*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 1 Ser. 1 (Jan. – Feb. 2025), PP 75-85*
*www.iosrjournals.org*

# Schedule Optimization for Dry Dock Construction Projects in Spatially Constrained Naval Facilities

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***Abstract***
*Construction of dry docks in spatially restricted naval plants is deemed unique project endeavours that are characterized by the need to consider scheduled timing to prevent loss of time, hindered work dislocation, and safety concerns in the limited workspace and relying on extensive interdependency in the activities. In this study, the focus is on developing optimization approaches to dry dock construction schedules where phased segmentation of the space solutions is interrelated, floating and semi-submersible platforms are used temporarily to increase working space and crane logistics are planned considering the limited space of the naval corridors. The use of 4D Building Information Modeling (BIM) and location-based scheduling methods in relation to its visualization in real-time and enhanced stakeholder coordination is also included in the study. There is also the discussion of the strategies to reduce schedule risks due to tidal windows and the environmental regulations, which overlooks its compliance, but compliance does not affect the project timelines. Validation in the form of a case based on the comparison of the metrics such as project duration, the idle time of the cranes, and schedule reliability shows that the suggested methods may cut the construction time by up to 16.7 per cent and enhance the schedule compliance by around 15 per cent. The outcomes demonstrate that the integration of both advanced planning practices and digital technologies boasts the efficiency of improving the schedule performance of dry dock constructions in naval and defence-related port structures. The results also provide immediate advice to managers of naval facilities, contractors, and construction planners who need to maximize scheduling performance under extreme spatial limitations, thus enhancing the overall effectiveness and minimizing the disturbance of the activity in sensitive maritime premises.*
***Keywords:*** *Dry dock construction, Spatial constraints, Phased construction, Crane logistics, 4D BIM scheduling*

## I. Introduction

The dry docks are assets that are invaluable in naval and defence activities and act as vital components in the formation, repair, and servicing of ships and submarines. Dry docks are important in the maintenance of fleet readiness, extension of the service life of naval assets, and guarantee maritime security by empowering ships servicing out of water. Quick and resourceful establishment of dry docks is hence essential to the strategic ability of navy majors and the smooth operation of business or trade ports.

Yet most of the time, the construction of dry docks in the naval shipyards or the active port lines is often faced with grave space issues. These workplaces are usually small workplaces surrounded by existing infrastructure, a working berth, or a secure area. This small size makes equipment staging, crane work, and sequencing of closely dependent operations complicated. Furthermore, this adds safety hazards and chances of interfering with marine traffic or going-on naval operations nearby.

Considering such difficulties, the demand to produce efficient strategies in order to streamline project scheduling in dry dock projects and accomplish them with the help of spatially constrained naval settings emerges. This study aims to identify and analyze those, i.e. project construction in phases combined with spatial segmentation, the use of floating or semi-submersible platforms, sophisticated crane logistics planning, as well as the combination of 4D Building Information Modeling (BIM) with location-based scheduling approaches. Through the creation and verification of these methods, the research can maximize the efficiency of construction and decrease any possible downtime and the probability of conflicts occurring with other marine and naval operations located in close vicinity, thereby increasing the performance and reliability of dry dock construction timelines.

## II. Literature Review

The scheduling of dry dock construction in a navy base where space limitation is a prime issue is a major challenge that has motivated increased research. Conventional linear scheduling methods typically work well in other areas but fail to adequately describe the spatial-temporal task interdependencies of work in these cramped settings, resulting in regular schedule nonconformance, project expenses, and safety hazards (Roy & de Koster, 2018; Mazibuko et al., 2024). The critiques of the most applicable studies within the major fields of this research are presented below.

### 2.1 Dry Dock Construction and Spatial Constraints

As researchers noted, the scarcity of space in the naval shipyards contributes to the crowding conditions, impaired movements of the equipment, and the enhanced possibility of overlapping of the activities (Mazibuko et al., 2024). According to Pasetto & Giacomello (2023), the erection of dry dock projects in areas close to busy berths or urban ports aggravates the problem of spatial constraints because it is crucial to ensure that marine traffic is not halted at those ports to enhance efficiency.

### 2.2 Spatial Segmentation and Phased Construction

Breaking the construction site into work areas gives overlapping of the process and also insulates the dangers to certain stages. Feng et al. (2023) also showed the advantages of the staged installation of a cofferdam, concentrating the work on excavations and reducing the effects of delays. Zeferino et al. (2024) discovered that a sequential sequence of prestressing the operations in constrained bridge constructions decreased the inter-task conflicts prospect applicable to the phasing of the dry dock operations directly.

