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MANUFACTURING SYSTEMS USED IN THE SHIPBUILDING INDUSTRY FROM YEARS 2000 UP TO NOWADAYS

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Abstract. *The continuous growth in demands for product quality and their utility properties in today's competitive environment places increased requirements on activities ranging from pre-production stages to sales completion. From these facts, it is evident that special attention must be paid to material selection, product design, and the construction of individual components, as well as the technologies used in their production and processing. Achieving high technical parameters for products while simultaneously optimizing the cost/performance or cost/utility value ratio compels designers and engineers to explore new progressive materials with high mechanical, chemical, and physical properties. They must also consider technologies that ensure efficient and precise manufacturing*.
Keywords: *shipbuilding; Industry 4.0; manufacturing systems; artificial intelligence.*

1 INTRODUCTION

In shipyards of global significance, both river and sea vessels are currently manufactured for various clients with highly specialized requirements. These vessels are constructed according to the rules of classification societies such as German Lloyd, American Bureau of Shipping, Bureau Veritas, and Lloyd's Register. Like other industrial sectors, the shipbuilding industry faces intense global competition. Labor costs are rising, and the risk of production errors due to the so-called "human factor" is significant. To remain competitive in this challenging environment, shipyards aiming to excel must analyse their current state and develop a strategic plan for the technical preparation of production. Subsequently, they can propose feasible production technologies. Despite dealing with large-scale steel structures, a considerable percentage of shipbuilding processes can be mechanized and automated. These innovations are crucial for maintaining competitiveness in today’s demanding environment.

Mechanization and automation allow for minimizing the impact of the human factor, increasing work productivity, and improving the precision and quality of products. Another positive effect that should not be underestimated is the enhancement of working conditions for employees in the shipbuilding industry. As the achievable profit directly correlates with production efficiency, most shipyards have adopted modern project and design methods, followed by the implementation of mechanization and automation in production and assembly processes [1].

2 THE SITUATION

The shipbuilding industry faces challenges in transitioning from old, legacy systems to newer, more integrated approaches. On the other hand, here are some challenges that the modern shipbuilding industry must address: [2]

1) Technological Advancements: Keeping up with cutting-edge technologies is crucial. Shipbuilders need to adopt digitalization, automation, and innovative materials to enhance efficiency and reduce environmental impact.
2) Complexity and Customization: Ships are becoming more complex, with specialized designs and features. Meeting customer demands while maintaining cost-effectiveness is a challenge.
3) Supply Chain Management: Coordinating suppliers, managing lead times, and ensuring timely availability of materials and equipment are critical for smooth production.
4) Environmental Regulations: Stricter environmental standards require shipbuilders to design eco-friendly vessels and reduce emissions.
5) Labor Costs and Skills: Labor costs are rising, and skilled workers are essential. Upskilling and attracting talent are ongoing challenges.
6) Global Competition: Asia-Pacific countries (Japan, Korea, and China) dominate shipbuilding. European shipyards face intense competition and must innovate to stay competitive.
7) Risk Management: Making early decisions in ship design can impact costs and project success. Balancing risk and innovation are essential.
8) Sustainability: Shipbuilders must focus on sustainable practices, including recycling, energy efficiency, and minimizing waste.

These challenges highlight the dynamic nature of the shipbuilding industry and the need for continuous adaptation and improvement.

1. Legacy Work Processes: Many shipyards operate with established, traditional work processes. These legacy systems often hinder collaboration due to silos and lack of integration between different departments. For instance, enterprise resource planning (ERP) solutions may not communicate effectively with design tools, leading to inefficiencies.

2. Data Silos: The existence of functional silos creates difficulties in problem-solving. Differences in data structures, formats, and naming conventions

make it challenging to identify and trace issues. This lack of cohesion affects agility and responsiveness to change.

3. Collaboration and Expertise: Shipyards increasingly rely on external contractors and suppliers for various aspects of vessel design and construction. To form an effective ship delivery team, information must be integrated and accessible across the organization.

