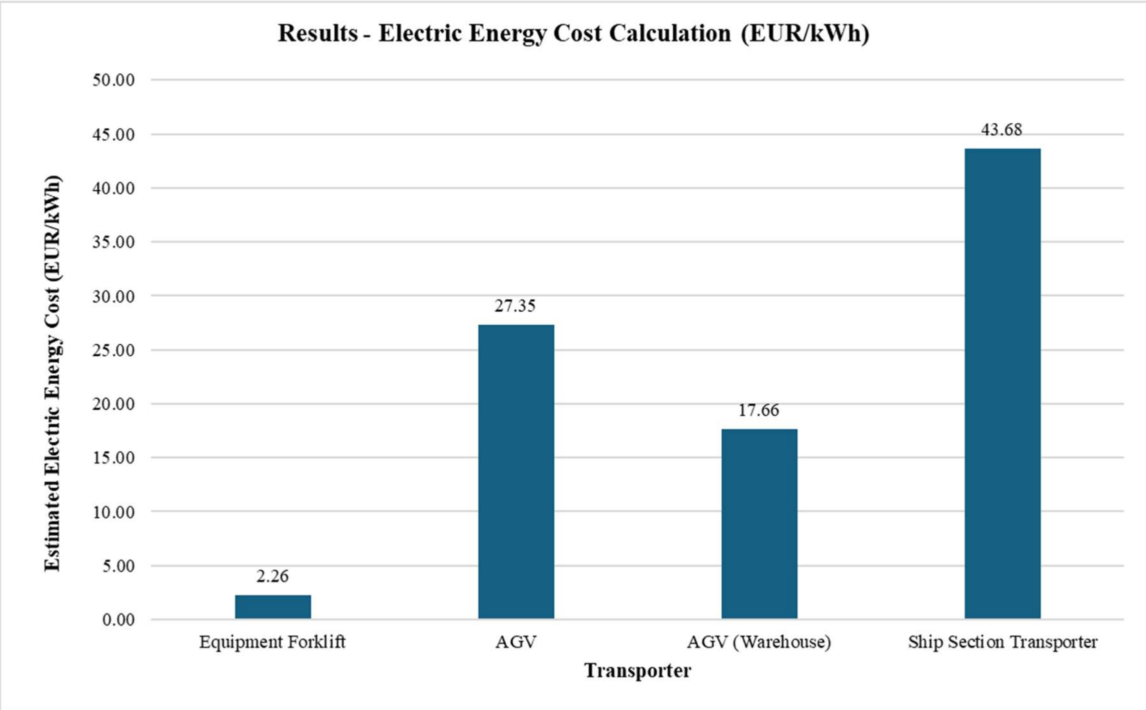
The time series chart for electric energy (kWh) consumption is shown in the plot (Graph **6**):



Graph 6. Results – Time Series Vs Total Energy (kWh) Consumption (Complete Project)

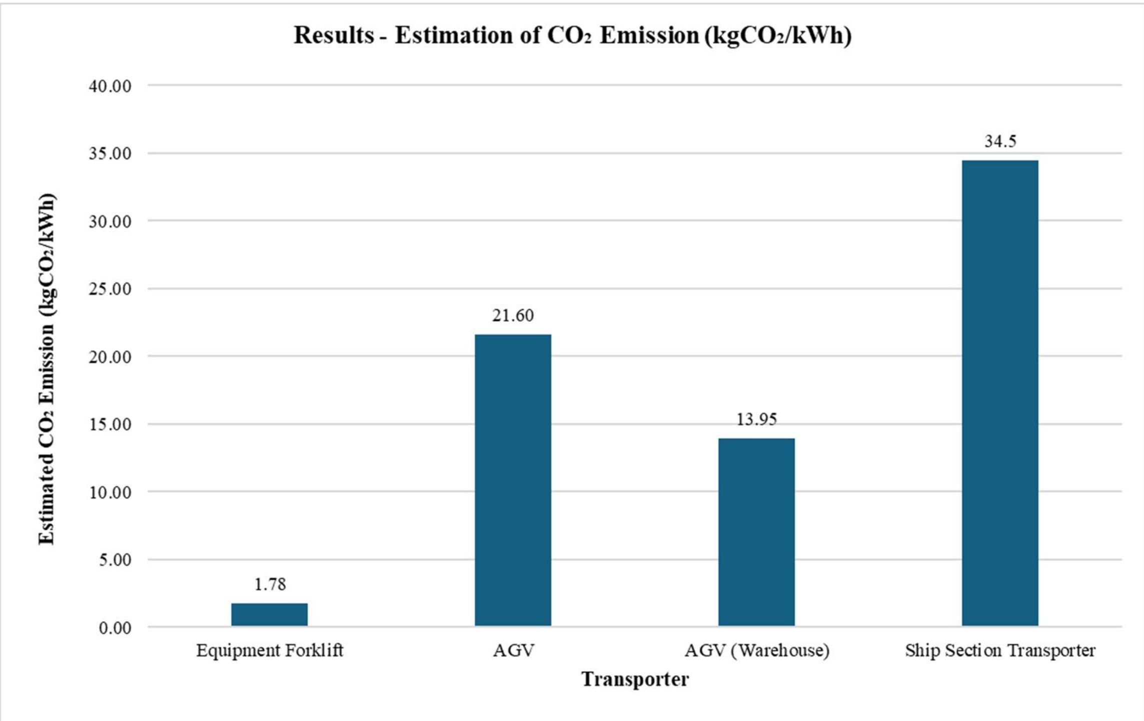
5.3.3. Results – Electric Energy Cost Calculation and CO2 Emission Estimation

The results for the estimated electric energy cost (EUR/kWh) are shown in the plot (Graph **7**):



Graph 7. Results – Estimated Electric Energy Cost (EUR/kWh)

The results for estimated CO_2 emission ($kgCO_2$/kWh) are shown in the plot (Graph **8**):



Graph 8. Results – Estimated CO_2 Emission ($kgCO_2$/kWh)

5.4. Simulation-Based Optimized Decision Support

5.4.1. Optimization Process – Components

In this section, proposed optimization components are described in figure (Figure **52**) below:

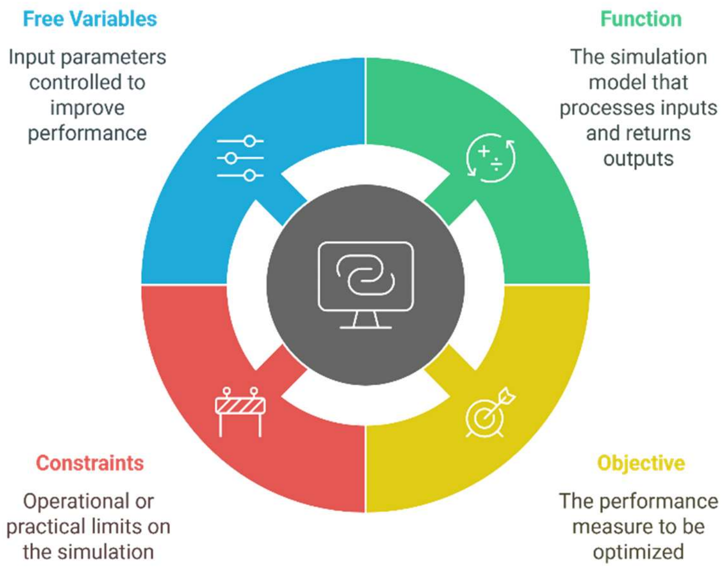


Figure 52. Simulation-Based Optimization Components (Generated by Napkin.AI)

For the advanced simulation model, the simulation-based optimization components are defined without explicit mathematical equations based on the Theory of Constraints (TOC) and LEAN Six Sigma (DMAIC), as discussed below.

5.4.2. Optimization Component – Function

The advanced simulation model is considered as a function with the following shipbuilding parameters, as explained below:

1. **Efficient Flow:** Movement of material for smooth flow at the shipyard in terms of:
   a) Raw material (plates and profiles)
   b) Equipment (pre-fabricated brackets and pre-fabricated large profiles)
   c) Fabricated material (fabricated plates, fabricated profiles, fabricated griders)
   d) Large steel structure (produced sub-assemblies, produced sections, assembled blocks, painted-assembled blocks).

2. **Mix and Discrete Transportation:** Efficient utilisation of production logistics transporters as listed below:
   a) Automated Guided Vehicles (AGVs)

b) Ship Section Transporters
c) Forklifts

3. **Eliminating Bottlenecks and Unwanted Material Handling:** The shipyard layout must avoid unnecessary material handling and transportation for the following measures:
   a) Prioritizing the material routing to/from the bottleneck
   b) Transporters are prioritized for moving materials to/from the bottleneck station.
   c) Preventing the transportation of excess materials, which is causing a piling up at the bottleneck.

5.4.3. Optimization Component – Objectives

In this multi-objective optimization process, there are two types of objectives such as Ecological and Technical, as explained below:

1. **Technical – Just-In-Time Material Delivery**:
   For JIT material delivery, the objectives are listed below:
   a) Maximize Production Efficiency: Meeting the planned production timelines without any delay.
   b) Minimize the WIP (Work-In-Progress): Delivering the production material at the required production station just before the next production process starts.
   c) Maximize Buffer Zones: All production stations must have the required buffer capacity at the infeed or buffer spaces to ensure JIT material delivery when it is required.
   d) Maximize Transporter Utilization: Eliminate the risk factors affecting the efficient utilization of logistic transporters.

2. **Ecological - Lowest Energy Consumption:**
   To achieve energy-efficient production at the shipyard, the objectives are listed below:
   a) Minimize the distance travelled by Transporters
   b) Minimize the idle and waiting time for Transporters

5.4.4. Optimization Component – Constraints

The following table (Table **59**) describes the constraints for the optimization process, considering different production parameters as below:

Table 59. Optimization – Constraints

Sr. No	Constraint	Explanation
1	Throughput of Production Station	Achieving the production target according to the production plan
2	Buffer Store Capacity	Adjusting the size of the buffer store to eliminate waiting time for upcoming material caused by space availability at buffer stores, which leads to lower WIP (Work-In-Progress).
3	Availability of Logistic Transporter	A suitable fleet size, maintenance time, and charging time for EVs.
4	Shipyard Traffic Management	Fixing the route blockage, collision risks, and congestion management.

