- units should be arranged so that all piping runs are as short as possible and only in the transverse and longitudinal directions. Diagonal runs should be avoided unless absolutely necessary to suit unit design,
- in conjunction with the arranging of units, distribution system corridors should be established. Where possible major routing corridors should be integrated with floor plates, gratings, walkways and their supports,
- personnel access systems (floor plates, gratings, etc.) should only be that required to provide access to equipment for necessary service functions such as normal and emergency operation and maintenance,
- maintenance lifting or pulling arrangements should be fully considered when designing the arrangement and incorporated into the unit where practical,
- handrails should be arranged for safe access and protection, both during construction and after installation of the unit in the ship,
- combine as many systems as possible into a unit with good design and producibility in mind. For example, if large vent ducts are in the vicinity, attempt to combine them with walkways (Figure 14.77), and
- valves should be located so as to come up at the side of the floor plates and grating, and not below or through the middle of the floor plates.

***Space Allocation*** The selection of the locations for all equipment, appurtenances and systems should be performed in a logical and formal way. This is true for all parts of a ship but is essential for machinery spaces. An aid to this process is the analysis of existing ships to determine space requirements for the various machinery, equipment, distribution corridors, etc.

**TABLE 14.II** Equipment Association List

**SYSTEM**

Propulsion Diesel Engine L. 0. Service

**MAJOR EQUIPMENT**

Propulsion Diesel Engine

**ASSOCIATED EQUIPMENT**

L. 0. Standby/Prelube Pump
L.0. Filter
L.0. Cooler
L.0. Duplex Strainer
Rocker L. 0. System Tank
Rocker L. 0. Standby Pump

Major independent machinery and standard auxiliary machinery units can be represented by the circumscribing block. To this can be added the surrounding space necessary for access, operation and maintenance. Such space should be designated as to whether it is inviolate. Then these can be used to develop a functional machinery space layout. Such a layout is conceptually shown in Figure 14.78 taken from reference 47. It is important to logically design the distribution corridors and not just provide space for them. When the corridors for different systems such as vent, pipe and wireways must cross each other, the concept of how this will be done must be developed.

***Equipment Grouping*** Even before the concept of advanced outfitting it was good design practice to prepare an equipment association list for any major piece of equipment to be arranged and installed in a ship. This association list was used for a number of purposes, such as checking vendors supplied unattached equipment. However, for the purpose in mind, it was and should be used to develop location in the system of all the items and the connections between them. Equipment, which requires a foundation, can also be noted. The addition of valves, gages, switches, etc., is accomplished when preparing the diagrammatic. The equipment association list was then used to develop a connection network, which became the basis for the system diagrammatic. For advanced outfitting *On-Unit* construction, it is necessary to use the equipment association list and the connection network to select the best grouping of the equipment on the unit. A typical equipment association list is shown in Table 14.II. Figure 14.79 is the resulting network. Figure 14.80 shows a typical design diagrammatic prepared without any consideration of equipment association grouping. It is easy to see the illogical location of the equipment. Figure 14.81 shows the same diagrammatic developed from an equipment association network.

***Floor Plates*** One area where many shipyards spend an inordinate amount of effort is in the installation of machinery space floor plates. This is usually because they are designed independently of other systems and always seem to have much interference. To avoid this they end up being custom-fitted onboard the ship. The application of advanced outfitting *On-unit* approach will eliminate much of this problem as can proper design sequence when advanced outfitting is not used. Notwithstanding the many bad experiences with floor plates, it is possible to successfully design and install a standard floor plate system (Figure 14.82). It is beneficial to keep the area alongside the propulsion machinery clear of systems so as to eliminate the possibility of foundation/system interferences.

This also provides a maintenance work area and by incorporating hinged floor plates, maintenance and access to the machinery is improved. The practice of designing machinery space handrail stanchions of pipe as well as the rails should be discouraged and the simpler *hull type* flat bar stanchions should be used instead.