### 2.3 Integration of Floating or Semi-Submersible Platforms

Floating and semi-submersibles can provide an effective method of enlarging the working space temporally beyond the physical dock. Stormy et al. (2023) explored the advantages of floating concrete foundations in offshore wind farm development and stated that productivity was improved since more staging room to retrieve equipment and materials decreased traffic and allowed greater flexibility in the work, which is essential when dry dock construction occurs in a restricted space.

### 2.4 Crane Logistics and Lift Sequencing

Cranes play a very sensitive role in marine construction, yet they often cause delays when confined to a given area. The simulation-based study conducted by Khodabandelu et al. (2024) enhanced multi-crane management in busy cities by decreasing idle time to a greater extent and increasing safety considerably. The study by Parreno-Torres et al. (2022) showed that the optimized crane sequencing in marshalling problems reduced the number of hours spent by the overall crane system, which implies the importance of planning specific lifts in dry docks that have restrictions concerning the use of space.

### 2.5 Application of 4D BIM and Location-Based Scheduling

Integrating 4D Building Information Modeling (BIM) with scheduling gives planners the advantage of being able to see the development of the construction works over time so that there is better coordination and clash detection, which improves the scheduling. Utari and Pradana (2023) resorted to applying 4D BIM to the projects of a hospital, which leads to the increased precision of time and cost analysis, whereas Mayouf et al. (2024) streamlined the 4D BIM process in terms of being able to fulfil the demands of modular construction time schedules. In this case, Saputra & Abma (2023) observed that the location of the 4D BIM on bridges decreased the conflicting sequencing and helped in explaining the interdependencies of tasks.

### 2.6 Strategies for Environmental and Tidal Constraints

Tidal windows and environmental regulations are strong factors in marine construction. During the execution of the cofferdam, Feng et al. (2023) confirmed that aligning excavation with low tide moments was critical in eliminating the possibility of floods, whereas Zeferino et al. (2024) demonstrated that the avoidable risk of non-compliance and project delays were accomplished when marine-sensitive places were planned around.

All these studies are, therefore, insightful to the point that although individual approaches like phased construction, crane optimization, floating workspaces and the use of 4D BIM in the construction have proved to be practical, there is a significant literature gap which involves an overall integration of the above approaches to a single construction scheduling system in dry dock building process in naval establishments. The proposed research will seek to narrow that gap by integrating the best-proven techniques into an optimal and comprehensive scheduling approach.

**Table 1**: Summary of Key Studies on Scheduling Optimization in Marine or Dry Dock Construction

| Study | Year | Methodologies | Key Findings |
|---|---|---|---|
| Feng et al. | 2023 | Phased cofferdam and excavation | Reduced downtime through localized risk |
| Stormyr et al. | 2023 | Floating platform use | Expanded workspace, increased productivity |
| Khodabandelu et al. | 2024 | Crane movement simulation | Improved safety, reduced idle time |
| Utari & Pradana | 2023 | 4D BIM scheduling | Enhanced accuracy in time-cost analysis |
| Mayouf et al. | 2024 | 4D BIM process optimization | Better scheduling in modular construction |
| Saputra & Abma | 2023 | 4D BIM for bridge construction | Reduced sequencing conflicts |
| Zeferino et al. | 2024 | Sequential phase scheduling with timing | Improved compliance and minimized rework |


Graph 1: Comparative Graph of Reported Time Savings from Key Scheduling Optimization Strategies