5.4.5. Optimization Component – Free Variables

The following table (Table **60**) describes the free variables for the optimization process:

Table 60. Optimization – Free Variable

Sr. No	Free Variables	Explanation
1	Route for Transporter	Utilization of STS Transport Management to find a suitable route
2	Selection of Transporter	Based on operational requirements and availability in STS Library
3	No. of Working Shifts	STS Work Shift Control is used to define the working shifts.

The following figure (Figure **53**) summarizes the translation of the problem statement to perform the optimization process using the advanced simulation model:

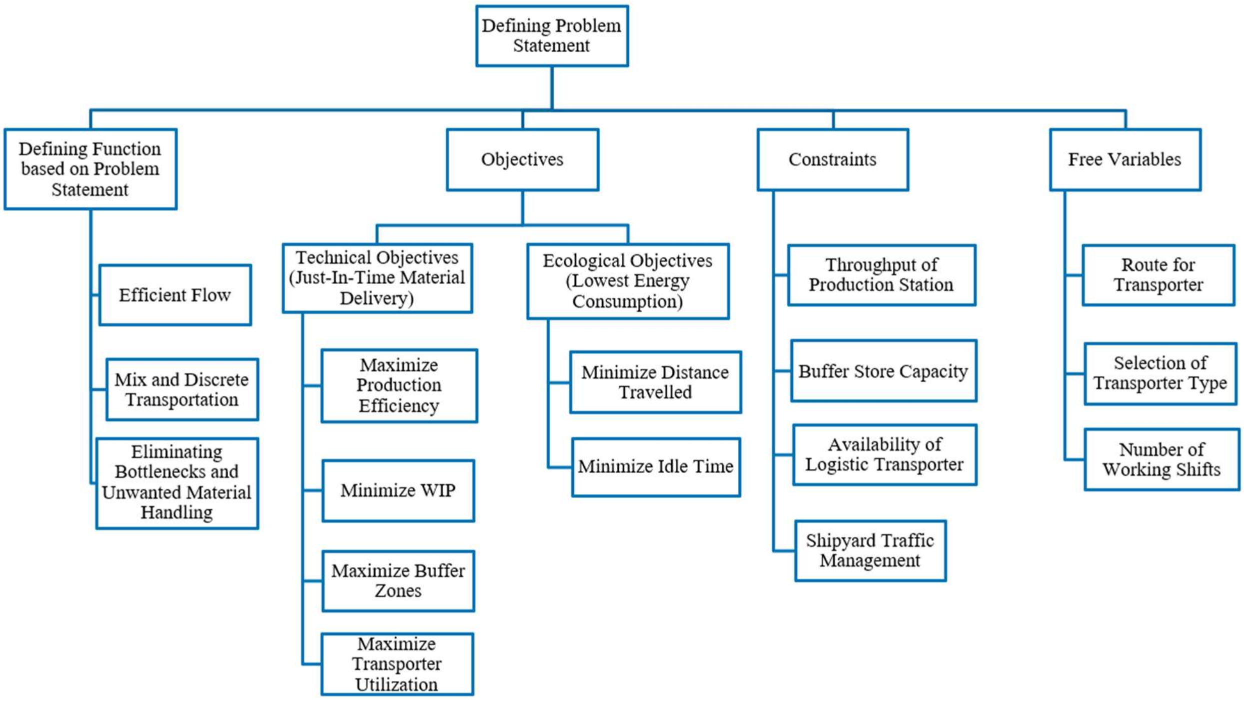


Figure 53. Optimization – Summary for Translation of Problem Statement

6. DISCUSSIONS

6.1. Interdependency: Material Flow, Energy Consumption, and Production Schedule

The Shipyards consist of complex subsystems, which are interconnected to form a complete production system. The interaction between these complex sub-systems affects the overall productivity in shipbuilding in case of any delay caused in any sub-system. Because it propagates throughout the production system. In the advanced simulation model, STS Transport Control and STS Statistic Model Tool provide the transportation data and throughput data. The integrated Eco-Monitor with STS Transport Control Tool provides an opportunity for the transporter to reschedule to reduce the energy usage by optimizing the logistic movements. The rescheduling of these critical buffer zones will help to reduce idle time and energy cost. Along with the energy-efficient production processes, the delays in material delivery provide an opportunity for engineers to locate the bottlenecks using throughput data recorded by the STS Statistic Model Tool. Usually, the delay in material delivery is caused by the disrupted material flow due to transporter congestion in the simulation models. In this way, this advanced simulation model helps the engineers synchronize the production schedules and production logistics planning. This synchronization will help to ensure JIT (Just-In-Time) material delay by eliminating WIP for all production sub-systems in the simulation model. Similarly, the energy peaks can be minimized during production processes by synchronizing the transporter scheduling with minimum energy demand durations. It is possible that the transporter routes managed by STS Transport Control may not align every time with the energy-efficient logistic routes. In this case, it is suggested to implement the trade-off strategy in terms of the minimum energy consumption routes and higher productivity routes. It is because the shortest transportation routes may maximize the Work-In-Progress for buffer spaces. This is the reason that we have used multi-objective optimization for the feedback loop as structured for the advanced simulation model of shipyard production logistics. The feedback loop helps to reduce the Work-In-Progress (WIP) state for production sub-systems by evaluating the transportation time, energy consumption, and throughput of each sub-system. Energy-efficient routes may not always align with shortest-time routes. In this case, the dynamic energy consumption is calculated for the duration when all production systems are being utilized 100% which is identified as the starting date of full production is when the plate cutting is completed by the cutting machine at the plate fabrication station, and the ending date of full production when the section production starts at the section production station. This duration is used to evaluate the throughput data for the final optimization of the transportation time and distance. The initial optimization in terms of dynamic re-routing of logistic transporters based on the high congestion routes and shift changes has already been done by using the STS transport control tool in the advanced simulation model. The interdependency between the Material Flow, Energy Consumption, and Production Schedules is summarized in the figure (Figure **54**) below:

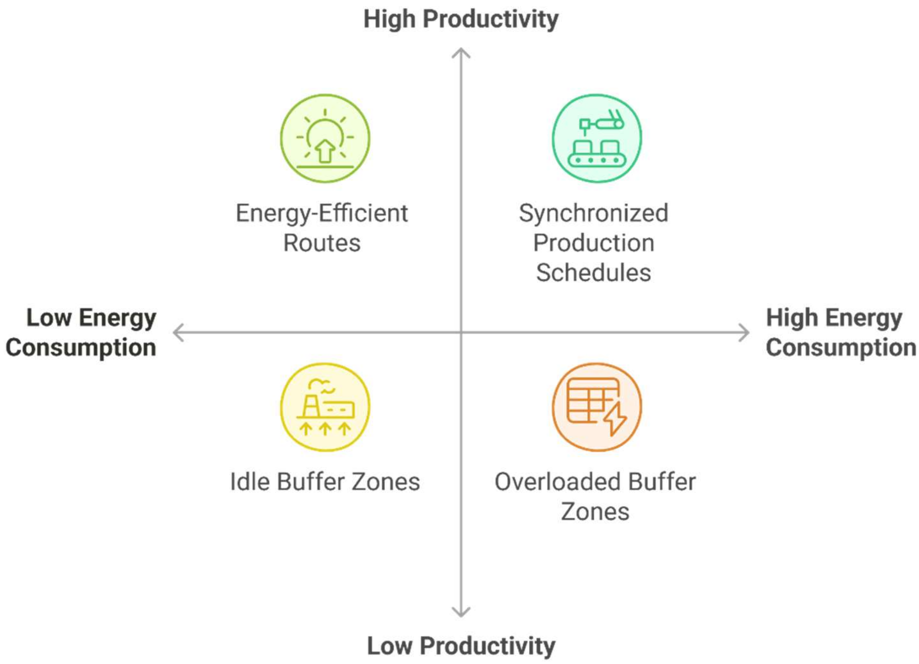


Figure 54. Productivity Vs Energy Consumption (Generated by Napkin.AI)

6.2. Performance Metrics: Material Flow, Energy Consumption, & Resource Allocation

The performance evaluation of this advanced simulation model in terms of efficient material flow is made based on the operational parameters of each production station, such as the WIP (Work-In-Progress) stages, production cycle time, buffer storage capacity, and throughput statistics. Similarly, the evaluation in terms of energy-efficient processes is made based on the operational parameters of each logistics transporter, such as the transportation distance, delivery time, waiting time, fetching time, and moving empty time. In this way, the eco-monitor data can be compared for the same type of transporters (eliminate the extra transporters to increase the transporter utilization) and the number of working shifts at the shipyard. Also, the impact of the source of energy can be considered in terms of electric or fossil fuel for the same type of transporter, such as the idle time for diesel transporters and the charging standby time for electric transporters. After the performance evaluation, careful resource allocation can be done based on the transporter utilization and productivity index of working shifts. In this way, this advanced simulation model can implement the dynamic resource allocation of the production logistics in the shipyards.

