CHAPTER 14

Design/Production Integration

Thomas Lamb

14.1 INTRODUCTION

It is hard to conceive that anyone would deliberately design something that could not be built. Yet the author has seen many cases of ship design that either could not be manufactured as designed, or else was very costly to build. That this situation is even broader than shipbuilding can be seen from the proliferation of Design for X, where X can be Manufacturing, Production, Assembly, Maintenance, etc. In the United States this resulted, in part, through the introduction of *Scientific Management* by engineers such as Taylor (1) and Fayol (2), who persuaded managers to organize their companies into specialized units and to even specialized skills within the units. While this was successful in many industries with many repetitive tasks at that time, and it has been credited with the rise of mass production and the great increase in U.S. productivity in the early 20th century, it also resulted in the current lack of design/production integration.

Design with a production friendly focus is not unique to shipbuilding. Design for Assembly (DFA) has been applied to other industries, particularly the automotive industry for many years. It has been credited with significant benefit and improvement in performance. A well known book on DFA is by Dewhurst et al (3). They identified eight guidelines including the order of importance as follows:

1. reduce part count and part types,
2. strive to eliminate fitup/adjustments,
3. design parts to be self-aligning and self-locating,
4. ensure adequate access and unrestricted vision,
5. ensure the ease of handling parts from bulk,
6. minimize the need for reorientations during assembly,
7. design parts that cannot be installed incorrectly, and
8. maximize part symmetry if possible or make parts obviously asymmetrical. The similarity with the DFP guidelines can be seen from the list in subsection 14.3.1.

The author contrasted the two extremes of design/production integration as *Isolated Engineering* and *Integrated Engineering* a long time ago (4). Today they would be called *Stove Pipe Operation* and *Concurrent Engineering (CE)* (see Chapter 5 – The Ship Design Process).

The improvement claims for CE and Integrated Product and Process Development (IPPD), such as 30% improvement in productivity and 50% improvement in build cycle; show just how bad an impact this lack of integration has had on companies and industries over the past 50 years.

British Shipbuilders found that they had a problem in having their designers adequately consider the production needs for their designs and prepared a formal *Design for Production (DFP) Manual* (5) in the 1970s. The U.S. had this problem as well and had A&P Appledore prepare a *Production Guidance Manual* for bulk carriers (6), in 1980, and the first conference on DFP was held at the University of Southampton in 1984 (7). Unfortunately it was too late to save *British Shipbuilders*. However, some of the developers of the original manuals became consultants and eventually prepared *Design for Production Manuals* for the U.S. (8,9). In 1987 the author prepared a book for the NSRP titled *Engineering for Ship Production* (10), which described the need for design/production integration and the application of DFP.

That this subject was of prime concern to the U.S. shipbuilding industry can be seen from the forming of one of the National Shipbuilding Research Program panels as the SP-4 Design/Production Integration Panel. This panel ceased its operation in 1998 when the NSRP was reorganized to fit in the new NSRP—Advanced Shipbuilding Enterprise (ASE). However, the subject has remained in the forefront of the concerns of two new panels, namely the *Product Design and Materials Technologies* and the *Shipyard Production Process Technologies* panels.

Design/production integration includes the following concepts:

- focus on Design for Production (DFP)
- preparation of all design/engineering information in the most suitable way for Production,
- feedback of needs/preferences from Production to Engineering,
- direct communication and collaboration between Engineering and Production,
- providing each other with the knowledge and information they require to do the best possible job for each other,
- establishing the best information transfer between them thus eliminating unnecessary reworking of the information by Production to suit their needs, and
- standardization and documentation of processes, information flow, and all relevant attributes of the interim products.

These can be seen in the following current shipbuilding practices:

- use of 3-D product model as design/ production integrator,
- Product-oriented Work Breakdown Structures (PWBS),
- intermediate product catalogs/databases,
- development of Shipbuilding Policies,
- use of Build Strategies,
- preparation of engineering as workstation information packages,
- use of Concurrent Engineering and associated teams to ensure design/production integration, and
- the use of design and build plans by the most recent design/planning teams for proposed new U.S. Navy programs.

Concurrent Engineering is briefly discussed in Chapter 5 – Ship Design Process. It is covered in greater detail in references 11 to 13. This chapter will only address it in the way it enables design/production integration. This chapter will focus on DFP and how engineering should be prepared to best suit and support production and a number of approaches that can assist/enable this to happen.

The integration of design and production depends on a great amount of information. Today, this is enabled through the use of 3-D product models and different information technology systems. Some Computer Aided Design (CAD) systems, used by shipbuilders, provide most of the required capability, but have not yet reached the totally integrated system or Computer Integrated Manufacturing (CIM).

14.2 ENGINEERING APPROACH

The format of engineering information, including the content of drawings, has developed over many years. Changes and improvements have occurred very slowly, and in some shipyards and design offices, not at all. Traditionally, shipyards were craft-organized and only required the minimum number of drawings for which accuracy was not essential. The loft prepared the templates and made everyday decisions on structural details. The pipefitters worked from diagrammatics and developed their own pipe templates from the ship being built. This system was also true for the other shipyard crafts.