### 14.3.3.5 Piping

The design of piping systems for a Contract design usually only consists of unsized diagrammatics for propulsion and operational essential systems. Like all other systems, standardization will assist in accomplishing design for production. Not only standard components but standard complete systems, such as shown in Figure 14.83, and standard routing corridors. Again, whether or not advanced outfitting will be utilized, the steps outlined in the section on Machinery Arrangement should be followed and expanded, namely:

- prepare equipment association lists,
- prepare equipment connection networks,
- prepare system diagrammatics, and
- prepare routing diagrammatics.

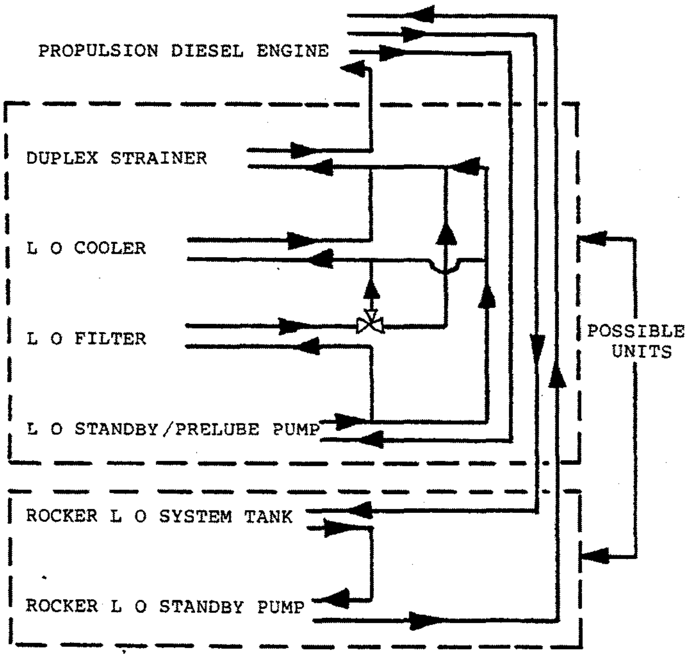


**Figure 14.79** Equipment Connection Network

### 14.3.3.6 HVAC

In traditional design and construction of ships, systems such as piping, HVAC and electrical are always *fighting* each other for space. To overcome this problem some designers allocate space priorities to different systems such as HVAC first, large piping next and electrical wireways last. Unfortunately, from experience it is known that this approach does not work well. This traditional conflict does not end with design and engineering. It continues out in the shops and on the ship during construction. Added to this shipboard conflict caused by design, is the *field run pipe* and *who gets there first* problems. However, these problems can be changed into planned integration of systems by applying the approach described herein.

An essential step to ensure production friendly design of HVAC systems is to plan the distribution corridors early in the design development at the same time as the corridors for the other systems. Again, the use of standards for HVAC components and diagrammatics is an effective DFP approach. Obviously, the standards should be minimum work content designs. By correctly planning the design of HVAC systems