Later, the output of this dynamic resource allocation can be evaluated based on KPIs, as shown in the figure (Figure **55**) below:

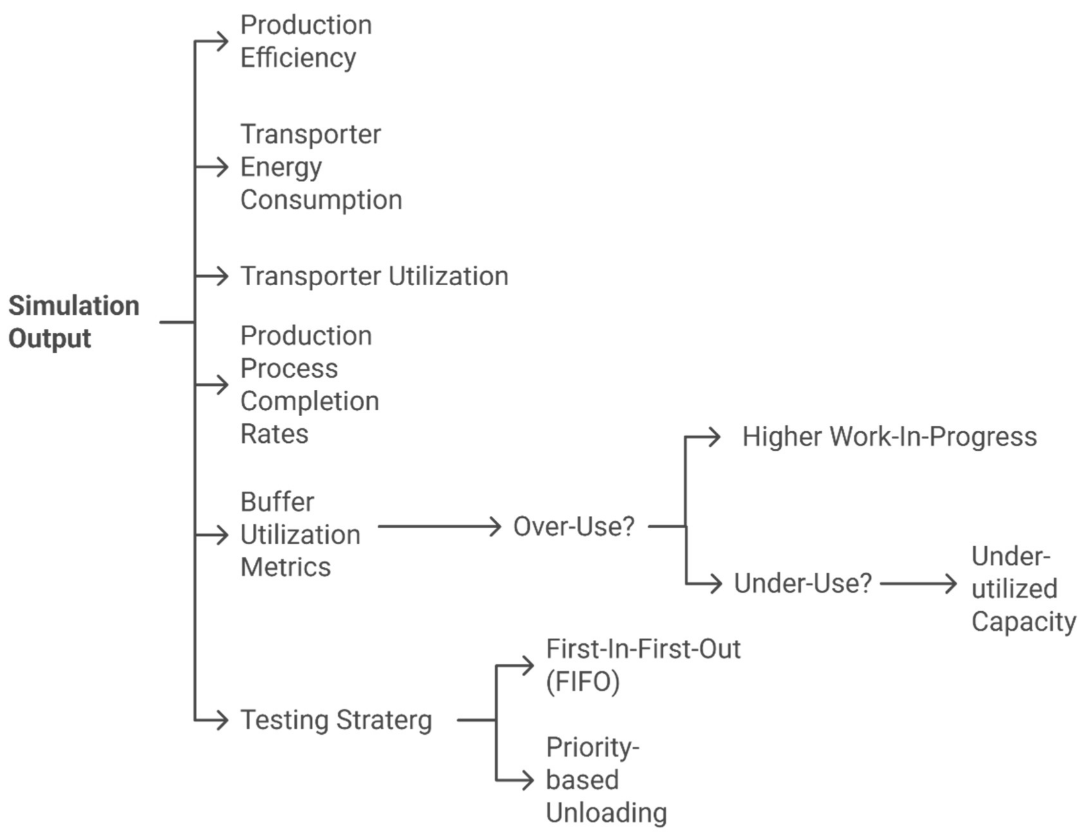


Figure 55. Output of Dynamic Resource Allocation (Generated by Napkin.AI)

6.3. Application for a Real Shipyard

This advanced simulation model has adaptability for a real shipyard as explained below:

1. Real shipyard can also model by adjusting the layout and production phases in the advanced simulation model.
2. Flexible for real input data in terms of production capacity, transporter types, and production schedules.
3. Configurable simulation model for different ship classes.

Later, for the integration of this simulation model into a real shipyard in terms of production control, the real-time tracking of production logistics will be required. This can be done by using the RFID (Radio Frequency Identification) and historical production logs of the real shipyard. This explanation is summarized in the figure (Figure **56**) below:

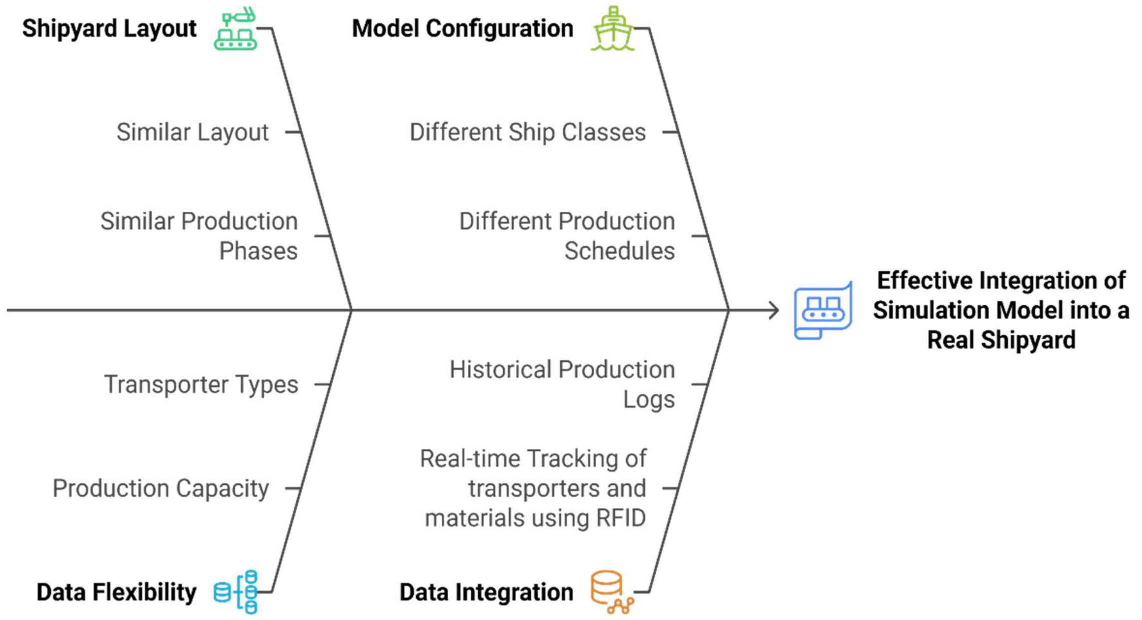


Figure 56. Integration into a Real Shipyard (Generated by Napkin.AI)

The practical benefits of applying this fictional advanced simulation model to a real shipyard are summarized in the figure (Figure **57**) below:

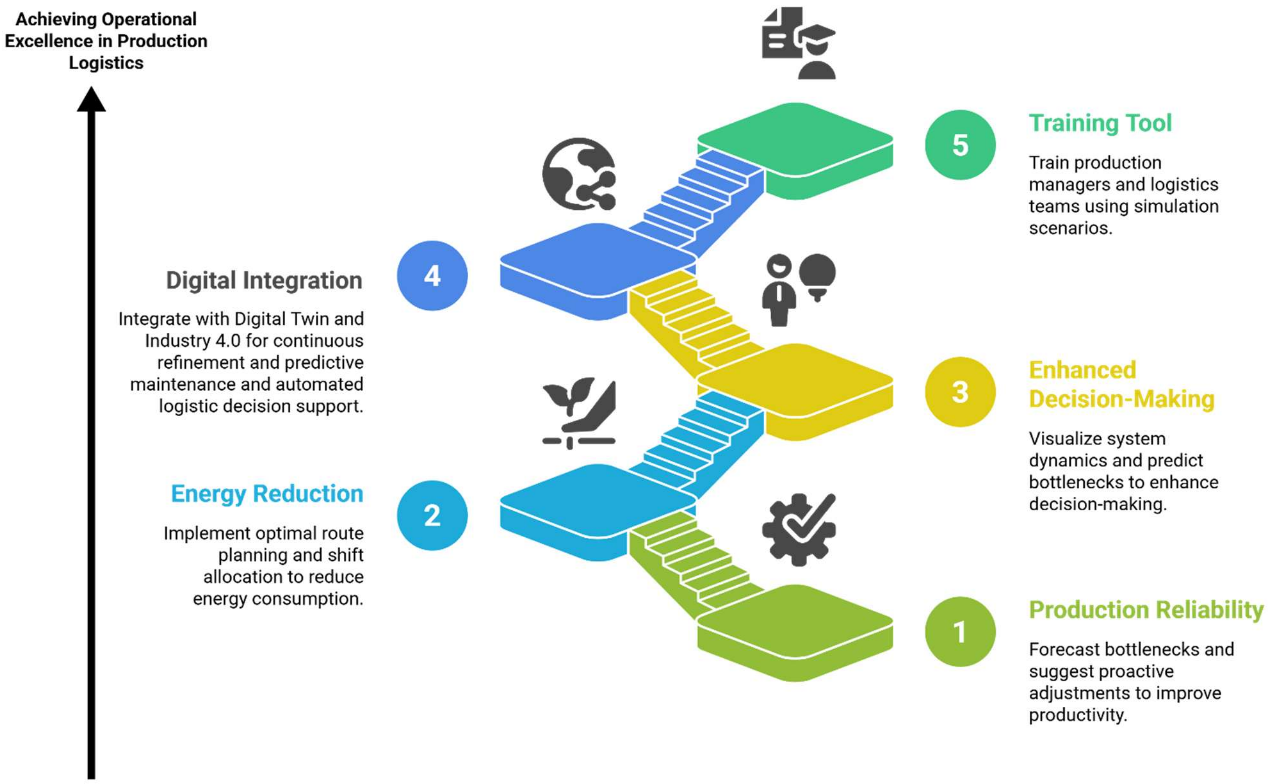


Figure 57. Practical Benefits (Generated by Napkin.AI)

7. FUTURE DEVELOPMENTS

The advanced simulation model developed in this master's thesis shows a strong potential to optimize the complex production processes in terms of efficient material flow based on maximum process productivity, energy efficiency, and environmental sustainbility. There is a good potential for future improvements in the simulation model to facilitate the shipbuilding transition into green, smart, and digital production eco-systems. The potential future developments are listed below:

7.1. Integrating Advanced Simulation Model into Shipyard's Digital Twins

At the shipyards, the IoT sensors and GPS trackers can be used for synchronization of real shipyard data into the shipyard simulation model, as summarized in the figure (Figure **58**). This will provide the real-time data, which can be utilized with the feedback loop to provide the live-decision decision-making to the engineers for optimizing the material flow and production processes. At the production station level, it will provide predictive data for the production logistics to identify the bottlenecks based on real operational scenarios, such as the machine health of the transporters and production machines, for dynamic re-routing in case of maintenance delays.

