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Shipyard Design of the Highest Technological Level Using the Simulation Modeling Method

Abstract

Modern shipbuilding faces a series of challenges driven by the demand for higher efficiency, shorter construction times, increased automation, and reduced emissions in accordance with global environmental regulations. Particular emphasis is placed on the digitalisation of production processes and the optimisation of material flow, as these elements directly determine the productivity and competitiveness of shipyards. The development of high-technology shipyards requires a clearly defined spatial and technological organisation supported by advanced analytical tools. In this context, the feasibility of establishing a linearly organised production system based on digitally monitored operations from steel prefabrication to final outfitting was examined. Special attention was given to simulation modelling, recognised as a key method for assessing capacity and identifying bottlenecks in the early design stages. Simulation of the plate-processing workshop demonstrated that an optimal balance between capacity, throughput, and equipment utilisation is achieved with a configuration of three plasma cutting stations, whereas the introduction of a fourth station results in system saturation and decreased overall efficiency. These findings confirm that a properly designed simulation model enables informed technological decision-making and prevents unnecessary or ineffective investments. The results indicate that the integration of digital technologies with simulation-based planning forms a fundamental prerequisite for the development of next-generation, high-technology shipyards.

Keywords: shipyard, digitalisation, automation, material flow, workshops, simulation model, plasma cutting

1. Introduction

Modern shipbuilding faces growing pressure to increase productivity, shorten construction time, and integrate advanced automation while complying with strict environmental requirements. These demands highlight the importance of digitalised production processes and optimised material flow, which are essential for ensuring shipyard efficiency and competitiveness. With this aim, a conceptual design of a high-technology shipyard was developed for Khalifa Port in Abu Dhabi, a location offering favourable technical and logistical conditions. The proposed shipyard is based on a linear, digitally monitored production process extending from steel prefabrication to final outfitting. To support early design decisions, simulation modelling of the plate-processing workshop was conducted using Tecnomatix Plant Simulation [1]. By analysing different configurations of plasma cutting stations, the model provides insight into system capacity, throughput, and potential bottlenecks. The results demonstrate the value of simulation as a tool for defining optimal technological solutions and ensuring a stable and efficient production flow.

2. Shipyard development methodology

The development of a modern shipyard layout follows a structured process consisting of three principal phases: preliminary design, basic design, and detailed design. Each phase contributes a specific level of definition to the spatial organisation, production capacity and technological requirements of the shipyard. [2]

Phase		Object
Phase1	Pre-liminary design	- Design a concept layout of the main shop and work stages considering the capacity of the building berth (input) and the ship construction cycle (e.g. 5 ships/year)
Phase2	Basic Design	- Simulate the concept layout considering a ship block data and transportation, in order to define the capacity of each shop and inter-operability - Make a modified layout from the concept layout, which can satisfy the requirements (production volume, lead time per ship, etc.)
Phase3	Detail Design	- Design each shop and work stage in detail - Production line flow - Design block assembly line and its configuration - Workstage definition - Location and arrangement of each work stage definition - Design number and size of work stages

Figure 1. Phases of shipyard layout design.

In the preliminary design phase, a concept layout of the main production shops and work stages is established. This includes steel storage and prefabrication areas, plate and profile processing lines, the panel line, sub-assembly and block assembly zones, painting facilities and pre-outfitting areas. At this stage, key strategic decisions are made, such as the selection of the shipyard location. In the present study, Khalifa Port in Abu Dhabi was identified as the optimal site based on technical, logistical and infrastructural criteria. Additionally, the preliminary phase defined the production programme (product mix) focused on mid-size tankers and small-capacity LNG carriers, as well as a linear material-flow concept that aligns with modern requirements for automation and efficient logistics.

The basic design phase involves the evaluation and refinement of the concept layout using analytical and simulation-based methods. Ship block dimensions, expected transport routes, shop inter-operability and required capacities are analysed to determine whether the proposed layout can meet the desired production rate and lead time per vessel. In this work, the core activity of the basic phase was the development of a simulation model of the plate-processing workshop using Tecnomatix Plant Simulation. By testing different configurations of plasma cutting stations, the model provided insight into throughput, equipment utilisation and potential bottlenecks. These results enabled modifications to the initial layout to ensure that the system can support the annual steel-processing capacity of approximately 60,000 tonnes and the planned output of four ships per year. [1]

The detailed design phase focuses on the exact configuration of each workshop, including the number and size of production lines and workstations, internal transport arrangements and the precise positioning of equipment. Although this phase extends beyond the scope of the current article, the outcomes of the preliminary and basic design phases establish a coherent technical foundation for detailed engineering development. [2]

3. Material flow and production concept

The proposed shipyard concept is based on a linear and sequential material flow, designed to support high production efficiency, reduced internal transport, and a high level of automation. The production system is organised to ensure continuous progression of steel from prefabrication to final outfitting, without backtracking or unnecessary handling.