The changeover from a traditional craft-organized shipyard to one of advanced technology has obviously had a tremendous effect on all shipyard departments. It should have had its second greatest impact on the engineering department. However, many engineering departments did not rise to this challenge and, therefore, lost what might have been a lead position for directing and controlling change. Engineering simply ignored the needed changes and left them to be incorporated into the shipbuilding process after their work was completed in the traditional manner. Shipyards responded to this problem by getting the necessary production information from other sources, usually new groups that may have been called *industrial* or *production engineering* or perhaps from an existing planning group. Some shipyards even accepted the fact that engineering information was inadequate for production and left it to production workers to perform as best they could. This situation often resulted in the same work being done many times before it was reluctantly accepted by the inspectors.

Production performance depends largely on the quality, quantity, and suitability of technical information supplied by engineering. By organizing for integrated engineering and preparing design and engineering for zone construction, engineering can take its proper place and play an essential role in the improvement of shipbuilding performance. This section discusses how this can be done, but first considers what is production-compatible engineering (integrated engineering) by comparing it with traditional engineering.

14.2.1 Traditional Engineering

Usually all the visual information used by a shipyard production department today is not prepared solely by the engineering department. Most shipyards still have various preparation phases divided in a way developed and used 30 to 40 years ago. At that time, the following division of labor made sense because of the methods used:

- Engineering
  - design and working drawings
- Loft
  - full-size fairing of lines
  - layout of structural parts
  - template construction
- Pipefitters
  - pipe templates and sketches
- Sheet metal workers
  - layouts, developments, and templates
- Shipwrights
  - full-scale layout on ship

However, most shipyards have been improving their production processes for years, and their information needs have changed during that time. Some shipyards utilize structural block construction, pre-outfitting, advanced outfitting and, more recently, zone construction. To perform these tasks from traditional engineering is not impossible, but it requires additional planning and even more design and engineering to be prepared after traditional engineering is complete. This system obviously involves wasted effort, additional man-hours and does not assist the move to short build time.

The preparation of traditional engineering structural drawings has really not advanced much from the days of the iron ship. That is, they still prepare structural drawings as item drawings, such as tank top, shell plating or expansion, decks, bulkheads, and frames.

Traditional engineering piping drawings are for individual systems for the complete ship. They may or may not show pipe breaks, hangers, and some production-added information. The same is true for HVAC and electrical, except that electrical drawings are sometimes little more than pictorial concepts with no locating dimensions for equipment.

Usually interference control in traditional engineering is provided by space composites, although engineering models are also used extensively for this purpose. A major problem with this approach is that in some shipyards the electrical crafts go ahead and complete their *hot work* before many of the other detailed systems and composites are completed. The work is performed in the easiest location without checking it or even feeding it back to engineering to locate it in the composites. Apparent production work progress is achieved early in the project, and everyone is happy until the interference problems start and extensive rework is required. This problem is avoided in those shipyards that utilize 3-D product models in which the electrical system is included

Traditional engineering usually includes the bills of material on the drawings or as a sheet of a multi-sheet drawing. It also makes use of large drawings, often up to 4 m in length. Figure 14.1 graphically portrays the problem this system creates on the ship compared to the smaller sheets of

