

Shipbuilding—An Analysis from the Perspective of Enterprise Resources Planning System

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Abstract

Designed as a tool for business intelligence, resource planning is used to manage the essentials of a business by integrating processes into a single system. Enterprise Resource Planning (ERP) solutions ensure all the organizational, operational, and procedural structures interconnection, which can be both an advantage and a disadvantage, knowing that inefficiency within one structure will lead to inefficiency in others. The originality of the approach consists in the unitary analysis of all processes which shipbuilding involves (design; evaluation of ship construction possibilities; contracting of works; contracting of supply of materials and equipment; presentation of inspections for the completed works reception; delivery of the ship into operation). The systemic approach is a notable contribution by highlighting the input and output quantities for the analyzed processes. Also, where it was found relevant, the diagrams highlight the owners of the process and show the interconnectivity of the functional departments within a shipyard. Although it is obviously the expression of in-depth knowledge of the peculiarities of Romanian shipyards, the authors hope that the work can support any shipyard that may be interested in knowing these structures (as a logical scheme mandatory to design a custom ERP software system).

Keywords

Shipbuilding, Shipyard, Production Structures, Enterprise Resource Planning, Processes Flow

1. Introduction

Anyone who reads this paper might ask, as the authors did before they set to

work, “why would it be necessary to structure the shipbuilding processes in a shipyard?” Using the available research resources [1], the authors were interested in the results published by other authors and, consulting an extensive bibliography (published in journals or presented at conferences) contributed to outlining some interesting conclusions.

At present, the main concern of any shipyard is to ensure that ships are delivered on time, with as low possible costs, are following quality requirements and a high level of customer satisfaction is ensured. Thus, since 1979 Cpt. Kaune [2] found that there is a basic management plan which controls the shipyards. The entire process can and must be optimized, but maximizing any part without regarding the total, will lead to problems. They suggest a method of developing a successful process and discuss management methods to assure its success after its development.

A shipyard’s competitiveness is determined by the level of production management capability that it possesses. Many shipyards have made great efforts to improve their productivity by introducing higher level planning systems and process management systems, by applying the Product, Process, Resource, and Schedule (PPR-S) model [3] [4] which is suitable for a shipyard production environment. The notorious relevance of shipbuilding in the global context has led shipyards to improve their production processes [5] seeking to reduce construction costs as well as manufacturing and outfitting time, to meet the increasingly competitive market that demands greater productivity. One of the biggest problems of the shipyards is planning and controlling the production development, so scheduling method [6], which is updated based on current performance and a production control system must be investigated. Through a reasonable arrangement of the production plans (including the virtual flow operation) can be achieved all production activities of the shipbuilding enterprise, with high efficiency and flexibility [7].

A shipyard is a complex shipbuilding and/or ship repair business comprising: workshops, slideways, docking docks, berths and numerous installations and technical means capable of carrying out the entire design, execution and necessary testing process for the shipbuilding (including launching) and the ships repair works. The functional organization (sections, workshops, team works, working places) in a shipyard includes workspaces and equipment for all processes and depends on both the technical capabilities of the operational structures and the human resources, in terms of quantity, quality and structurally, these conditioning the choice of the strategy with reference to the type and number of newbuilding that the shipyard can contract in a determined period. There are authors concerned with the organization, reorganization, and modernization of shipyards, especially in crisis situations, when the international socio-economic and financial context becomes difficult. The operational structure of a shipyard (with reference to dimensions, technical characteristics, number of workspaces and equipment needed to carry out the processes) is designed to allow the op-

timal development of shipbuilding processes, considering the number of projects that it is intended to run simultaneously. The intense competition in this field of activity has determined the shipyards to take care of: application of CAD-CAM-CAE techniques related to design processes; use of advanced production technologies (robotics, automation, programming); the information technologies implementation within various operational structures. Due to the rational sizing of this paper, the authors did not retain bibliographic references on the previous mentioned topics. It was found that some quantitative and qualitative factors influence competitiveness of shipyards. In general, regarding performance, quantitative variables are analyzed through mathematical and linear models. However, the qualitative variables, due to its subjectivity because it deals with human perceptions, it is not common for organizations to work on the performance of these factors [8]. Also of interest are topics such as: the application of the principles of continuous improvement of organizational performance [9], the application of quality control theory to shipyard practices [10] and the concept of total value management (introduction to the concept of “zero defects” versus “tolerance of construction” [11]).

If the concept of Industry 4.0 is considered, the authors of this paper were not surprised to find that there are many researchers interested in programming, modelling, and simulating different processes, even going so far as to virtualize shipyards. Simulation is a powerful tool that is used to understand and analyze the effect of changes on real systems, including in shipbuilding industry [12]. It is interesting to follow the chronological evolution of this concept in the works consulted by the authors of this paper. In 2003, the System Dynamic Continuous Computer Simulation Model of the Organization Production Shipbuilding Process was introduced [13]. Having a multilevel function of its goal, the most important ones to mention are: enabling business production managing structure to continuously check the dynamics of shipbuilding process; efficiently giving the forecast of the possible effect of “bottleneck” in shipbuilding process; optimizing the particular process parameters; finding the most valuable scenario of the future realization of the shipbuilding process [14]. Then, in 2005, followed the Decision Support System (DSS), which uses discrete event simulation models and heuristic optimization, enabling efficient use without detailed knowledge of methodologies [15]. The year 2010 brought to attention a simulation framework that manages both DEVS (Discrete Event System Specification) and DTSS (Discrete Time System Specification) to meet different requirements [16]. Then in 2013 the process improvement model, OPT (Optimized Production Technology) [17] together with the active discrete event simulation using probability distribution of shipbuilding process was proposed [16]. Next, in 2016, the data model for shipyard production simulation model generation was defined by analyzing the iterative simulation modeling procedure [18]. Also in 2016, a simulation system called SIMSON (SIMulation System Of New production planning) was presented, which emphasizes that the simulation results are in har-

mony with the real situation and the application of SIMSON to the simulation of production planning in shipyards is quite feasible [19]. The following year, a heuristic simulation approach was introduced to address the issue of shipbuilding programming in a multi-stage production system. It allows the evaluation of the actual production of many blocks and sub-blocks, while satisfying a large set of constraints [20]. In 2020 some authors propose a simulation method based on backward simulation and process-oriented simulation to consider the characteristics of shipbuilding production. The shipyard production planning process was investigated to analyze the detailed process, variables, and constraints of mid-term production planning. Backward and process-centric simulation methods were applied to the mid-term production planning process and an improved planning process, which considers the shipbuilding characteristics, was proposed [21]. In 2000, for the first time, the authors [22] discovered that discrete event simulation could be used for virtual prototyping of new production units. Models built for this purpose must be easy to use, flexible and provide a realistic graphical view of the proposed system. The approach allows for quick analysis of the technology. In 2007, one paper [23] referred to simulation-based approaches in the shipbuilding industry, such as digital shipbuilding, Simulation-Based Design (SBD), and a virtual shipyard. Shipbuilding 4.0 [24] to the principles of Industry 4.0, transform the design, production, operation, transportation, services, production systems, maintenance, and value chains in all aspects of the shipbuilding industry. Among the various Industry 4.0 technologies, some works focus on augmented reality, the application of which in the industrial field has led to the concept of Industrial Augmented Reality (IAR). The paper [25] first describes the basics of IAR and then conducts an in-depth analysis of the latest IAR systems for industrial and shipbuilding applications. Then, to build a practical IAR system for shipyard workers, the main hardware and software solutions are compared. Recently, various production technologies [26] have been developed to promote the production environment of the shipyard under the influence of Industry 4.0 towards automation, smart factories, and smart planning systems. In 2021, an overview of current state-of-the-art digital twin and digital technology in industrial operations [27] was provided (the twin/thread framework encompasses specifications that include organizational architecture layout, security, user access, databases and hardware and software requirements). In the paper [27] it was highlighted that the framework is expected to be applicable to improve the optimization of operational processes and the traceability of information in the physical world, especially in an industrial shipyard 4.0.

2. Method and Contribution

An effective way to understand complex industrial processes is to outline them. The scheme is a formal language for the management system of an organization and is a tool to simplify the structure, organize it in a logical sequence and in-

interpret the information to exercise the decision-making act. The authors of this paper approached the schematization of processes as a working method, having in mind their experience of shipbuilding activity.

Regarding the original contributions made by this paper, they could be listed and summarized as follows:

The inclusion, in the analysis, of all the processes leading to the construction of a ship, given that the consulted literature usually highlights the singular approach of the processes, and some of them are not targeted (e.g., the process of assessing the shipbuilding construction possibilities or the process of the finalized works presentation for reception inspections).

The schemes have been constructed in such a way that process owners can be identified, which is particularly important for the shipyard management system.

The schematization approach from a systemic perspective, with the input and output quantities indication for the analyzed processes.

The schemes allow the informational routes between the functional departments observation and highlight the relations between them (collaboration/subordination).

In addition to the schematization of all the processes carried out in a shipyard for a shipbuilding execution, perhaps the most important contribution brought by this paper refers to the decomposition of the processes into stages and phases of work. This decomposition, together with the schematic construction, significantly contributes the processes evolution understanding and the works succession in the execution which makes it possible to be able to build algorithms (logic schemes) that define ERP software.

The construction stages of a ship represent milestones in the development of the construction processes, being characterized by the completion of the execution of a volume of works (defined quantitatively and qualitatively). In principle, the construction stages of a ship are: design, construction of the ship's hull, launching of the ship's hull, outfitting on board the ship laid on berth, trials of the ship on dockside and at sea, delivery of the ship in operation.

The execution phases represent the ship's stages of evolution by carrying out the execution of the works related to the respective stage. Thus, in principle, the execution phases related to the stages previously mentioned are:

The phases for the ship design stage: the basic design; the technical project; the detail project.

The phases for the shipbuilding stage: the steel plates and profiles cutting; the panels construction; the modulated section blocks construction and superblocks construction; assembly of the ship's hull on the platform and in the dock.

The phases for launching the ship's hull: the outfitting on the ship; installation on the ship the superstructure and the exhausted gases funnel; execution and installation of hull marks, draft scales, name, and port of registry of the vessel; mounting the anodic protection on the hull; execution of the treatment works for the surface of the hull external; launching the ship.

The phases for the outfitting completing on board the ship in floating condition: execution of works for the completion of the installation of equipment, pipes and valves, electrical cables; execution of commissioning works for equipment, installations, and on-board systems; execution of the final painting works of the ship (exterior and interior); execution of superstructure arrangement works.

The phases for the ship delivery stage: execution of the dockside and at sea trial test; execution of works for the delivery of inventories, spare parts, and technical documentation.

The sequences schemes establish that the works carried out in an execution phase and are part of the Project Management activity which streamlines the development of the ship construction process in case of distortions in the development of other processes (designing, contracting of materials and equipment, approval, certification, and inspection of the works).

The process flow in a newbuilding shipyard is described in **Figure 1** and includes:

The process of design with the phases of the basic design project, the technical project and the detail project of the shipbuilding works development.

The process of evaluating the possibility of the shipbuilding works execution.

The process of contracting the execution of shipbuilding works.

The process of the materials and equipment necessary for the construction of the ship contracting and supplying.

The process of the execution of shipbuilding works developing.

The process of the shipbuilding works execution.

The process of presentation to inspections (Classification Society and Client) for the reception of the ship's construction works execution.

The process of delivery the ship in operation with dock and sea trials.

The development of the ship's construction processes in a shipyard is in a relation of mutual conditioning, the disturbances that may occur in the evolution of a process causing the disruption of the development of other processes, at different intensities, the consequences being possible to be quantified only at the ship's delivery in operation.