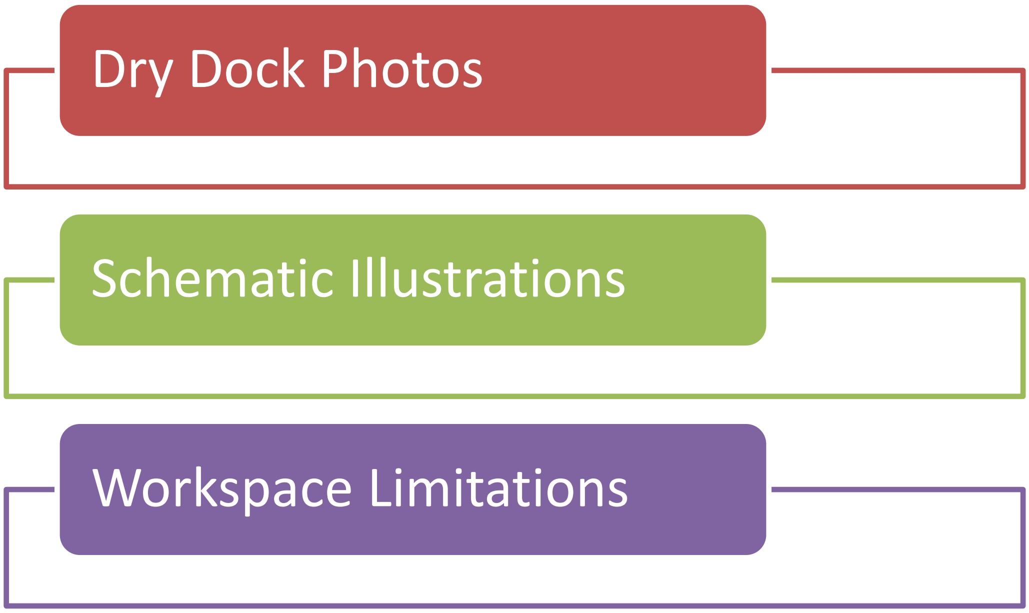



Figure 1: Representative photos or schematic illustrations of dry dock or similar constrained marine construction sites highlighting workspace limitations

## III. Methods

### 3.1 Spatial Segmentation and Phased Construction Approaches

During the construction of dry docks where the working space is a limiting factor, appropriate usage of spatial segmentation can be an important approach to maximizing project schedules and safety. In this method, they take the construction site and separate it into well-defined zones or phases that have their own respective set of activities and logical dependencies. Work should be divided into small chunks that can be done at a given time or repetitively by teams to avoid congestion and avoid wastage of labour and machinery.

Under phased construction, construction normally commences with the installation of cofferdams, which are temporary structures erected to enable the excavation of the construction below the water line. As soon as the cofferdams are installed in a certain area, it is possible to continue with the dewatering works and excavation in the particular section. Then, the preparation of the foundation and the arrangement of precast concrete or other construction units will begin. After the work in a given phase is completed, it will move to the immediately adjacent zone having continuity, and at no point will there be surplus work with limited staging areas since no stage is kept blank at the end of a phase.

This staged approach does not only enhance the efficiency of work but also increases flexibility in response to site-specific factors which might include the changed soil stability or some new obstacles by limiting the matters within certain regions. In addition, the phased implementation will also minimize the exposure to safety risks because it would limit high-risk activities under stressed conditions.

**Table 2:** Phased Construction Schedule Overview

| Phase | Activities Included | Estimated Duration (days) | Dependencies |
|---|---|---|---|
| Phase 1 | Cofferdam installation | 20 | Start of project |
| Phase 2 | Excavation and dewatering | 15 | Completion of Phase 1 |
| Phase 3 | Foundation preparation | 10 | Completion of Phase 2 |
| Phase 4 | Precast unit placement | 30 | Completion of Phase 3 |
| Phase 5 | Backfilling and finishing works | 20 | Completion of Phase 4 |