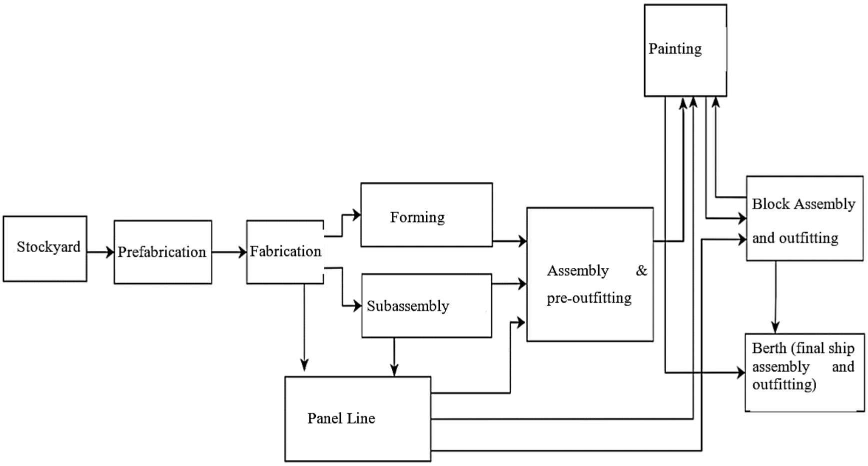
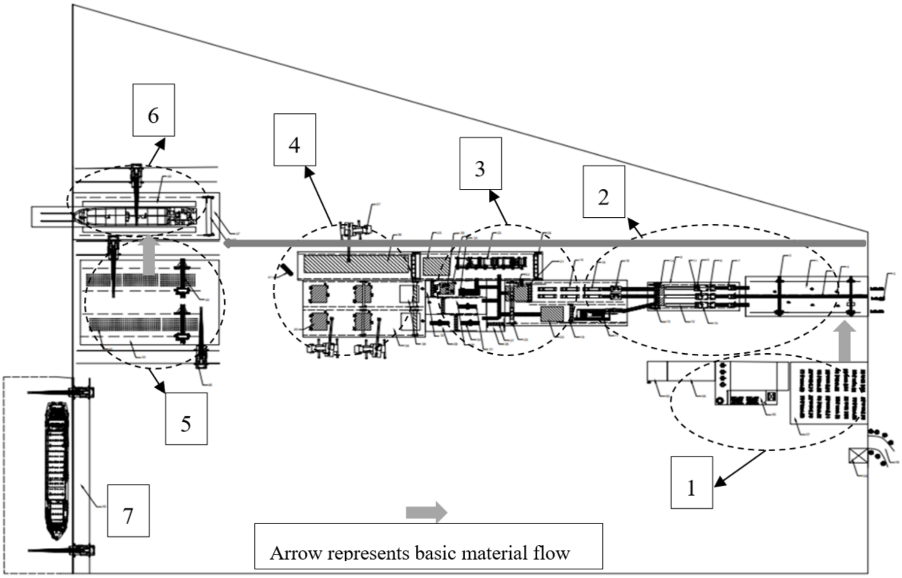


Figure 2. Schematic representation of the linear material flow in the shipyard.

Based on the defined product mix and target annual capacity, the material flow integrates the main production stages: steel storage and prefabrication, plate and profile cutting, panel production, sub-assembly and block assembly, surface treatment, hull erection, and final outfitting. The arrangement of these stages follows the technological sequence of ship construction and enables the early integration of selected outfitting activities during block fabrication.

The concept emphasises early outfitting, digital process supervision and automated internal logistics as key elements for reducing lead time and improving production stability. Internal transport is supported by roller conveyors, automated plate handling systems and crane-based logistics, allowing predictable material movement between workshops.