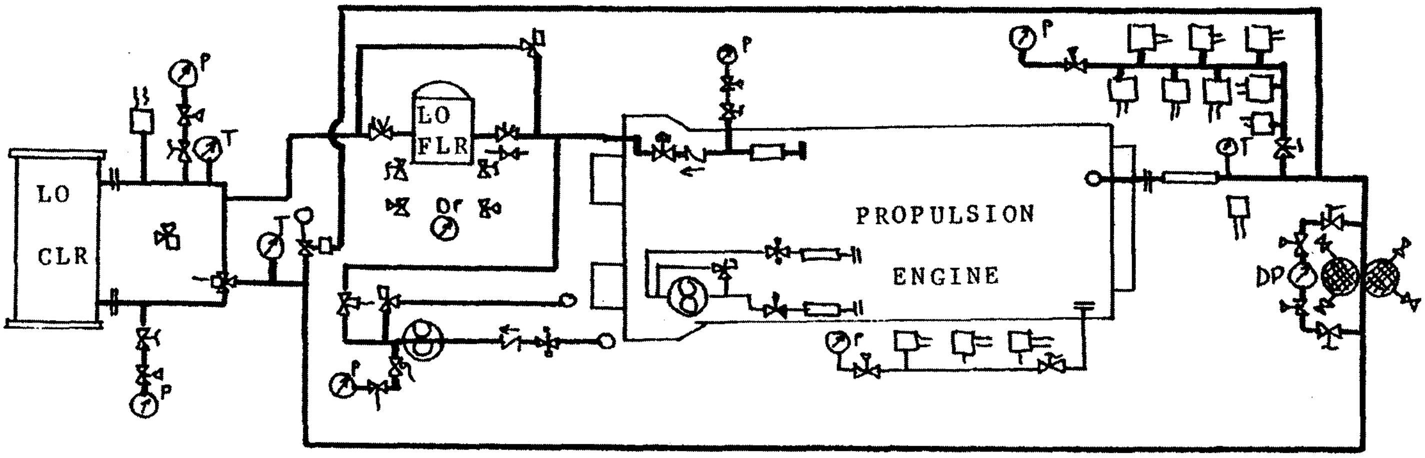


**Figure 14.80** Illogical System Diagrammatic

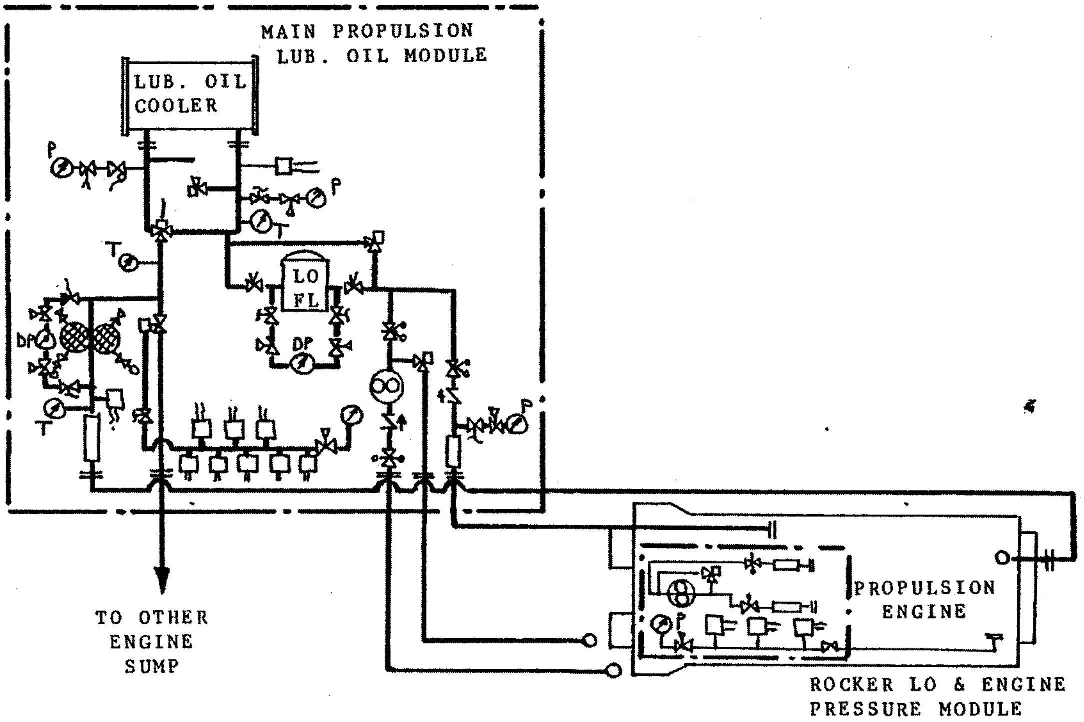
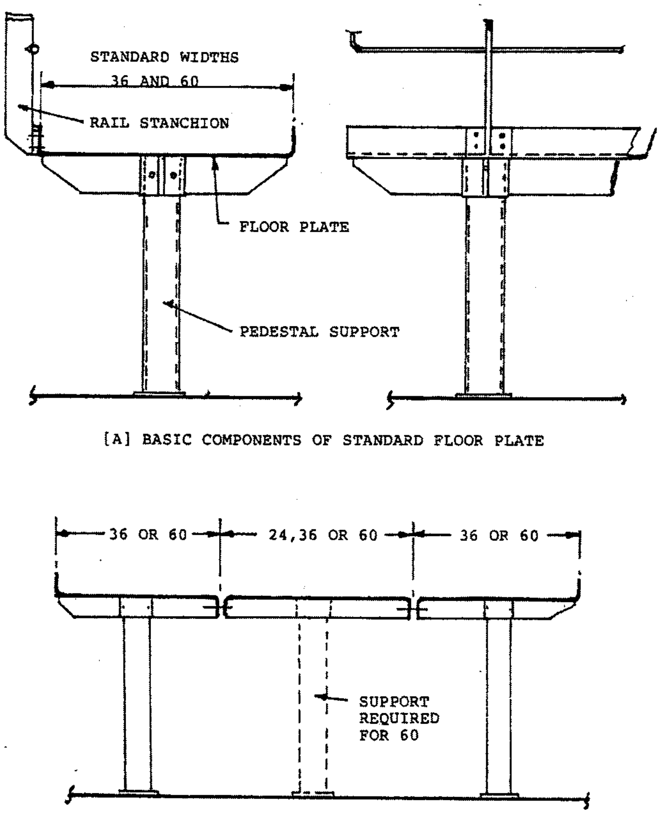


