Simulation of Block Assembly Process in Shipbuilding by Petri-nets

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Shipbuilding Industry has undergone major changes in the past two decades. Maritime sector has grown rapidly and so has the competition. In order to survive in this competitive environment shipyards have to organize and utilize their resources at optimum capacity and efficiency. Planning and management of resources is a very crucial aspect of shipbuilding industry. There are many constraints on production planning in a factory. The most efficient production schedule should be planned taking these constraints into account. Professional skill is necessary to plan the best schedule. A scheduler must deal with a large amount of information on product planning, so as to evaluate the best schedule. In order to design efficient factory model, which is capable of utilizing its resources to the full extent, it is necessary that we understand various types of flow taking place in a manufacturing factory. Production in shipbuilding can be classified from the viewpoints of product flow and job flow.

To improve efficiency of manufacturing factory it is necessary that the 'flow' should be smooth. To simulate the flow of product a simulation package called Petri-nets [4] is used. This software has the ability to simulate various dominated system in shipbuilding process. It is very tedious job to simulate the complete ship fabrication in a single model so simulation is done by dividing the ship into smaller blocks which can then be simulated individually. Simulation of the block assembly process improves understanding of the manufacturing process and also helps in determining hindrances like 'bottlenecks' in the assembly line flow.

In the present work, a midship section (Nomenclature Block 04 here) of a container vessel weighing 212 tonnes is used as a test to simulate the block assembly process. The simulation exercise also estimates the down-hand and overhead welding requirements at different stages of the block assembly process Block 04. Following shipbuilding practices, Block 04 divided into smaller sub-assemblies and each one the sub-assemblies are simulated individually. Further extending the concept of simulation to actual shipbuilding practices, simulation for two and than three blocks is carried out with appropriate phase lag. The approximate total time required by the Block-04 for fabrication by this simulation exercise is presented along with occurrence and location of bottlenecks.
The paper also discusses how the simulation of the two and three block assembly process exercise is helpful in locating the bottle-necks over longer time span of the production process and at what rate the blocks can be accepted at the erection stage of shipbuilding. In order to achieve faster production it is necessary to reduce the occurrence as well as time span of bottlenecks. Simulation of multiple block assembly process also gives an idea whether the present assembly area is adequate to meet the production schedule.

KEY WORDS
Shipbuilding; Assembly; Block Assembly; Petri-net; Simulation.

INTRODUCTION
Ship production is a complex process and cannot be classified as a typical manufacturing industry in the strict sense because of high customization. It is more often a "one of kind" production and therefore has significant differences from a mass production based industry. Also in the recent past, shipbuilding has gradually evolved from a systems based infrastructure to a product and process based infrastructure.

The main phases of the product life cycle of ships are concept /tender design; preliminary/contract design; detailed design; production; trials and commissioning; operations (service); and disposal (scrapping). On obtaining the contract, the design department proceeds with the design. At this stage, the designer bases his calculations on the functional system of the ship. Here the design and drawings are produced to satisfy the owner's requirements, classification society and other statutory bodies. This is followed by a transition stage where information generated for functional groups is mapped in terms of "constructional groups" based on the constraints imposed by resources and production practices of the shipyard. Resource requirements in terms of manpower, facilities and due date of completion of each construction group is calculated which in turn can be related to the total material requirements and the cost of the product.

Today in the world of advanced computing, there are comparably fast computers which have facilitated the development of several software packages on planning and management. Many manufacturing systems have been developed and are used to deal with a large amount of manufacturing information efficiently. Various design systems, such as computer-aided design systems (CADs) have been developed and are used to generate production information. In addition, computer-aided engineering systems (CAEs) have been used aggressively to evaluate information on the designed products. Recently, information technology has given designers a work environment so they can plan the production more easily. In fact, to evaluate the possibility and effectiveness of the generated schedules, the professional skills, experience, and intuition of a schedule planner are necessary. A scheduler must deal with a large amount of information on product planning, so as to evaluate the best schedule. In order to design efficient factory model which is capable of utilizing its resources to the full extent it is necessary that we understand various types of flow taking place in a manufacturing factory.

SHIPBUILDING

Shipbuilding is an assembly process involving hundred of thousands of individually prefabricated parts and items of machinery, equipment and outfit. The productivity of the ship production process depends on how efficiently one can assemble them together. Figure 1 shows a flow diagram of a typical modern shipbuilding process. Modern shipbuilding practice requires that larger proportions of the man-hours be spent planning for production. This is to ensure that not only less time is needed to build a ship, but also more ships can be built from a single position (dry dock). Economically, this can be justified as return on investment on modern facilities (dry dock and block/grand block assembly areas) can be recovered by spreading the fixed cost over a large number of ships.

As seen in Figure 1, the ships are now built by assembly of blocks or grand blocks having reasonable outfit content. Therefore, the role of a modern design department would now include the following four tasks:

1. Design and Engineering: The traditional task of the design department was functional design which includes the detailed specification of all structure, material and equipment, meeting all the relevant regulatory requirements. The additional task now is production engineering which aims to map the functional groups into constructional groups. This involves the development of all the detailed drawings, sketches, instructions and other documentation needed by the shipyard to build the ship.
2. Production Planning: Based on the information obtained from production engineering there are three steps in production planning:
   - Build Strategy – is a document that attempts to capture design, planning, production methods and practices for a specific task into an integrated system. The document spells out objectives, constraints, potential difficulties, and other information that needs to be developed up front before the main task can commence. The production engineer develops and refines the build strategy as more information is available during the design development. The initial build strategy addresses the whole ship and then an interim product.
   - Scheduling – decides the time order in which the jobs are to perform so as to complete the production process
   - Resource Allocation – decides the material and manpower requirements at each stage in the production process
3. Materials Planning and Procurement: Information from production engineering and production planning provide the basis for materials planning. Procurement of major and long lead time machinery and equipment get decided at this stage. Drawing and work instruction are generated for subcontracted work.
4. Production Control: At this stage, the progress of the actual production process is monitored and necessary feedback is provided to production planning when the manufacturing deviates from the plan so as to take corrective measures in the production planning.

In modern shipbuilding, product-oriented work breakdown structure classifies the ship on the basis of its interim products/blocks. Group technology concepts have been successfully used in integrating the interim blocks with zone outfitting and zone painting [2]. Hull Block Construction Method forms the basis by which the ship is divided and subdivided into blocks (Figure 2). These blocks form the basis for control of the production process and also have an impact on the Zone Outfitting Method and the Zone Painting Method. The size, shape and the number of blocks will determine the subsequent nature and work package of the interim products and thus will have a large influence on the productivity of the yard. The division of the ships into manageable blocks should be such that:

- The blocks are simple and have logical boundaries.
- The number of blocks should be minimised, if necessary by joining the blocks, so as to exploit the largest capacity crane at the erection site. There may be sometimes an additional manufacturing level in which the blocks are joined together into grand blocks.
- The shape of the blocks should be such that they have a stable configuration and can stand on their own with minimum or no external support.
- An attempt must be made to minimise scaffolding, lifting and turning of the blocks during its fabrication process.
- The blocks should be configured such that the various sub-assemblies that make up to form the block can be assigned to one of a minimum number of work package groups considering similarities in problem area and need to minimise variations in working times.
- Identify assembly and erection process of the blocks consistent with safety and need for block accuracy and rigidity.