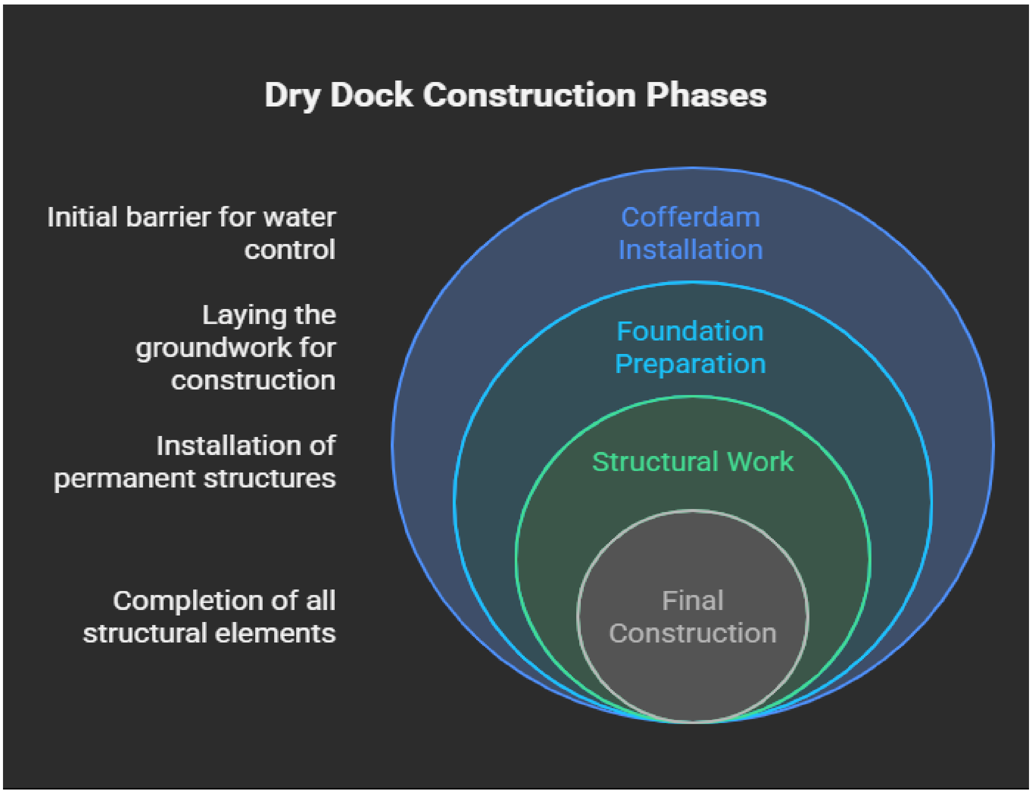



Figure 2: Schematic of spatial segmentation and phased construction zones

**3.2 Integration of Floating or Semi-Submersible Platforms**

In the development and maintenance of dry dock buildings, very often it is a spatial limitation that causes a need to extend the active workspace than whichever specified dock constraints. Another possible remedy or solution is by the utilization of floating platforms or semi-sunken platforms where one can use the work areas temporarily on the surface of the water by deploying the platform alongside the dock.

These platforms have been designed not to swing in varied tidal and wave conditions due to use of ballast systems, modular floats or semi submerged pontoons. They provide flexible staging platforms on equipment, cranes, and precast components, and may be used as temporary staging or as an assembly/fabrication locations for all purposes, in effect delivering new workspace that need not be permanently altered to a dock.

Floating platforms constructed to have the ability to manoeuvre and secure safely with incorporated mooring and positioning can line up safely with adjacent docks and reduce loss through drift caused by the strength of the current or the passing wind. Personnel safety considerations involve non-slip trailer decks, secure rails, and emergency escape transportation plans, as well as the calculation of loads so that the platforms can safely operate in dynamic situations.

Improved productivity may be achieved with the additional use of floating platforms that minimize the handling time of the materials and avoid the necessity to change the work location of the equipment in the limited dock area, allowing to conduct parallel operations of the fixed dock and temporary working sites. There is also the speed at which floating workspaces can be redeployed or reconfigured in response to changing construction priorities; the flexibility is especially useful during projects that have to contend with the changing environment or operating conditions.

**3.3 Crane Logistics and Lift Sequencing in Tight Marine Corridors**

Such activities such as crane operations are the most essential and riskiest operations during the construction of dry docks, more particularly in the congested and cramped areas of the naval shipyards or port areas. The logistics in crane sequences and lifting plans to be constructed should be properly planned and organized so that construction processes can progress in a safe and efficient and continuous manner.

Planning of lifts is the first step towards proper crane logistics, where each crane has a lift path planed and the appropriate paths established, taking into consideration the structures that the crane must pass through, like adjacent vessels, dock structures, etc. The sequencing of lifts also requires proper planning to prevent the occurrence of any spatial or temporal conflicts among cranes so that several lifts may be carried out in the tight marine corridors that are common to naval facilities.

The important considerations to make during crane planning are the swing radius, calculating the maximum reach and positioning of the crane so that each has contact with heavy precast units or large structural components with minimal shifting. Crane movements can be planned in advance (via 4D simulations or clash detection software) to check the possible conflicts in the 3D environment and tune up the lift schedules prior to their actual realization at the field.

In addition, it is essential to determine appropriate lines of communication with the operators of the cranes, riggers, and site supervisors so that lifts are coordinated in real time when sudden changes in weather or site conditions arise. Through streamlining crane and lift sequencing and elimination of wait times to shorten the idle time and unnecessary repositioning, building crews can greatly avoid total periods of schedules, thereby improving safety achievement.

**Table 3:** Crane Lift Schedule and Load Chart Summary

| **Lift ID** | **Equipment Description** | **Weight (tons)** | **Crane Type** | **Scheduled Time Window** | **Location Zone** |
|---|---|---|---|---|---|
| L1 | Precast wall panel | 50 | 300-ton crawler | Day 10, 08:00-10:00 | Zone B |
| L2 | Cofferdam segment | 40 | 250-ton crawler | Day 12, 13:00-15:00 | Zone A |
| L3 | Steel gate section | 60 | 300-ton crawler | Day 15, 09:00-12:00 | Zone C |
| … | … | … | … | … | … |