**Figure 14.81** Logical System Diagrammatic



[B] COMBINING STANDARD COMPONENTS

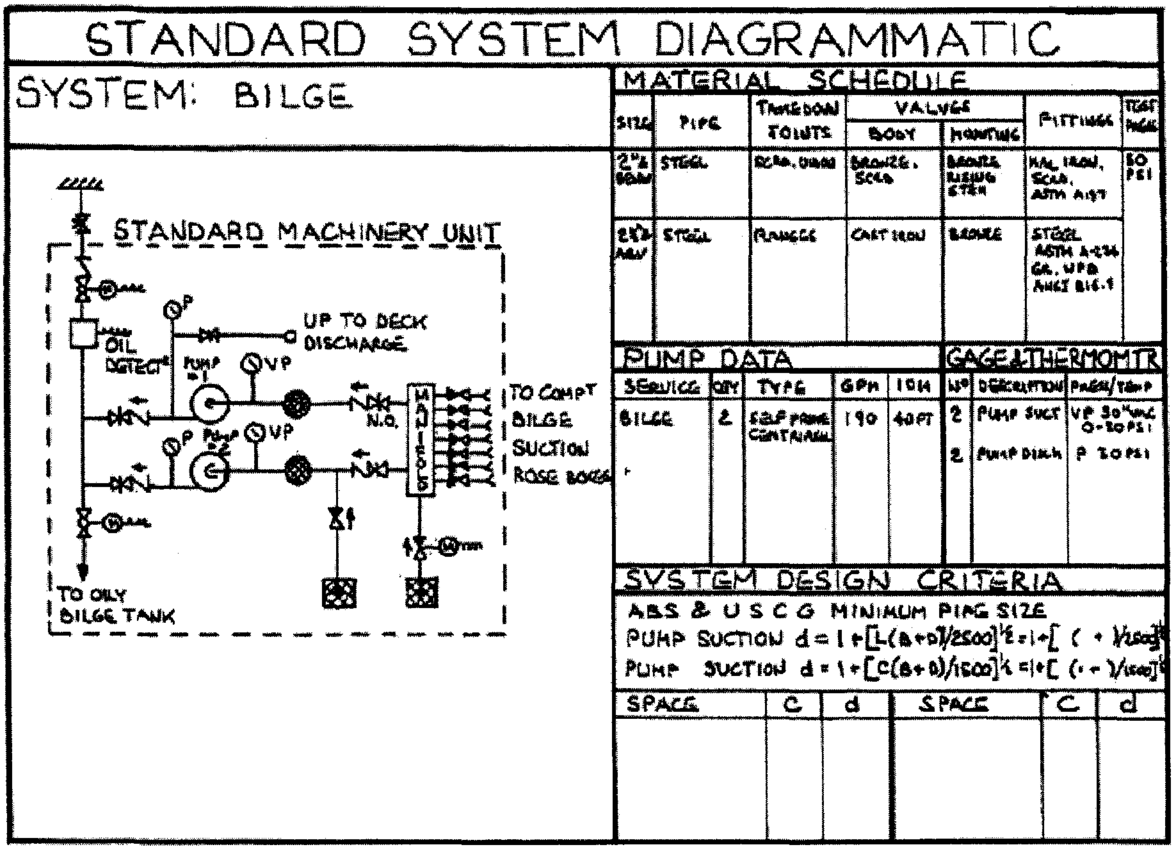
**Figure 14.82** Standard Floor Plate System