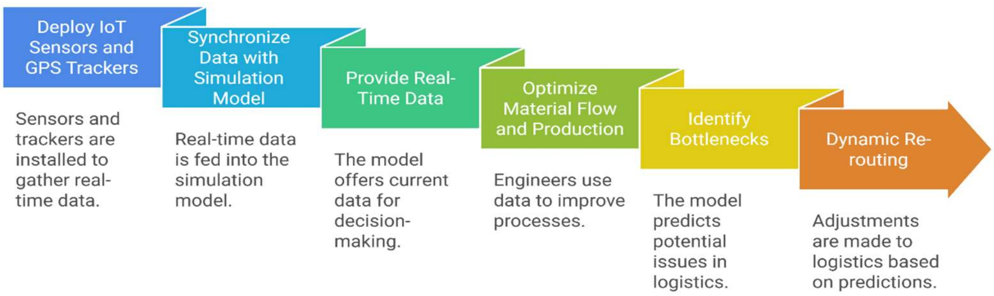


Figure 58. Integrating into Digital Twins (Generated by Napkin.AI)

7.2. Predictive Optimization using Artificial Intelligence

AI Tools can be utilized to train this advanced simulation model for finding the optimal routes by scheduling the production logistics based on a trial-and-error rule. The generated big data can be used to perform predictive analysis to predict the delays in production and logistic congestion based on the historical patterns. These predictive analyses can be supported by genetic algorithms based on multi-agent production systems, where every production logistic and working station is considered as an individual intelligent agent with shared resources at the shipyard. This will help in accurate resource allocation for realistic improvements in shipyard simulation model by following AI-Driven Optimization Cycle, as shown in figure (Figure **59**).

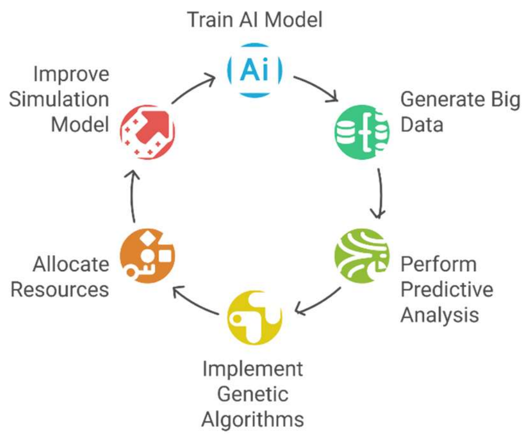


Figure 59. AI-Driven Optimization Cycle (Generated by Napkin.AI)

7.3. Utilization of Virtual Reality to Visualize the Simulation Model

Virtual Reality can be used for visualization of the material flow, congestion at buffer stores, and bottlenecks in terms of production logistics. This will help managers and engineers in identifying and fixing the production inefficiencies (bottlenecks) at the shipyards using the VR-Driven Production Optimization Cycle, as shown in the figure (Figure **60**).

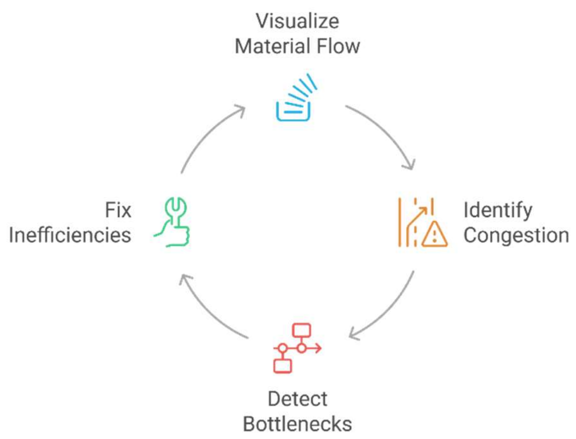


Figure 60. VR-Driven Production Optimization Cycle (Generated by Napkin.AI)

7.4. Improvement in Energy Modelling

The Eco-Monitor in the STS Library of Plant Simulation Software can be improved for tracking CO_2 emissions. So, it will be possible to model footprints of CO_2 in the advanced simulation model based on energy consumed by the transporters and production systems in the shipyard. It will provide an opportunity for a hybrid transporter simulation to compare diesel transporters' energy consumption with electric transporters for the same duration and time of transportation between respective stations. It will help to evaluate the practical impacts of renewable energy integration at shipyards, especially for charging stations of the e-transporters. The summary for enhanced energy modelling for CO_2 tracking is provided in the figure (Figure **61**).

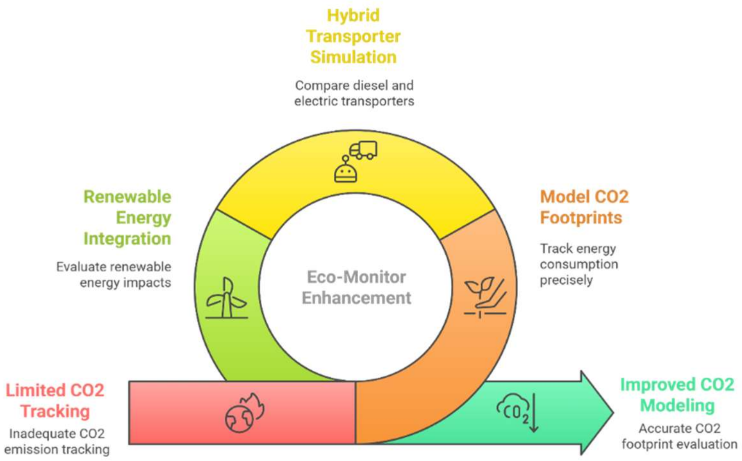


Figure 61. Enhanced Energy Modeling (Generated by Napkin.AI)

7.5. Economic Module for ROI (Return on Investment) Analysis

In the advanced simulation model, the economic module can be introduced for production cost modelling. This will help to calculate the ROI for each transporter in the fleet, which will provide decision support to management during decision-making for transporter fleet upgradation. In this way, the engineers can justify the potential investments required for adopting the energy-saving logistic technologies at the shipyard in terms of economic feasibility of green solution by implementing suitable ROI Models as described in figure (Figure **62**):

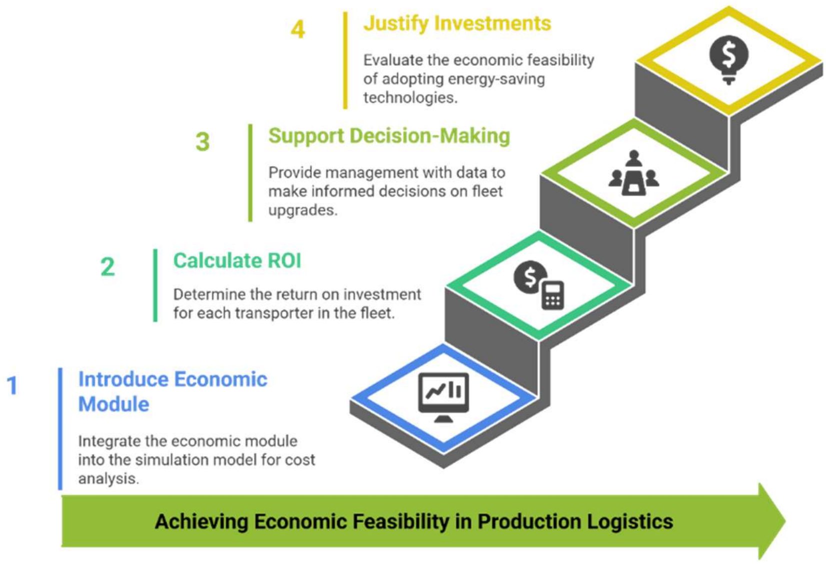


Figure 62. Economic Module for ROI Analysis (Generated by Napkin.AI)

8. CONCLUSION

In this thesis, the initial simulation model (provided by SimPlan AG) is updated using SIEMENS Plant Simulation Software to develop an advanced simulation model for simulating the material flow for energy-efficient production processes in a fictional shipyard. The input data is based on the industrial experience of experts at SimPlan AG and SIEMENS. First, the initial simulation model was evaluated based on the operational requirements of production logistics. In SIEMENS Plant Simulation Software, the required improvements were modelled to update the initial model into an advanced simulation model. It includes the implementation of complete production logistics, rack management, integration of Eco-Meter in STS Transport Control Tool, and utilization of STS Eco-Monitor Tool for analysing the energy consumption.

The methodology includes a systematic simulation-based framework focused on continuous improvements in initial shipyard layout in terms of shipyard production logistics. The advanced simulation model is utilized for dynamic material flow analysis (dMFA) to simulate and evaluate the production logistics, such as automated guided vehicles (AGVs), forklifts, and ship section transporters. These production transporters are used for efficient movement of raw material, equipment, plates, profiles, sub-assemblies, sections, and blocks. A detailed methodology is proposed for the utilization of proposed optimization tools to perform the multi-objective optimization based on real scenarios for techno-ecological objectives. The STS Transport Control Tool, STS Model Statistics Tool, and STS Eco-Monitor Tool are used to collect the example results such as distance travelled, transportation time, and energy consumption by the production transporters. These example results are used for estimation of electric energy cost and CO_2 emissions by each transporter in the fictional shipyard. A detailed evaluation of these results is performed to explain the interdependencies between material flow, energy consumption, and production schedules. In this way, the advanced simulation model is proposed to rectify the operational inefficiencies and bottlenecks for shipyard production logistics. It provides a foundation for the performance evaluation of the simulation model for accurate resource allocation. The adaptability conditions are finalized for real shipyard application based on the physical shipyard layout, simulation model configuration, and input data integration. This thesis provides a solid foundation to use this advanced simulation model for predictive optimization of shipyards' digital twins using artificial intelligence, utilization of virtual reality to visualize the simulation model, and advanced energy monitoring focused on economic feasibility. So, this advanced simulation model is validated as a significant contribution to achieving operational excellence in shipyard production logistics.

9. REFERENCES

[1] Agustin, A., & Widjajati, E. (2024). " Analysis lean and green manufacturing in the ship production process at PT XYZ." Operations Excellence: Journal of Applied Industrial Engineering **16**: 247-259.