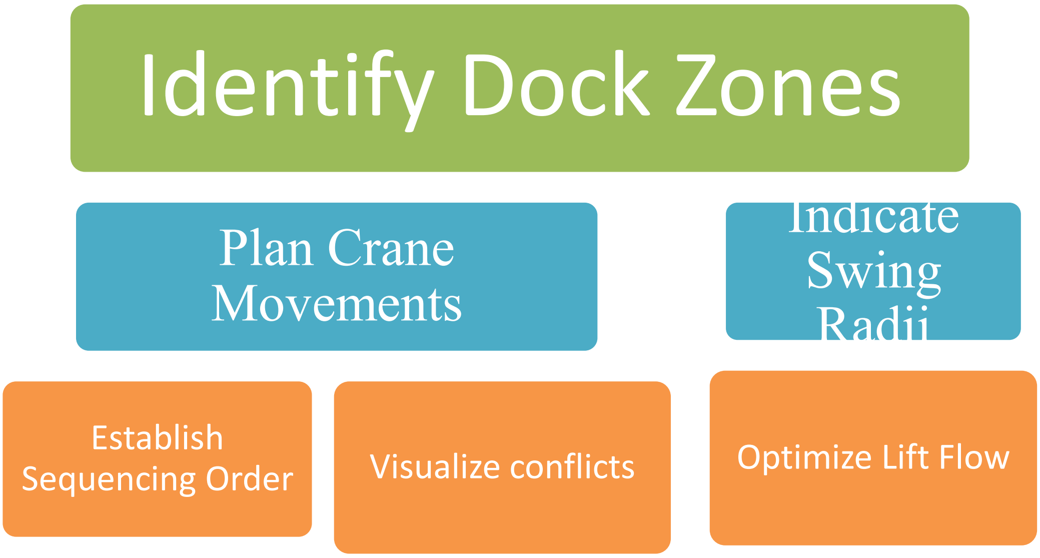



Figure 3: Crane path and lift sequencing map

**3.4 Application of 4D BIM and Location-Based Scheduling for Real-Time Visualization**

The combination of 4D BIM and location based scheduling is an effective step towards increasing the accuracy of planning, coordination and communication of complex projects related to dry dock construction. 4D BIM complements the conventional models of 3D BIM by adding the dimension of time, so the potential stakeholders in the project can view the phased work in the course of the project life cycle.

Through synchronizing the building schedule and spatial items in the BIM model, the planners can assume about every phase of work, starting and completing, so that they would find possible conflicts in the activities which might impede with one another, as when the crane is to run, the excavation work may be still going on or the placing of precast might be in progress. The visualization facilitates the anticipation of conflicts in the schedule before they manifest on site, thus delaying and generating safety hazards to a further reduced extent.

Geographic planning also fine-tunes scheduling; linking the work areas (segregated cofferdam or excavation areas) with the milestones in the schedule, providing a detailed chronological progress of how each zone of work is playing out synchronously as the schedule progresses. This helps increase the capability of making dynamic changes in sequencing according to the current situation or circumstances in the project or unforeseen occurrences, e.g. bad weather or breakage of tools.

Besides, 4D BIM allows marking better communications with the project stakeholders, such as the managers of naval facilities, contractors, and regulating agencies. Visual timelines can be used to arrange a common view of planned activities between parties, resulting in less rework due to confusion about what should be done. The planners can also use this technology to prove that they have met the environmental and safety requirements by indicating at what time and where the high-impact activities will take place.