- The blocks should provide maximum accessibility, both in terms of area and volume, for on-block outfitting and on-block painting so as to:
  - install machinery and other components in the engine room
  - arrange deck machinery, mooring gear, piping, fittings, etc., and
  - perform as much painting as possible before erection of the block

The hull block construction method can have a 7-tier hierarchical framework so as to optimise the hull structural production process. The number of hierarchical divisions may vary depending on the shipyard's facilities and the type of ship it is building. The interim products manufactured at each level in the hull block construction method (except for the Grand Block and Erection Level) are examined for similarities in their production aspects. Accordingly, the interim products at different manufacturing levels are grouped so as to:

- further modularise the production process
- justify the presence of expensive but highly efficient facilities achieve manpower savings

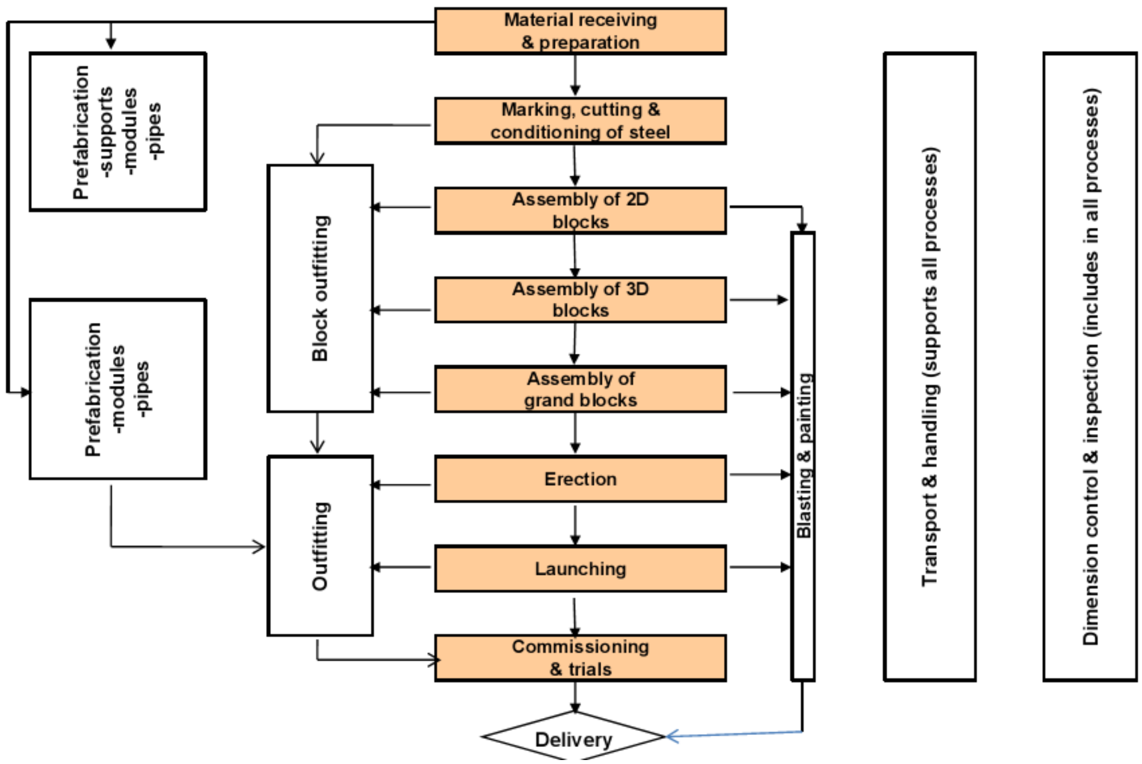

Figure 1: Stages in Shipbuilding Process [1]

SHIPBUILDING PROCESS AND PETRI-NETS

In shipbuilding there are three important production activities, namely :

1. *Operational Activity*: In this activity the form of the product changes during each production stage, e.g. cutting, welding and fabrication of sub-assembly, assembly, block assembly, erection, etc.
2. *Transportation Activity*: In this activity only the position of product changes. Products such as piece-parts, subassemblies and assemblies are transported between various production stages.
3. *Storage Activity*: In this activity neither form nor position of product changes. This activity controls the progress of the product. Ideally this activity should be avoided or minimized, but sometimes it is necessary to incorporate this so as to have a smooth product flow.

Ship production process can be viewed from two aspects: product flow and job flow [3]. Product flow of an interim product can be defined as logical and sequential movement of a product through different production stages, whereas the job flow is the sequence of jobs at each assembly stage. For interim block production, the activities under product flow are sub-assembly, assembly, block assembly and erection, whereas the job flow activities will mainly include fitting, tack welding, welding and inspection.

The production of an interim product (block) at different stages can be viewed as a series of cells each having the above mentioned production activities. The product flow and job flow at all stages must be decided so as to ensure high production efficiency.

Simulation of ship building process provides deep insight of the fabrication and assembly process. The hull block construction method divides the ship into manageable blocks using the top-down approach. The simulation of the complete ship can be seen as sum of simulation of the individual blocks. Simulation of each block is further divided into sub-assemblies like flat panel, curved panel etc. Each sub-assembly is simulated individually and finally all these sub-assemblies are combined into a single model with suitable time lag given to each sub-assembly resulting in the simulation of complete block production process.

A Petri-net (also known as a place/transition net or P/T net) is one of several mathematical representations of discrete distributed systems. As a modeling language, it graphically depicts the structure of a distributed system as a directed bipartite graph with annotations. Petri-net was invented in 1962 by Carl Adam Petri [4]. The four important components of petri-net shown in Figure 4 are:

1. Places: It shows the state of activity and they are represented by a circle.
2. Transition: It shows the starting and ending of activity or we can say duration of activity. Transitions are shown by rectangles.
3. Token: It shows the movement of a product. Token (modeled as a product) is shown by big black dot.
4. Arcs: The arcs show the movement of tokens (i.e. product flow). There are two types of arcs.
   - Input arc: These arcs start at place and end at transition
   - Output arc: These arcs start at transition and end at place.

Petri-nets have undergone various changes in the past few decades; it has been modified at various levels to suit modeling. By adding more attributes or parameters of modeling it is become easier to model the systems more efficiently. In shipbuilding, time is an important parameter and in this work “Timed Petri-nets” has been used wherein time is the additional parameter in Petri-net modeling [5, 6].

As we know, a shipyard has to deal with high level of uncertainty and complexity during production. Activities in shipyard are dependent on each other so if there discrepancy in one activity it will effect the whole production. Shipyard activities can be divided into sequential, parallel, dependent and limited resource activities. Petri-net is suitable tool for modeling these type of activities efficiently.