The defined material flow is illustrated in Figure 2. Based on this flow logic, the conceptual shipyard layout shown in Figure 3. was developed, including the spatial arrangement of production areas as well as the selection of required workshop equipment and internal transport systems. The resulting layout ensures that technological requirements, capacity demands and logistical constraints are consistently aligned with the proposed production concept. [3]



Legend: Major production areas: 1-Stockyard; 2-Prefabrication/Fabrication; 3-Subassembly; 4-Panel line and Assembly and pre-outfitting; 5 – Blocks Assembly and outfitting; 6-Berth (final ship assembly and outfitting; 7- On ship outfitting

Figure 3. Shipyard layout derived from the linear material flow concept.

4. Simulation modelling approach

In the early stages of shipyard design, the preliminary production concept and material flow definition typically raise practical questions that cannot be reliably answered using purely analytical sizing methods most notably, how many workstations are required to achieve the target capacity without creating idle investment or production bottlenecks. [4] This is especially relevant for workshops that represent critical nodes in the shipbuilding chain, such as the plate-processing shop, where the largest share of structural steel elements is processed.

To reduce investment risk and validate design assumptions before physical implementation, discrete-event simulation (DES) was applied as an engineering decision-support tool. In general, simulation model development follows an iterative sequence: (1) preparation and problem definition, (2) model building, (3) testing, (4) results analysis with interpretation and model modification, and (5) practical application of the validated model for planning and optimisation. Such an approach enables evaluation of system behaviour prior to construction, including capacity verification, utilisation balancing, and identification of potential bottlenecks under realistic operating logic. [6]

In this study, a simulation model was developed in Tecnomatix Plant Simulation, selected for its capability to dynamically represent production/logistics interactions and to test alternative operational scenarios without disturbing real production The objective was to quantify workshop performance indicators (throughput and utilisation) for alternative equipment configurations, and thereby confirm or revise preliminary design assumptions regarding workshop sizing and equipment selection.

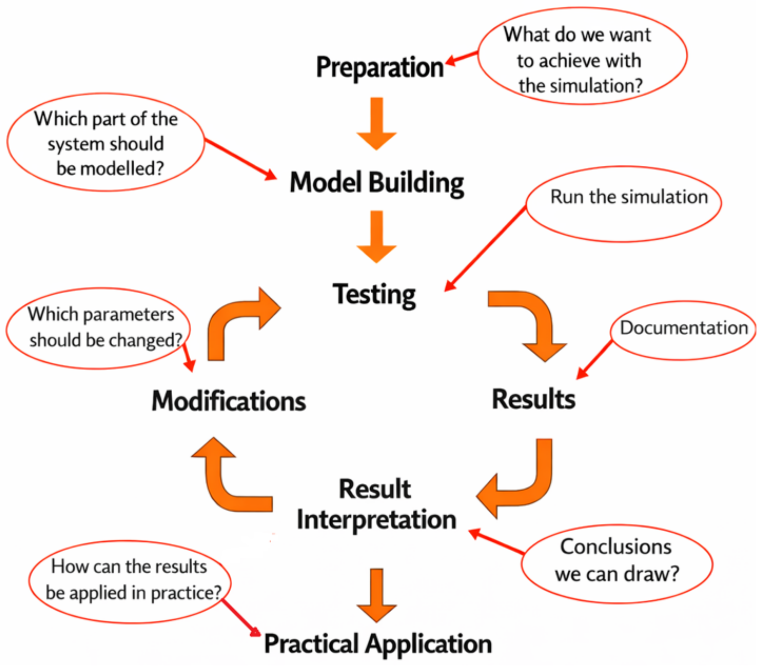


Figure 4. Simulation system development workflow

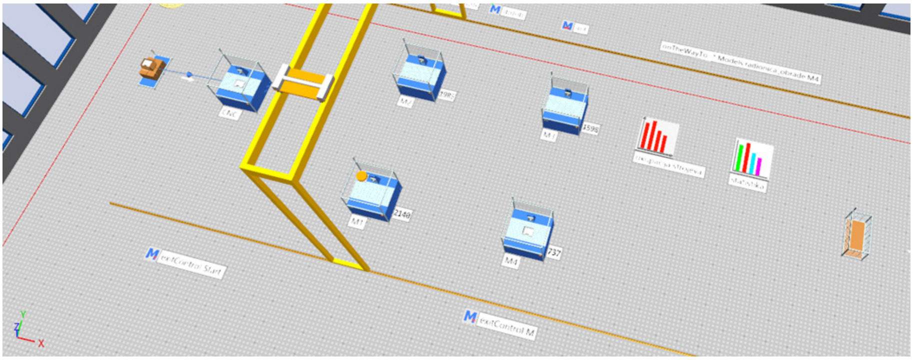


Figure 5. Plate-processing workshop simulation model in Tecnomatix Plant Simulation.