[2] Antunović, S., B. Ljubenkov and K. Prlac (2022). "Development of the ship hull assembly sub-process." St open **3**: 1-22.

[3] Ballou, P. (2013). "Ship Energy Efficiency Management Requires a Total Solution Approach." Marine Technology Society Journal **47**: 83-95.

[4] Bock, T., T. Linner and N. Eibisch (2011). "Vertical Shipyard: Technology Transfer from Automated Con- and Deconstruction."

[5] Cai, Y., E. Kutanoglu and J. Hasenbein (2011). Production Planning and Scheduling: Interaction and Coordination. Planning Production and Inventories in the Extended Enterprise: A State-of-the-Art Handbook, Volume 2. K. G. Kempf, P. Keskinocak and R. Uzsoy. New York, NY, Springer New York**:** 15-42.

[6] Caprace, J., M. Freire, L. Assis, M. Pires and P. Rigo (2011). Discrete Event Production Simulation in Shipyard Workshops.

[7] Christodoulou, A. and K. Cullinane (2022). "Potential alternative fuel pathways for compliance with the 'FuelEU Maritime Initiative'." Transportation Research Part D: Transport and Environment **112**: 103492.

[8] Deng, T., Y. Zhang and C. Fu (2023). "Modelling dynamic interactions between material flow and stock: A review of dynamic material flow analysis." Ecological Indicators **156**: 111098.

[9] Dharmavaram, V. G. (2025). "Al-Driven Predictive Maintenance in Shipyards: Enhancing Project Management Efficiency and Operational Cost Reduction through Statistical, Data-Driven Strategies for MRO Services." Journal of Information Systems Engineering and Management **10**: 63-75.

[10] dos Santos, V. A., P. P. da Silva and L. M. Ventura Serrano (2024). "An economic and CO2 assessment of using Fischer-Tropsch diesel in the European maritime sector." International Journal of Environmental Studies **81**(4): 1529-1562.

[11] Fitriadi, F. and A. Ahmad Faisal Mohamad (2024). "Optimizing Traditional Shipyard Industry: Integrating VSM and Sustainability Indicators for Continuous Improvement." Journal of Advanced Research in Applied Sciences and Engineering Technology **46**(2): 155-170.

[12] Fitriadi, F. and A. F. M. Ayob (2023). "Optimizing Traditional Shipyard Industry: Enhancing Manufacturing Cycle Efficiency for Enhanced Production Process Performance." International Journal of Industrial Engineering, Technology & Operations Management **1**(1): 15-24.

[13] Ghasemi, A., F. Farajzadeh, C. Heavey, J. Fowler and C. T. Papadopoulos (2024). "Simulation optimization applied to production scheduling in the era of industry 4.0: A review and future roadmap." Journal of Industrial Information Integration **39**: 100599.

[14] Giboulot, O., E. Lemelin, C. Binetruy and N.-E. Abriak (2024). "Material Flow Analysis: An Analytical Tool for Strategic Planning Towards a Zero-Waste Solution for End-of-Life Ballast Flows on a Track and Ballast Renewal Site (French Conventional Line)." Resources **13**(12): 165.

[15] Guo, H., J. Wang, J. Sun and X. Mao (2024). "Multi-objective green vehicle scheduling problem considering time window and emission factors in ship block transportation." Scientific Reports **14**(1): 10796.

[16] Hong, H., X. Zhang, K. Ren, H. Bei, C. Deng and H. Wang (2023). Modelling and Simulation of Ship Block Production Scheduling Optimization Problem Considering the Multiple Resources Constraints. 2023 3rd International Conference on Electronic Information Engineering and Computer Science (EIECS).

[17] Hovanec, M., P. Korba, S. Al-Rabeei, M. Venceľ, B. Rácek and J. Tkáčová (2023). Simulation of a Digital Factory Using Tecnomatics Plant Simulation to Evaluate Production Processes and Improve Logistics Safety. 2023 IEEE 21st Jubilee International Symposium on Intelligent Systems and Informatics (SISY).

[18] Jebbor, I., Z. Benmamoun and H. Hachimi (2023). "Optimizing Manufacturing Cycles to Improve Production: Application in the Traditional Shipyard Industry." Processes **11**: 3146.

[19] Kim, H., S. S. Lee, J. Park and J. G. Lee (2005). "A model for a simulation-based shipbuilding system in a shipyard manufacturing process." Int. J. Computer Integrated Manufacturing **18**: 427-441.

[20] Köberlein, J., L. Bank, S. Roth, E. Köse, T. Kuhlmann, B. Prell, M. Stange, M. Münnich, D. Flum, D. Moog, S. Ihlenfeldt, A. Sauer, M. Weigold and J. Schilp (2022). "Simulation Modeling for Energy-Flexible Manufacturing: Pitfalls and How to Avoid Them." Energies **15**: 3593.

[21] Kocak, S. (2024). A PRODUCTIVITY EVALUATION AND IMPROVEMENT METHODOLOGY FOR SHIPYARDS.

[22] Krenczyk, D., W. M. Kempa, K. Kalinowski, C. Grabowik and I. Paprocka (2017). "Production planning and scheduling with material handling using modelling and simulation." MATEC Web Conf. **112**: 09015.

[23] Lee, Y. G., J. SuHeon and J. H. and Woo (2020). "Simulation-based planning system for shipbuilding." International Journal of Computer Integrated Manufacturing **33**(6): 626-641.

[24] Liangou, T. and A. Dentsoras (2021). Optimization of motion and energy consumption of an industrial automated ground vehicle. 2021 12th International Conference on Information, Intelligence, Systems & Applications (IISA).

[25] Liu, J., R. Liao, F. Dong, C. Huang, H. Li, J. Liu and T. Zhao (2024). "Low-carbon technology selection and carbon reduction potential assessment in the shipbuilding

industry with dynamically changing grid emission factors." Journal of Cleaner Production **441**: 140707.

[26] Liu, J., J. Yin and R. U. Khan (2022). "Scheduling management and optimization analysis of intermediate products transfer in a shipyard for cruise ships." PLoS One **17**(3): e0265047.

[27] Liu, L., P. Cao, Y. Zhou, Z. Long and Z. Jiang (2024). "Integrated Optimization Scheduling Model for Ship Outfitting Production with Endogenous Uncertainties." Journal of Marine Science and Application **24**.

[28] Lun, F., Y. Wang, X. Gao, Z. Zhong, Y. Bai and P. He (2021). "Experimental Study on Energy Consumption Distribution of Electric Forklift." DEStech Transactions on Environment, Energy and Earth Sciences.

[29] Matulja, T., Hadjina, M. & Kolić, D. (2016). "Shipyard Production Processes Re-Design Methodology Based on Expert Approach and Simulation Modeling." Pomorski zbornik **51**: 25-41.

[30] Mo, A., Y. Zhang, Y. Xiong, F. Ma and L. Sun (2024). "Energy–Logistics Cooperative Optimization for a Port-Integrated Energy System." Mathematics **12**(12): 1917.

[31] Mohamed, N. and J. Al-Jaroodi (2024). A Framework for Energy-Efficient Manufacturing using Digital Twins. 2024 International Conference on Smart Applications, Communications and Networking (SmartNets).

[32] Mun, S., M. Nam, J. Lee, K. Doh, G. Park, H. Lee, D. Kim and J. Lee (2015). Sub-assembly welding robot system at shipyards.

[33] Negemiya, A. (2023). "Analysis the Material Handling System Using Automated Guided Vehicle (AGV)." **5**: 1-3.

[34] Niemeyer, G. and P. Shiroma (1996). Production scheduling with genetic algorithms and simulation. Parallel Problem Solving from Nature — PPSN IV, Berlin, Heidelberg, Springer Berlin Heidelberg.

[35] Okubo, Y. and T. Mitsuyuki (2023). "Study of the practical application of production planning method using shipbuilding process simulation." Journal of the Japan Society of Naval Architects and Ocean Engineers.

[36] Purnama Sari, I., A. Ilasabilirrosyad, Y. Tanjov and S. Rahayu (2023). "Occupational Health and Safety Risks in the Shipbuilding Industry, Case Study at PT Blambangan Bahari Shipyard." Buletin Jalanidhitah Sarva Jivitam **5**.

[37] Ren, Y., L. Zhang, P. Shi and Z. Zhang (2022). "Research on Multi-Energy Integrated Ship Energy Management System Based on Hierarchical Control Collaborative Optimization Strategy." Journal of Marine Science and Engineering **10**(10): 1556.

[38] Rouco-Couzo, M., D. Crespo-Pereira, A. Garcia-Del-Valle, M. Cebral-Fernandez and R. Rios-Prado (2016). Discrete event simulation to improve cutting-welding workshop in a shipyard. 28th European Modeling and Simulation Symposium, EMSS 2016, Dime University of Genoa.

[39] Rubesa, R., M. Hadjina and T. Matulja (2022). "Criteria for Evaluation the Technological Level of Ship Pre-Outfitting in Shipyard." Journal of Maritime & Transportation Science **Special edition 4**: 201-210.

[40] Savvidis, G., S. Ramasamy, K. Bengtsson and X. Zhang (2024). A Smart Tool for Optimal Energy use of AGVs in the Manufacturing Industry. 2024 IEEE 29th International Conference on Emerging Technologies and Factory Automation (ETFA).

[41] Schmitt, T., S. Mattsson, E. Flores-García and L. Hanson (2025). "Achieving energy efficiency in industrial manufacturing." Renewable and Sustainable Energy Reviews **216**: 115619.

[42] Schmitz, L. and J. Stenzel (2024). "Simulation Model for AGVs in Production Environments under Consideration of the Facility Layout Problem." SNE Simulation Notes Europe **34**: 91-100.

[43] Seo, Y., D. Sheen and T. Kim (2007). "Block assembly planning in shipbuilding using case-based reasoning." Expert Syst. Appl. **32**: 245-253.