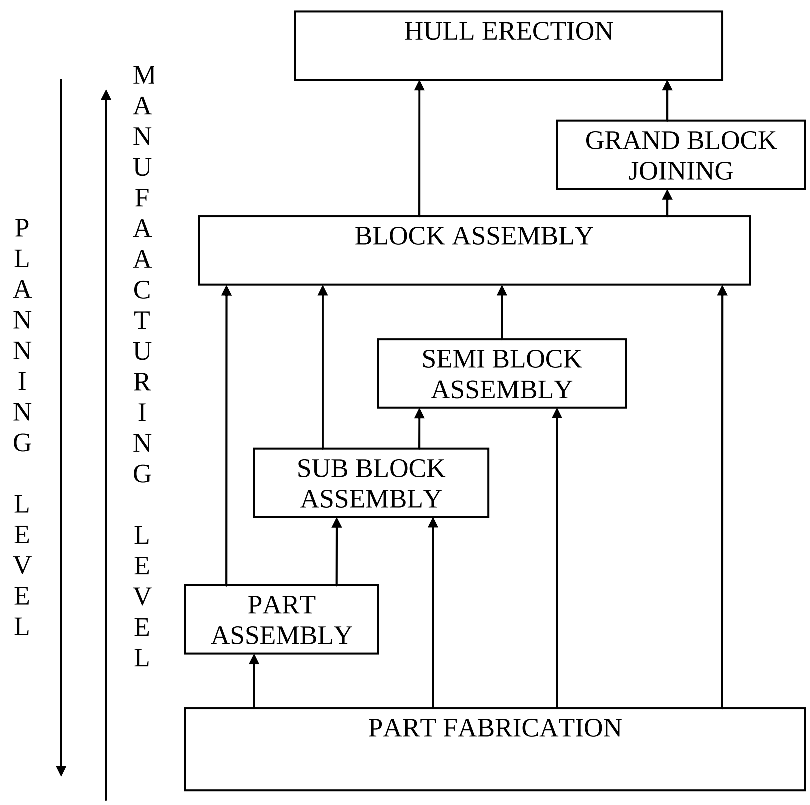

Figure 2 Hull Block Construction Method [2]

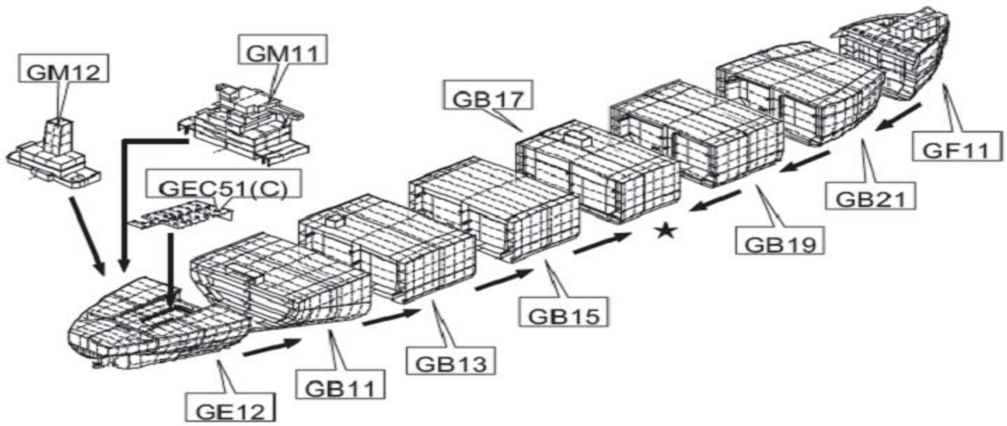

Figure 3 Division of Ship into Blocks [3]

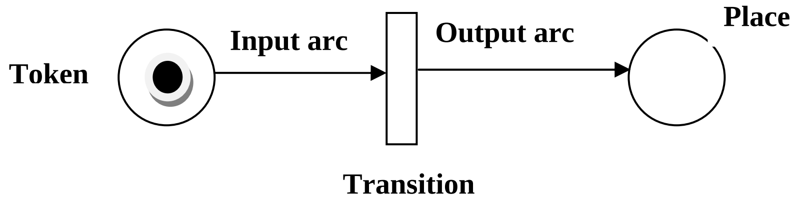

Figure 4: Model of an Activity by Petri-net

REPRESENTATION OF SHIPBUILDING PROCESS BY PETRI-NETS

In order to model an activity it is necessary to define activity's parameters in terms of Petri-net's parameters. To simulate product flow it is necessary to define each and every activity in job shops and movement of product through these job shops.

***Representations of event and activity*:** There are two types of events in production activities. One is an "event at the activity start" and the other is the "event at the activity end." Activity is denoted by '*Transition*' which shows the duration of an activity.

The 'state of the activity' that exists between 'activity' is modeled by place, as is the condition of an event. Figure 4 illustrates the connection of transition with place. To simulate production, it is necessary to consider the passage of time during the activity. Hence, a "time Petri-net" is introduced. A place modeled as the state of activity holds reign until a specified time passes.

Representation of production. A product is modeled as a token and therefore product flow is represented by a token's movement. Information on the product model of parts, sub assembled modules, and so on is linked to a token. A token moves from one place to another. Because the place is modeled as the state of an activity, the scheduler is made aware of the state of an activity by a token's position. In addition, a history of activities is acquired by collecting histories of tokens' movements.

As mentioned earlier, there are three major activities in shipbuilding, i.e. Operational, transportation and Storage. The principle behind modeling of these activities using the Petri-net components (transition, place and token) is briefly explained below:

- ***Operation activity***. Operation activity is produced when the products are carried in the workplace. Product flow between workplaces is represented by transaction firings of "transporting in" and "transporting out" of the workplace.
- ***Transportation activity*:** Transportation activity is used to move a product in and out of workplaces. The activity begins by placing a product on transporting equipment.
- ***Storage activity***. Storage activity is used for keeping a product in a storage space intentionally to produce efficient production activity. This activity is modeled by the Petri-net, similar to operation and transportation activities, with consideration of the limited storage space.

Software used for simulation of the block assembly process is **HPSim**. HPSim was developed to support the design and simulation of Petri-nets, both in a graphical and intuitive manner. The software features Place/Transition Nets, Stochastic Petri-nets and Petri-nets with time. The actual simulation is visualized as a Token Game Animation. This can be executed in single step or continuous mode. Besides that, a fast forward mode is also available, in which the graphical representation of the token is not synchronized with the simulated actual position. When transition is *"yellow"* it shows that 'token'/product is under certain activity. When transition turns green it shows the activity is over, token is ready to fire or product is ready to move to the next stage. Time of activity is fed into transition a separate parameter. A status bar below keeps track of time as the simulation proceeds. When simulation is over it shows the total time elapsed which is the total time for assembly. Similarly, there are counters in transition and places which keeps track of number times of certain activity and number of items undergone that activity. Simulation speed is flexible which can be increase or decrease if required. It also maintains a XL Data Sheet for marking and firing request.

SIMULATION OF BLOCK ASSEMBLIES

A test simulation is done for a Block 04 weighing 212 tones of a container vessel. This block is located amidships and shown in Figure 5.

For simulation of block assembly process, the Block 04 has been further broken down into sub-assemblies of smaller size and weight. The sub-assemblies of Block 04 are shown in Figure 6 with the nomenclature P and S to identify the port starboard side blocks. The assembling order is determined after considering the relation between sub-assemblies. The assembling order and the network of activities for Block 04 are shown in Figure 7.

Simulation for all the sub-assemblies is carried out using HPSim. For identical sub-assemblies the simulation is done only. Figures 8, 9, 10 and 11 shows the simulation for the sub-assemblies Block 04-01, Block 04-02, Block 04-03 and Block 04-06 respectively. Appropriate time for marking, cutting and welding including the variation of time depending on welding type and position have been incorporated in the model.