during Basic Design the need for high work content penetrations, duct jogging and section changes can be eliminated. By considering louvers and plenum chambers as integral parts of the structure instead of HVAC fittings, considerable design and construction man-hours can be saved. The use of high-pressure ventilation systems will reduce the size of the ducting and can result in worthwhile installation man-hour savings. However, the cost of any special noise attenuation treatment could cancel the savings out. The use of individual room convector heater/cooler and even hotel type through the wall units should be examined as a potential productivity improver without any operational disadvantages. Again, the above ideas must be considered during the preparation of the Contract Specifications to ensure that they can be utilized if found of benefit to a shipyard.

### 14.3.3.7 Electrical

As for the other traditional disciplines, the first design for production requirement for electrical systems is that they be considered along with and integrated with the other systems. This integration of all systems is essential if an efficient and easily constructed ship is to be designed. Routing corridors for wireways should be assigned during Basic Design and used for cable routing as the design is developed.

Marine electrical design and engineering is the ship dis-



| SIZE | PIPE | THREADED JOINTS | VALVES BODY | VALVES MOUNTING | FITTINGS | TEST PRESS |
|---|---|---|---|---|---|---|
| 2"& BELOW | STEEL | SCRD. UNION | BRONZE, SCRD | BRONZE RISING STEM | MAL. IRON, SCRD, ASTM A197 | 50 PSI |
| 2½" & ABOV | STEEL | FLANGES | CAST IRON | BRONZE | STEEL ASTM A-234 GR. WPB ANSI B16.9 | |

| SERVICE | QTY | TYPE | GPM | TDH |
|---|---|---|---|---|
| BILGE | 2 | SELF PRIME CENTRIFUGAL | 190 | 40 FT |

| NO | DESCRIPTION | PRESS/TEMP |
|---|---|---|
| 2 | PUMP SUCT | VP 30"VAC 0-30 PSI |
| 2 | PUMP DISCH | P 30 PSI |

ABS & USCG MINIMUM PIPE SIZE
PUMP SUCTION $d = 1 + [L(B+D)/2500]^{1/2} = 1 + [\ (\ +\ )/2500]^{1/2}$
PUMP SUCTION $d = 1 + [C(B+D)/1500]^{1/2} = 1 + [\ (\ +\ )/1500]^{1/2}$

| SPACE | C | d | SPACE | C | d |
|---|---|---|---|---|---|
| | | | | | |

**Figure 14.83** Standard System Diagrammatic

cipline that has had the least effort expended to improve it. The design for production potential is therefore large and it should be targeted for significant development. The impact of advanced outfitting and zone construction is substantial on traditional marine electrical design but can be used to guide the required electrical design for production development. Aspects such as combined control panels for units, On-block and zone electrical installation; erection of completed deckhouses, etc., must be considered and, again allowed for in the design approach and the Contract Specifications. Typical electrical DFP concepts are shown in Figure 14.84

### 14.3.3.8 Integration of systems

Everyone knows that the most cost and operationally efficient ship is one in which all its components are well integrated. Many also know that the integration of the many systems also offers work content reductions. Therefore, the deliberate efforts to integrate the ship systems during dezsign are an essential part of design for ship production. The approach is not new. It is just that the traditional engineering specialization/organization divides responsibility for individual systems in the same part of a ship to many groups. Also the preoccupation with independent system design and current approach to working schedules apparently prevents many designers from attempting integrated design.