Figure 14.1 Large Drawing Handling Problem

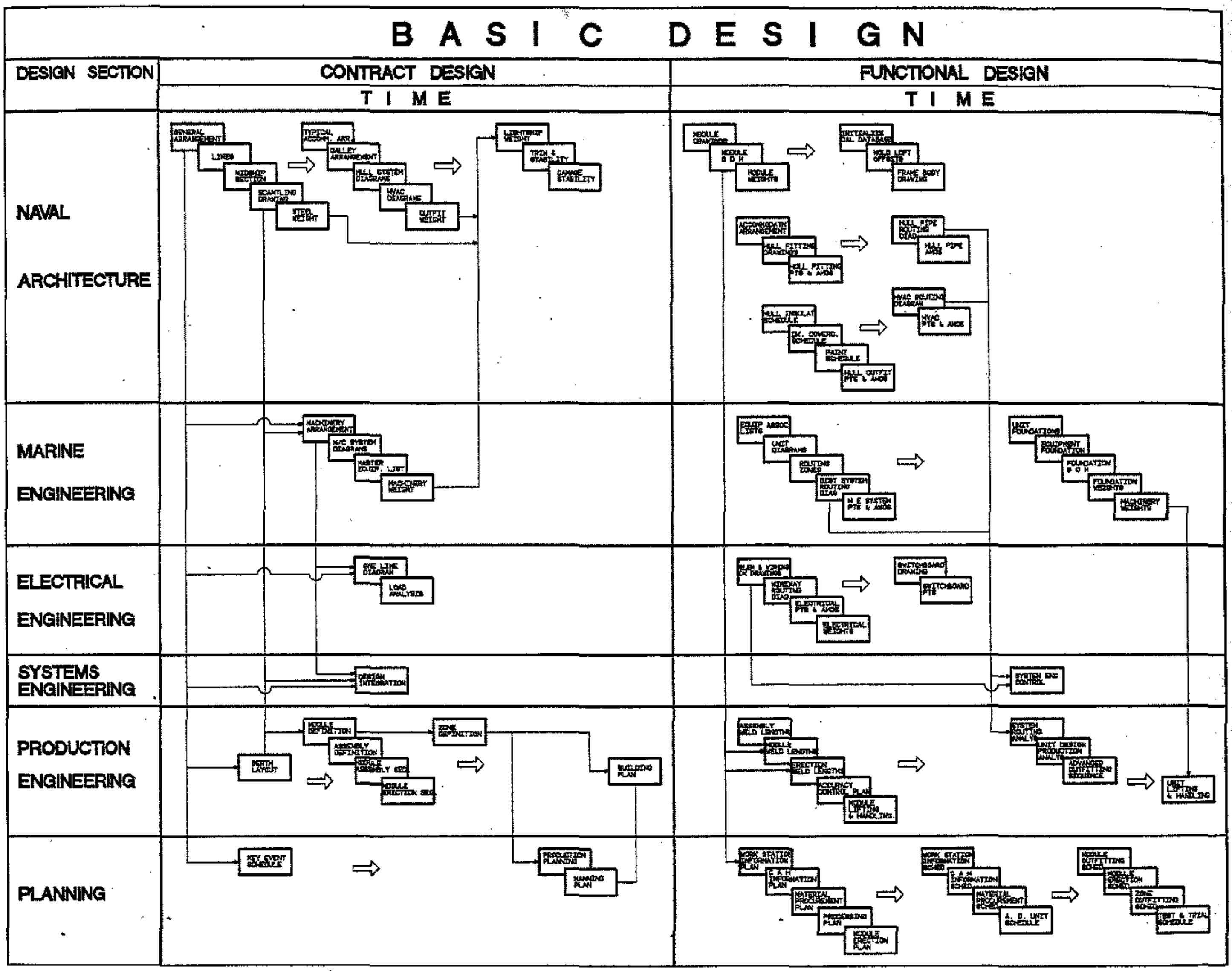

Figure 14.2 Basic Design Process Flow

the proposed Engineering for Ship Production booklet. Since each drawing is for the total ship, but is required each time part of it is used in each module or zone, the drawing must be printed and issued many times, resulting in wasted paper and duplicated effort. Also when reissued because of a revision, planning and production must spend time to determine how many modules or zones are impacted by the revision.

Traditional engineering drawings contain little production-required information such as module weights, module breaks, system breaks, lifting pad locations, bolting torque, pipe hanger locations, system testing, tolerances, and quality requirements.

Some shipyards attempt to provide some of this information on traditional engineering drawings by having prints of the drawings marked up with production data by the planning/production control groups for incorporation into the original drawings before formal issue. Others provide the required production information on unique additional documents to the traditional engineering drawings.

The traditional engineering practice of referencing drawings, ship specification, standard specifications, and other data on the drawing, instead of including the information, is a serious problem to production. To expect production workers or even their supervisors to have access and knowledge of the references is impractical. Because of this situation, items are often ignored and the work is not *done to spec*.

Traditional engineering is not suitable for high productivity, short-build cycle shipbuilding, and therefore has no