Figure 12 shows the simulation model for the complete Block 04.

A simulation study was carried out using this model to understand the ship production process assuming two identical (Block-04 and Block –05) and three identical Blocks (Block-04, Block-05 and Block-06) of the similar configuration as Block-04. The simulation shown in Figure 13 shows the movement of sub-assemblies through various shops during fabrication of two identical Blocks (Block-04 and Block-05). In modeling the simulation of two blocks (Fig. 13) two assembly lines are provided.

Simulation of assembly of three identical Blocks (Block-04, Block-05 and Block-06) is show in Figure 14. In modeling the simulation of three blocks (Fig. 14) only two assembly lines are provided. Such studies help us identify whether the assembly line is of adequate capacity or needs expansion. In these models, stockyard, plate treatment shop and the prefabrication areas are shown. The prefabrication area is further divided into curved panel area, flat panel area and floor preparation area. The fabrication of 2D curved sections takes place in the curved panel area.

HPSim keeps a token count, which helps in determining the occurrence of particular activity. This allows us to determine how much resource is consumed for a particular activity and how much additional resource is required further for completion of this activity.

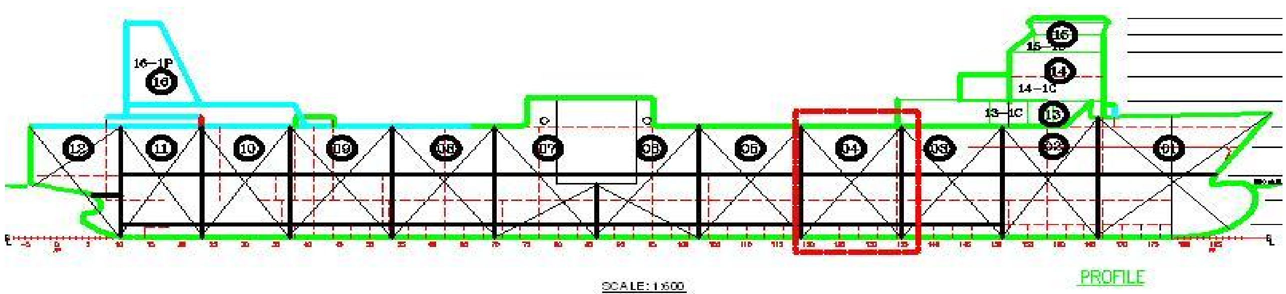

Figure 5: Division of Ship into blocks, Block 04 Marked with red.