In summary, the shipbuilding industry must overcome legacy systems, foster collaboration, and embrace integrated information flow to enhance efficiency and quality in ship design and production processes.

The goal of this article is to analyse the current state of automation in design and construction processes within the field of technical production preparation. It aims to establish fundamental principles for designing process with a focus on achieving the highest possible level of automation in this field.

Significant attention must be devoted to the integration of CAD systems and the automated production system to ensure rapid and accurate data transfer. Furthermore, addressing issues related to quality control of finished products and suggesting potential solutions for conflict resolution due to inaccuracies in the environment are essential aspects [3].

3 CREATION OF A COMPLEX MODEL OF THE VESSEL

After considering the factors mentioned earlier, we can conclude that the so-called complex mathematical model of the vessel could be the optimal solution to the problems outlined in the preceding sections. This comprehensive model incorporates all geometrical information, interlinking various parts and components. When changes occur in one area, they necessarily impact other components. By doing so, users receive alerts to correct either the source of the change or initiate a chain reaction of adjustments. This collaborative approach among experts working on the same object ensures continuous relevance and accuracy of shared data within the geometric database [4].

From the perspective of communication between distinct mathematical models, the transmission of information about changes is ensured either in real time or through periodic updates. For users of such computer systems, the communication possibilities mirror those between mathematical models. Each user is assigned specific permissions and design elements, granting them the right to create and modify certain components. Other elements can be viewed but not altered. Users can annotate requested changes on other elements, and the associated owner will implement necessary adjustments after assessing eligibility.

When multiple users collaborate within the same space and simultaneously, a “real-time update” becomes feasible. However, this solution may strain computing devices. From a security and information transfer speed standpoint, this method remains optimal. Nevertheless, the constant flux of changes and adjustments in an ever-evolving environment can evoke a sense of uncertainty for designers [5].

The concept of a “batch update” system can indeed address the challenges you’ve outlined. This approach involves transmitting new components and elements, along with any changes, to other users at specified time intervals. The interval is carefully chosen to optimize data updates, preventing system overload, and minimizing disruptions caused by constant modifications. Users can then focus on their work without being constantly interrupted by unfinished solution variants. This method strikes a balance between timely updates and maintaining a stable work environment.

Figure 1. Engine room 3D model [1]

4 USE OF THE “CONCURRENT ENGINEERING” METHOD

The “Concurrent Engineering (CE)” method represents the pinnacle of convenience in terms of the volume and type of managed information [1]. In this approach, we utilize what is known as the production model of the spatial vessel. This model encompasses not only geometric data but also associative and parametric relationships, along with what we refer to as non-geometric information.

What does this comprehensive model provide? It offers the technical and logistical details necessary for describing and supporting the design of the complete product—the vessel. Across the entire life cycle of the vessel, it integrates information from various domains: design, construction, technology, production, logistics, and sales.

The fundamental concept behind the CE system is continuous access to shared data and information. By establishing a robust CE system, we achieve several benefits:

- Reduced Production and Overhead Costs: Streamlining processes leads to cost savings.
- Accelerated Technical Preparation Stage: Faster decision-making and collaboration.
- Shortened Production Cycle: Efficient workflows lead to quicker results.
- Reduced Product Launch Time: Getting the vessel to market promptly.

In summary, the CE method fosters collaboration, optimizes efficiency, and ensures that everyone works with the most up-to-date information.

Advantages of the "concurrent engineering" concept are [1]:

- Product development time: 30-70% reduction
- Design changes needed: 65-90% reduction.
- Time to market: 20-90% reduction
- General quality increased by 200-600%
- Work productivity, efficiency increased by 20-110%
- Business turnover increased by 5-50%
- Return on Assets increased by 20-120%

At first glance, it is evident from the data above that the advantages resulting from the implementation of the Concurrent Engineering (CE) method yield economic outcomes, ensuring a relatively swift return on the necessary investments in this technology.