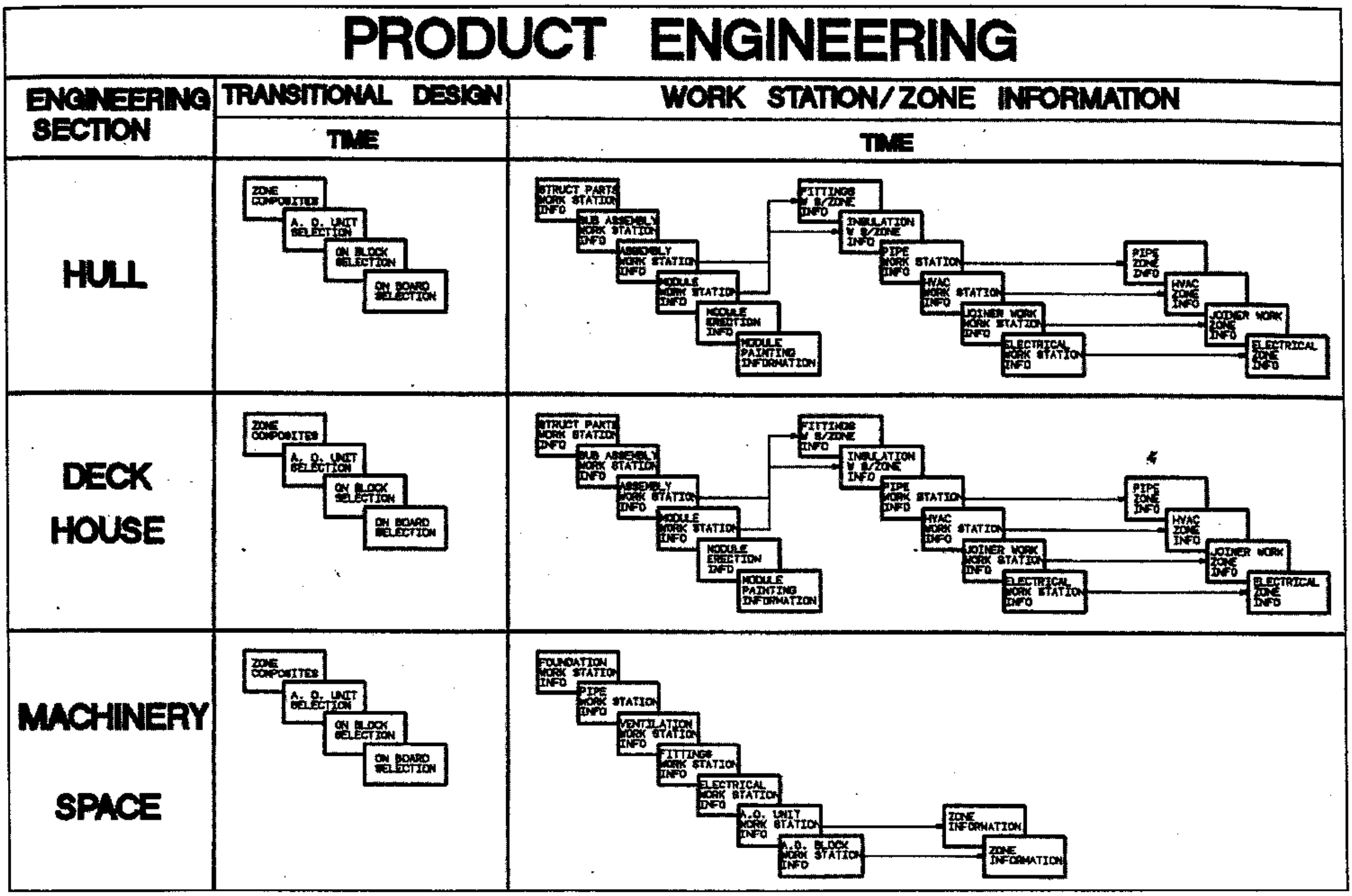

Figure 14.3 Product Engineering Process Flow

place in today's struggle to maintain some semblance of' competitive shipbuilding.

14.2.2 Production-compatible Engineering

The first break from the traditional systems drawings occurred when some shipyards introduced structural block drawings. The next stage was the use of subassembly, assembly, and module-sequenced drawings, but these were initially prepared in addition to the structural module drawings.

Next, the outfit drawings were prepared for zones. Finally, pipe sketches or drawings for pipe assemblies were prepared by engineering, first manually and later by computer-aided design.

Currently computer-aided design/computer-aided manufacturing is being used to provide production information for both pipe and sheet metal products. Today the goal for optimum data transmittal is to have an engineering information package for each workstation (including zones Onboard the ship). This is not only for structure, but also for all other material and equipment. A work station drawing shows all the work that occurs at one location, either shop or ship zone. It can be one sheet showing the completed product at the end of all work at a given work station with written sequence instructions, or it can be a booklet of drawings (see Figure 14.1) showing the sequenced buildup for the product from its received status to its completed status for the work station.

This process of design and engineering is integrated with construction planning and is in constant participation and communication with the production department. This integration can be seen in Figure 14.2, which shows the process flow during contract and functional design. Figure 14.3 shows the process flow during transitional design and work station/ zone information preparation. Note that all planning is completed during contract and functional design and in the proposed approach this includes advanced outfitting planning.

The use of the Build Strategy Approach, with its Shipbuilding Policy and Build Strategies, is a very effective if not essential tool to the proposed engineering approach (14,15). It is further beneficial if all manufactured and purchased material to construct the ship is categorized within a standard classification system (product definition). If the production methods to be used (product processes) are defined, workstations can be decided.

All this information will be contained in the Shipbuilding Policy to be used by engineers and planners when preparing the contract design and the building plan. The product definition can be based on a group technology classification and coding system, or it can be a simple listing of major product. The product processes will be based on a process analysis for each product and the available workstations. It is easy to see that this is a worthwhile tradeoff.

Suggestions on how engineering can best be provided to the production department will be presented for each of the individual groups within the engineering department, even though it is obvious that standardization of data preparation is the ultimate goal.

14.2.3 Benefit

With the traditional engineering approach, construction cannot be started until a number of item drawings are complete (Figure 14.4). In an actual case, one block required 13 drawings to be completed before the block could be lofted. With the zone approach, construction can commence when the first block drawing is complete (Figure 14.5). Also, it is necessary for someone (production planning) to prepare block parts lists and sequence assembly sketches.

With the zone approach, production can use engineering prepared drawings directly, thus saving additional effort and time. On-unit advanced outfitting has been demonstrated to be a significant productivity improver.

By integrating all system diagrammatics in a given space, the grouping for piping of various systems can be considered. Also, knowing that the diagrammatics are more accurate allows material to be ordered with greater confidence, which reduces the need for margins. More complete diagrammatics are acceptable for complete owner and classification approval; that is, it is not necessary to send detailed production drawings for approval.

14.2.4 Transitional Design

The transitional design can be likened to building a prototype, except that it is constructed on paper. If CAD is used, the prototype is effectively modeled in the computer. The most important task in transitional design is the selection of the zone/subzone breakdown for the design effort. For example, a subzone could be a compartment surrounded on all sides by major structural divisions, such as deck/flat/tank top, transverse bulkheads, side shell, and longitudinal bulkheads.

Zone design arrangements are similar to the traditional composites. However, they are prepared from distribution system routing diagrammatics developed during functional design. The traditional composites are prepared from completed system arrangement and detail drawings. Traditional composites are drawn as an interference-checking tool and, for this purpose, are slices through the compartment, showing only the items in the immediate layer below. Zone design arrangements show all the visible items seen from the viewing plane. All products should be included no matter their size. The traditional engineering practice of excluding pipe below 40 mm diameter is no longer acceptable. When the zone design arrangements are prepared manually, the backgrounds can be provided by the Computer-aided Lofting (CAL) system. Manually prepared zone design arrangements could be drawn with single line pipe representation. However, it is preferred to show double line, including insulation where appropriate. Once the zone design arrangement is completed, the products are identified as follows: zone or unit, pipe assembly, vent assembly, wireway, foundation, and floor plate group.