In the followings, will be explained, commented, and detailed by illustrative schemes, the processes identified for the execution of the shipbuilding works related to the process flow presented in **Figure 1**.

2.1. Evaluating the Execution Possibilities of the Shipbuilding

The process is presented in **Figure 2**, and consists, in principle, in the development of a market study, a design theme and a design project.

The market research is performed by the Marketing Department. It prospects the maritime shipping market in order to assess: type of ships required by ship ownership at the moment, the technical characteristics that the ship have to comply with, the level of prices charged on the new buildings market by other

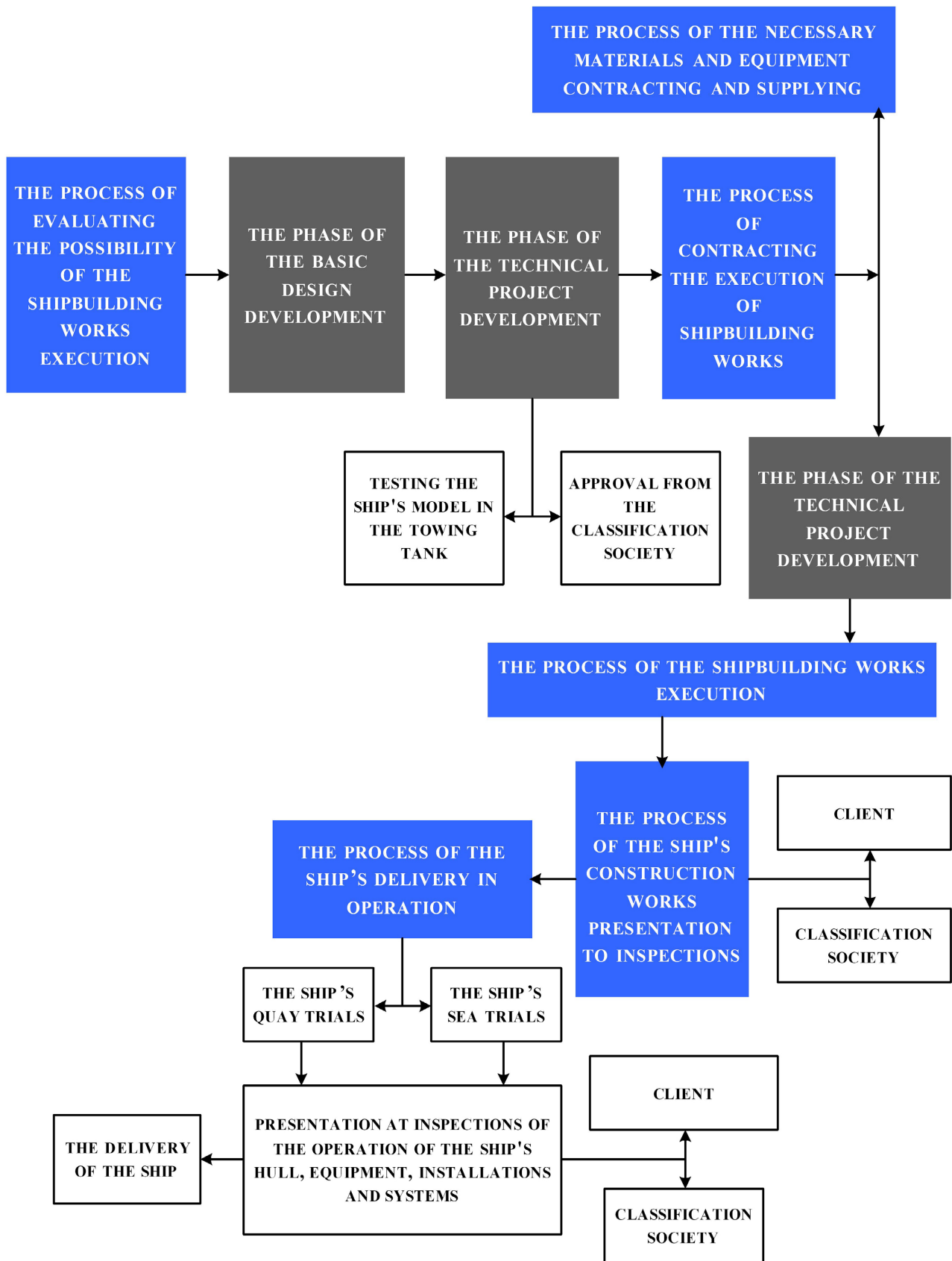


Figure 1. The process flow for the execution of the shipbuilding works.

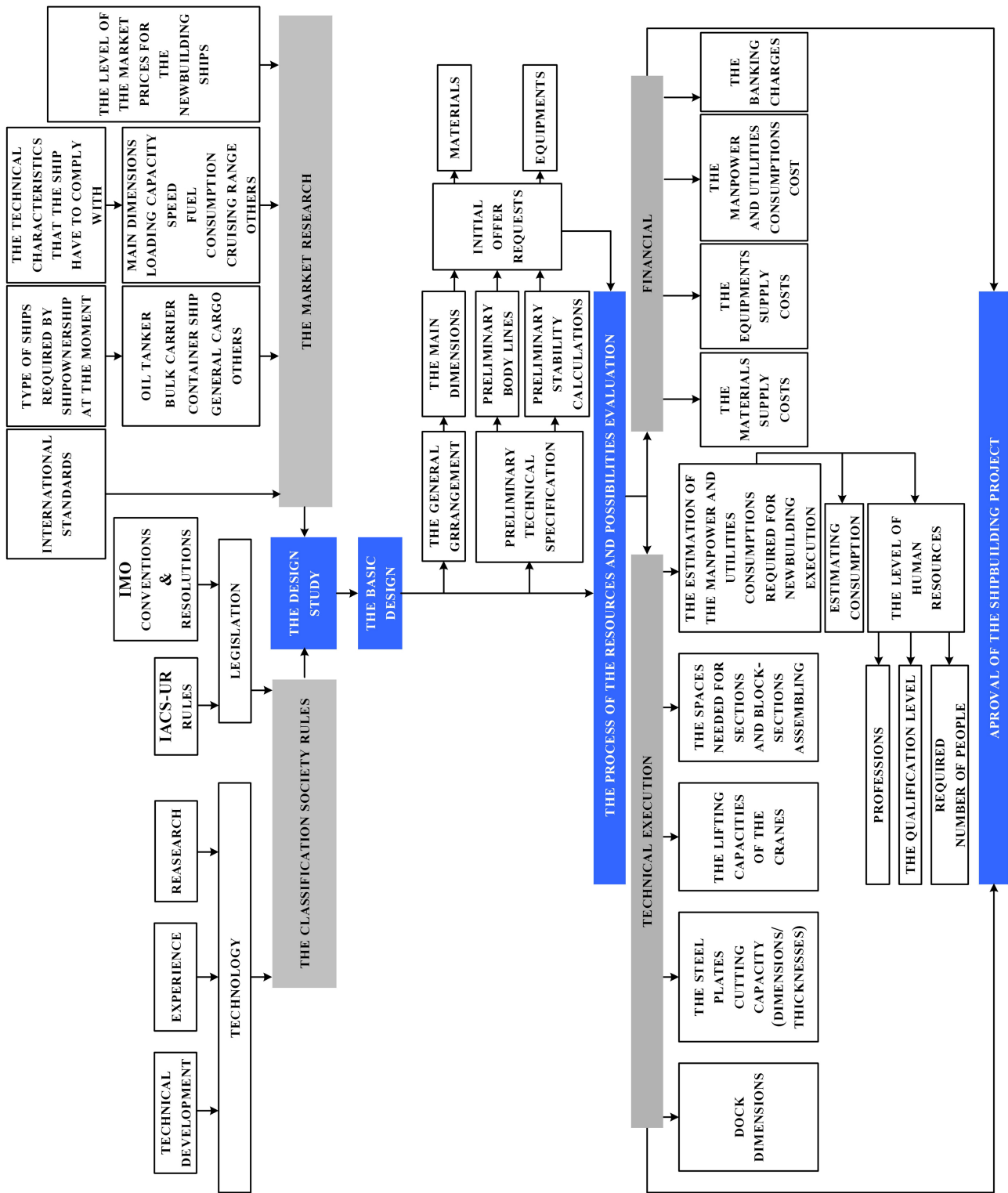


Figure 2. The process of evaluating the execution possibilities of the ship construction works.

shipyards.

The design study is developed by the Marketing Department, being the result of the market research and is submitted to the Design Department for a design

specification preparation. The Design Department proposes the Classification Society which must approve the design project and supervise the execution of the shipbuilding works at the shipyard. The preliminary technical specification is made by the Design Department, based on the design and the market research studies. So, it develops the basic design phase which is correlated with the basic technical requirements (necessary to be met in terms of materials and equipment) to be included in the development of the technical design phase, according to the rules and requirements of the classification societies, at the estimated date of delivery of the ship. The basic design, as part of the design process, is based on the conclusions of the design study. Thus, having defined and identified the requirements, the obtained minimum volume of initial information is used, by the Design Department, for the preparation of the general arrangement and preliminary technical specification of the ship.

The structure and composition of the basic design project is shown in **Figure 3**.

Based on the basic design project, the Planning & Programming Department will evaluate the level of resources and the possibilities of execution of the project, depending on the technical characteristics of the existing capacities of the shipyard. The Marketing Department and the Supply Department, based on the information provided by the basic design project regarding technical characteristics of the equipment and materials, will contact different manufacturers/suppliers, requesting detailed information regarding the description of the technical characteristics, price, and delivery time. The shipyard management, based on the information provided by the above-mentioned departments, will assess the need for resources (human, technical and financial) to carry out the project and, if deemed appropriate, the Board of Directors will recommend this project for the Board of Administration analysis. After the Board of Administration approves the shipbuilding project, the development phase of the technical project (part of the design process and the contracting process for the execution of the shipbuilding works) will begin.

2.2. Contracting the Execution of a Newbuilding Works in a Shipyard

The process is presented in **Figure 4**, its composition including the development phase of the technical project, the bidding phase of the construction of the ship and the phase of contracting the execution of shipbuilding works. In the phase for the ship technical project developing, the Design Department elaborates the preliminary technical project which constitutes the necessary documentation to obtain the approval of the project by the Classification Society under the supervision of which the construction works of the ship will be carried out. In the phase of bidding for the execution of shipbuilding works, the Marketing Department is the process owner for the phase of bidding for the execution of shipbuilding works, consisting in the elaboration of the offer for the execution