By transitioning to more advanced computing systems, CE technology opens new possibilities within the realm of virtual reality. Virtual reality represents the pinnacle of interactive design facilitated by CE technology. The fundamental concept involves creating a complex mathematical model — a computer-generated representation — of the vessel. This model not only incorporates geometric and database data but also allows for interactive engagement. In essence, users can interact with the model as if it were a physical prototype, mimicking the behaviour of a real vessel. Unlike a static element, this dynamic model possesses the properties of an actual physical body.

The NUPAS-CADMATIC system for example, implemented in several shipyards, encompasses all the necessary properties, and meets usability criteria for preparing inputs into a flexible production system. This solution, based on NUPAS-CADMATIC, significantly enhances productivity, and leads to an optimal spatial model of the vessel, particularly in areas with limited space. By doing so, it elevates workshop pre-production capabilities, effectively shifting the workload from shipbuilding to technologically advanced workshop spaces. Ultimately, this approach reduces product transit time and significantly cuts production costs. Thanks to its highly intelligent graphical user interface, the system requires minimal user training [6].

The software solution makes it possible to share design information between individual designers from different professions. The most important design information is public and available to everyone. Such a solution reduces the time for coordinating the location of individual equipment and components of pipeline systems. This increases the quality of the construction solution and the overall quality of the vessel. By using the same system in different areas of construction work, the so-called method of parallel engineering - Concurrent Engineering - becomes a reality [1].

Using this system, components are created only once, it contains their spatial mathematical model. All other component views are derived from that mathematical model and are kept up to date according to pre-defined and set rules. The modification of the component in the model is indicated based on the stated rules, and its other views are updated according to the need and decision of the designer. It means high consistency of construction and correct exact information for production.

The advantage of the production model is that the designer, by defining the component in the model, automatically creates the production data in one step. This means extremely precise and exact information for production, which is always up to date according to the latest construction status. The system enables its freely programmable export generators to forward the necessary information in the required form for other systems, for example, for material management, warehouses, purchasing and logistics, financial evaluation, and the like. In the field of pipeline systems, the creation of a model of pipeline systems is based on an intelligent database, which contains not only the design data of individual components, geometry, but also the logic of mutual connection - pressure class, number of screws, type of seal, etc. Based on this database, connection diagrams of individual pipe systems are created. It is possible to insert only such a component into the schemes, which is included in the database. Of course, the missing component can be added at any time, but first it must be defined with all the necessary properties in the database and then it can be used in the schema. After completing the scheme and verifying the functionality and correctness of the connection, it is possible to start creating a spatial model. The relationship between a spatial model and a wiring diagram is the same as that between diagrams and databases. Only components that have been included in the scheme can be used in the model. Such a solution ensures the unequivocal correctness of the model and its consistency with the functional scheme. All standards, regulations and requirements of the shipyard are stored in the database and are automatically considered during the creation of the model. By using the CE – Concurrent Engineering method, it is possible to increase the efficiency of material use and effectively use the available space [1].

It is possible to save a lot of time by generating all other information necessary for production from the spatial model, such as isometric drawings of pipe branches, a breakdown of the material used, and a cutting plan. Accurate information for production also contributes to increasing production accuracy and reducing the overall error rate.

What is created while modelling can no longer be called just a geometric model, but due to the complexity of the information contained in it, we speak of a so-called production model - Product Model. In addition to geometric information, this model also contains information on physical properties and technological and production information for production. As an example, it is possible to mention that the places of pipeline transitions through watertight walls are inserted at the stage of creating a spatial model of pipeline systems, but the information about the necessary openings in individual dividing walls becomes part of the geometry of the sheet metal, their geometry is burned on NC automatic burning machines. A change in the pipe system also causes a change in the dividing wall, the change in geometry is reflected in the control program for the movement of the firing head, which ensures a high degree of data consistency for production. Similarly, it is possible to describe the state after checking collisions between individual components or between devices, steel structure and pipe systems. The structure of NUPAS-CADMATIC allows dividing the model into smaller integrated blocks with a precisely defined interface and connection, which enables parallel processing of the created blocks. Of course, it means a significant saving of time, and in the final phase the entire complete model is assembled in one integrated database of the production model of the vessel. The production space model allows you to use the so-called virtual vessel bypass function. It is possible to define the route of a camera or a visitor who can - it is true that without the possibility of intervention in the model and without the possibility of its modification - pass the entire object and see for himself the quality of the technical solutions used. This option is also a great help for the production itself, as it allows you to interactively check and see the model in its real form before production. Another advantage is that changes made in the mathematical model are immediately reflected in the production information [1].