The required zone/unit material quantity is also developed at this time. By accumulating the material quantities as zone design arrangements are prepared and deducting the material from advance material orders, effective material ordering control is possible. A list of all the products in a zone/subzone provides an accurate compartment check off list.

Obviously, during the preparation of zone design arrangements, all systems are developed for interference avoidance and checked for interference as the work progresses.

It should be obvious that the use of CAD for this design phase has many advantages. Three-dimensional solid modeling CAD systems enable a true prototype to be modeled and all working, maintenance, and access requirements to be checked prior to any construction.

14.2.5 Workstation/Zone Information

Many successful shipyards claim that their success is based on better work organization. This is accomplished through better planning and better instructions/information and work packages. The work package concept is the division of a total task into many work packages for small tasks. A typical guide is that a work package should be as follows.

- 2-week duration maximum;
- 200 hours of work maximum;

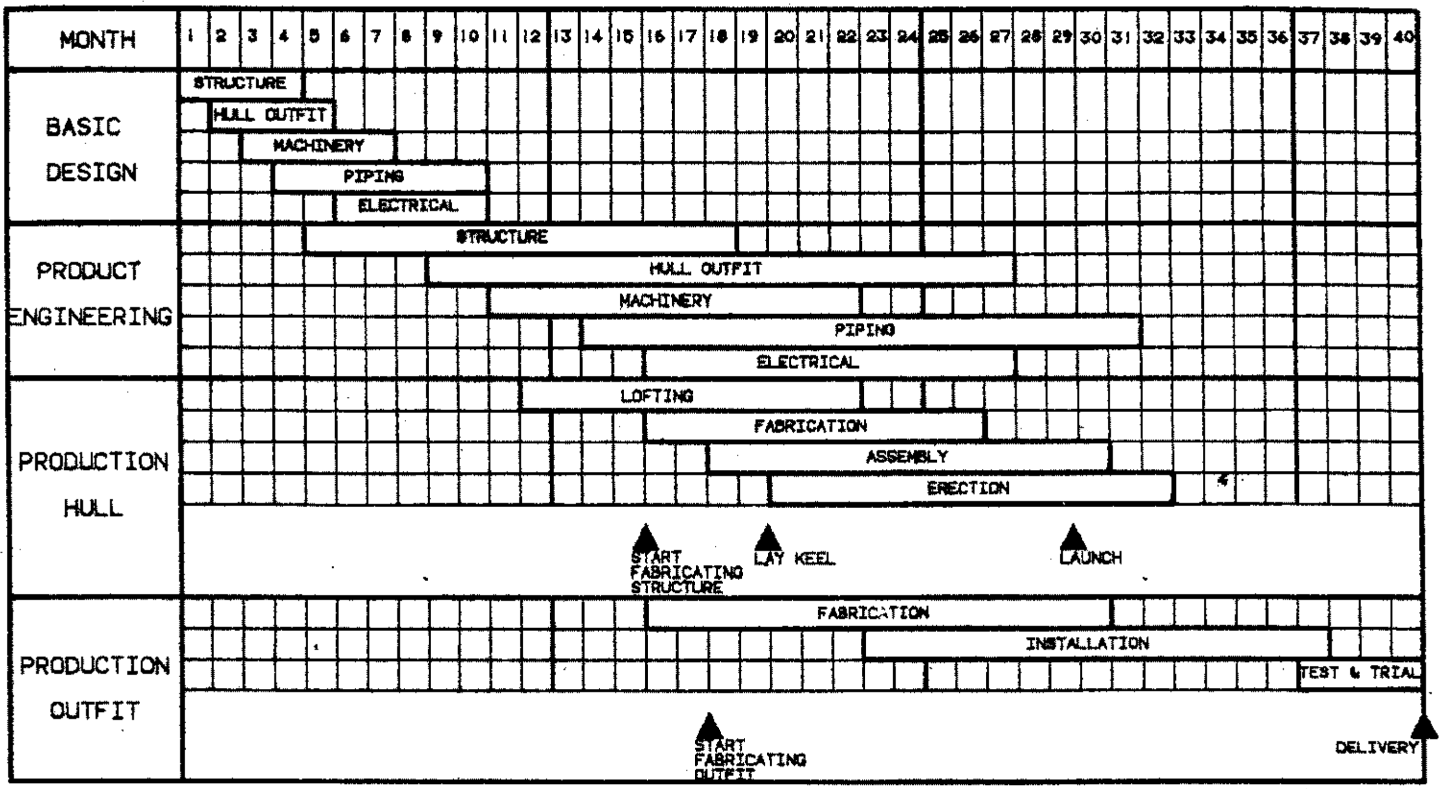

Figure 14.4 Traditional Detailed Design and Construction Appoach Time Cycle

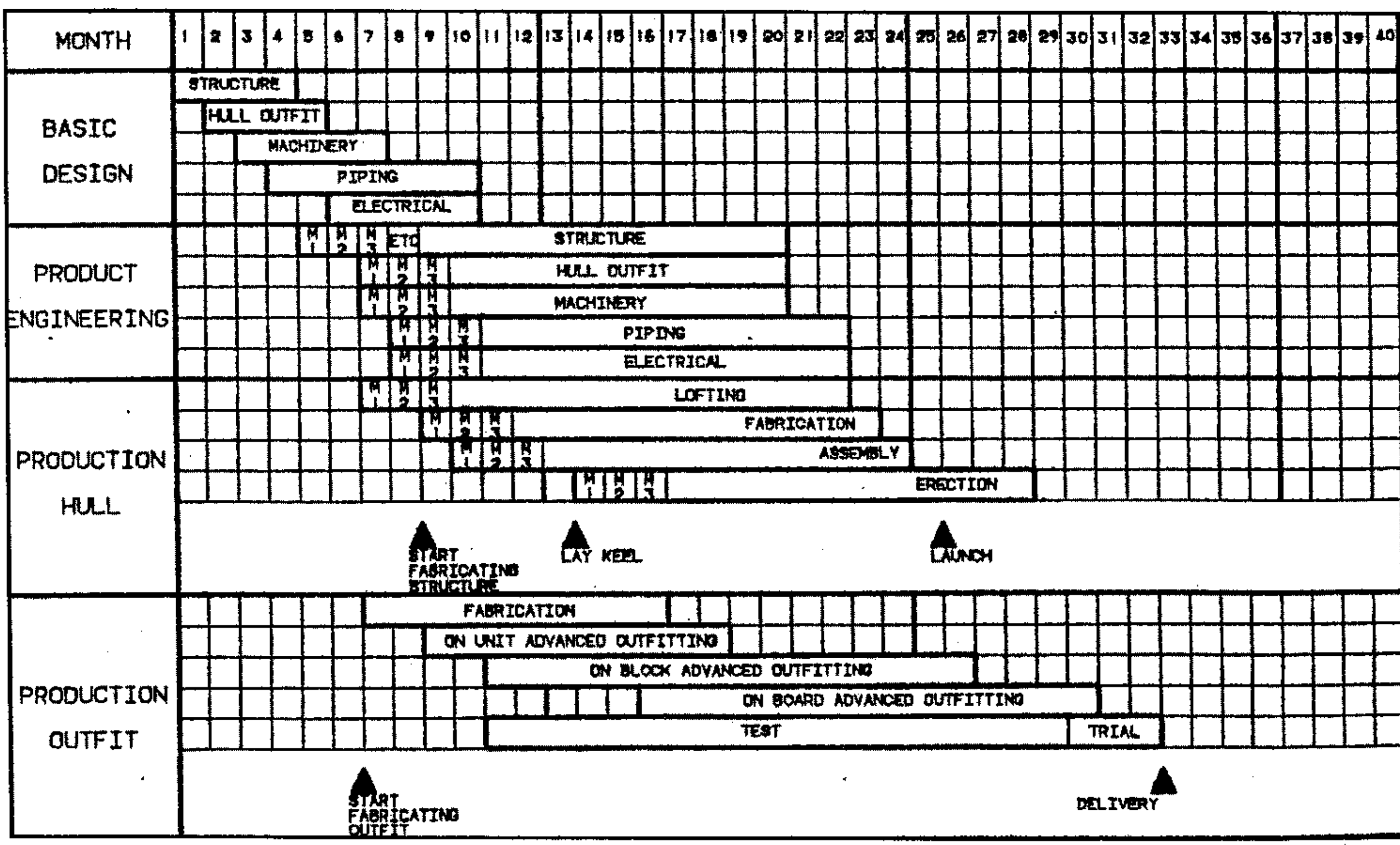

Figure 14.5 Block and Zone Approach Time Cycle

- work for a maximum of three workers;
- include only (but all) the information required by workers to complete the work package tasks, including drawings, parts lists, and work instructions; and
- include production aids such as N/C documentation, templates, and marking tapes.

The first three items are difficult to adhere to for certain shipbuilding tasks on the berth but are achievable for most shop work.

Engineering can effectively participate in preparing some of this information and, in doing so, eliminate a lot of current duplication of effort. Planning will select the tasks to meet the first three requirements. Engineering can prepare the information covered in the last two.