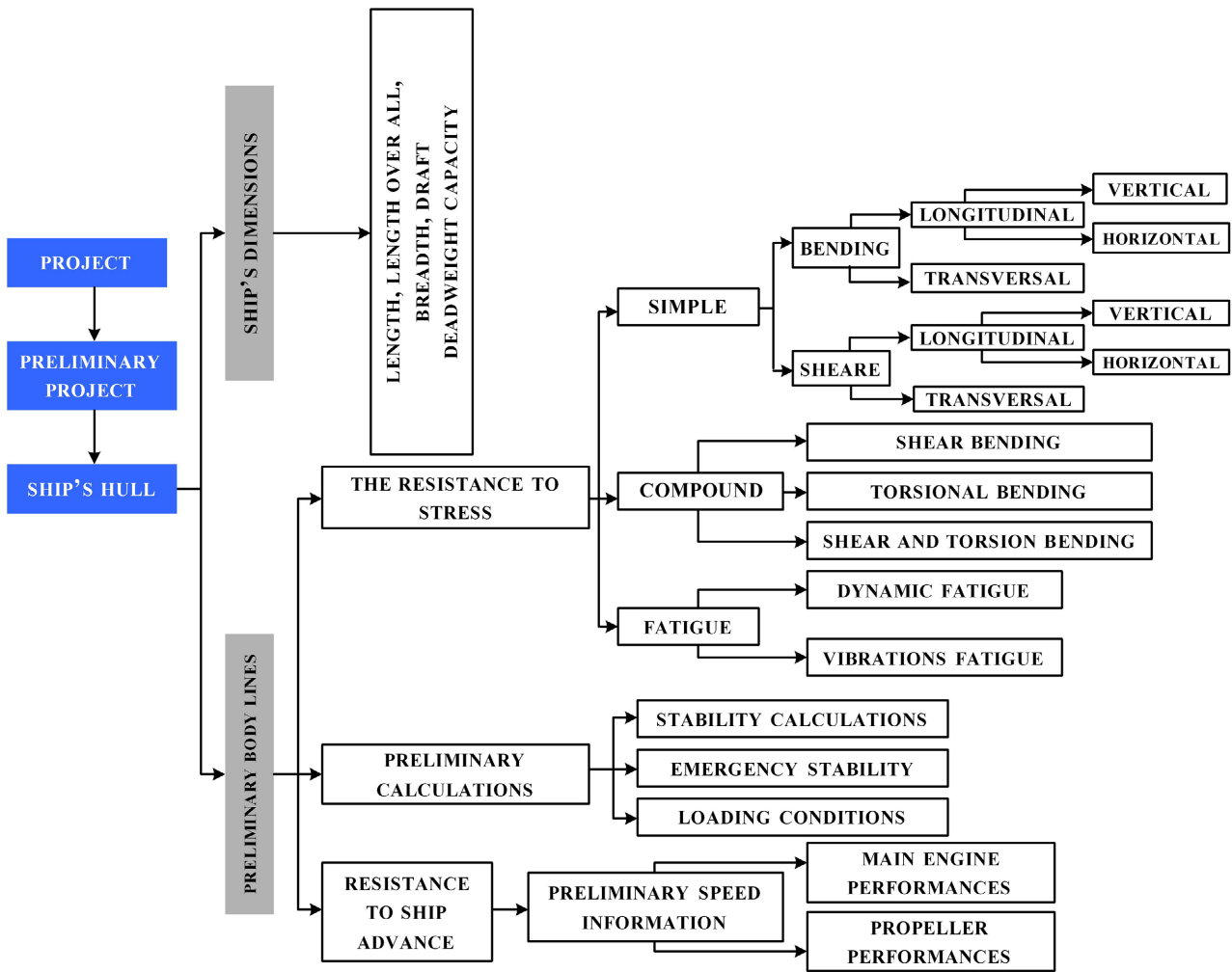


Figure 3. The structure and composition of the basic design project.

works, based on the prices and the necessary period, according to the preliminary technical project requirements. In the contracting phase for the execution of the shipbuilding works, the Marketing Department is still the process owner for the contracting phase, activities consisting in the execution of the contract proposal for the shipbuilding works elaboration, based on the terms agreed with the Client and approved by the Management of the Shipyard in the bidding phase. The condition for the shipbuilding contract entering into force is the Boards of Administration of the two partners (Shipyard and Client) approvals obtaining. Figure 4 highlight that the information (concerning the preliminary technical design and the estimated internal costs related to: the necessary materials and equipment supplying according to the preliminary technical project specifications; the execution of shipbuilding works manpower costs) represents the input data to the Marketing Department for the bidding phase. The negotiations of this phase also represent the input data for the contracting phase whose output data are represented by the shipbuilding contract which entered into force.

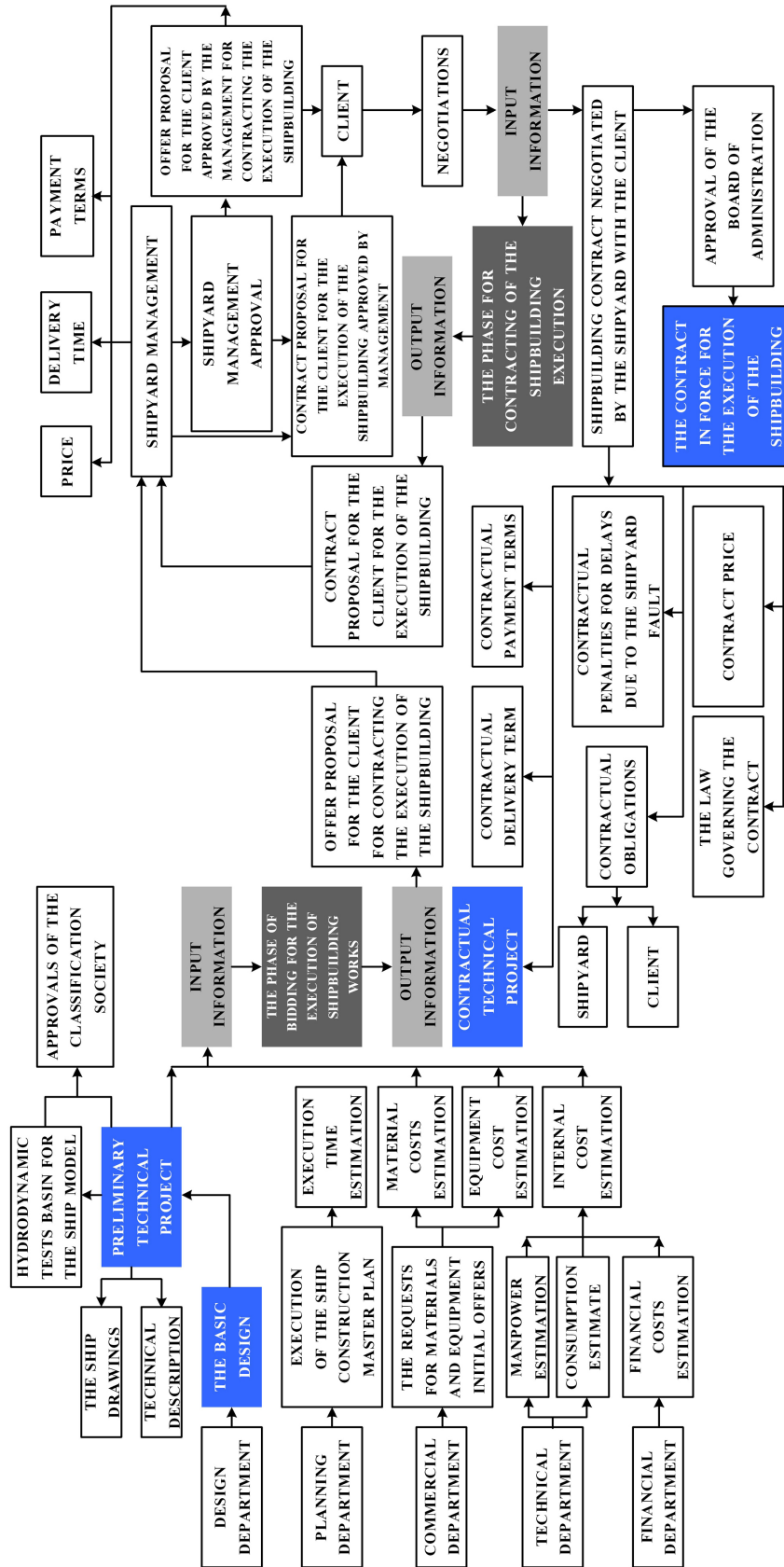


Figure 4. The process of contracting the execution of a newbuilding works in a shipyard.

The Technical Project was illustrated in **Figure 5**.

2.3. Developing the Execution of Shipbuilding Works Shipyard

The process is presented in **Figure 6**, its composition including the development phase of the technical project, the bidding phase of the construction of the ship and the phase of contracting the execution of shipbuilding works.

After the shipyard Board of Administration approval, the Marketing Department informs the Planning & Programming Department which will act for:

- The nomination of the coordinator of the project (Project Manager) for the execution of the shipbuilding works according to the contractual obligations.
- The contractual technical project analysis together with the Design, Technical and Production Departments for establishing the hull construction sequences scheme in the shipbuilding works development phases necessary to be carried out to meet the completion deadline assumed by the shipyard, according to the contract. drawing up the of the shipbuilding construction works detailed schedule, which establishes deadlines for the completion by types of works, up to the level of workshop/production section and compartment/department according to the flow of stages and execution phases (**Figure 6**).

The flow of stages and phases for execution of shipbuilding works includes:

- The stage of the hull building with the following execution phases: the hull steel plates and hull profiles cutting; the panels construction; the block-modulated sections construction; the hull assembly on the platform and in the dock.
- The stage of the ship's hull launching, with the following execution phases: outfitting; the accommodation and the exhaust gases funnel installation on-board; the execution and installation of waterlines marks, loading lines, draft scales, the ship's name and port of registry; the hull anodic protections mounting; the treatment works for execution the hull external areas coating protection.
- The stage of outfitting on board the ship berthed with the following execution phases: execution of the works for finalizing the assembly of equipment, pipes and valves, electrical cables; execution of works for the commissioning of equipment, installations, and systems; execution of the final painting works of the ship (internal and external); the execution of the superstructure arrangement works.
- The stage of the ship delivery, with the following execution phases: execution of dockside and the sea trials; execution of works for the inventories, spare parts, and technical documentation delivery.

Figure 7 details the process of the shipbuilding works execution developing. The owner developing the execution of the ship's building works process is the Planning & Programming Department through the Project Manager. The input information of the execution of the ship's building works development process is constituted by the contractual terms for:

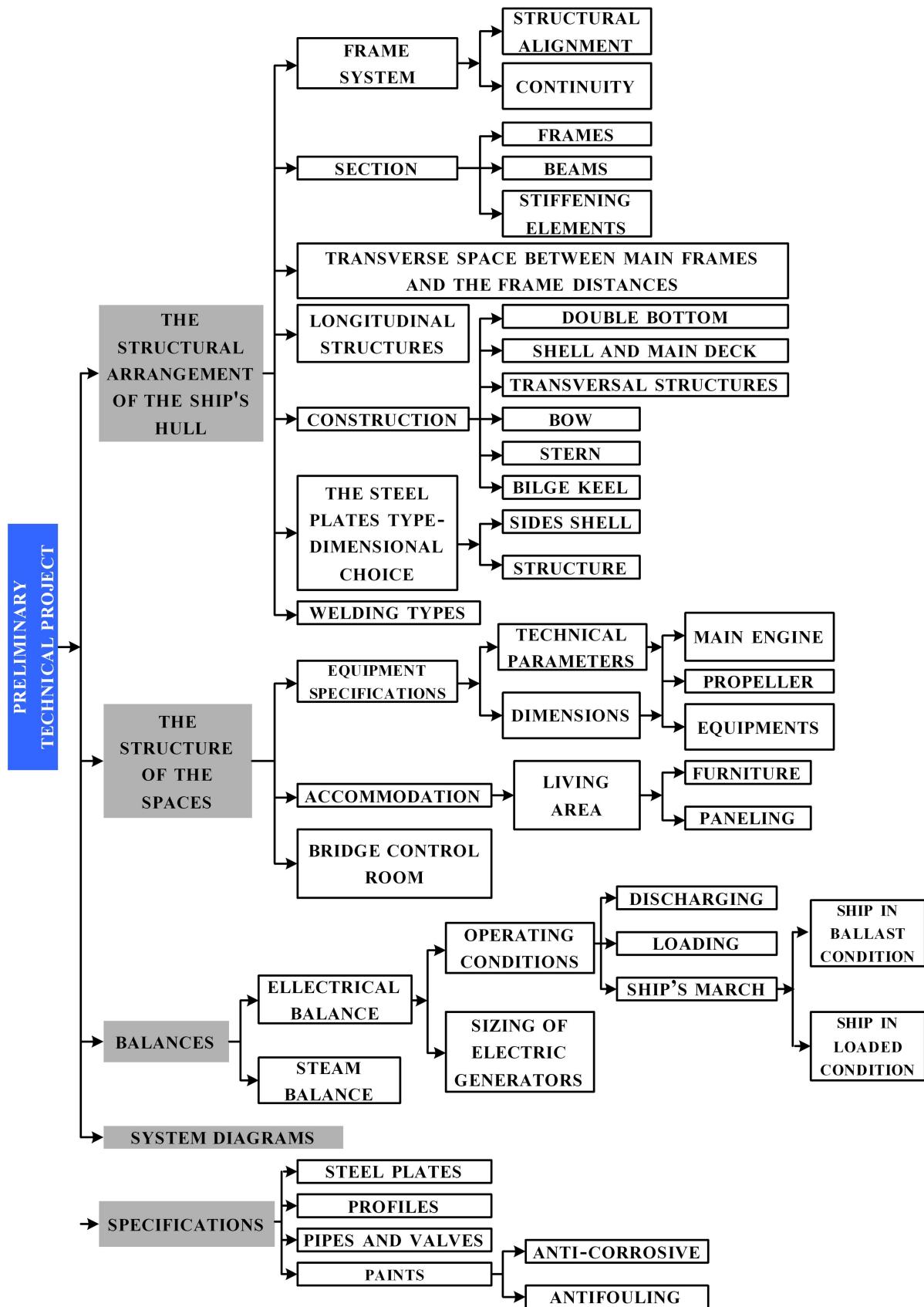


Figure 5. The structure and composition of the technical project.