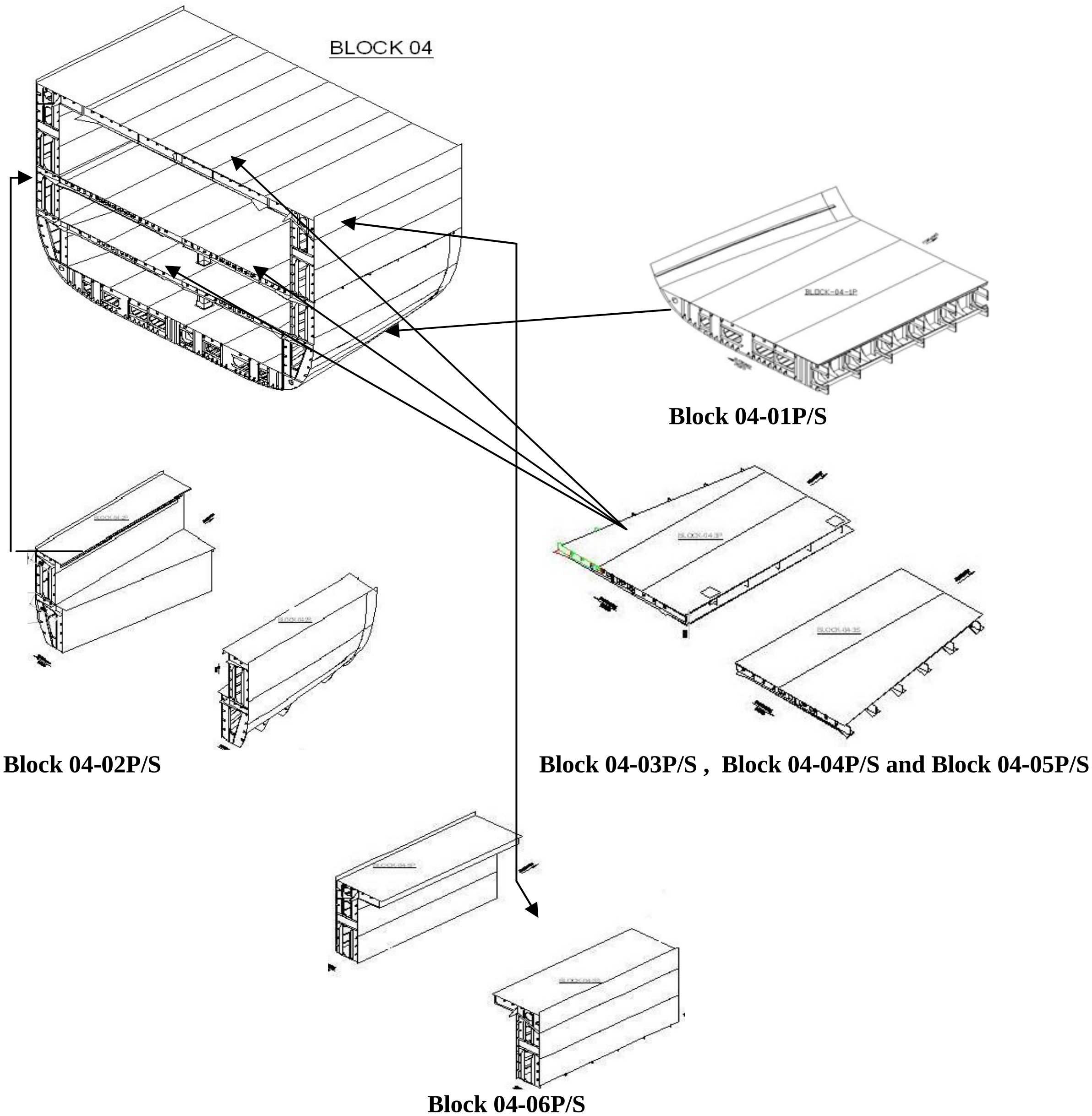

Figure 6: Breakdown of Block 04 into sub-assemblies

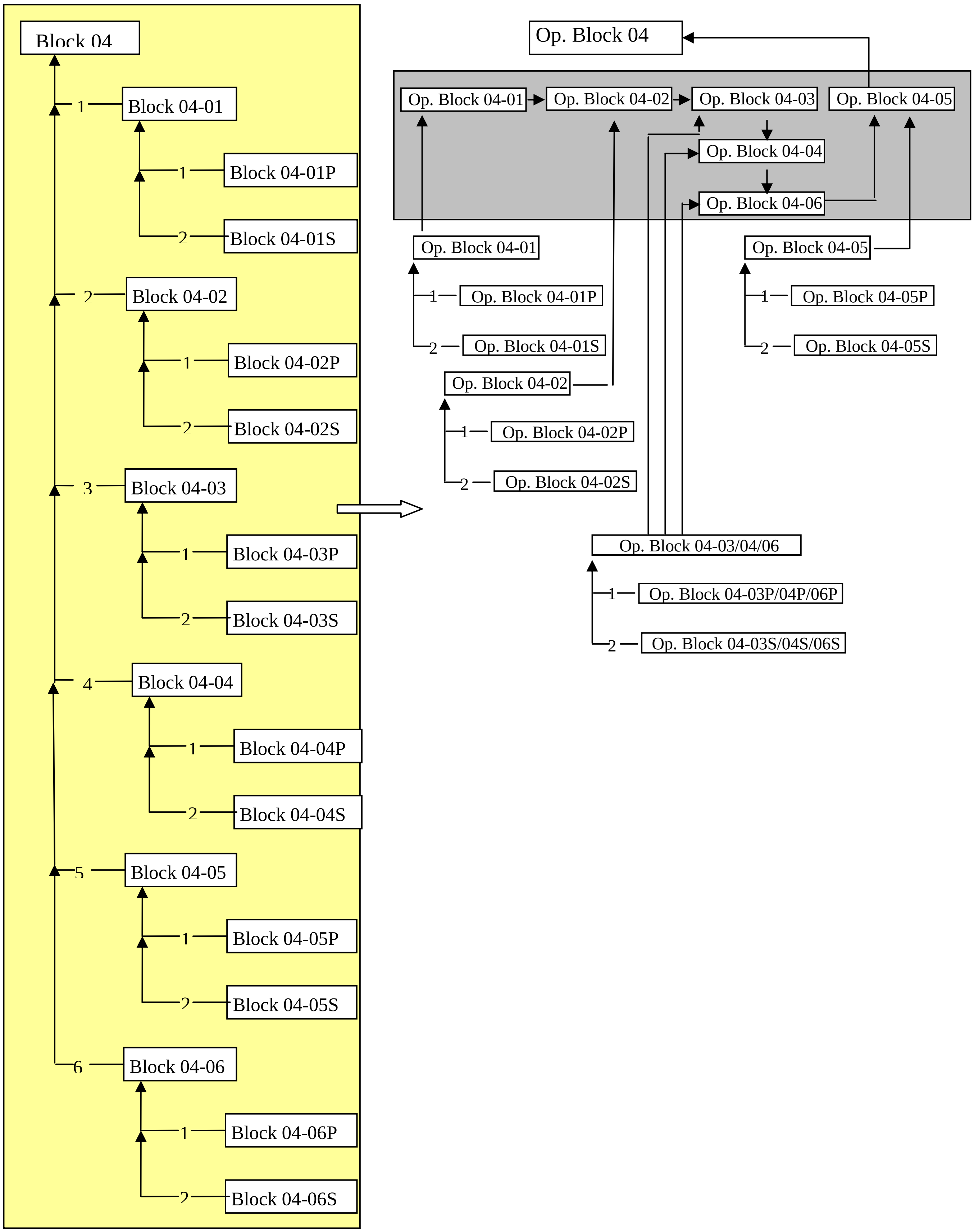

Figure 7: Assembly Order and Network of Activity for Block-04

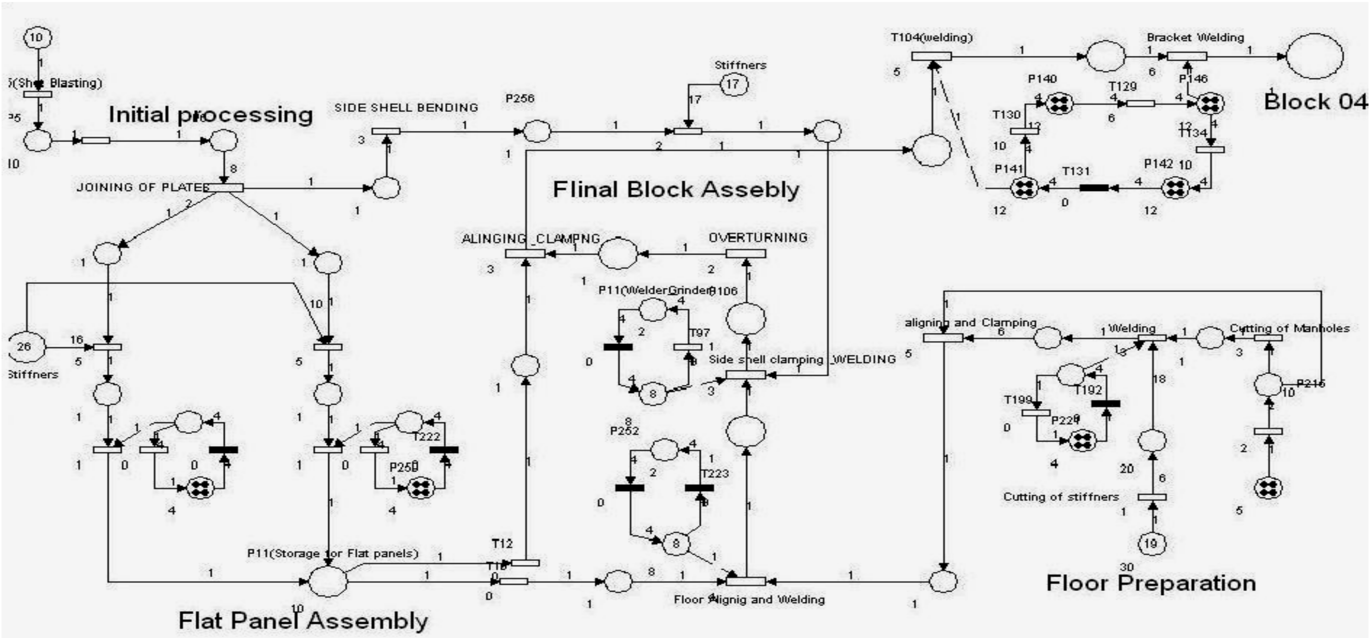

Figure 8: Simulation model for assembly of Block 04-01P

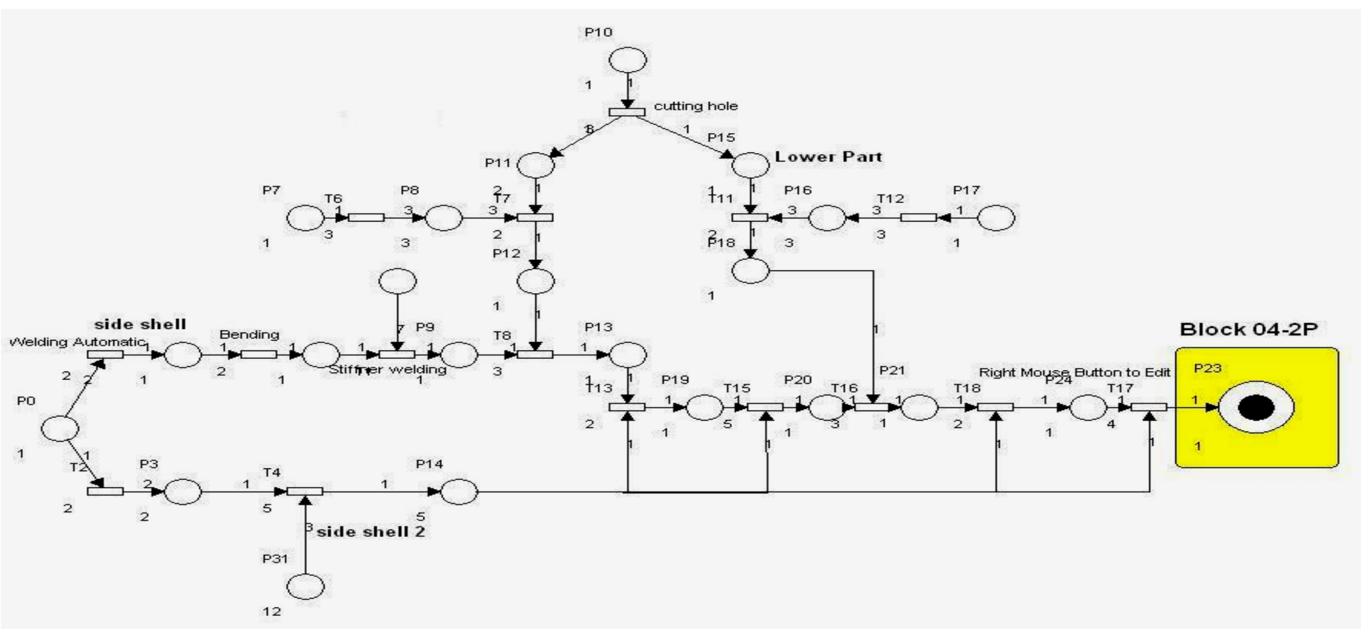

Figure 9: Simulation model for assembly of Block 04-02P

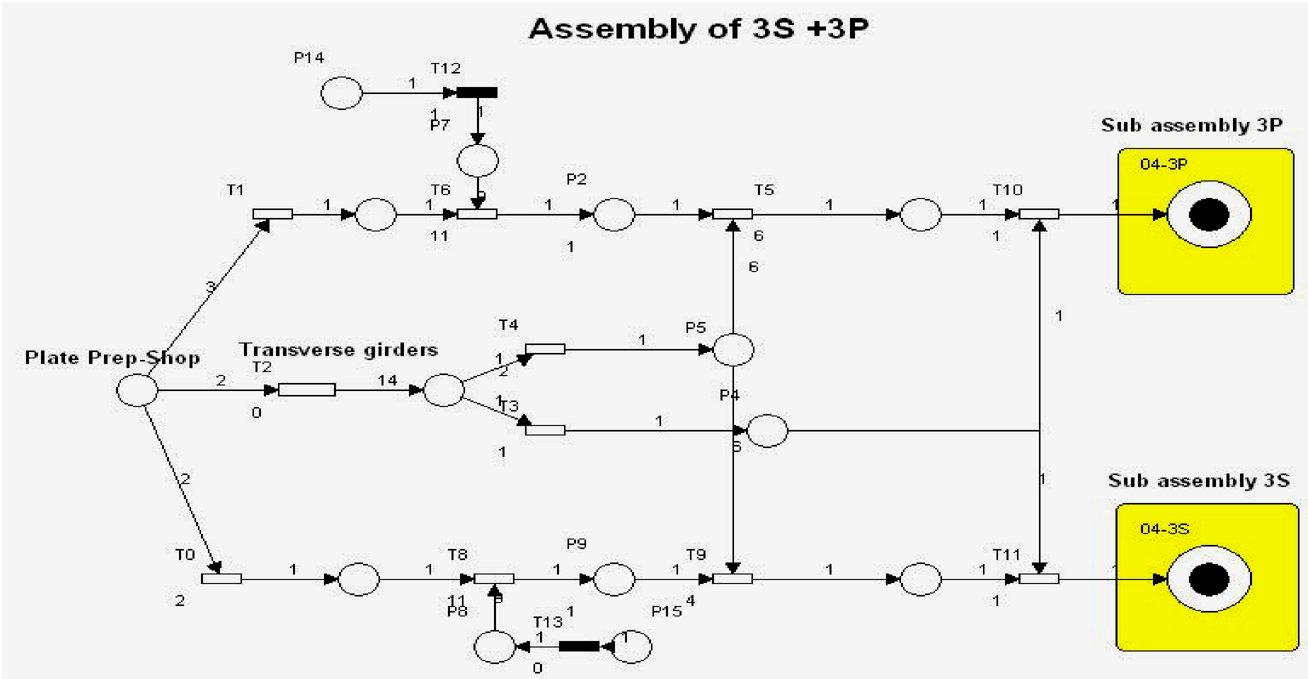

Fig 10: Simulation model for assembly of Block 04-03P

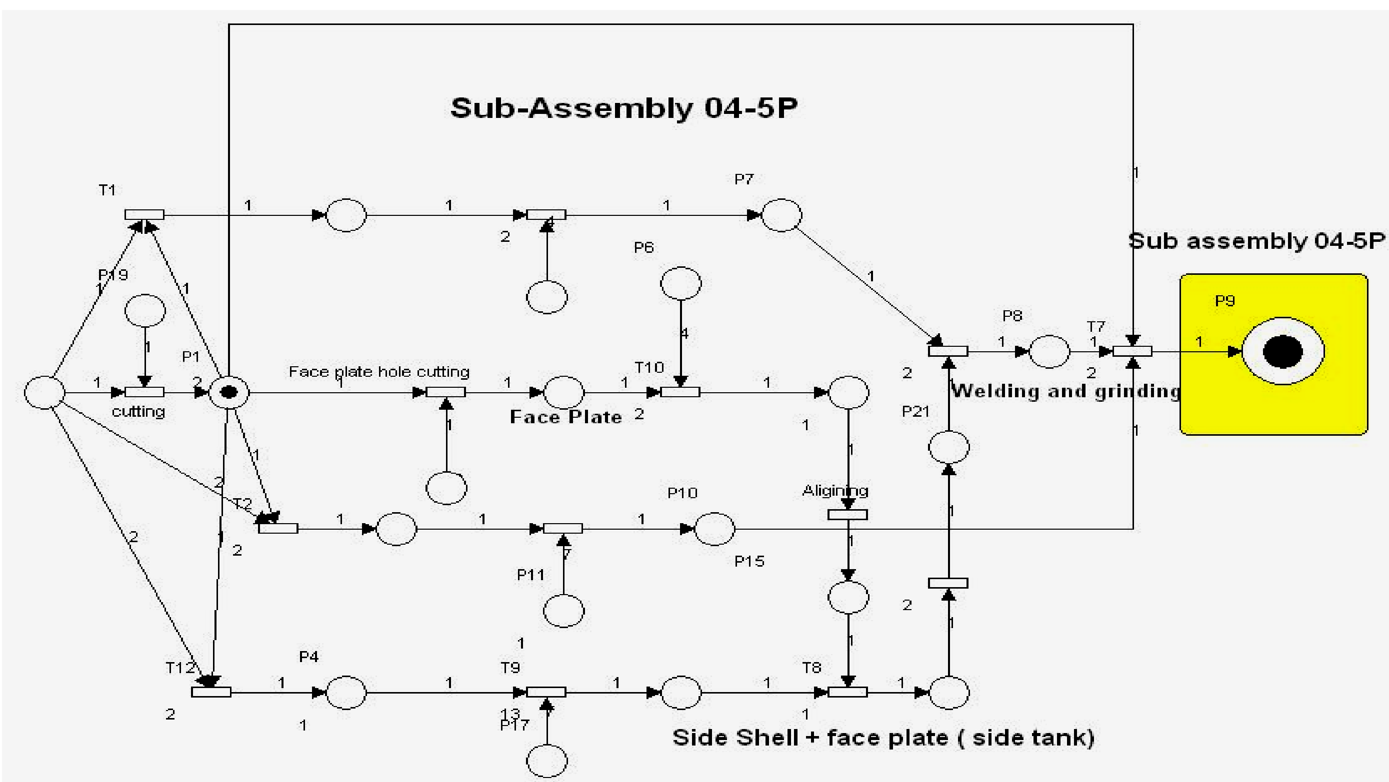

Fig 11: Simulation model for assembly of Block 04-05P

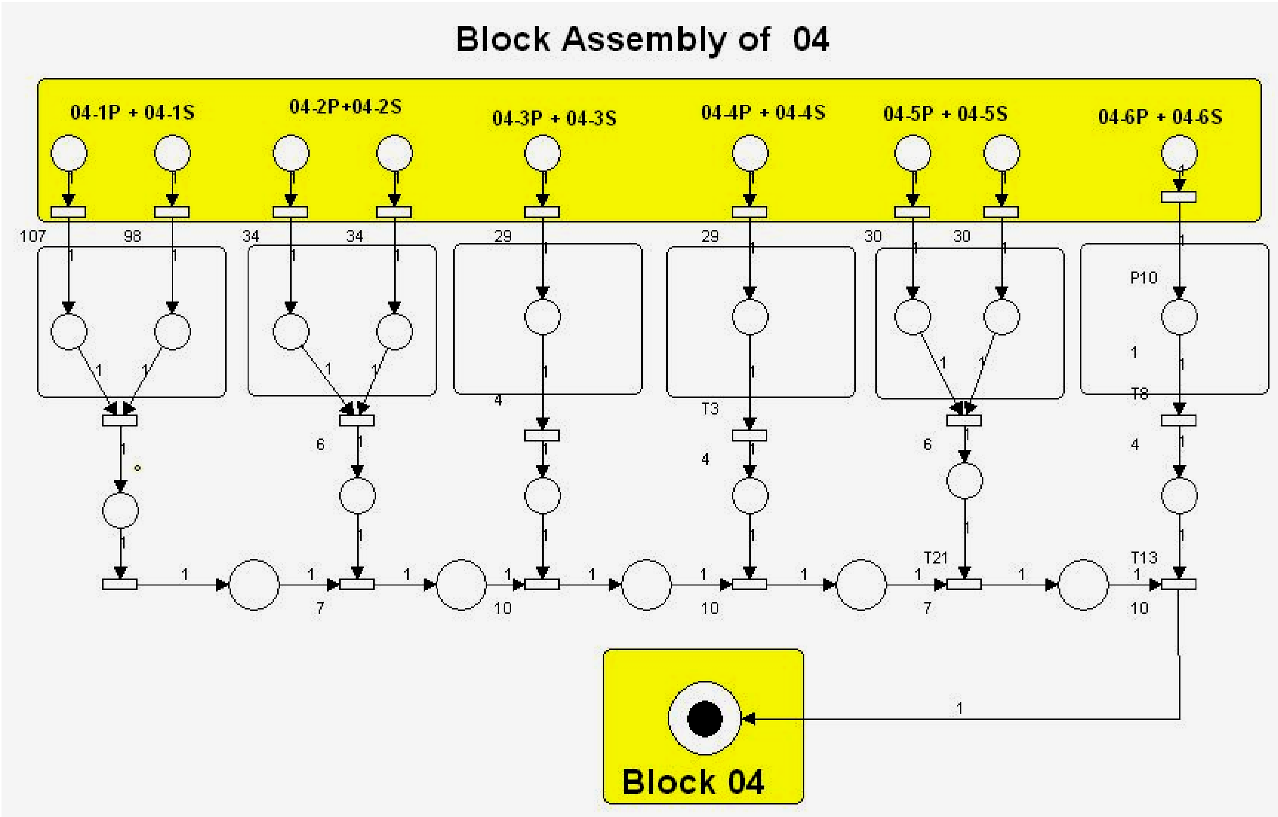

Figure 12: Simulation model for final assembly of Block 04

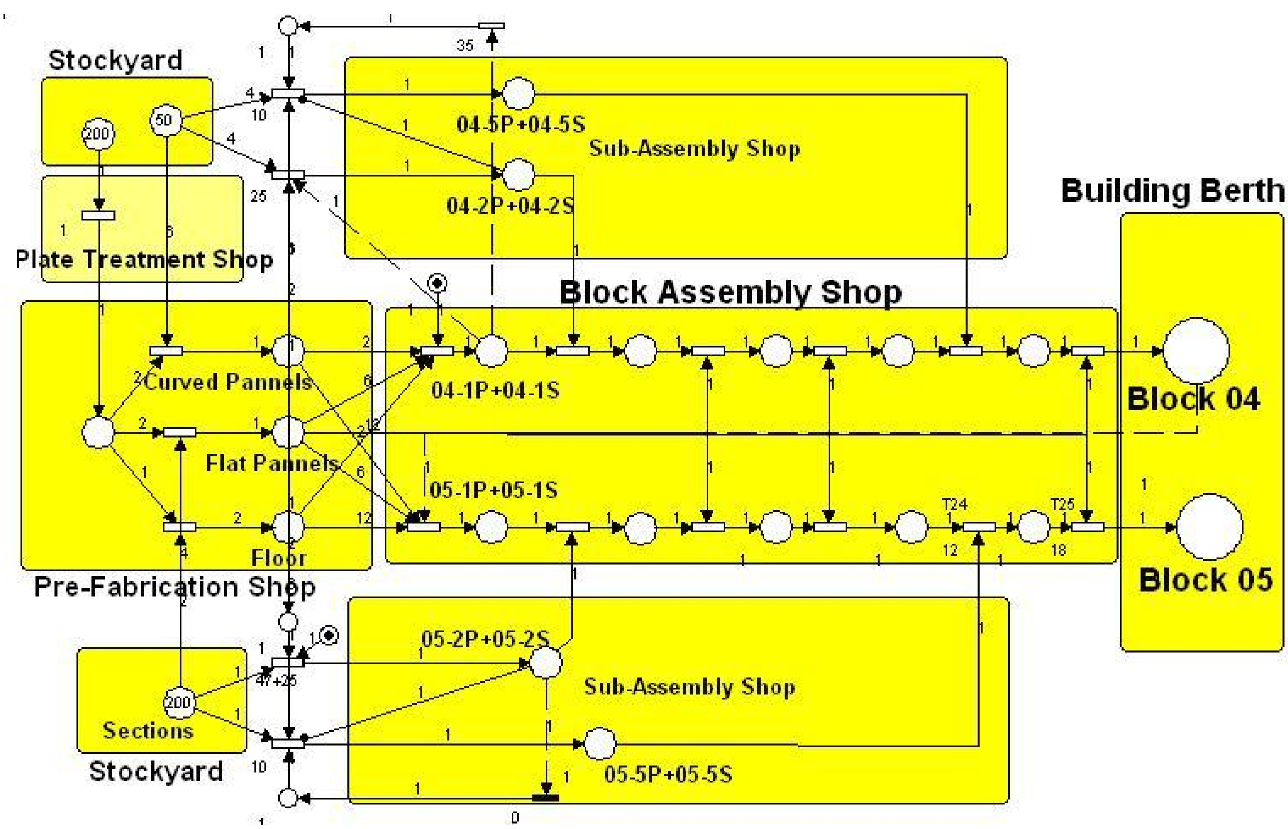

Figure 13: Simulation model for assembly of two consecutive Blocks 04 and 05

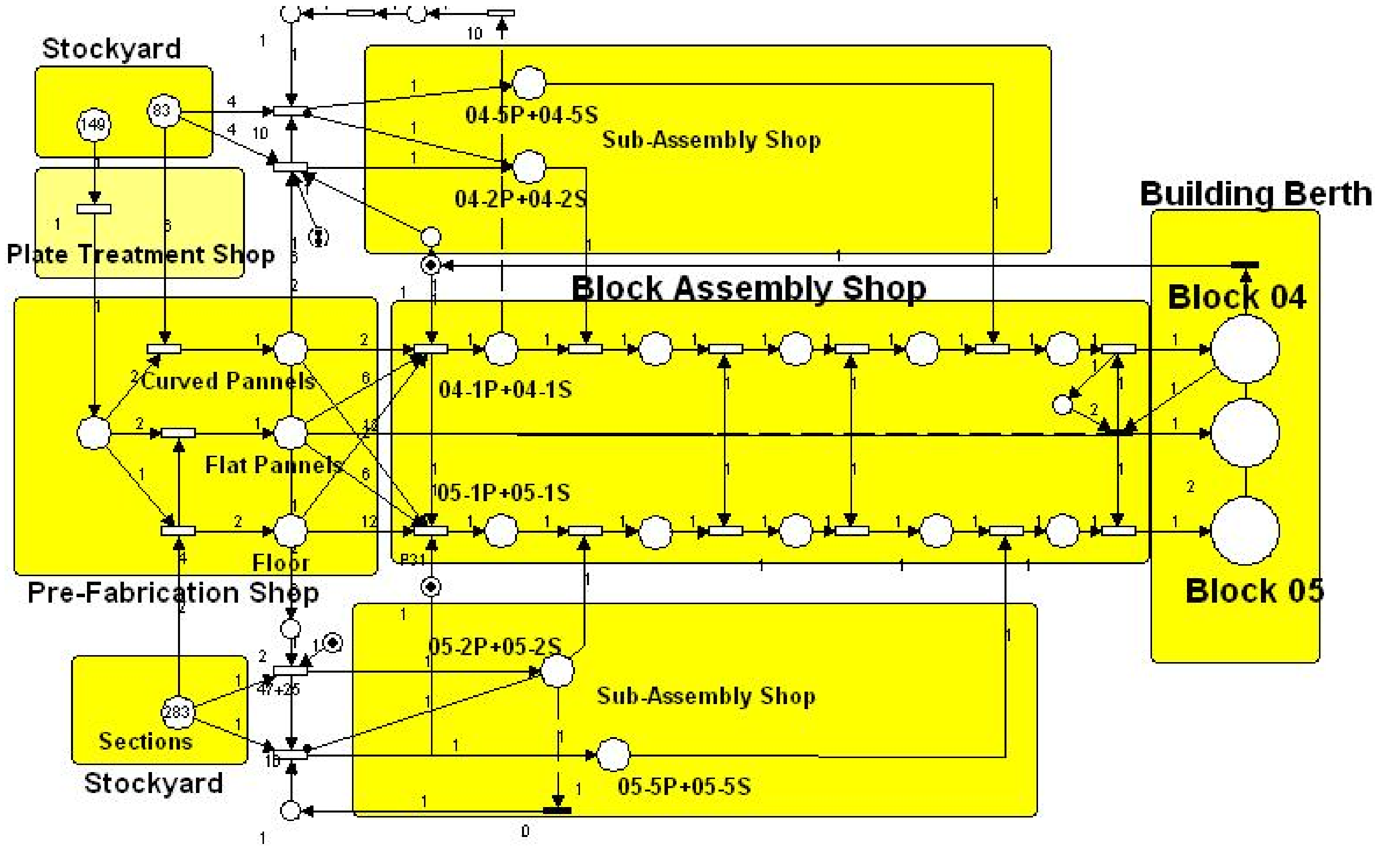

Figure 14: Simulation model for assembly of three consecutive Blocks 04, 05 and 06

RESULTS AND DISCUSSION