For this approach, it is proposed that separate workstation information be prepared for each work package. Workstation information should be prepared on the following basis:

- information should show only that necessary for a given workstation.
- information should consist of sketches and parts list.
- complete information for the tasks must be given.
- no referencing allowable.
- separate work packages should be prepared for each craft (trade). Sketches and parts lists should not mix work that must be done by different crafts.
- sketches should be prepared to show work exactly as workers will see it. For equipment, piping, or other products that will be installed on an assembly when it is upside down, the sketch should be drawn that way rather than for the final attitude plan view.
- a reference system should be used, and all dimensions should be from the reference system planes.
- information should be prepared so it can be issued on A4 sheets.

14.2.5.1 Structural workstation information

Today most shipyards use integrated CAD/CAM to prepare the lofting and to develop the necessary production aids for construction of the ship structure. This system eliminates the need for manual measuring and layout of plates. Therefore, the drawings used for subassembly, assembly, and module construction need not contain any dimensions other than check (accuracy control/dimensional tolererance) and quality assurance control dimensions. What is needed is a way to provide required information that is completely compatible with the way in which it will be used in various stages of construction of the structural hull and deckhouse.

This can be effectively and efficiently accomplished by using the following data packages:

For burning plate: Nest tape sketches and CNC information (Figure 14.6),

For cutting shapes: Process sheets, CNC information, and sketches (Figure 14.7),

For processing plate or shapes: Process sheets and templates,

For subassembly: Subassembly drawing and parts list,

For assembly: Assembly drawing and parts list,

For block construction: Block assembly sketches and parts list,

For on-block outfitting: Block outfitting sketches and parts list, and

For block erection: Hull block erection drawing and moving and lifting instructions.