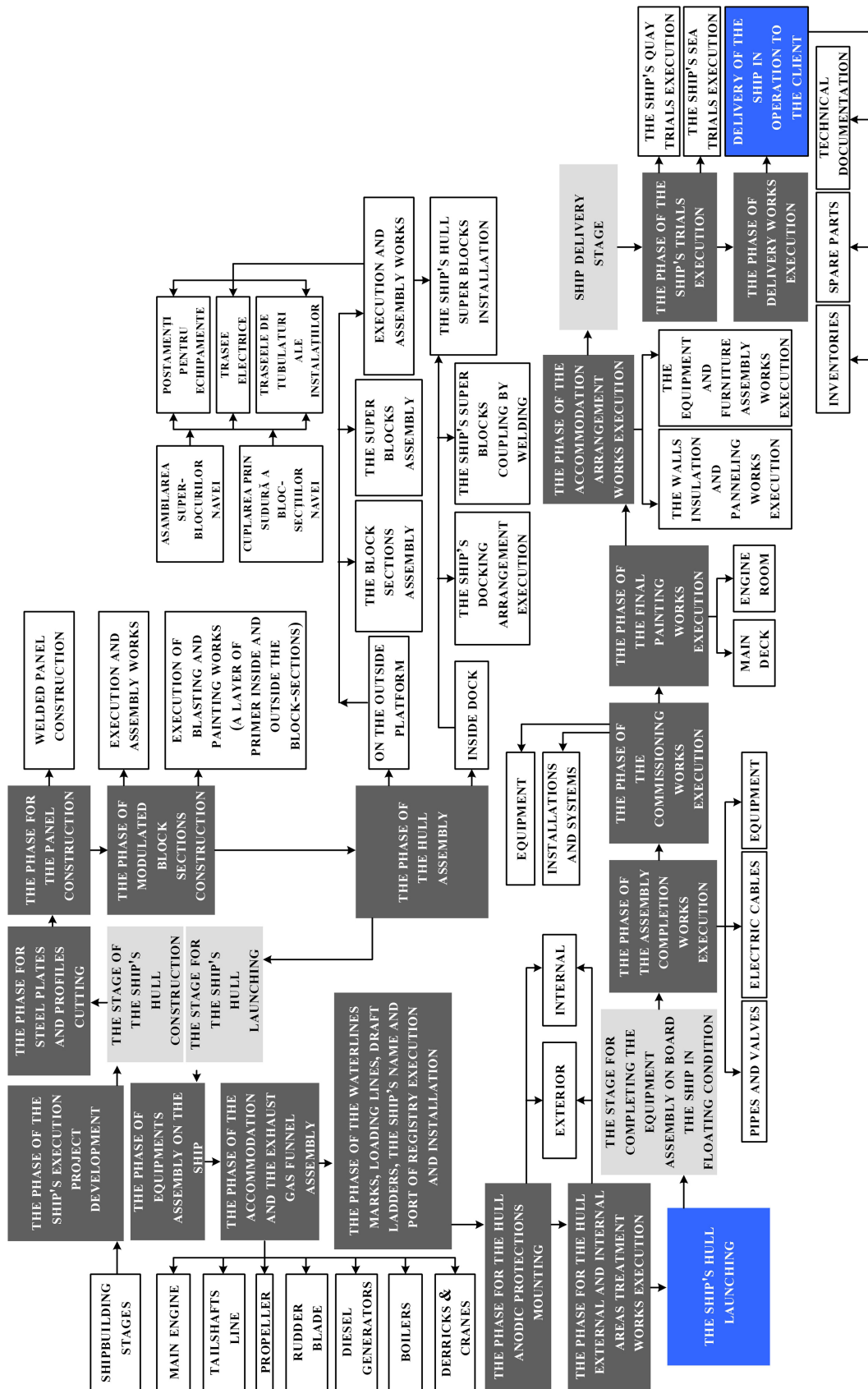


Figure 6. The stages and phases flow for shipbuilding works execution.

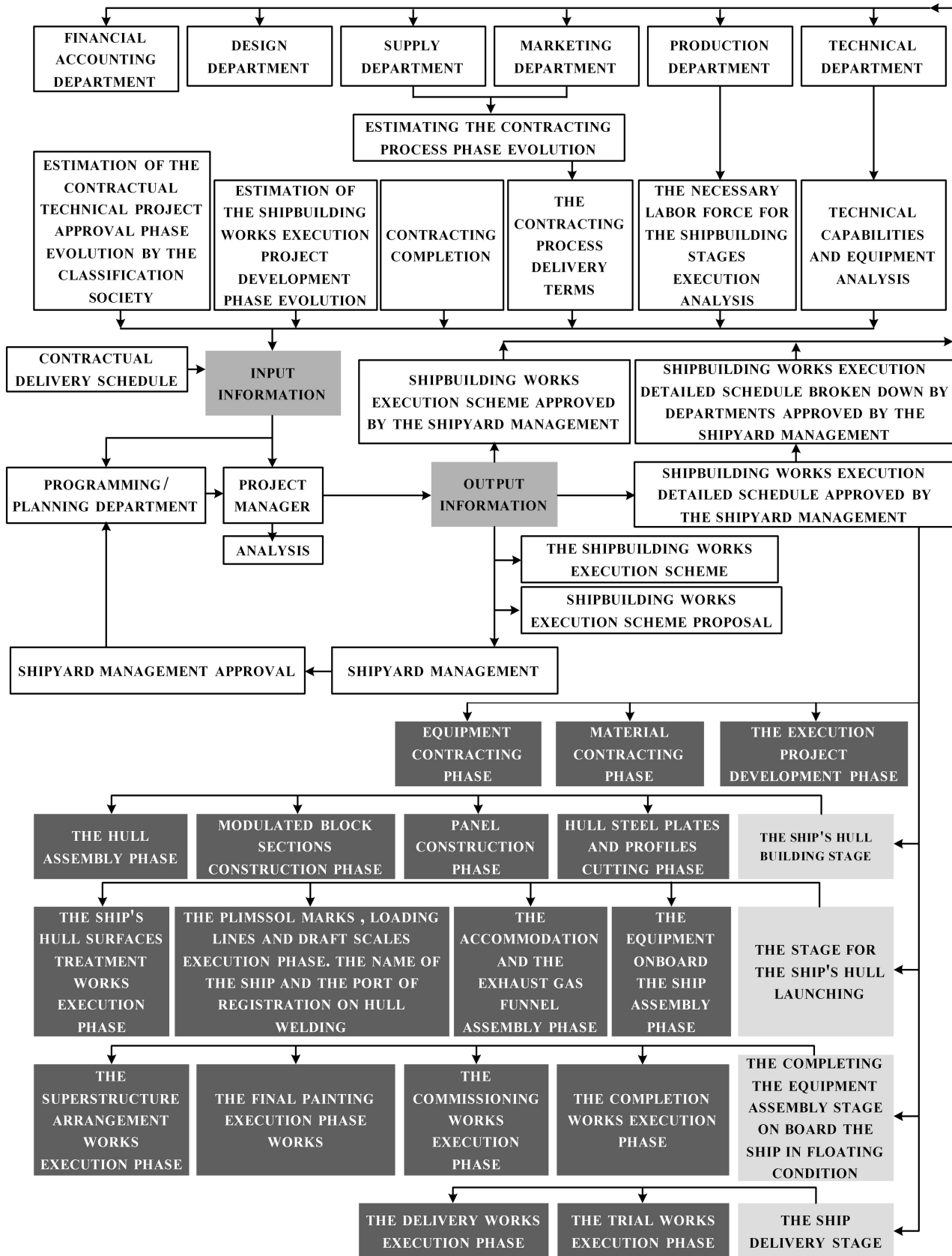


Figure 7. The process of the shipbuilding works execution developing.

- The date of the hull steel plates and profiles cutting phase beginning within the construction stage of the ship's hull.
- The date of the modulated block-sections construction phase beginning within the construction stage of the ship's hull.
- The date of the launching the ship's hull phases representing the date of the ship's launch stage completion.
- The sea trials phase completion date within the dockside and sea trials stages.

The shipbuilding development process output information is constituted by the shipbuilding works execution detailed schedules by stages and execution phases for each department.

2.4. Procurement Process for the Supply of Materials and Equipment

The process is presented in **Figure 8**, its composition including the development phase of the technical project (which includes testing the ship model in the towing tank), the bidding phase of the construction of the ship and the phase of contracting the execution of shipbuilding works. The contracting and supplying process of the equipment necessary for the ship construction is carried out in two phases: the preliminary phase, where, based on the preliminary technical project specifications requests quotations for the delivery of equipment and materials are drawn up and sent by the Marketing Department and the Supply Department, respectively, to different manufacturers or suppliers the final phase, where, based on the contractual technical project specifications with reference to materials and equipment, the offers from the preliminary phase are updated. The process for contracting the necessary materials supply for the ship construction is carried out by the Supply Department, and the process for contracting the supply of equipment is carried out by the Marketing Department. The principle of the two processes is identical, according to the presentation in **Figure 8**. As a result of the received offers comparative analyzes, it is proposed to the Management of the shipyard the list of producers with whom to negotiate for contracting. As a result of the received offers comparative analyzes, it is proposed to the Management of the shipyard the list of producers with whom to negotiate for contracting. Based on the Supply Department and the Marketing Department proposals, the shipyard management approves and signs the contracts for the delivery of materials/equipment, the two departments continuing to carry out the contracts for the products delivery on site and their reception upon arrival. The input information for the materials and equipment contracting and supply process for the shipbuilding execution works is represented by the materials and equipment specifications prepared by the Design Department. The outputs, resulting from the process, are represented by the delivery of products (materials/equipment) on site, because of supply contracts.