The real benefit of this solution, in addition to the above, is that control programs for DNC burning and bending automata of sheet metal parts, control programs for DNC cutting and bending automata of pipes and profiles, or for others, such as assembly and welding robots, are generated and exported from an accurate mathematical model. The support of the automatic production line by the software consists in supplying the automatic warehouse of semi-finished products with the necessary information to produce pipe branches, a computer-controlled handling line, a cutter-saw, a pipe marker, and a DNC bending centre. With the generation of isometric drawings of pipe branches, information for direct control of the DNC bending centre is also generated. In addition to information such as branch number, material, surface treatment, number of block or higher assembly, order of assembly, orientation of holes in the flange are contained in the file. Part of this information can be printed on a label and stuck on the pipe branch, respectively in the form of a barcode or in the form of a 2D Data Matrix code, it can be stamped on the surface of the branch. By combining design software with computer-controlled manufacturing, manual handling, and preparation of data for production is eliminated. An important aspect of the mentioned solution is that the information coming from the program already contains technological data.

An optimally designed construction solution results in an optimal production batch, and with such a solution, it is possible to extremely increase the share of workshop preparatory production and reduce the share of expensive, time- and material-intensive modifications directly on the vessel.

In addition to the mentioned information, the system can cooperate with the largest software solutions in the field of purchasing, logistics and material management, and of course also software solutions for production management. Design, technologically correct organization, increase the capacity of the workplace, which will ensure the production of pipeline components based on information from a complex computer model of the vessel, was the scope of the assignment. The results clearly show the feasibility of the proposed solution. The analysis attempted to outline a wide range of problems in the transition of technical preparation from classical manual methods to the most modern, computer-aided methods of competitive engineering. The basis of the solution is a complex mathematical spatial model of the vessel. Expanding this model with structural, material-technological, production information means the creation of the already mentioned production model of the vessel. Based on the created production model, it is possible to formulate the basic requirements for the technological process of production and pipeline branches about securing the automated production system with information.

By using design-construction computer systems, it becomes possible to supply the entire region with custom-made, surface-modified components of pipeline systems, it is possible to separate the design and construction activity from the production of parts, we come to believe that such a project must be effectively applicable and usable [7].

5 RESULTS

The basic goal of our work was to provide an analysis of the current state of the technology of the production of pipe branches in the conditions of a shipyard. Part of our work is also the proposal for the use of new technology for the technical preparation of production and at the same time for the technological preparation of production. Detailed cost analysis, workability analysis and review of the feasibility of the entire project demonstrated the complexity and complexity of the investigated issue.

The basic characteristics of the control system working based on fuzzy logic were presented. A description of the characteristics of the control computer and the control hierarchy of automatic production systems was given. Based on the facts mentioned above, an integrated flexible production system was designed, which can automatically change its production program based on input information without the need to stop work and possibly adjust the used components.

Concrete results and benefits of the solution described above are listed below. Figure 2 shows the number of necessary changes for modelled and non-modelled vessels during manufacturing process.