[44] Sokolov, S. and A. Antonova (2024). "Application of Simulation Modeling in Ship Construction Processes." Intellectual Technologies on Transport: 44-51.

[45] Stanic, V., M. Hadjina, N. Fafandjel and T. Matulja (2018). "Toward shipbuilding 4.0- an industry 4.0 changing the face of the shipbuilding industry." Brodogradnja **69**: 111-128.

[46] Strandhagen, J. W., Y. Jeong, J. H. Woo, M. Semini, M. Wiktorsson, J. O. Strandhagen and E. Alfnes (2020). Factors Affecting Shipyard Operations and Logistics: A Framework and Comparison of Shipbuilding Approaches. Advances in Production Management Systems. Towards Smart and Digital Manufacturing, Cham, Springer International Publishing.

[47] Tamer, S., B. Barlas, S. A. Gunbeyaz, R. E. Kurt and S. Eren (2023). "Adjacency-Based Facility Layout Optimization for Shipyards: A Case Study." Journal of Ship Production and Design **39**(01): 25-31.

[48] Tantan, M. and H. Akdağ (2023). The Effect of Green Supply Chain Management Practices on the Sustainability Performance of Turkish Shipyards.

[49] Tao, N.-r., X. Cui, Z. Jiang and Y. Chen (2012). "Research and Application of Location Assignment and Routing Strategies in Block Storage Yard of Shipbuilding." Applied Mechanics and Materials **246-247**: 974-978.

[50] Vakili, S., A. Schönborn and A. I. Ölçer (2023). "The road to zero emission shipbuilding Industry: A systematic and transdisciplinary approach to modern multi-energy shipyards." Energy Conversion and Management: X **18**: 100365.

[51] Varga, B. O., F. Mariasiu, D. Moldovanu and C. Iclodean (2015). Principles of Modeling and Simulation Processes. Electric and Plug-In Hybrid Vehicles: Advanced Simulation Methodologies. B. O. Varga, F. Mariasiu, D. Moldovanu and C. Iclodean. Cham, Springer International Publishing**:** 1-8.

[52] Wahidi, S. I., S. Oterkus and E. Oterkus (2024). "Robotic welding techniques in marine structures and production processes: A systematic literature review." Marine Structures **95**: 103608.

[53] Walentynowicz, P., & Omiotek, P. (2023). "Application of Lean Concepts in Shipbuilding On The Example of Çimtas Module & Shipyard." IBIMA.

[54] Wang, C., Y.-s. Mao, Z.-q. Xiang and Y.-q. Zhou (2015). "Ship Block Logistics Simulation Based on Discrete Event Simulation." International Journal of Online Engineering (iJOE) **11**: 16.

[55] Wang, C., K. Wang, J. Tao and Y. Zhou (2020). "Research on Real-Time Optimal Path Planning Model and Algorithm for Ship Block Transportation in Shipyard." Journal of Marine Science and Engineering **8**(12): 991.

[56] Wang, J., B. Liu, Z. Bao, W. Jiang, Z. Zhuo, Y. Shu and L. Gan (2024). Ongoing of Energy Saving and Emission Reduction during Fabrication Processing in China's Shipyards. Welding - Materials, Fabrication Processes, and Industry 5.0. S. Kumar. Rijeka, IntechOpen.

[57] Yao, F., B. Alkan, B. Ahmad and R. Harrison (2020). "Improving just-in-time delivery performance of IoT-enabled flexible manufacturing systems with AGV based material transportation." Sensors **20**(21): 6333.

[58] Yongquan, Z., K. Xu and J. Yu (2011). "Modelling and optimisation of hull erection process." International Journal of Production Research **49**: 4157-4174.

[59] Yuan, Y., M. Chen, J. Wang, W. Yu and B. Shen (2022). "A novel hybrid energy management strategy of a diesel-electric hybrid ship based on dynamic programing and model predictive control." Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment **236**: 147509022110689.

[60] Yue, W., C. Wang, Q. Zhang and H. Fan (2012). Research on the Production Logistics System of Shipbuilding Enterprise Based on MRP and TOC. International Conference on Transportation Engineering 2007**:** 2536-2541.

[61] Yushak, M., Y. Boustead, N. Shipyard, R. Dolah and N. Bakar (2018). "Lean principles reduces resistance to change in transforming a shipyard operations." International Journal of Business and Society **19**.

[62] Zhang, Z., T. Qu, K. Zhao, K. Zhang, Y. Zhang, L. Lei, J. Wang and G. Q. Huang (2023). Optimization Model and Strategy for Dynamic Material Distribution Scheduling Based on Digital Twin.

10. APPENDICES

10.1. Appendix A – Gantt Chart

The Gantt chart is shown figure (Figure **63**) below with timelines followed for each component:

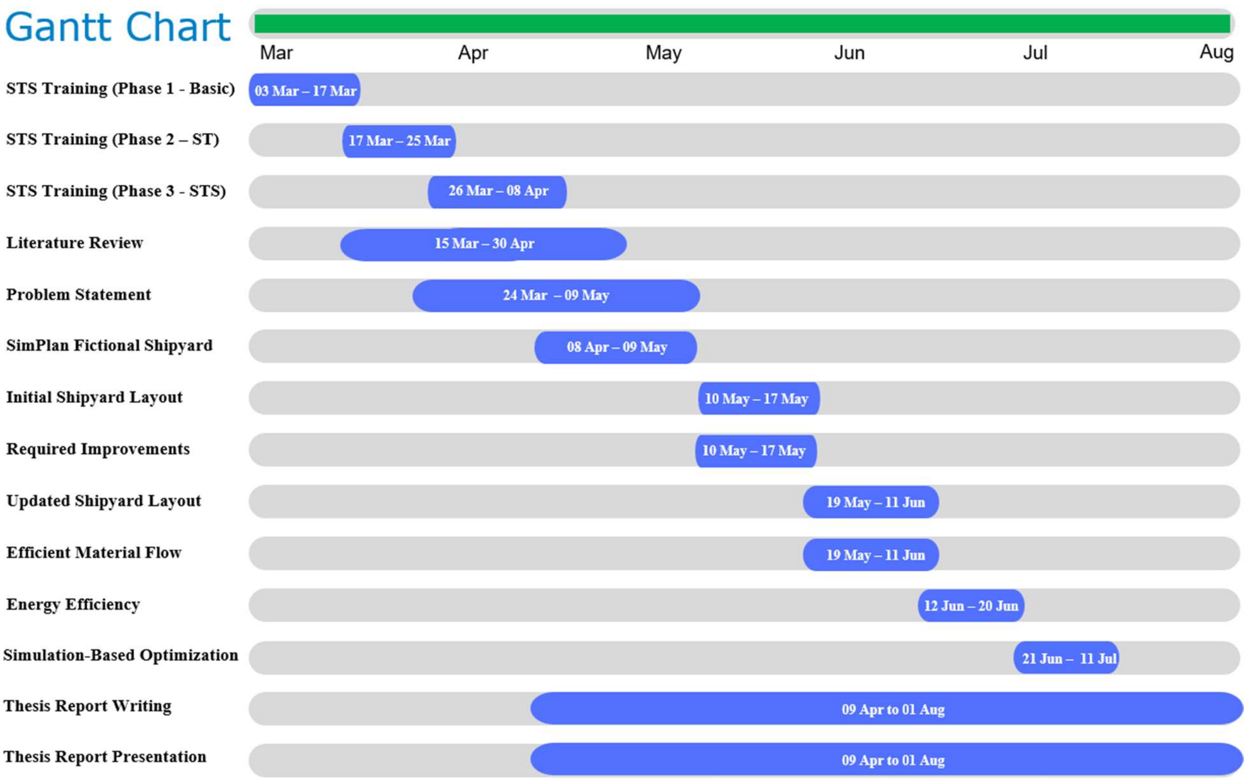


Figure 63. Gantt Chart

10.2. Appendix B – STS Transport Control

Table 61. Results by STS Transport Control

Sr No.	Identification Number	Activity Number	Origin Station	Destination Station	Transporter	Distance (km)	Duration (Minutes)
1	STS_Stack.1	P001-S02009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
2	STS_Stack.2	P001-S02010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
3	STS_Stack.3	P001-S02009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
4	STS_Stack.4	P001-S02009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
5	STS_Stack.5	P001-S02010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
6	STS_Stack.6	P001-S02010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
7	STS_CombRack.1	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
8	STS_CombRack.3	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
9	STS_CombRack.4	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2

10	STS_CombRack.2	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
11	STS_TransportTable_large.1	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
12	STS_TransportTable_large.2	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.00	4
13	STS_TransportTable_large.3	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
14	STS_TransportTable_large.4	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.00	4
15	STS_Stack.7	P001-S03009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
16	STS_Stack.8	P001-S03010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
17	STS_Stack.9	P001-S03009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
18	STS_Stack.10	P001-S03009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
19	STS_Stack.11	P001-S03010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
20	STS_Stack.12	P001-S03010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
21	STS_CombRack.8	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
22	STS_CombRack.11	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
23	STS_CombRack.9	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
24	STS_CombRack.19	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
25	STS_TransportTable_large.9	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
26	STS_TransportTable_large.10	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
27	STS_TransportTable_large.7	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
28	STS_TransportTable_large.8	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
29	STS_Stack.13	P001-S04009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
30	STS_Stack.14	P001-S04010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
31	STS_Stack.15	P001-S04009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
32	STS_Stack.16	P001-S04009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
33	STS_Stack.17	P001-S04010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
34	STS_Stack.18	P001-S04010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
35	STS_CombRack.25	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
36	STS_CombRack.27	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
37	STS_PipeRack.9	P001	Equipment Store	Section Production Station	Equipment Forklift	0.26	8
38	STS_CombRack.7	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
39	STS_CombRack.5	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
40	STS_CombRack.10	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
41	STS_CombRack.28	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
42	STS_CombRack.30	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2