Figures 14.8, and 14.9 show the workstation information packages for typical subassembly, and block, respectively. Note that for the assembly and module, the parts lists are separate from the drawings. The parts list should be sequenced in the way the product is to be constructed. Again, the product/phase chart can be used to develop the sequencing.

It is important to remember that all the information required by the workers to perform a work package should be included in the package. The worker should not have to obtain or look at any other drawing, work package, standard, etc., to complete the task.

14.2.5.2 Outfit workstation/zone information

The workstation/zone information will be provided for shops, assemblies, modules, and zones. The product/stage chart is helpful in deciding the work packages. Workstation information for shops for both processing and assembly will be required for hull fittings, pipe, sheet metal, foundation structure, joiner, paint, and electrical work. It is suggested that *zone* be used instead of the term *workstation* for all the logical breakdown of the total machinery space design and engineering, and the provision of workstation/zone information packages in place of traditional working drawings. The machinery arrangement becomes a series of major pieces of machinery, units, and connecting system corridor/floor plate units. However, the quantity of information provided to production is vastly increased in scope compared to traditional engineering, plus all systems are given equal depth of consideration and are shown to the same detail. Figure 14.10 shows a typical work station/zone instruction sketch for outfit.

Workstation information for shops for both processing and

HULL NO. 75

NEST TAPE NT M3103

RUN NUMBER 1 REV. 0

STEEL BILL P13 PLT. SIZE 72 × 96

SCALE ½ = 1' BURN TIME HRS.___ MIN.___

NUMBER OF PLTS. NEEDED PER SHIP 4

LIKEWISE ONLY ☒ MIRROR IMAGE ONLY ☐

LIKEWISE AND MIRROR IMAGE NEEDED ☐

2 AXIS TAPE ☒ 3 AXIS TAPE ☐

WORKED BY ____________ DATE ____________

CHECKED BY ____________ DATE ____________

VALIDATED BY ____________ DATE ____________

APPROVED BY ____________ DATE ____________

PARTS NESTED

PART NO.	QTY	ASSY	PART NO.	ASSY
1	1	M35		
2	1	↓		
3	8	↓		
4	10	↓		
5	2	↓		
6	1	↓		
7	1	↓		
8	2	↓		
9	2	↓		
10	1	↓		
11	1	↓		
12	1	↓		