2.5. The Process of the Shipbuilding Works Execution

The process of the shipbuilding works execution, carried out by the Production

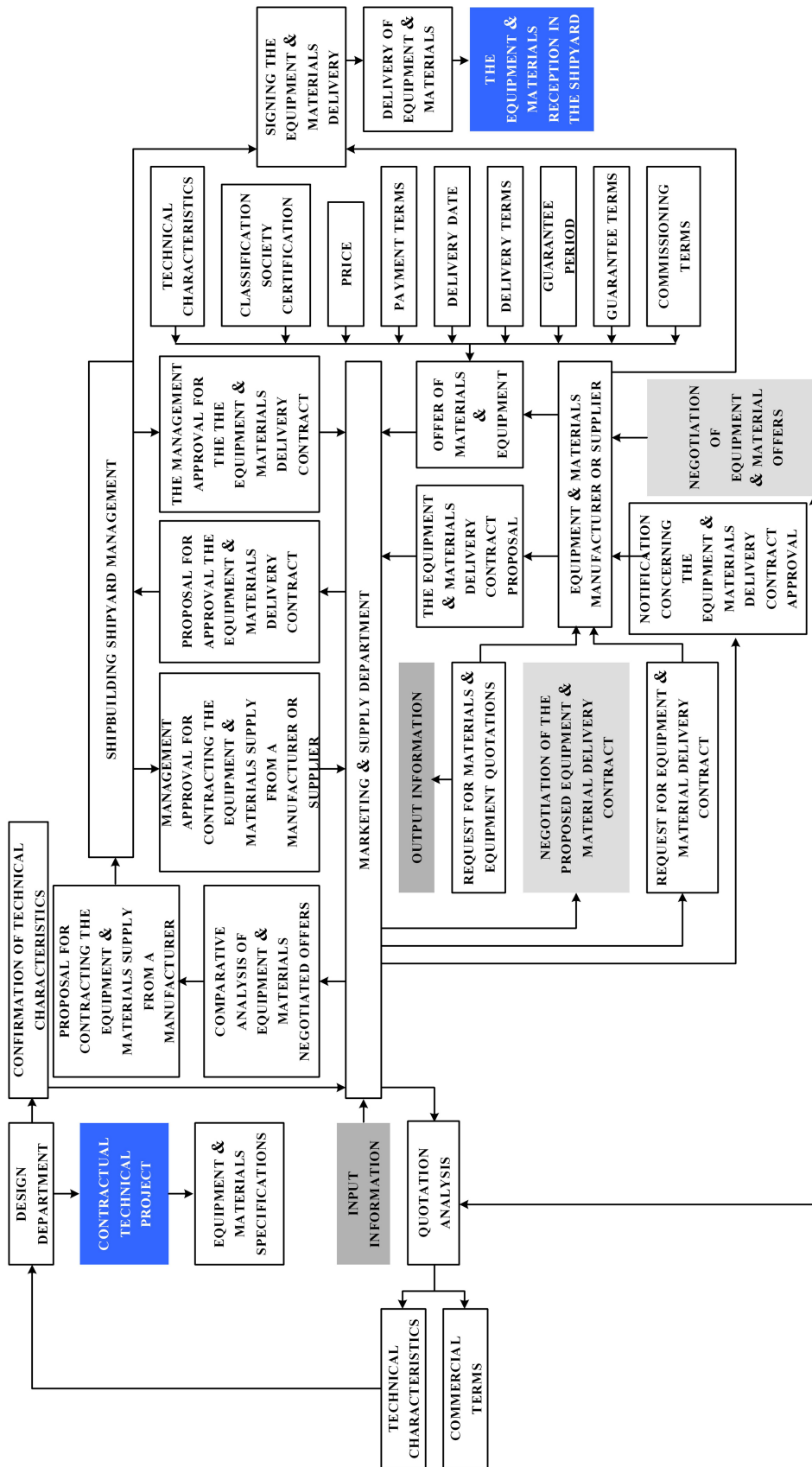


Figure 8. Procurement process for the materials and equipment supply.

Department as process owner, is according to the presentation in **Figure 9**.

The input information for the shipbuilding works execution process is the detailed schedule for the shipbuilding works execution, prepared by the Planning & Programming Department and the shipbuilding detail project prepared by the Design Department. These documents are updated whenever the status of additional work orders appears.

The input information for the process also includes the manpower, materials and equipment consumption vouchers prepared by the Technical Department based on the technical documentation within the detail project.

The output information of the shipbuilding works execution process consist in handing over the works performed by the Production Department to the Quality Control Department (QCD) and then to the Classification Society and Client or Client Representatives on site.

Based on the detailed schedule for the shipbuilding execution works, prepared by the Planning & Programming Department, the Production Department establishes the deadlines for the completion of the works at the teams and work teams' level.

2.6. Finalized Works Presentation for Reception Inspections

The process of the finalized shipbuilding works presentation at the Classification Society and the Client inspections is according to the presentation in **Figure 10**, being carried out by the QCD as process owner. The process is carried out on the basis of the input information consisting of: the detail project technical documentation prepared by the Design Department and approved by Classification Society and Client; the ship's building sequences scheme and the detailed schedule of the shipbuilding works execution, prepared by the Planning & Programming Department.

The outputs of the process finalized shipbuilding works presentation at the Classification Society and the Client inspections are represented by the inspected works acceptance by the QCD based on the Inspection Call Log.

The inspection considers the verification of the essential aspects with reference to: the technical and execution documentation verification regarding: class certificates for the materials and equipment included in the inspected works; the approved plans for the structures or the installations/systems where the works are executed; certificates of professional competence of the work execution personnel (e.g. welding works); verification, in situ, of the safety conditions for the inspection of the executed works regarding: access, lighting, ventilation, ensuring, cleaning, etc.; the quality of the works execution according to the existing standards.

2.7. Delivery of the Ship with Dockside and Sea Trials

The shipbuilding delivery in operation process, as presented in **Figure 11**, consists in the dockside and sea trials phase execution, followed by the delivery

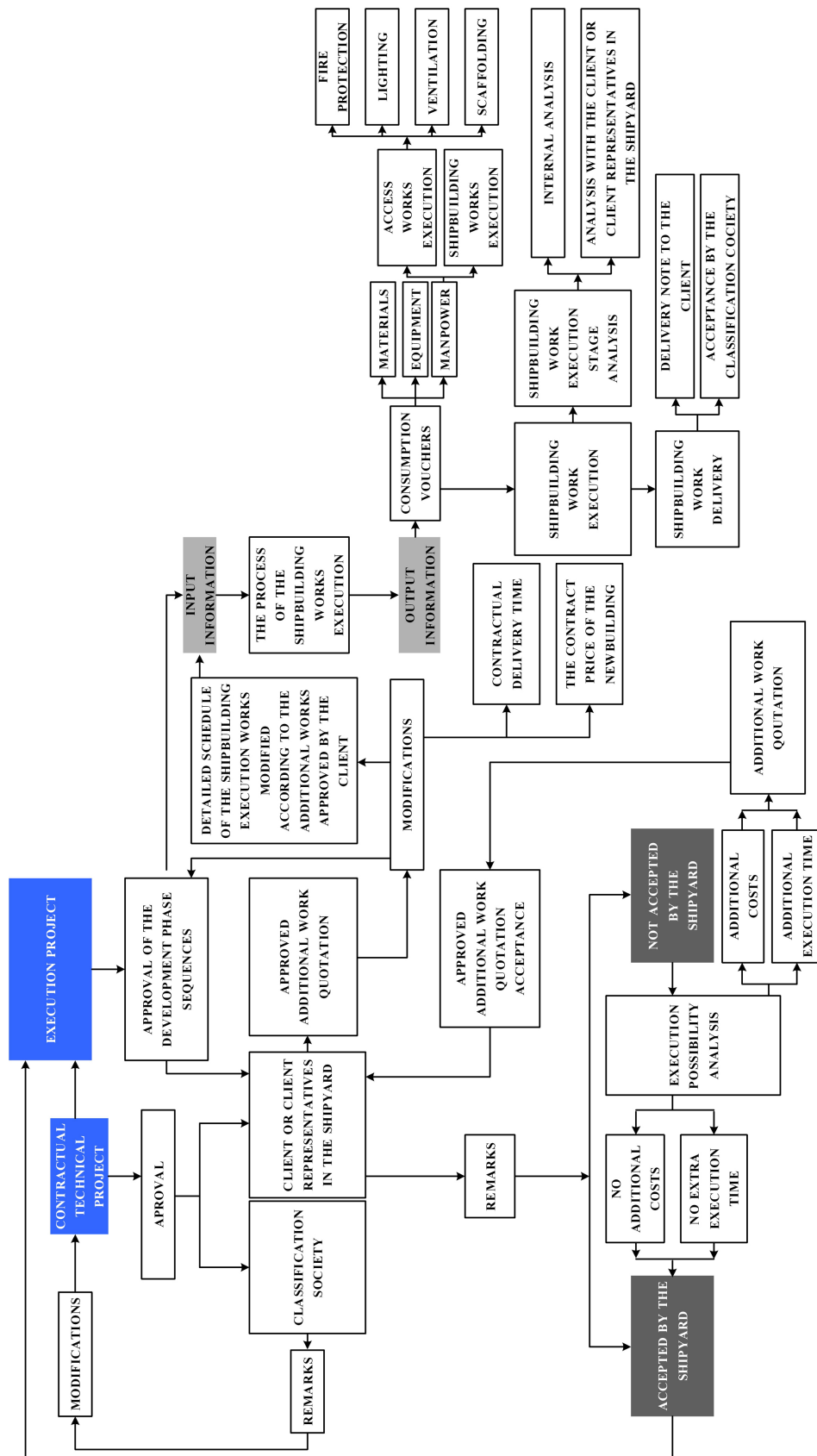


Figure 9. The process of the shipbuilding works execution.