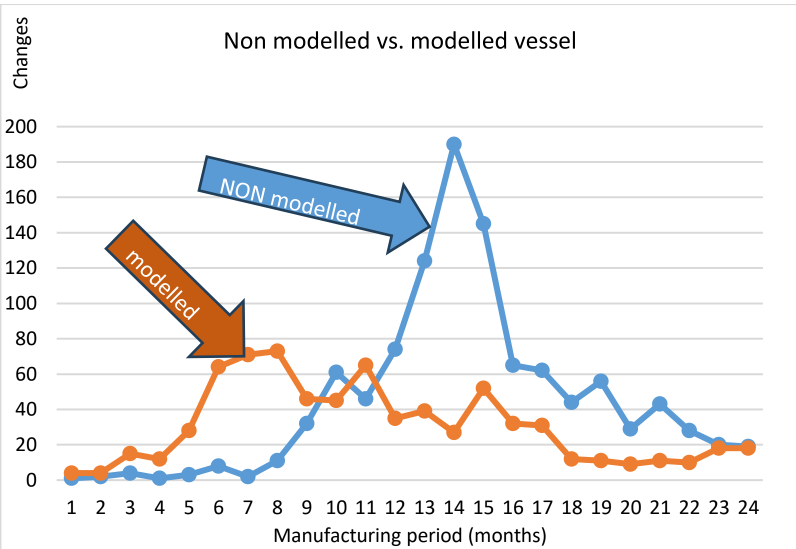

Figure 2. Non-modelled vs. modelled vessel - number of necessary changes during manufacturing process [1].

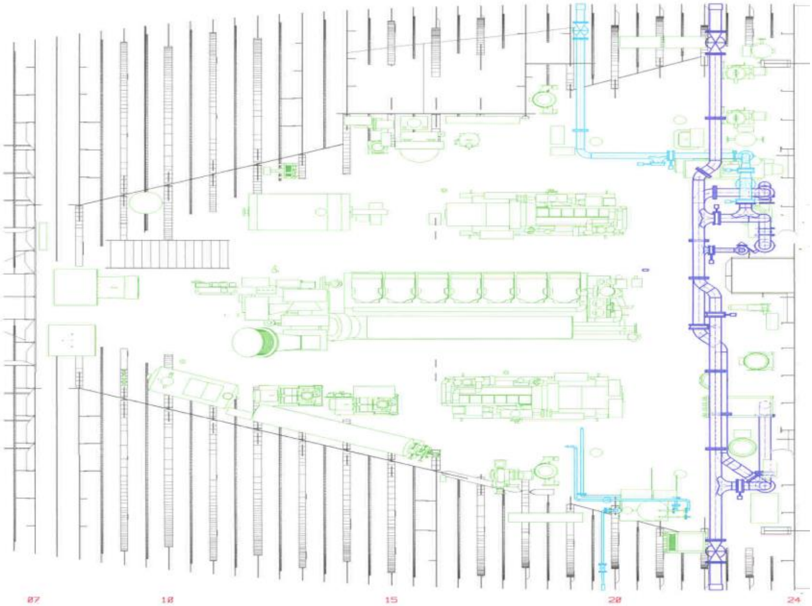

Figure 3. Engine room of a vessel [1].

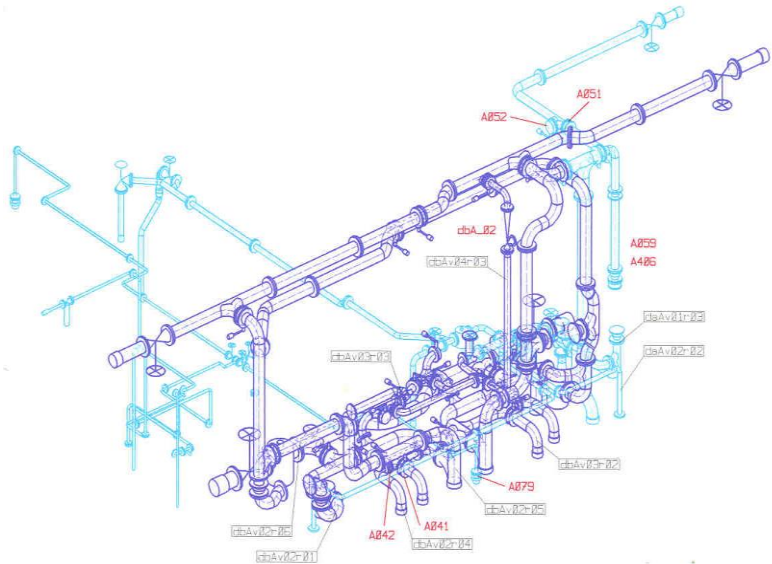

Figure 4. Pipeline systems of a vessel [1].