5. Model description and input data

The model represents the plate-processing workshop from plate marking to the output buffer, including: a CNC marking station, a bridge magnetic crane, plasma cutting stations, and an output intermediate storage. The model logic includes an automated crane rule that identifies workstation availability and assigns plates to the first free plasma cutter, providing a realistic representation of dispatching logic in a workshop with parallel machines. [5]

Input data were defined from the planned shipyard production programme and annual steel consumption. The baseline annual steel consumption is 60,000 t, while the analysed plate flow for four ships per year corresponds to approximately 38,640 t of plates annually, i.e., about 11,040 processed plates per year used as the model input capacity target. The cutting time for standard shipbuilding plates (6–12 mm) was modelled with an average of approximately 42 min/plate (normal distribution), while crane handling was defined with an average manipulation time of 6 min including lifting, transport, and positioning. The workshop operating regime was assumed as two shifts of eight hours (16 h/day), corresponding to approximately 4,000 effective operating hours per year, enabling consistent comparison between scenarios. To evaluate both short-term and long-term behaviour, each scenario was simulated over three horizons: 1 working day, 30 working days, and 250 working days. Input material availability at the workshop entry was assumed sufficient to avoid starvation and isolate internal workshop behaviour. [1]

6. Simulation experiments and results

After model testing and verification confirmed correct material routing, dispatching logic and numerical stability, three equipment configurations were analysed:

6.1. Scenario 1: Two plasma cutting stations

This configuration represents a minimum-capacity setup. The model shows high cutter utilisation (~90% daily), but insufficient annual throughput for the planned programme. Results were:

- ◊ 1 day: 35 plates processed; cutters ~90% utilisation; crane <10%
- ◊ 30 days: 1,039 plates processed; average cutter utilisation ~80%; crane <10%
- ◊ 250 days: 8,293 plates processed, corresponding to ~75% of the required ~11,000 plates/year; cutter utilisation <80%; crane <10%

This scenario is therefore capacity-limited and cannot meet the planned annual requirement.

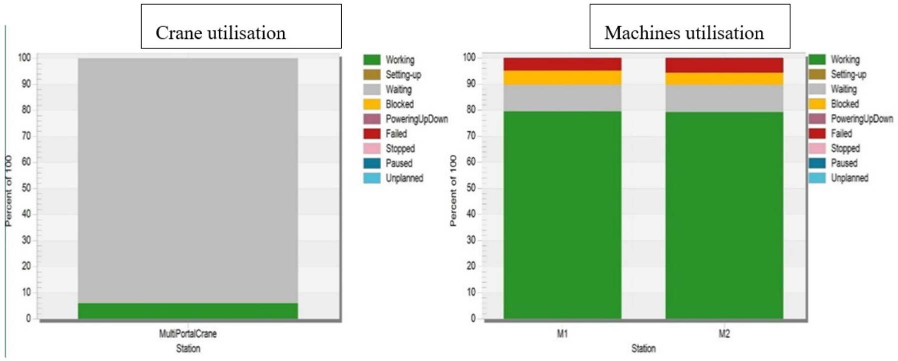


Figure 6. Equipment utilization over 250 working days for the configuration with two plasma cutting stations.

6.2. Scenario 2: Three plasma cutting stations

Adding a third cutter improves throughput and balances the system. Reported results were:

◊ 1 day: 55 plates processed; cutter utilisation ~90%; crane ~10%

◊ 30 days: 1,232 plates processed; cutter utilisation ~70%; crane below 10%; idle periods appear

◊ 250 days: 11,040 plates processed, matching the planned annual demand (≈11,040 plates/year); stable operation with average utilisation slightly above ~70%; crane ~8%

This configuration provides the best balance of capacity, stability and utilisation, meeting the target production volume with reasonable reserve.