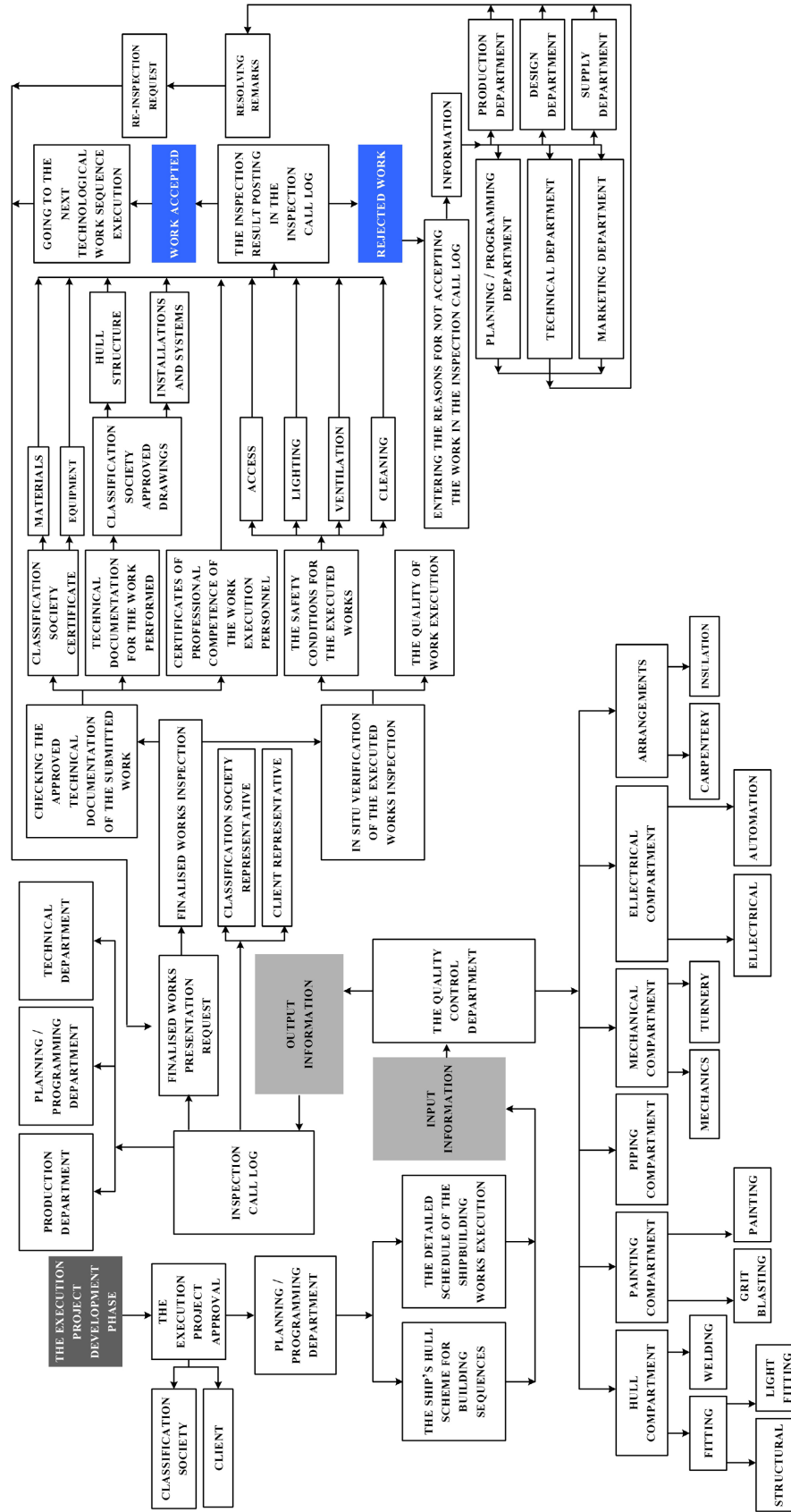


Figure 10. The process of the finalized works presentation for reception inspections.

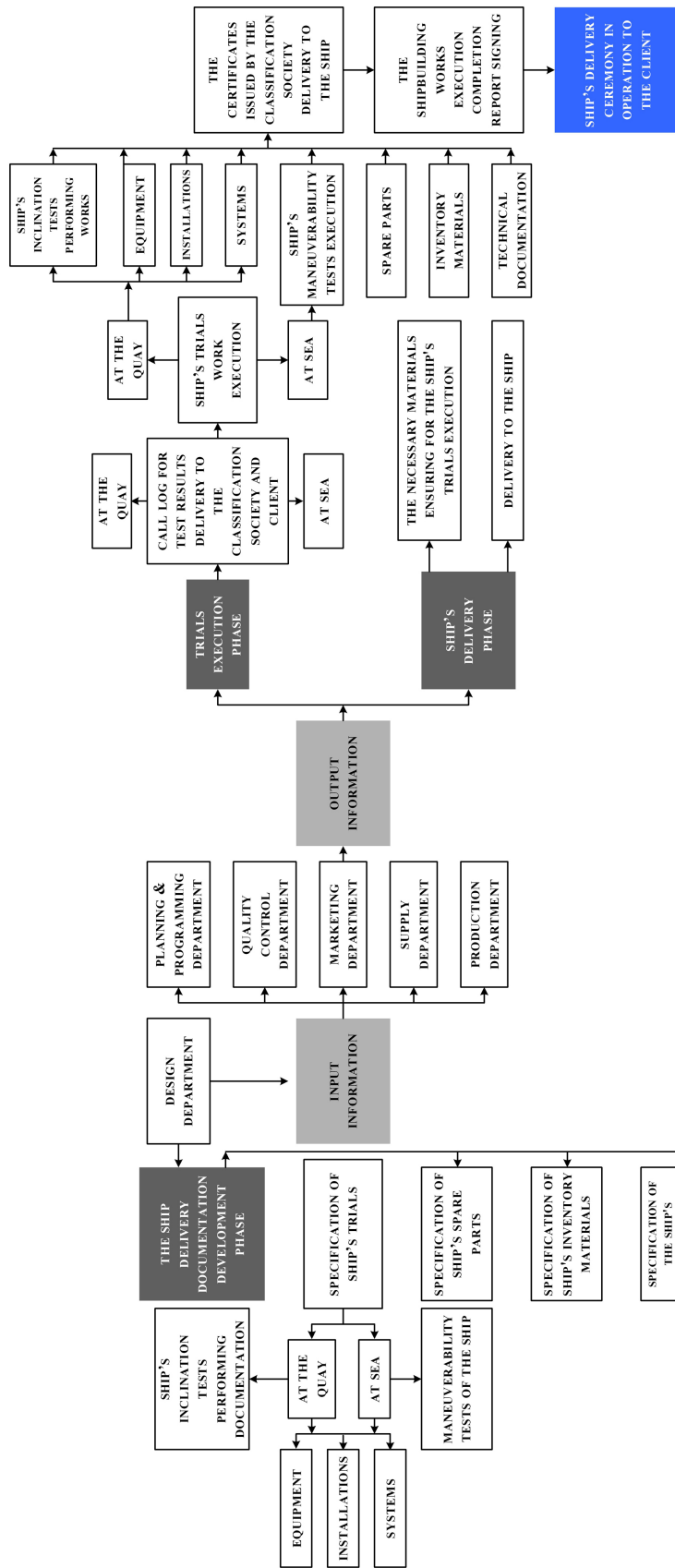


Figure 11. The delivery process of the shipbuilding with quays and sea trials.

phase of the ship. The delivering the ship into operation process is the process by which the shipbuilding execution works are completed. The dockside and at sea trials during execution phase are coordinated by the QCD based on the call log for delivery of the execution works performed by the Production Department. Execution of operational test works for ship-mounted equipment, installations and systems shall be performed on the ship at the quay and at sea trials specifications basis prepared by the Design Department.

The ship delivery phase is coordinated by the Planning & Programming Department for the delivery to the ship of inventories, spare parts, and technical documentation in accordance with the specifications prepared by the Design Department. Deliveries are made by the Supply Department for materials and the Marketing Department for spare parts and technical documentation.

The input information of the shipbuilding delivery into operation process are represented by the technical documentation and the output information, following the execution phases, consist in the Classification Company Certificates issuance, the shipbuilding works execution completion report signing by the Client or Client Representatives, the final payment done by the Client and the transfer of ownership of the ship from the shipyard to the Client, during the delivery ceremony of the ship.

3. Study Case

The chance of survival in a strong competitive environment increases for those shipyards that discover and minimize their vulnerabilities very quickly and, moreover, implements advanced tools for planning and managing resources (material, financial, human). Considering that an informatic system like “Enterprise Resource Planning, ERP” covers the main information flows and ensures the transmission of data between the structures of a company, in real time and with direct effects in the management accounting and financial system, the need to protect information on this advanced resource planning and management tool becomes obvious. Therefore, an ERP system has a protected, confidential informational content and this case study, must be understood and accepted from this perspective. The initiative of implementing an ERP informatic system within the Constanta Shipyard started from the finding that it represents a complex software solution, the components of which, integrated in a common platform, ensures the planning of activities, the management of the company’s resources (human, material, financial) and supporting internal business processes, ensuring data transparency, access to any useful information in the current development of activities and streamlining the decision-making system.

The opportunity analyses carried out within the company, identified the following objectives:

- The development of a new information system, which serves the activity of the shipyard on the two essential directions: new buildings and ship repairs activities.
- Integration of data operation processes into a single system, at organization level.

- Management of material resources, ensuring the traceability of afferent supporting documents, the process must be a unitary one, carried out online in real time and to provide the reporting basis for the decision-making process.
- Management of the problem of the single ship project (both in the design and execution phase) for all resources: labor hours, materials, critical machinery, and costs.
- Comparative management of costs (budgeted versus realized) at ship/project level, at department level respectively.
- Unitary management of labor hours (including that related to subcontractors) and providing support for analysis and decision.

Also, the business needs that the implementation and operation of an ERP system can generate, at different levels, have been identified and considered. Risks at the decision-making level anticipate that: the new IT system implementation involves the modification, replacement, supplementation of some responsibilities at the level of the departments (through top management decisions and the imposition of new system procedures); some of the employees could be reluctantly receivers with the new system (which will generate new responsibilities and lead to increased transparency of activities), which generate some malfunctions (syncope in data accuracy or updating) being necessary organizational measures, external to the informatic system, imposed from the top management level).

The risks identified at the level of responsibility highlight that:

- An integrated IT system increases the level of responsibility, because, although it can ensure (with certain limits) the correct and efficient operation of the data (through access rights, error messages, warnings, etc.), cannot replace the responsibility of human factors.
- An integrated system supposed advantages (e.g., it may create the possibility that, after the first operator in the system works with information, it will be accessible to other interested operators, for the operation or display of reports) but also disadvantages (e.g., failure to operate data on time, blocks the activity of subsequent departments in flux).
- Each department must know very well its own responsibilities in the system, the implications of one's own activity on others and, mutual, the activity of others on their own activity.

In the internal control activity, the following risks to ensure the accuracy of the data are highlighted:

- Lack of operational procedures may affect data accuracy leading to the reduction/annulment of the benefits that the integrated IT system can bring. It is necessary that the sequence of phases/stages/processes is strictly observed, which implies the elaboration of business rules at the level of each department (e.g., listing certain stock reports on a specific date, will provide actual data only on condition of the chronological operation of the stock documents that have affected the stock up to that point).
- Since certain business decisions are based on data currently existing in the system, it is necessary for them to be up-to-date and in line with the business real-

ity, otherwise it may give rise to inappropriate decisions (e.g., it is important to note that supply decisions are based on the accuracy of data on existing stocks). Finally, post-implementation opportunities of an ERP system were considered:

- Increasing the efficiency of the activity of the employees involved in the collection of data and in the processing of analysis information, which will reduce the time needed to obtain data.
- Elimination of parallel transaction registration and reporting processes, obtaining the consistency of the processed information, by standardizing and systematizing the information input in the database.
- The possibility of planning, correlating, and controlling the activities in an efficient way, on the information flow.
- The possibility of reducing the costs of stock management of materials.
- Efficient control in respect with deadlines and budgets.
- The possibility of obtaining, in real time, the information necessary for the management to substantiate the financial-accounting decisions.

For the arborescent construction of the logical scheme that substantiates the personalized ERP information system of the Constanta Shipyard, the processes were sequenced into 12 processes flows, as follows:

Process flow No.1. Management of contracts and projects portfolio (newbuilding ship, ship repairs, various projects), involves the planning of activities, the allocation and optimization of human resources, planning/replanning production capacities, monitoring and control of projects.

Process flow No.2. Technological budgeting of human and material resources, involves the technological preparation of the activities on the projects, determination of the raw material requirements, generating and recording the supply needs.

Process flow No.3 Management of overhead activities (maintenance activities of machinery/equipment, investments for fixed assets and inventory items, various general overhead activities for sections and docks): it involves the planning of activities, technological budgeting of human and material resources, generating and recording the supply needs, monitoring and control of overhead orders.

Process flow No.4. Management of planning activities, involves planning the supply of standard materials, ship equipment, consumables (supplier orders, supplier invoices, reception, stock records) for projects, newbuilding ships, ship repairs, investments, fixed assets, inventory items, overhead orders, various.

Process flow No.5. Production Management involves the weekly scheduling of activities (for work formations and subcontractors), issuing work orders, scheduling of cutting activities on machines, daily programming of human resources (by activities), control of the implementation of the production program (for work formations and subcontractors).

Process flow No.6. Material inventory management involves the configuration of management activities, consumption notes, refund receipts, change of reservation context, including inventory objects, management of steel plates formed scraps, management transfer notes, inventory, accounting processing of stock.