6 CONCLUSION

The working place of automated production system - APS for pipe systems of vessels is connected to the 3D CAD system for preparing of working documentation for pipe systems. The 3D model of pipe systems is used as a base. From the automated design of 3D model is processed the technological background for production with output applicable straight in the automated production process. The production process is provided by the flexible production system includes subsystems for manipulation, transport, material preparing, production, testing, sorting, and stocking. Automated production line includes numerical controlled daily stock of raw material, computer-controlled workplace for measuring and cutting of pipes. This workplace is connected to the workplace with NC bending machine continuing with numerical controlled welding machine – robot for flange welding. Other workplaces for geometry checking and welding quality verification are included into the automated production line too. The production system is designed based on the actual accessible results of science and research in this field. The production line is characterized as a Flexible Production System – FPS controlled by fuzzy logic. The system can react to the necessary changes of the product assortment. After the change of the control information the system is able immediately to start production of other assortment of products. Our flexible production system is an automated production line, where the change of the product assortment is done by changing of the controlling programs.

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ВИРОБНИЧІ СИСТЕМИ, ЯКІ ВИКОРИСТОВУЮТЬСЯ У СУДНОБУДІВНІЙ ПРОМИСЛОВОСТІ ВІД 2000 РОКУ ДО СЬОГОДЕННЯ

Анотація. *Безперервне зростання вимог до якості продукції та її корисних властивостей у сучасному конкурентному середовищі висуває підвищені вимоги до промисловості, починаючи* *від етапів підготовки виробництва до його завершення і продажів. З цих фактів видно, що особлива увага повинна бути приділена вибору матеріалів, дизайну виробів і конструкції окремих компонентів, а також технологіям, що використовуються при їх виробництві та обробці. Досягнення високих технічних параметрів виробів з одночасною оптимізацією співвідношення витрат і продуктивності або витрат і корисностей змушує конструкторів та інженерів досліджувати нові прогресивні матеріали з високими механічними, хімічними та фізичними властивостями. Вони також повинні враховувати технології, які забезпечують ефективне та точне виробництво. Робоче місце автоматизованої виробничої системи – АВС для трубних систем суден підключено до системи 3D CAD для підготовки робочої документації для трубних систем. Виробничий процес побудови суден забезпечується гнучкою виробничою системою, що включає підсистеми маніпуляцій, транспортування, підготовки матеріалів, виробництва, тестування, сортування та складування. Автоматизована виробнича лінія включає в себе щоденний запас сировини з числовим програмним управлінням, комп'ютеризоване робоче місце для вимірювання і різання труб. Це робоче місце з'єднане з робочим процесом за допомогою згинального верстата з ЧПУ, продовжуючи зварювальним апаратом з числовим програмним управлінням – роботом для зварювання фланців. Інші робочі місця для перевірки геометрії та перевірки якості зварювання також включені в автоматизовану виробничу лінію. Виробнича система проектується на основі актуальних доступних результатів науки і досліджень в даній області. Виробнича лінія характеризується як гнучка виробнича система – ГВС, керована нечіткою логікою. Система може реагувати на необхідні зміни товарного асортименту. Після зміни контрольної інформації система здатна відразу ж приступити до випуску іншого асортименту продукції. Така гнучка виробнича система являє собою автоматизовану виробничу лінію, де зміна асортименту продукції здійснюється шляхом зміни керуючих програм.*

Ключові слова: *суднобудування; Індустрія 4.0; виробничі системи; штучний інтелект.*