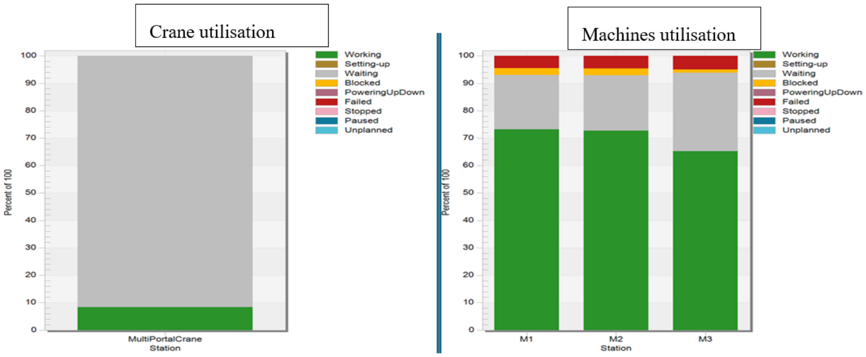


Figure 7. Equipment utilisation over 250 working days for the configuration with three plasma cutting stations.

6.3. Scenario 3: Four plasma cutting stations

The fourth cutter increases nominal cutting capacity, but system behaviour indicates saturation: throughput increases only marginally, while utilisation drops significantly.

- 1 day: 67 plates processed; average utilisation ~80% (some cutters up to 90%); crane ~8%
- 30 days: 1,450 plates processed; cutter utilisation ~50–70%; crane ~8%; idle periods appear
- 250 days: 12,000 plates processed; cutter utilisation ~40–60%; crane ~8%

The results confirm that adding a fourth station leads to lower investment efficiency, since the incremental throughput does not justify the reduced utilisation and higher capital/maintenance cost.

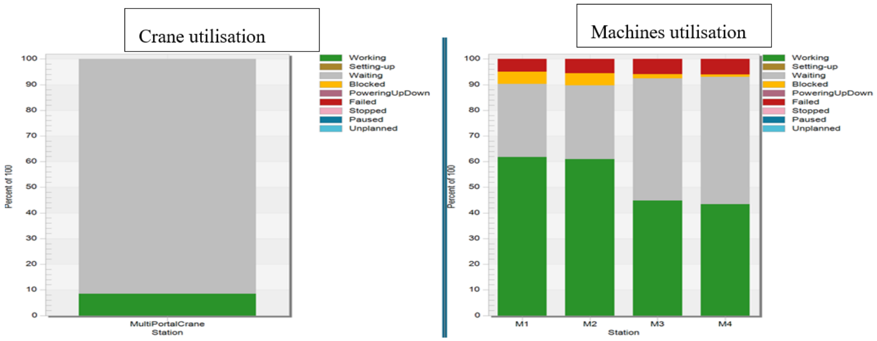


Figure 8. Equipment utilisation over 250 working days for the configuration with four plasma cutting stations.

7. Discussion and design implications

The comparison of scenarios demonstrates a classic shipyard sizing problem: under sizing results in a hard capacity shortfall (2 cutters), while oversizing produces idle capacity and reduced utilization (4 cutters). The three-cutter configuration is therefore identified as the optimal workshop sizing for the planned production program, achieving the required annual output (~11,040 plates) with stable operation and balanced machine loads.

An important design insight is that system constraints are not dominated by crane utilization (which remains ~8–10% in all cases), but by the interaction between handling logic, process synchronization and workstation availability. When four cutters are installed, the additional station cannot be consistently fed and cleared at a rate that would maintain high utilisation, leading to partial saturation and idle periods. This confirms that simulation-based verification is essential in the basic design phase because it prevents "intuitive" oversizing and supports rational capital allocation.

Based on the observed behavior, the following improvement directions are technically justified for future optimization: increasing crane handling capability (speed or parallel handling), introducing alternative internal transport solutions, and refining dispatching/scheduling logic for plate distribution. Such measures can be evaluated within the same modelling framework prior to any physical investment.

Beyond capacity sizing and bottleneck identification, simulation can also be used to optimise resource and energy consumption, which directly affects operating costs and the shipyard's environmental footprint. Discrete-event models can be extended with energy-related parameters (machine operating states, idle times, auxiliary systems and transport cycles) to quantify electricity demand and evaluate alternative operating strategies that reduce non-value-added time and unnecessary handling. Such optimisation supports lower CO_2 emissions through improved utilisation, reduced waiting and fewer internal transport movements, aligning shipyard planning with modern decarbonisation objectives.

From a greenfield shipyard perspective, simulation-based planning enables structured evaluation of design decisions before construction, including not only workshop sizing but also layout feasibility, logistics performance and operational robustness under varying production scenarios. This capability is increasingly integrated within Shipyard 4.0 / digital twin approaches, where simulation supports planning, monitoring and process analysis across the shipbuilding lifecycle.

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