Process flow No.7. Human resources and salary, this flow refers to the man-

agement of organizational structures by departments, functions of employees and subcontractors (access cards, timesheets, salary calculation, generation, export of salary accounting note).

Process flow No.8. Supply-Subcontractors refers to the activities of providing services and the registration of invoices regarding the activities carried out by subcontractors.

Process flow No.9. Sale refers to the production executed according to the contracts signed with the clients.

Process flow No.10. Fixed assets involve the record of fixed assets (corporable, intangible) and the calculation of redemption.

Process flow No.11. Accounting-Financial refers to the activities regarding the financial-accounting records.

Process flow No.12. Management accounting considers post-calculation activities, activities regarding the budget of incomes and expenses.

The first five flows refer to business processes and the following are support processes flows.

Figure 12 illustrates the organization of business process flows (planning, monitoring, control) and inter-conditioning with procurement processes, inventory management and human resources processes.

It was necessary for the Flow No.5 of the Production Management process to be decomposed into two subcomponents: Flow 5A, weekly production scheduling and control; Flow 5B, daily production scheduling and control.

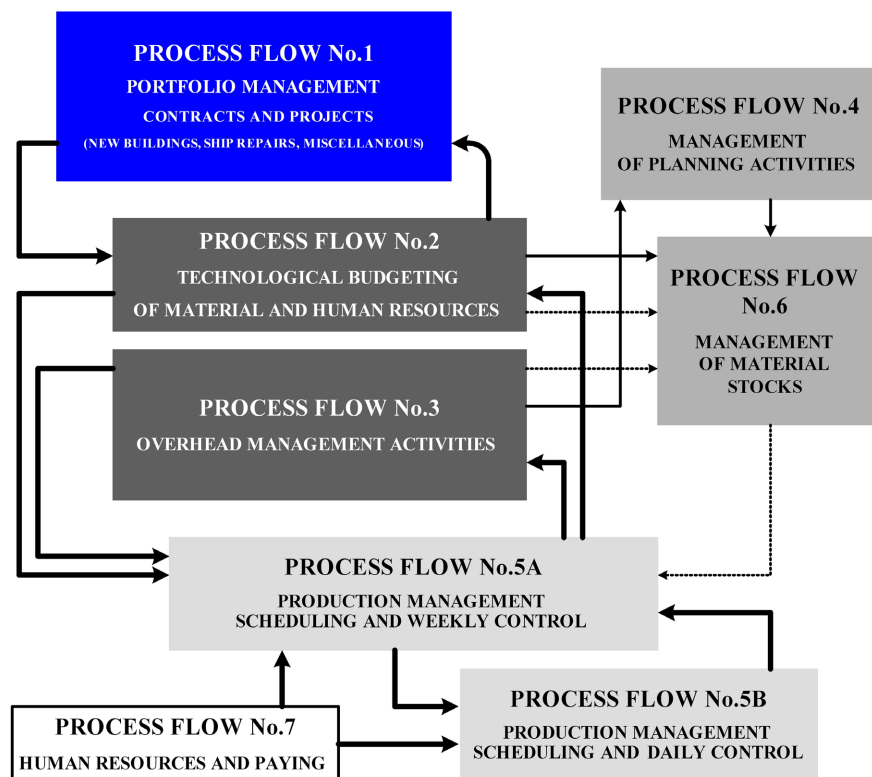


Figure 12. Business process flows.

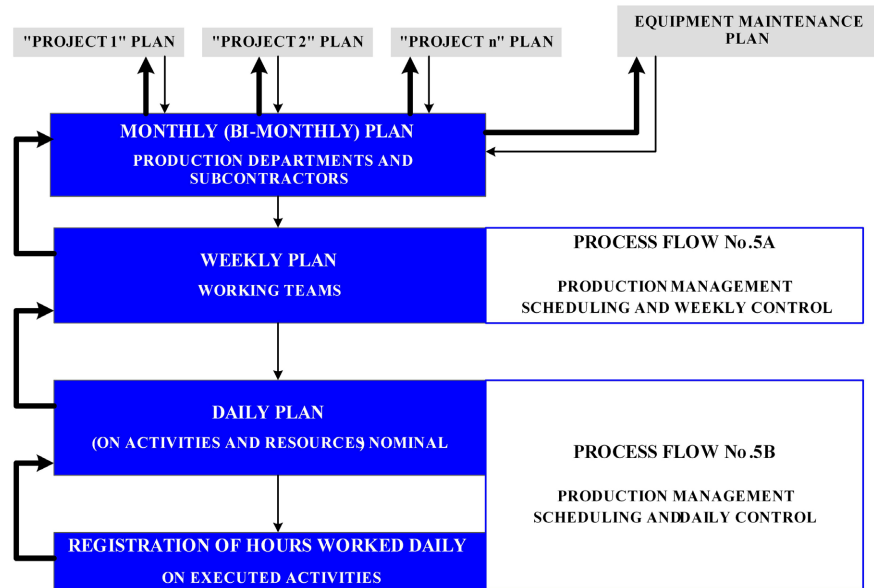


Figure 13. Integration of planning, monitoring and control levels.

Figure 13 shows the integration of planning, monitoring and control levels (including corrective actions), on projects carried out and on time horizons (weekly and daily).

Process Flow No.5A Production Management. Weekly production scheduling and control is ranked as follows:

A.a1 - Programming (on working teams and responsible foremen) of the activities (projects and overheads) budgeted and with reserved materials;

A.a2 - Distribution of production activities to subcontractors (by projects);

A.b - Generating work orders for the scheduled activities (on work teams, production sections and subcontractors);

A.c- Scheduling of steel plates cutting activities (on machines) and recording of cut sheets (“steel production”);

A.d - registration of executed pieces (on production processes, for which this reporting mode is established);

A.e1 - Monitoring and control of the implementation of the weekly program (by production sections and working teams);

A.e2 - Monitoring and control of the execution of the activities assigned to subcontractors;

A.f1 - Periodic confirmation of the timesheets and of the distribution of the hours consumed by activities;

A.f2 - Periodic confirmation of the subcontractors’ timesheets and of the distribution of the hours consumed by activities;

A.g - Validation and bimonthly reporting on the physical stages (at project and activity level) on the standardized forms.

Process flow No.5B Production Management - Daily production programming and control (distribution of workers by activities and recording the consumed hours for the activities performed) is ranked as follows:

B.a1 - Scheduling of work shifts and activities (per worker, per day);

B.a2 - Nominal programming and distribution of subcontractors (by activities, per day);

B.b1 - Corrections on the scheduling of activities (per worker, per day) elimination of the absent ones;

B.b2 - Corrections regarding the programming and nominal distribution of subcontractors (by activities, per day) elimination of the absent ones;

B.c1 - Checking and correcting the timesheets, for its own staff, according to the calculation of daily hours (it is performed on the current day - for the previous day);

B.c2 - Checking and correcting the timesheets, for subcontractors, according to the calculation of daily hours (it is performed on the current day, for the previous day);

B.d1 - Verification and correction/modification of nominal distributions by activities, for their own staff (it is carried out on the current day - for the previous day), dividing the hours on several performed activities, according to the sheets registered at the workplace by the designated persons in charge ;

B.d2 - Verification and correction/modification of nominal distributions by activities, for subcontractors (it is performed on the current day - for the previous day);

B.e1 - Daily control and validation of the program carried out on the previous day (on production sections and working teams) by the hierarchical heads;

B.e2 - Daily control and validation of the program performed on the previous day (at the level of subcontractor companies) by the production managers in charged with the activity of subcontractors.

The components of the ERP system implemented in the Constanta Shipyard (**Figure 14**) are:

- Primavera Project Management (ensures the planning of activities on projects).
- Charisma Human Capital Management (ensures the management of the organizational structure by departments and staff (own and subcontractors), including the salary calculation).
- Order Management, Microsoft Management Console (considers the daily scheduling of activities, the nominal allocation of employees to activities and the splitting of daily hours worked).
- Charisma Access-Timesheet (ensures the recording of access data and the calculation of the worked hours, automatic calculation, manual corrections, confirmation of timesheets).
- Charisma ERP with the two components: portfolio management and production (contains dictionaries, structure of cost centers, internal orders, contracts, projects, technology, production, acquisitions, stocks, fixed assets, inventory objects, sales, accounting, post-calculation, financial).
- Integration interfaces between system components and modules (synchronization lines).

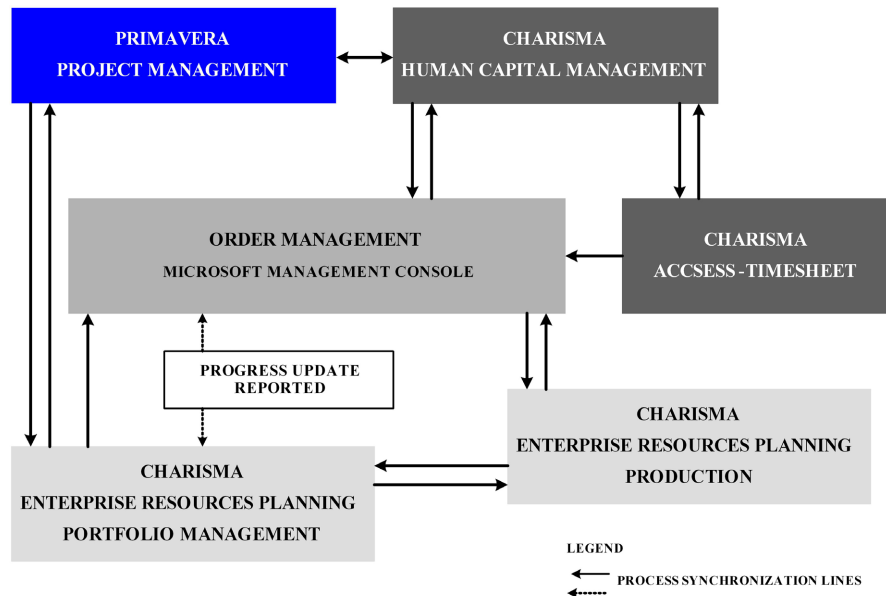


Figure 14. Components of the ERP system implemented in the Constanta Shipyard.

In conclusion, the ERP system provides access to a new technology, through which all primary data can be allocated on multidimensional and complex structures, thus ensuring a multitude of possibilities for the aggregation of information in the database, by configuring reports, for purposes requested by the shipyard management, providing managers with a systematic and structural point of view, supporting the understanding of related costs, and increasing operational efficiency.

4. Discussions

The ship, as a finished final product, is the result of complex processes that include stages consisting of execution phases and schemes of construction sequences based on technical documentation consisting of plans and technical specifications. A shipyard is an Engineer to Order (ETO) company that designs and manufactures new products when orders are placed. Various tasks are performed simultaneously, which makes process management considerably important. It is especially important to plan and to control production activities [28], as production is the bulk of the overall process. It is paramount importance to develop a production planning system based on an Advanced Planning System (APS). Each shipyard has developed its own production planning system and is necessary to apply methods aimed at process innovation and reengineering to develop a production planning system for shipyards [29].

Enterprise Resource Planning (ERP) as an advanced tool for managing production processes, including in shipyards, is beginning to crystallize and show its advantages. From 1991 to 1993, Korea Advanced Institute of Science and Technology (KAIST) and Daewoo co-led the Daewoo Shipbuilding Scheduling (DAS) project. To integrate expert planning systems for shipbuilding, a hierarchical

planning architecture was used. A three-stage development strategy has been devised consisting of three phases: 1) vision revelation, 2) data-dependent realization, and 3) prospective improvement [30]. Some authors are beginning to assert themselves [31] [32] pointing out that ERP has become an important information management tool for integrating different production modules through an online network, thus providing access in a single window. Part I, discusses a methodology for manufacturing management: planning and integration of ship manufacturing processes for the modularly designed ships in a medium size shipyard. Part II discusses the nucleus driven integrated marketing management model in an ERP environment for a shipyard.