Using this simulation model, the total time taken for the fabrication of the 212 tonnes Block-04 was 171 man-hours. The focus of this exercise was to detect bottlenecks that occurred at the sub-assembly and assembly stages. In the above simulation exercise bottlenecks were detected in the assembly of the Sub-block-04-01(P/S), Sub-block-04-02(P/S) and Sub-block-04-05(P/S). In the Sub-block-04-01(P/S), the largest delay took place as floor fabrication took a large time, whereas for Sub-block-04-02(P/S) and Sub-block-04-05(P/S) the side shell fabrication where bending of plates and stiffeners and their were involved caused the delay. Therefore, to improve production rate it is necessary to remove the bottleneck at the Sub-block-04-01(P/S) level.

The total fabrication time for two blocks (Block-04 and Block-05) simulation was 380 man-hours with Block-04 getting completed after 217 man-hours and Block-05 at the end of 380 man-hours. In this simulation exercise also the main bottleneck was detected in the assembly of the Sub-block-04-01(P/S) due to the larger time required for fabrication of floors. After elapse of 102 man-hours bottlenecks were detected at Sub-block-04-02(P/S) due to unavailability of resources. The fabrication time for Block-05 was less than Block-04 as assembly of Sub-block-05-02(P/S) started as soon as Sub-block-04-02(P/S) got over.

The total fabrication time for three blocks (Block-04, Block-05 and Block-06) simulation was 525 man-hours with Block-04 getting completed after 217 man-hours, Block-05 at the end of 380 man-hours and Block-06 at the end of 525 man-hours. In this simulation exercise, fabrication of Block-06 took less time than that for Block-05 as because when the assembly of Block-06 started the Sub-block-06-02(P/S) was over.

Due to unavailability of data, in all the above simulation exercises only the fabrication and assembly times for the steel piece parts and sub-blocks were considered. If zone outfitting method and zone painting method are to be incorporated, Petri-net for outfitting and painting are to be modeled and incorporated at the appropriate level in the above models.

CONCLUSION

In this work, an attempt has been made to show how ‘Product flow’ can be simulated by the Petri-net. In shipbuilding, activities are dependent on each other to large extent so each and every job shop has to work efficiently to carry out whole production smoothly and efficiently.

The main advantage of this simulation model is that it allows the modeling of blocks of different configurations, but having the same fabrication sequence which is the case in modern ship production. Simulation of two blocks and three blocks give the idea about phase difference between consecutive block fabrications and determines at what rate blocks can be accepted in the erection yard. With duplication of assembly line the rate of fabrication increases but this may become constant after setting up 2, 3 or more assembly lines for particular set of resources. Assembly of 2 and 3 blocks shows the bottlenecks in long run of fabrication process, arrival or departure material at various sub-assembly and assembly areas, critical paths and dependencies of job shops among each other.

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