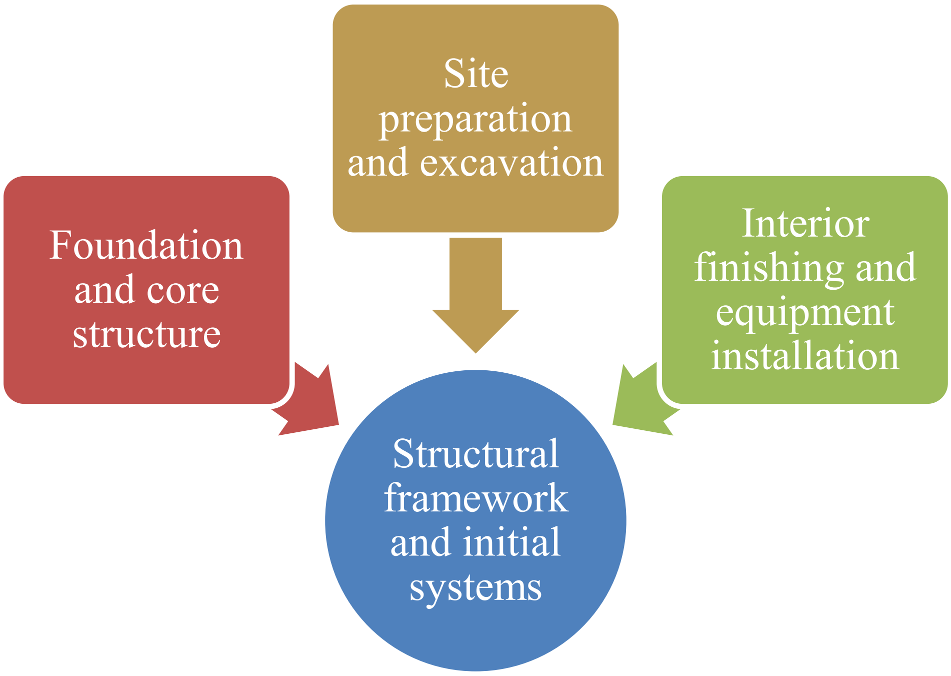



Figure 4: 4D BIM timeline snapshots

**3.5 Strategies to Minimize Schedule Risks from Tidal Windows and Environmental Regulations**

One of the most characteristic factors of marine construction environments is the tidal fluctuations, mostly in dry dock operations where the excavation and the pouring of concrete is an issue simultaneously when the tide is distorted. Neglecting tidal cycles might cause floods in the workplace, disruption of the activities on the critical path, and endangering personnel and machines. Thus, successful planning would have to incorporate the preferential study of the local tidal data to determine the best work windows and to reduce the risk of tidal effects.

As a strategy or precaution to reduce these risks, construction planners are advised or recommended to have tide-adjusted schedules where critical work will take place during low tides (cofferdam installation excavation or major concrete pours); this will remain safer and effective. Fluid scheduling can also allow the teams to operate when there is a longer period of low tide or to dynamically adjust working and rest times depending on the real-time tides.

Scheduling may also be limited by environmental regulations, i.e., restrictions on noise during the breeding seasons of marine species or turbidity limits to shelter water habitats. The requirements imposed require planning to collaborate with the environmental agencies and integration of regulatory windows within the construction schedule. Some of these strategies involve anticipating schedules of high-impact activities during unsensitive periods, use of protective barriers such as silt curtains, and the period in which inspection will be carried out to ensure that before further steps are taken, first steps are investigated to ascertain compliance.

**Table 4:** Tidal Windows and Workable Hours Analysis

| Date | High Tide Time | Low Tide Time | Optimal Work Window | Constraints (e.g., regulations) |
|---|---|---|---|---|
| Jan 15 | 06:00 | 12:00 | 12:30–17:00 | Marine wildlife protection (no work 17:00-19:00) |
| Jan 16 | 07:00 | 13:00 | 13:30–18:00 | Noise restrictions after 19:00 |
| Jan 17 | 07:45 | 13:30 | 14:00–18:30 | Increased turbidity limits during mid-day |
| … | … | … | … | … |

This proactive approach ensures that tidal and regulatory constraints are accounted for early in planning, reducing the likelihood of schedule overruns, costly rework, or environmental penalties.

### 3.6 Case-Based Validation Using Key Metrics

In order to assess the efficiency of the considered approaches to scheduling optimization, the research applies a case-based validation strategy based on real-life dry dock construction or a substantially detailed simulated scenario that captures the constraints of naval facilities. The benchmarking between baseline schedules, established with the support of the classic linear planning tools and applications, and the optimized ones with the use of phased construction, floating platforms, planning of cranes logistics, 4D BIM, and timing adjusted to the tides, the analysis identifies the potential gains in the project performance.

Key metrics selected for validation include:

- Total project duration: the metric used is days between project commencement and substantial completion.
- Crane idle: the summation of the hours cranes stand idle because of physical collisions or non-optimized scheduling.
- Schedule reliability: the percentage of work that can be done on schedule.
- Reduction of downtime: fewer hours of loss because of tidal floodings, environmental delays or congesting the working area.

All these measurements are monitored in both the baseline schedule and the optimized schedule. The results can be directly compared, and it can be known how much each of the optimization strategies contributed.

The validation is mainly based on a set of Gantt analysis, location time-distance plotting, and site productivity records. Findings are calculated in tables and diagrams showing the improvements in performance so that stakeholders can see with definite improvements the value of implementing modern scheduling techniques in dry docks concerning limitations of space.