REVISIONS

DESCRIPTION	WORK BY	DATE	CHKD BY	DATE	VALD BY	DATE	APRV BY	DATE

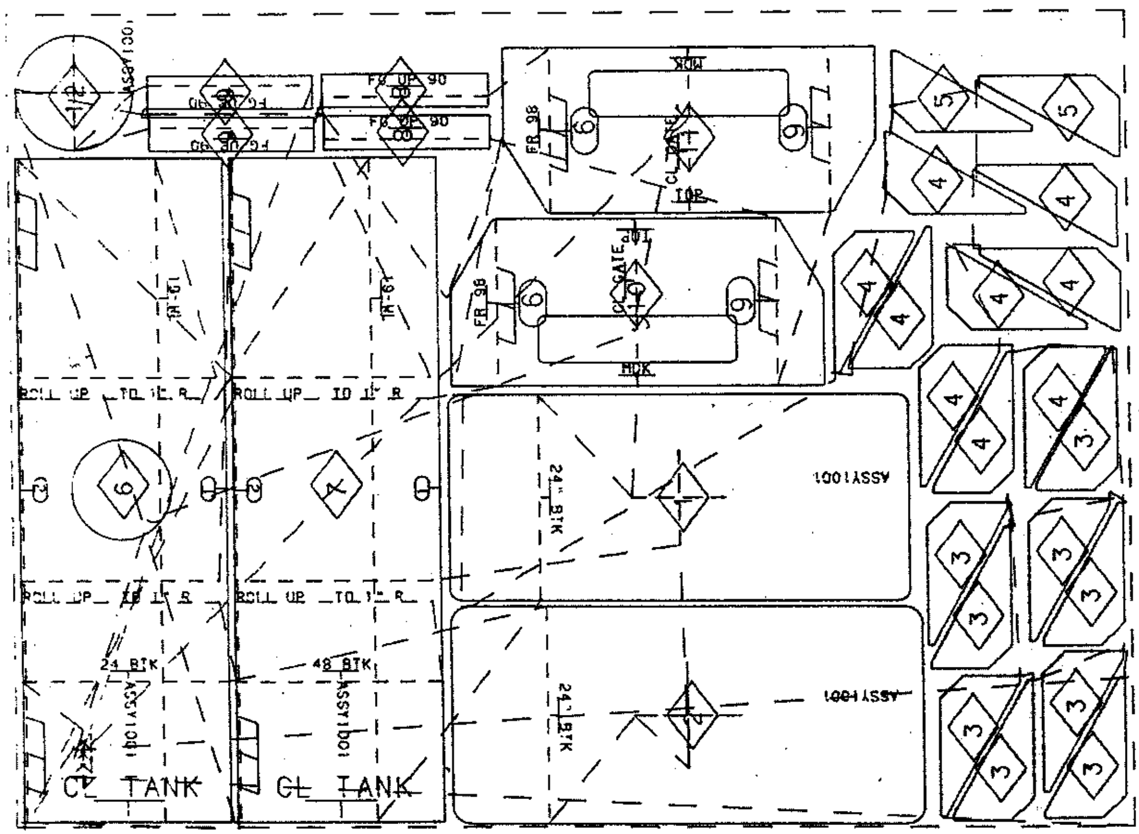

Figure 14.6 Structural Plate Process Sheet

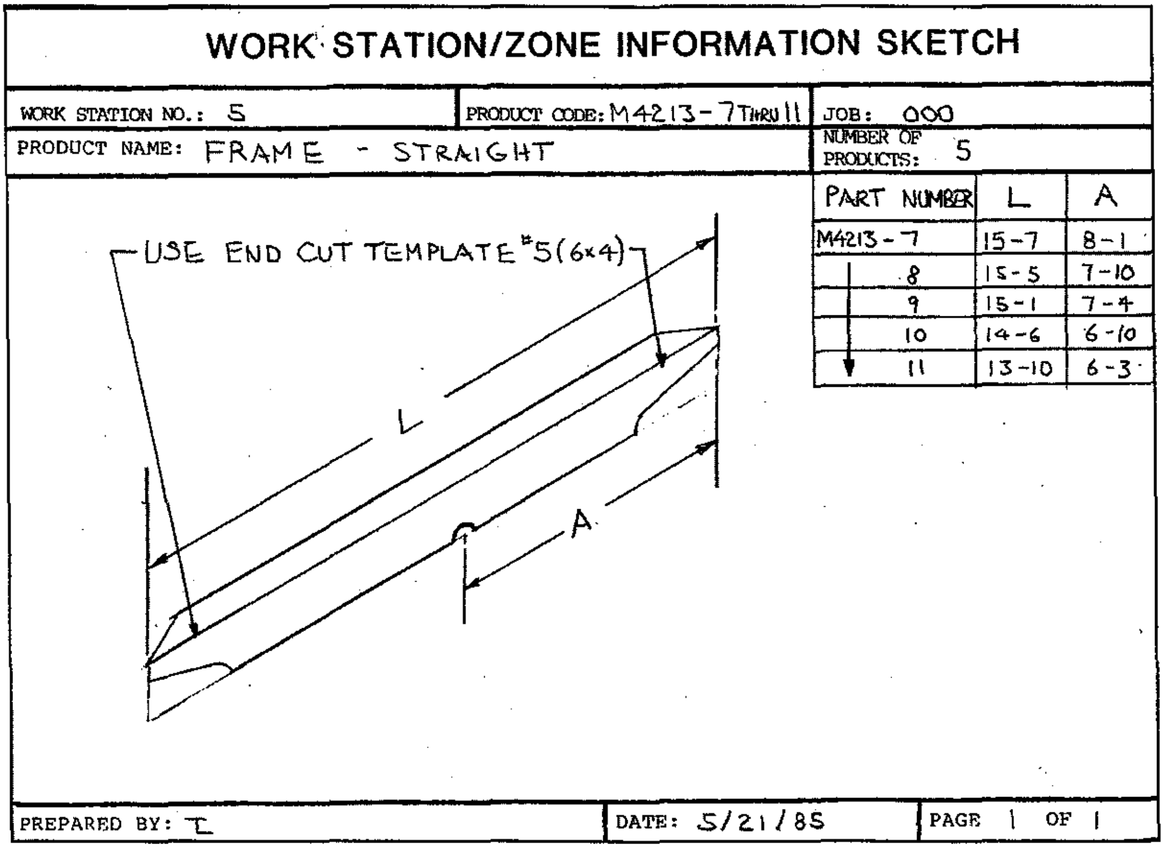

Figure 14.7 Structural Section Process Sheet

assembly will be required for foundation structure, pipe, sheet metal, paint, and electrical work. Workstation information will also be required for machinery installation, etc, for units.

Electrical fixtures in accommodation spaces should be located on the joiner work zone information sketches. All distribution panels, controllers, junction boxes, and other electrical equipment must be shown and located on installation sketches. The support connections to the structure should be included in the structural assembly and/or module workstation sketches.

14.2.5.3 Material requirements

Figure 14.11 summarizes the material definition approach for Engineering for Ship Production. It shows how the major equipment is defined by purchase technical specification during contract design. The majority of raw material is defined by advance material order per system during functional design.

During transitional design, all material remaining to be defined is identified. Also, through the product/stage chart approach (Figure 14.12), the preparation of the zone/unit lists is started. The sorting function, shown in Figure 14.11 under workstation/zone information, corresponds to the product/stage chart approach to work station parts list preparation.

A major requirement to ensure success of any material definition system is a detailed preparation and issue schedule compatible with the material ordering and material receipt requirements to construct the ship to plan. This integration of schedules must be a dynamic system, changing as circumstances change. It is not a once-prepared schedule that is followed even when it makes no sense.

14.3 DESIGN FOR PRODUCTION

It is possible to obtain significant increases in productivity in existing shipyards without large investments in plant by redefining the ship design approach and planning the ship construction at the same time the contract design is being prepared, thus being able to influence the design to suit the intended building approach.

This demands that ship designers become more production conscious as they design future ships. Design for Production applied to shipbuilding is really Design for Minimum Cost of Ship Production through ease of production.