It is well known that an algorithm consists of all operations that, executed in a certain order and using a set of values, produce another set of values. The correct construction of an algorithm involves the inputs defining (initial data, specifying the type, properties, and range of values) and the outputs (results) defining and the relationships between them specifying. The logic diagram is the graphical representation of the algorithm associated with a problem (it graphically represents all the steps that must be taken to create an algorithm). When a process is represented by using a graphical representation (process schematization), each activity can be analyzed, the relationships between different activities can be easily seen, the included subprocesses can be identified, and the contact with other processes can be defined. Must be noted that the schematization of a process allows the observation of the way in which the communication is carried out between the operational structures (between the functional departments, owners of the different processes) and the way in which the information is transmitted. At the same time, the existing problems can be clearly highlighted, giving the opportunity to initiate actions for improvement.

5. Conclusions

ERP software systems are created around a single, defined data structure (diagrams), which usually starts from a common database. This basic construction is then interconnected with business processes driven by workflows across all departments, connecting the systems and the people who use them. In short, an ERP solution is a people, processes and technologies means of integrating into a modern organization. Some of the processes (especially design, marketing, logistics and some production subprocesses, such as construction of sections, block-sections, and their assembly) have been analyzed singularly and progress has been made which can be considered remarkable.

The authors are not aware that the structural analysis of the processes in a shipbuilding shipyard has been presented, so far, with significant fullness and depth. The authors hope that their efforts towards the schematic structuring of the processes (with the presentation of the process owners, with the inputs and outputs of the analyzed system highlighted and, of course, with the illustration of the ways of communication and transmission of information between functional

departments) will be understood and appreciated in the field (or less). The schematics proposed by the authors are applicable to any shipyard and they believe that they could be a first step towards customizing these schemes on the particular profile of a shipyard in order to develop ERP software. The authors think that it is undeniable that without a correct and complete structuring of processes (through logic schemes and algorithms) it is almost impossible to be conceived that software could be built that would allow the efficient management of activity of the size and complexity of shipbuilding.

Considering all the above, taking into account the concerns of other researchers and trying to capitalize on their experience (engineering, academic and managerial) in the field of shipbuilding industry, the authors of this paper, hope, modestly, have brought a partial contribution in support of those interested in building an ERP software system. Aware of their own limitations, the authors will be grateful to all those who, in the future, will make their own contributions in this challenging field.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] “Mircea cel Bătrân” Naval Academy, Constanta, Romania. <https://www.anmb.ro/eng/>
- [2] Kaune, J.E. (1979) Managing the Shipyard Process—Key to Success. *Naval Engineers Journal*, **91**, 81-93. <https://doi.org/10.1111/j.1559-3584.1979.tb03914.x>
- [3] Lee, D.K., Kim, Y., Hwang, I.H., *et al.* (2014) Study on a Process-Centric Modeling Methodology for Virtual Manufacturing of Ships and Offshore Structures in Shipyards. *International Journal of Advanced Manufacturing Technology*, **71**, 621-633. <https://doi.org/10.1007/s00170-013-5498-4>
- [4] Jeong, D., Kim, D., Choi, T. and Seo, Y. (2020) A Process-Based Modeling Method for Describing Production Processes of Ship Block Assembly Planning, *Processes*, **8**, 880. <https://doi.org/10.3390/pr8070880>
- [5] Lameira, P.I.D., Loureiro, E.S.P. and Benjamin, C.M. (2015) Optimization Design of Planning and Production Control in a Shipyard-Case Study: The Amazon Region. In: *Maritime Technology and Engineering*, CRC Press, London, 373-383.
- [6] Kafali, M., Unsan, Y. and Ozkok, M. (2018) A Production Planning and Control Methodology Proposal for Shipyards. *Journal of ETA Maritime Science*, **6**, 47-59. <https://doi.org/10.5505/jems.2018.02986>
- [7] Song, T. and Zhou, J. (2021) Research and Implementation of Lean Production Mode in Shipbuilding. *Processes*, **9**, 2071. <https://doi.org/10.3390/pr9112071>

- [8] Pinto, P.J.F., Grecco, C.H.D. and Cosenza, C.A.N. (2020) Fuzzy Model for the Priorization Analysis of Variable Quality Performance: An Approach in Shipbuilding. *Fuzzy Information and Engineering*, **12**, 181-203. <https://doi.org/10.1080/16168658.2020.1792610>
- [9] Johannessen, J.A. and Hauan, A. (1992) Reaching Out for Hierarchy: A Study of the Reorganizing of a Norwegian Shipyard. *Cybernetics and Systems*, **23**, 169-189. <https://doi.org/10.1080/01969729208927456>
- [10] Bernhard, B.S. (1993) Benefits of Quality Control Techniques in Series Ship Construction by Computer-Integrated Manufacturing. *Marine Technology and SNAME News*, **30**, 308-318. <https://doi.org/10.5957/mt1.1993.30.4.308>
- [11] Dwivedi, S.N. and Maffioli, P. (2003) Total Value Management in Shipbuilding. *Total Quality Management & Business Excellence*, **14**, 549-569. <https://doi.org/10.1080/1478336032000053582>
- [12] Blanco-Novoa, Ó., Fernández-Caramés, T.M., Fraga-Lamas, P. and Vi-lar-Montesinos, M.A. (2018) A Practical Evaluation of Commercial Industrial Augmented Reality Systems in an Industry 4.0 Shipyard. *IEEE Access*, **6**, 8201-8218. <https://ieeexplore.ieee.org/document/8281493> <https://doi.org/10.1109/ACCESS.2018.2802699>
- [13] Munitic, A., Dvornik, J. and Simundic, S. (2003) System Dynamics Continuous Computer Simulation Model of Shipbuilding Process. *1st International Industrial Simulation Conference*, Valencia, 2003, 336-338. <https://www.bib.irb.hr/169783>
- [14] Greenwood, A.G., Vanguri, S. and Walden, C.T. (2005) Simulation Optimization Decision Support System for Ship Panel Shop Operations. *Proceedings of the Winter Simulation Conference*, Orlando, FL, USA, 4 December 2005, 9 p. <https://ieeexplore.ieee.org/document/1574490>
- [15] Cha, J.H., Roh, M.I. and Lee, K.Y. (2010) Integrated Simulation Framework for the Process Planning of Ships and Offshore Structures. *Robotics and Computer Integrated Manufacturing*, **26**, 430-453. <https://doi.org/10.1016/j.rcim.2010.01.001>
- [16] Ozkok, M. and Helvacioğlu, I.H.A. (2013) Continuous Process Improvement Application in Shipbuilding. *Brodogradnja*, **64**, 31-39.
- [17] Kang, S.K., Jung, H. and Lee, J.H. (2013) Active Discrete Event Simulation Using Probability Distribution of Shipbuilding Process. *4th International Conference on Information Science and Applications (ICISA)*, Pattaya, 24-26 June 2013, 1-3. <https://doi.org/10.1109/ICISA.2013.6579480>
- [18] Back, M.G., Lee, D.K. and Woo, J.H. (2016) A Study for Production Simulation Model Generation System Based on Data Model at a Shipyard. *International Journal of Naval Architecture and Ocean Engineering*, **8**, 496-510. <https://doi.org/10.1016/j.ijnaoe.2016.05.005>
- [19] Park, K.P., Ham, S.H. and Lee, C.Y. (2016) Application and Validation of Production Planning Simulation in Shipbuilding. *Ocean Engineering*, **114**, 154-167. <https://doi.org/10.1016/j.oceaneng.2016.01.008>
- [20] Basan, N.P., Achkar, V.G. and Garcia-del-Valle, A. (2017) A Heuristic Simulation-Based Framework to Improve the Scheduling of Blocks Assembly and the Production Process in Shipbuilding. *Winter Simulation Conference (WSC)*, Las Vegas, 3-6 December 2017, 3218-3229. <https://doi.org/10.1109/WSC.2017.8248040>
- [21] Suheon, J., Saenal, S., Huiqiang, S., Yong-Kuk, J. and Jong Gye, S. (2020) System Development for Establishing Shipyard Mid-Term Production Plans Using Backward Process-Centric Simulation. *International Journal of Naval Architecture and Ocean Engineering*, **12**, 20-37. <https://doi.org/10.1016/j.ijnaoe.2019.05.005>
- [22] Medeiros, D.J., Traband, M., Tribble, A., Lepro, R., Fast, K. and Williams, D. (2000)

- Simulation Based Design for a Shipyard Manufacturing Process. 2000 *Winter Simulation Conference (WSC)*, Orlando, 10-13 December 2000, 1411-1414.
<https://doi.org/10.1109/WSC.2000.899118>
- [23] Kim, H., Lee, S.S., Park, J.H. and Lee, J.G. (2005) A Model for a Simulation-Based Shipbuilding System in a Shipyard Manufacturing Process. *International Journal of Computer Integrated Manufacturing*, **18**, 427-441.
<https://doi.org/10.1080/09511920500064789>
- [24] Stanic, V., Hadjina, M. and Matulja, T. (2018) Toward Shipbuilding 4.0—An Industry 4.0 Changing the Face of the Shipbuilding Industry. *Brodogradnja*, **69**, 111-128. <https://doi.org/10.21278/brod69307>
- [25] Fraga-Lamas, P., Fernandez-Carames, T.M. and Vilar-Montesinos, M.A.A. (2018) Review on Industrial Augmented Reality Systems for the Industry 4.0 Shipyard. *IEEE Access*, **6**, 13358-13375. <https://doi.org/10.1109/ACCESS.2018.2808326>
- [26] Lee, Y.G., Ju, S. and Woo, J.H. (2020) Simulation-Based Planning System for Shipbuilding. *International Journal of Computer Integrated Manufacturing*, **33**, 626-641.
<https://doi.org/10.1080/0951192X.2020.1775304>
- [27] Pang, T.Y., Restrepo, J.P.D. and Miletic, M. (2021) Developing a Digital Twin and Digital Thread Framework for an “Industry 4.0” Shipyard. *Applied Sciences-Basel*, **11**, 1097. <https://doi.org/10.3390/app11031097>
- [28] Nam, S., Shen, H.Q. and Shin, J.G. (2018) SCP-Matrix Based Shipyard APS Design: Application to Long-Term Production Plan. *International Journal of Naval Architecture and Ocean Engineering*, **10**, 741-761.
<https://doi.org/10.1016/j.ijnaoe.2017.10.003>
- [29] Cho, S., Lee, J.M. and Woo, J.H. (2021) Development of Production Planning System for Shipbuilding Using Component-Based Development Framework. *International Journal of Naval Architecture and Ocean Engineering*, **13**, 405-430.
<https://doi.org/10.1016/j.ijnaoe.2021.05.001>
- [30] Lee, J.K., Lee, K.J. and Choi, H.R. (1995) DAS-Intelligent Scheduling Systems for Shipbuilding. *AI Magazine*, **16**, 78-94.
- [31] Sharma, R. and Sha, O.P. (2007) Development of an ERP Model for Modularly Designed Ships for Medium Scale Shipyards I: Manufacturing Management. *Journal of Marine Engineering and Technology A*, **10**, 17-43.
<https://doi.org/10.1080/20464177.2007.11081885>
- [32] Sharma, R. and Sha, O.P. (2007) Development of an ERP Model for Modularly Designed Ships for Medium Scale Shipyards II: Marketing Management. *Journal of Marine Engineering and Technology A*, **10**, 45-65.
<https://doi.org/10.1080/20464177.2007.11020202>