43	STS_CombRack.6	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
44	STS_CombRack.20	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
45	STS_CombRack.21	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
46	STS_Transport Table_large.13	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	0.10	3
47	STS_Transport Table_large.14	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
48	STS_Transport Table_large.11	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	0.10	3
49	STS_Stack.50	P001-S07009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
50	STS_Stack.51	P001-S07010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
51	STS_Stack.52	P001-S07009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
52	STS_Stack.53	P001-S07009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
53	STS_Transport Table_large.12	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
54	STS_Stack.54	P001-S07010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
55	STS_Stack.55	P001-S07010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
56	STS_CombRack.22	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
57	STS_CombRack.26	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
58	STS_CombRack.29	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
59	STS_CombRack.41	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
60	STS_CombRack.42	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
61	STS_CombRack.44	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
62	O_P001_S02009_P1.1	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
63	STS_CombRack.45	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
64	STS_CombRack.24	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
65	STS_CombRack.36	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
66	STS_CombRack.37	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
67	STS_Transport Table_large.17	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
68	STS_Transport Table_large.18	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
69	STS_Transport Table_large.15	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
70	O_P001_S02010_P1.2	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
71	STS_Stack.60	P001-S08009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
72	STS_Stack.61	P001-S08010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
73	STS_Stack.62	P001-S08009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
74	STS_Stack.63	P001-S08009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5

75	STS_Stack.64	P001-S08010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
76	STS_Stack.65	P001-S08010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
77	STS_CombRack.38	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
78	STS_CombRack.43	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
79	STS_CombRack.46	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
80	STS_TransportTable_large.16	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
81	STS_CombRack.58	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
82	STS_CombRack.60	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
83	O_P001_S03009_P1.3	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
84	STS_CombRack.39	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
85	STS_CombRack.54	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
86	STS_CombRack.56	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
87	STS_CombRack.63	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
88	STS_CombRack.69	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
89	O_P001_S03010_P1.4	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
90	STS_TransportTable_large.21	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	0.10	3
91	STS_TransportTable_large.22	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
92	STS_CombRack.55	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
93	STS_CombRack.68	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
94	STS_CombRack.70	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
95	STS_TransportTable_large.19	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
96	STS_TransportTable_large.20	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
97	O_P001_S04009_P1.5	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
98	STS_CombRack.78	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
99	STS_CombRack.80	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
100	STS_CombRack.57	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
101	O_P001_S04010_P1.6	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.14	20
102	STS_CombRack.83	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
103	STS_CombRack.84	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
104	STS_CombRack.79	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
105	O_P001_S07009_P1.7	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20

106	STS_CombRack.92	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
107	STS_CombRack.93	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
108	STS_CombRack.82	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
109	O_P001_S07010_P1.8	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
110	STS_Stack.69	P001-S09009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
111	STS_Stack.70	P001-S09010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
112	STS_Stack.71	P001-S09009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
113	STS_Stack.72	P001-S09009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
114	STS_Stack.73	P001-S09010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
115	STS_Stack.74	P001-S09010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
116	O_P001_S08009_P1.9	P001-280	Section Production Station	Section Store 03 (Section/Hull Erection Station)	Ship Section Transporter	0.24	20
117	STS_CombRack.101	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
118	STS_CombRack.103	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
119	O_P001_S08010_P1.10	P001-280	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
120	STS_CombRack.102	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
121	STS_CombRack.104	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
122	STS_TransportTable_large.25	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
123	STS_TransportTable_large.26	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
124	STS_TransportTable_large.23	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
125	STS_TransportTable_large.24	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
126	STS_Stack.77	P001-S09011-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
127	STS_Stack.78	P001-S09011-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
128	STS_Stack.79	P001-S09011-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
129	STS_Stack.80	P001-S09012-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
130	STS_Stack.81	P001-S09012-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
131	STS_CombRack.105	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
132	STS_CombRack.110	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
133	STS_CombRack.108	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.89	2
134	STS_CombRack.109	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.89	2
135	STS_TransportTable_large.27	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
136	STS_CombRack.106	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
137	STS_CombRack.118	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2

138	STS_CombRack.111	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
139	STS_TransportTable_large.29	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
140	STS_TransportTable_large.28	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
141	STS_TransportTable_large.30	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
142	STS_CombRack.119	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
143	STS_CombRack.121	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
144	STS_CombRack.107	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
145	STS_Stack.84	P001-S09013-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.15	4
146	STS_Stack.85	P001-S09013-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
147	STS_Stack.86	P001-S09013-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
148	STS_Stack.87	P001-S09014-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
149	STS_Stack.88	P001-S09014-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
150	STS_CombRack.130	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
151	STS_CombRack.131	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
152	STS_CombRack.132	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
153	STS_TransportTable_large.31	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
154	STS_TransportTable_large.32	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
155	STS_CombRack.134	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
156	STS_CombRack.122	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
157	STS_CombRack.138	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
158	STS_CombRack.133	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
159	O_P001_S09009_P1.11	P001-280	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
160	STS_TransportTable_large.33	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
161	STS_TransportTable_large.34	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
162	STS_CombRack.143	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
163	STS_CombRack.146	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
164	STS_Stack.91	P001-S09015-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
165	STS_Stack.92	P001-S09015-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
166	STS_Stack.93	P001-S09015-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
167	STS_Stack.94	P001-S09016-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
168	STS_CombRack.120	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
169	STS_Stack.95	P001-S09016-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5

170	O_P001_S09010_P1.12	P001-280	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
171	STS_CombRack.155	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
172	STS_CombRack.156	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
173	STS_CombRack.154	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
174	STS_TransportTable_large.35	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
175	STS_TransportTable_large.36	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
176	STS_CombRack.158	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
177	STS_CombRack.157	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
178	STS_CombRack.159	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
179	STS_CombRack.145	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
180	STS_TransportTable_large.37	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
181	O_P001_S09011_P1.13	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.26	30
182	STS_TransportTable_large.38	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
183	STS_Stack.96	P001-S09017-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
184	STS_Stack.97	P001-S09017-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
185	STS_Stack.98	P001-S09017-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
186	STS_Stack.99	P001-S09018-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
187	STS_Stack.100	P001-S09018-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
188	STS_CombRack.167	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
189	STS_CombRack.169	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
190	STS_CombRack.144	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
191	O_P001_S09012_P1.14	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
192	STS_CombRack.175	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
193	STS_CombRack.179	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
194	STS_TransportTable_large.39	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
195	STS_CombRack.178	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
196	STS_TransportTable_large.40	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
197	STS_CombRack.180	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
198	STS_CombRack.182	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
199	STS_CombRack.181	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
200	STS_CombRack.168	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
201	STS_TransportTable_large.41	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3

202	O_P001_S09013_P1.15	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
203	STS_Stack.101	P001-S09019-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
204	STS_Stack.102	P001-S09019-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
205	STS_Stack.103	P001-S09019-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
206	STS_Stack.104	P001-S09020-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
207	STS_Stack.105	P001-S09020-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
208	STS_TransportTable_large.42	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
209	STS_CombRack.185	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
210	STS_CombRack.187	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
211	STS_CombRack.166	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
212	O_P001_S09014_P1.16	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
213	STS_CombRack.198	P001-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
214	STS_CombRack.188	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
215	STS_TransportTable_large.43	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
216	STS_CombRack.197	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
217	STS_CombRack.196	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
218	STS_CombRack.200	P001-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
219	STS_TransportTable_large.44	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
220	STS_CombRack.199	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
221	STS_TransportTable_large.45	P001-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
222	STS_CombRack.186	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
223	O_P001_S09015_P1.17	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
224	STS_TransportTable_large.46	P001-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
225	STS_CombRack.206	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
226	STS_CombRack.208	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
227	STS_CombRack.183	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
228	O_P001_S09016_P1.18	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
229	STS_CombRack.216	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
230	STS_CombRack.217	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
231	STS_CombRack.207	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
232	O_P001_S09017_P1.19	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30

233	STS_CombRack.225	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
234	STS_CombRack.226	P001-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
235	STS_CombRack.201	P001-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
236	O_P001_S09018_P1.20	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
237	O_P001_S09019_P1.21	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
238	O_P001_S09020_P1.22	P001-280	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
239	P_P001_S10001_Ref.7239	P001	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
240	P_P001_S10002_Ref.7240	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
241	P_P001_S10003_Ref.7241	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
242	P_P001_S10004_Ref.7242	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
243	P_P001_S09001_Ref.7243	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
244	P_P001_S09002_Ref.7244	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
245	P_P001_S09003_Ref.7245	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
246	P_P001_S09004_Ref.7246	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
247	P_P001_S11001_Ref.7247	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
248	P_P001_S11002_Ref.7248	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
249	P_P001_S11003_Ref.7249	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
250	P_P001_S11004_Ref.7250	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
251	P_P001_S08001_Ref.7251	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
252	P_P001_S08002_Ref.7252	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
253	P_P001_S08003_Ref.7253	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
254	P_P001_S08004_Ref.7254	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
255	P_P001_S12001_Ref.7255	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30

256	P_P001_S1200 2_Ref.7256	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
257	P_P001_S1200 3_Ref.7257	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
258	P_P001_S1200 4_Ref.7258	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
259	P_P001_S0700 1_Ref.7259	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
260	P_P001_S0700 2_Ref.7260	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
261	P_P001_S0700 3_Ref.7261	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
262	P_P001_S0700 4_Ref.7262	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
263	P_P001_S1300 1_Ref.7263	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
264	P_P001_S1300 3_Ref.7264	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
265	P_P001_S0600 1_Ref.7265	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
266	P_P001_S0600 2_Ref.7266	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
267	P_P001_S0600 3_Ref.7267	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
268	P_P001_S0600 4_Ref.7268	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
269	P_P001_S1400 1_Ref.7269	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
270	P_P001_S1000 1_Ref.7239	P001	Section Store 02 (Section/Hull Erection Station)	Block Assembly Station	Ship Section Transporter	0.19	107
271	P_P001_S1000 5_Ref.7270	P001	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
272	STS_Stack.106	P002-S02009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
273	STS_Stack.107	P002-S02010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
274	STS_Stack.108	P002-S02009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
275	STS_Stack.109	P002-S02009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
276	STS_Stack.110	P002-S02010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
277	STS_Stack.111	P002-S02010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
278	P_P001_S0900 1_Ref.7243	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	7
279	STS_CombRac k.234	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
280	STS_CombRac k.236	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2