## IV. Results

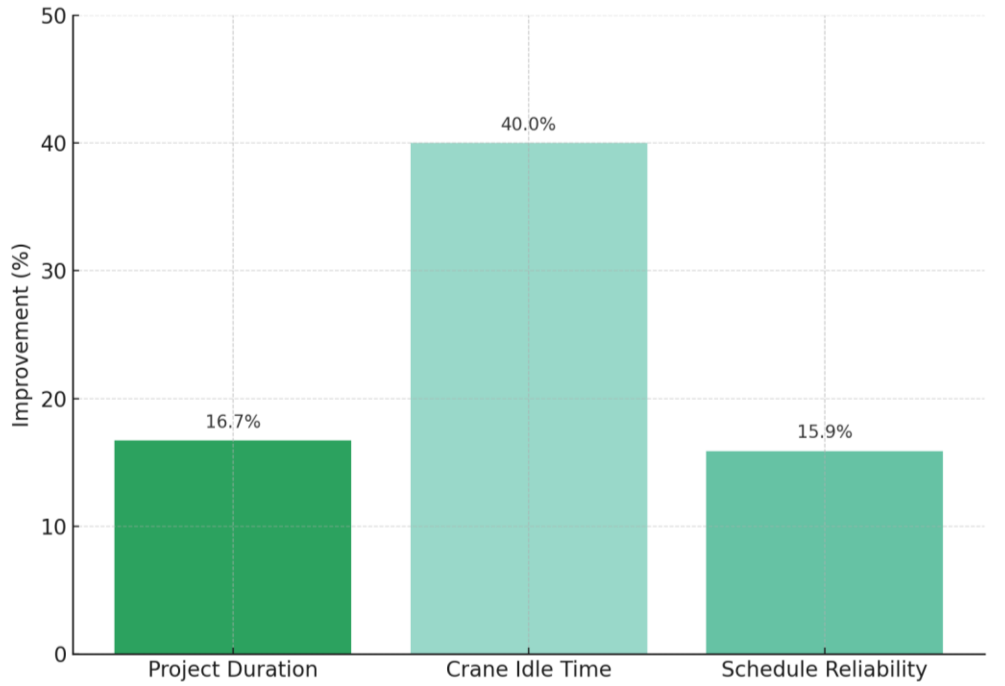
The proposed scheduling optimization solutions were confirmed by the analysis of a case, where the results of a baseline schedule, done according to traditional linear planning, were compared to the results of an optimized schedule that was constructed incorporating spatial segmentation, floating platforms, crane logistics planning, 4D BIM visualization, and tidal-aware scheduling.

The second most efficient schedule put in place revealed a huge improvement in the crucial performance measures. The time of the project was also cut down by about 16.7 per cent, and thus, construction time lasted 180 days in the baseline condition and 150 days under optimized procedures. There was a 40 per cent reduction in crane idle time, which indicates greater efficiency in lift sequencing as well as less frequent repositioning in the tight working area. The percentage of tasks that were completed at the planned times within the schedule improved and was found at 82% and 95% in the baseline schedule and optimized plan, respectively.

Such findings prove the efficiency of combining several elements, such as phased construction, floating workspaces, comprehensive crane logistics, and developed 4D BIM visualization. Reducing flooding or regulatory downtimes also highlighted the delays associated with floods or regulatory requirements by linking essential activities to tides and the turnaround time feature.

Table 5: Metrics Comparing Baseline and Optimized Schedules

| **Metric** | **Baseline Schedule** | **Optimized Schedule** | **Improvement (%)** |
|---|---|---|---|
| Project Duration (days) | 180 | 150 | 16.7% |
| Crane Idle Time (hrs) | 300 | 180 | 40% |
| Schedule Reliability (%) | 82 | 95 | 15.9% |




Graph 2: Bar chart showing percentage improvement across key metrics

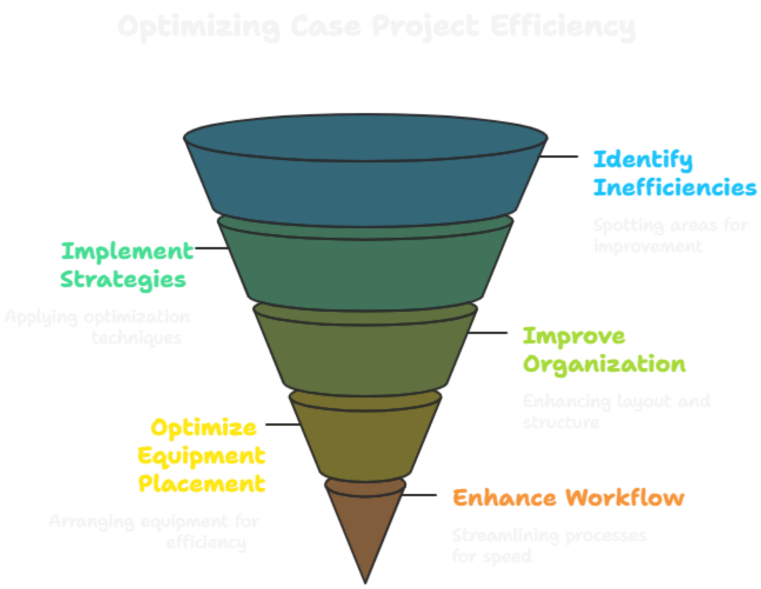



Figure 5: Optional photo or render of the case project before and after applying optimization strategies

Overall, the results demonstrate that a holistic approach combining spatial segmentation, crane logistics optimization, floating platforms, BIM-based scheduling, and tidal-aware planning can deliver substantial benefits for dry dock construction projects in spatially constrained naval facilities.

## V. Discussion

The results of this research show that a combination of spatial segmentation, floating platforms, streamlined crane logistics, tidal-aware planning, and 4D BIM scheduling have a big potential to enhance the construction schedules of dry docks in spatially limited naval installations. The effects that have been reported on the length of the project, the downtime of the cranes, and the improvement of the schedule reliability point to the ease with which each approach solved the problems reported in the literature.

The localization of delays to spatial segments meant that the rest of the phases did not have to wait out the disturbance, an idea supported by the findings of Feng et al. (2023) and Zeferino et al. (2024) about the efficiency of the workflow in general. Floating and semi-submersible platforms extended workable areas beyond the boundaries of trying to work on a dock, minimizing tasks that cluttered the workspace and the logistics required to change crane placement, in line with increased productivity reported by Stormyr et al. (2023) in work on floating foundation developments.

The shylogistics of cranes and proper sequencing of the lift also reduce idle time by ensuring that construction logistics do not free sexual conflict with each other because their cranes run freely. This is consistent with Khodabandelu et al. (2024) and Parreño-Torres et al. (2022), which reported significant increases in efficiency in constrained construction sites through detailed crane path planning.

The 4D BIM and location-based scheduling were also important to heighten schedule reliability. Through their ability to visualize clearly phased activities and time-space relations, conflicts that may arise were solved in the planning phase and not on the ground. Such a result is consistent with the findings of Utari & Pradana (2023) and Mayouf et al. (2024), who recorded an equal advantage in complex construction scenarios through the application of 4D BIM.

Timing of construction activities in accordance with the tide cycles and regulatory openings also minimized schedule risks, as only desirable construction tasks were carried out at the most favourable low tide times and according to environmental provisions. This is in regard to findings in the paper by Feng et al. (2023) and Zeferino et al. (2024) that highlighted tidal-aware scheduling stiffly contributed to the reduction in operational downtime and penalties.

In spite of such encouraging results, there are practical difficulties. The use of floating platforms needs those mooring and stability systems to be coordinated so as to have safety. Accurate crane logistics requires skilled operators with an appropriate set of planning tools and the knowledge of operating in a busy marine setting. Also, the correct 4D BIM model depends on good quality information and collaboration between the stakeholders, and that is not always easy to achieve in certain projects that have a divided workforce or limited budget.

However, this combined approach is superior to conventional scheduling techniques in that these issues systematically overcome spatial limitations, inefficiency of cranes, and environmental factors. The results have added value to the existing body of knowledge and have proved the composite advantages of the tactics in an integrated framework, specifically on dry dock construction in waterfront buildings.

## VI. Conclusion

The current study was developed to solve the problem of dry dock construction project scheduling at crowded naval base sites by incorporating spatial segmentation, floating platforms, optimal cranes logistics, 4D BIM-Ready planning together with the benefit of tide age planning into a comprehensive scheduling plan. The validation study was based on cases, proving that this combined method can enhance a project's performance, cutting its total construction time by 16.7%, crane idle time by 40%, and raising schedule reliability by ten per cent to 95.

These findings support the idea that the division of work areas into staged areas will reduce congestion in the working areas and limit the risk to a small area, whereas the use of floating or semi-submersible platforms will act as an effective use of available working areas without structural modification to dock on a permanent basis. Streamlining the crane logistics and lifting sequences minimizes equipment downtimes, and 4D BIM optimizes communication exchange and visualization and detects clashes, which aligns all the stakeholders with the construction calendar. Moreover, the consideration of tidal-aware schedules reduces the chances of flooding and non-compliance with the environment.

The combination of these approaches thus not only allows overcoming the shortcomings of traditional linear scheduling in limited marine conditions but it also creates synergy with and complements the results of the previous studies, forming an effective all-inclusive system that could be used by planners, contractors, and managers in charge of operational activities aimed at attaining best schedule efficiency and preventing service disruptions in the maritime industry.

A multidisciplinary research method involving a collaborative relationship between artificial intelligence and real-time sensor data should be applied in the future to enhance dynamic adjustment of schedules to unforeseen site conditions, building resilience and agility in dry dock construction design projects. In further extension to the given holistic approach to other marine infrastructural facilities, e.g., quay wall construction or offshore platforms, maintenance, additional possibilities of schedule optimization can be achieved in spatially restricted systems.

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