281	P_P001_S1100 1_Ref.7247	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	4
282	P_P001_S1000 6_Ref.7271	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.26	30
283	STS_CombRac k.235	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
284	STS_CombRac k.237	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
285	P_P001_S0800 1_Ref.7251	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	9
286	STS_Transport Table_large.49	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
287	STS_Transport Table_large.50	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
288	STS_Transport Table_large.47	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
289	STS_Transport Table_large.48	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
290	P_P001_S1000 7_Ref.7272	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
291	STS_Stack.112	P002-S03009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
292	STS_Stack.113	P002-S03010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
293	STS_Stack.114	P002-S03009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
294	STS_Stack.115	P002-S03009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
295	STS_Stack.116	P002-S03010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
296	STS_Stack.117	P002-S03010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
297	P_P001_S1200 2_Ref.7256	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	7
298	STS_CombRac k.243	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
299	STS_CombRac k.241	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
300	P_P001_S0700 1_Ref.7259	P001	Section Store 04 (Section/Block Assembly Station)	Block Assembly Station	Ship Section Transporter	0.30	4
301	STS_CombRac k.252	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
302	P_P001_S1000 8_Ref.7273	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
303	STS_CombRac k.244	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
304	P_P001_S1300 1_Ref.7263	P001	Section Store 04 (Section/Block Assembly Station)	Block Assembly Station	Ship Section Transporter	0.30	9
305	STS_Transport Table_large.55	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
306	STS_Transport Table_large.56	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
307	STS_Transport Table_large.53	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
308	STS_Transport Table_large.54	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
309	P_P001_S0500 1_Ref.7274	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20

310	STS_Stack.118	P002-S04009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
311	STS_Stack.119	P002-S04010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
312	STS_Stack.120	P002-S04009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
313	STS_Stack.121	P002-S04009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
314	STS_Stack.122	P002-S04010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
315	STS_Stack.123	P002-S04010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
316	P_P001_S06001_Ref.7265	P001	Section Store 04 (Section/Block Assembly Station)	Block Assembly Station	Ship Section Transporter	0.30	6
317	STS_PipeRack.54	P002	Equipment Store	Section Production Station	Equipment Forklift	0.26	9
318	STS_CombRack.258	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
319	STS_CombRack.240	P002-200	Sub-Assemblies Production Station	Section Production Station	AVG	0.20	6
320	STS_CombRack.261	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
321	STS_CombRack.238	P002-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
322	STS_CombRack.242	P002-200	Girder Fabrication Station	Section Production Station	AVG	0.11	3
323	P_P001_S14001_Ref.7269	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	4
324	P_P001_S05002_Ref.7275	P001	Section Production Station	Section Store 04 (Section/Block Assembly Station)	Ship Section Transporter	0.24	20
325	STS_CombRack.260	P002-280	Profile Fabrication Station	Section Production Station	AGV Warehouse	0.88	2
326	STS_CombRack.263	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
327	P_P001_S10005_Ref.7270	P001	Section Store 02 (Section/Hull Erection Station)	Block Assembly Station	Ship Section Transporter	0.19	9
328	STS_TransportTable_large.59	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
329	STS_Stack.155	P002-S07009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
330	P_P001_S05003_Ref.7276	P001	Section Production Station	Section Store 02 (Section/Hull Erection Station)	Ship Section Transporter	0.19	16
331	STS_Stack.156	P002-S07010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
332	STS_Stack.157	P002-S07009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
333	STS_TransportTable_large.60	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
334	STS_Stack.158	P002-S07009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
335	STS_TransportTable_large.57	P002-200	Plate Fabrication Station	Girder Production Station	AVG	0.12	4
336	STS_Stack.159	P002-S07010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
337	STS_TransportTable_large.58	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
338	STS_Stack.160	P002-S07010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
339	STS_CombRack.273	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.89	2
340	STS_CombRack.276	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.89	2

341	STS_CombRack.275	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.89	2
342	STS_TransportTable_large.63	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
343	STS_TransportTable_large.61	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
344	STS_Stack.162	P002-S08009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
345	STS_Stack.163	P002-S08010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
346	STS_Stack.164	P002-S08009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
347	STS_Stack.165	P002-S08009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
348	STS_Stack.166	P002-S08010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
349	STS_Stack.167	P002-S08010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
350	STS_CombRack.282	P002-280	Profile Fabrication Station	Section Production Station	AVG	0.88	2
351	STS_TransportTable_large.67	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
352	STS_Stack.168	P002-S09009-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
353	STS_Stack.169	P002-S09010-St200	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
354	STS_Stack.170	P002-S09009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
355	STS_Stack.171	P002-S09009-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
356	STS_Stack.172	P002-S09010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
357	STS_Stack.173	P002-S09010-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
358	P_P001_S10002_Ref.7240	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	22
359	STS_TransportTable_large.71	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
360	STS_TransportTable_large.69	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
361	STS_Stack.174	P002-S09011-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
362	P_P001_S05004_Ref.7277	P001	Section Production Station	Section Store 01 (Section Buffer Station)	Ship Section Transporter	0.36	30
363	STS_Stack.175	P002-S09011-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
364	STS_Stack.176	P002-S09011-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
365	STS_Stack.177	P002-S09012-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
366	STS_Stack.178	P002-S09012-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
367	P_P001_S09002_Ref.7244	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	22
368	STS_TransportTable_large.73	P002-200	Plate Fabrication Station	Sub-Assemblies Production Station	AVG	1.00	3
369	STS_Stack.179	P002-S09013-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
370	STS_Stack.180	P002-S09013-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
371	STS_Stack.181	P002-S09013-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
372	STS_Stack.182	P002-S09014-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5

373	STS_Stack.183	P002-S09014-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
374	P_P001_S11002_Ref.7248	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	22
375	STS_Stack.184	P002-S09015-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
376	STS_Stack.185	P002-S09015-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
377	STS_Stack.186	P002-S09015-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
378	STS_Stack.187	P002-S09016-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
379	STS_Stack.188	P002-S09016-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
380	O_P001_B141.977	P001-310	Block Assembly Station	Painting Process Station	Ship Section Transporter	0.19	15
381	P_P001_S08002_Ref.7252	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	22
382	STS_Stack.189	P002-S09017-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
383	STS_Stack.190	P002-S09017-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
384	STS_Stack.191	P002-S09017-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
385	STS_Stack.192	P002-S09018-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
386	STS_Stack.193	P002-S09018-St200	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5
387	P_P001_S12001_Ref.7255	P001	Section Store 01 (Section Buffer Station)	Block Assembly Station	Ship Section Transporter	0.17	22
388	P_P001_S09005_Ref.7278	P001	Section Production Station	Section Store 01 (Section Buffer)	Ship Section Transporter	0.36	30
389	STS_Stack.194	P002-S09019-St100	Warehouse (Raw Material)	Plate Fabrication Station	AGV Warehouse	0.14	4
390	STS_Stack.195	P002-S09019-St100	Warehouse (Raw Material)	Profile Fabrication Station	AGV Warehouse	0.16	5

10.3. Appendix C – STS Eco-Meter

Table 62. Eco-Meter - Energy Parameters and Criterion

Sr. No.	Subsystems	Criterion	State	Unit	Value Fix	Value Variable
1	AGV/Drive	ElectricalEnergy	idle	kWh	0.000	0.000
2	AGV/Drive	ElectricalEnergy	busy	kWh	0.025	0.700
3	AGV/Drive	ElectricalEnergy	pause	kWh	0.001	0.100
4	AGV/Drive	FuelConsumption	idle	liter/hour	0.000	0.000
5	AGV/Drive	FuelConsumption	busy	liter/hour	0.000	0.000
6	AGV/Drive	FuelConsumption	pause	liter/hour	0.000	0.000
7	AGV_Warehouse1/Drive	ElectricalEnergy	idle	kWh	0.000	0.000
8	AGV_Warehouse1/Drive	ElectricalEnergy	busy	kWh	0.025	0.700
9	AGV_Warehouse1/Drive	ElectricalEnergy	pause	kWh	0.001	0.100
10	AGV_Warehouse1/Drive	FuelConsumption	idle	liter/hour	0.000	0.000
11	AGV_Warehouse1/Drive	FuelConsumption	busy	liter/hour	0.000	0.000
12	AGV_Warehouse1/Drive	FuelConsumption	pause	liter/hour	0.000	0.000
13	Equipement_ForkLift/Drive	ElectricalEnergy	idle	kWh	0.000	0.000
14	Equipement_ForkLift/Drive	ElectricalEnergy	busy	kWh	0.015	0.450
15	Equipement_ForkLift/Drive	ElectricalEnergy	pause	kWh	0.010	0.150
16	Equipement_ForkLift/Drive	FuelConsumption	idle	liter/hour	0.000	0.000
17	Equipement_ForkLift/Drive	FuelConsumption	busy	liter/hour	0.000	0.000
18	Equipement_ForkLift/Drive	FuelConsumption	pause	liter/hour	0.000	0.000
19	ShipSectionTransporter/Drive	ElectricalEnergy	idle	kWh	0.000	0.000
20	ShipSectionTransporter/Drive	ElectricalEnergy	busy	kWh	0.030	2.000
21	ShipSectionTransporter/Drive	ElectricalEnergy	pause	kWh	0.010	0.400
22	ShipSectionTransporter/Drive	FuelConsumption	idle	liter/hour	0.000	0.000
23	ShipSectionTransporter/Drive	FuelConsumption	busy	liter/hour	0.001	0.020
24	ShipSectionTransporter/Drive	FuelConsumption	pause	liter/hour	0.000	0.000