The integration of systems for advanced outfitting units is simply a micro application of the approach compared to the macro application for the complete machinery space or the entire ship. The specialization of skills in both engineering and production relies on the ability of managers to ensure that the design and construction of individual systems result in an integrated final product.

It is obvious that there is a basic design need to ensure that all parts of a product are efficiently integrated and that the many compromises that are necessary during design are the best.

It is still possible today to see machinery spaces where individual pipe runs have obviously been designed and installed independently of all other pipe runs. Further, no attempt will have been made to integrate the pipe hangers with each system being independently *hangered* to the ship's primary structure. The foundations for the equipment will be individual and floor plate and vent duct supports will also be independent. When surrounded by this inefficient application of material and production effort, it is easy to see the additional cost and weight and why it takes so long to build.

Advanced outfitting necessitates integration of systems to obtain full benefits. An innovative but practical attitude is required to successfully integrate the systems and a major tool to assist this is a Distributive System Routing Composite Drawing incorporating the assigned system corridors.

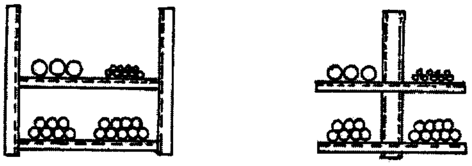


FIGURE 1.119 Typical hangers.

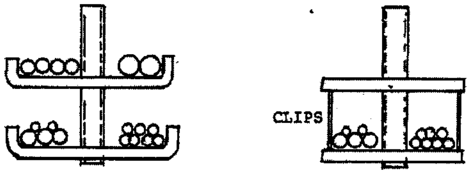
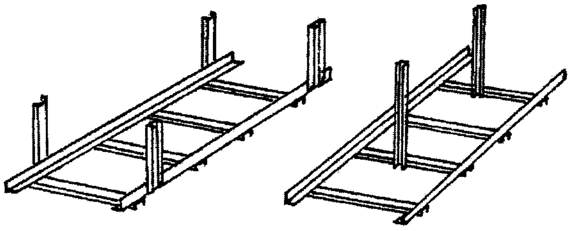
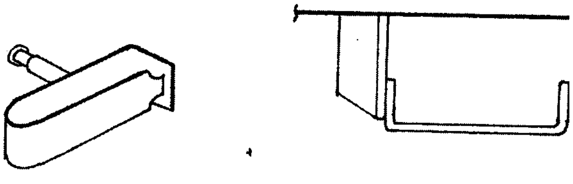


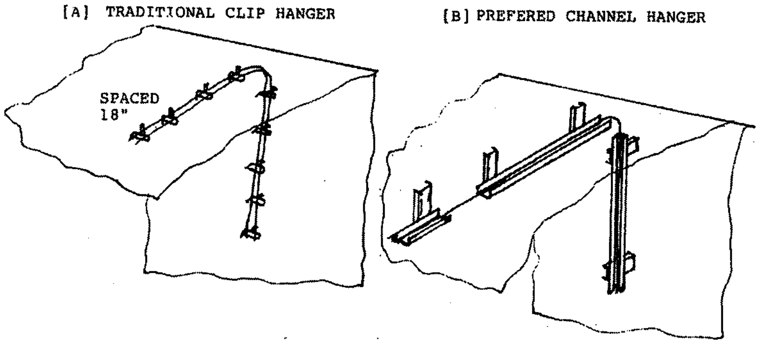
FIGURE 1.120 Cable-retaining methods.



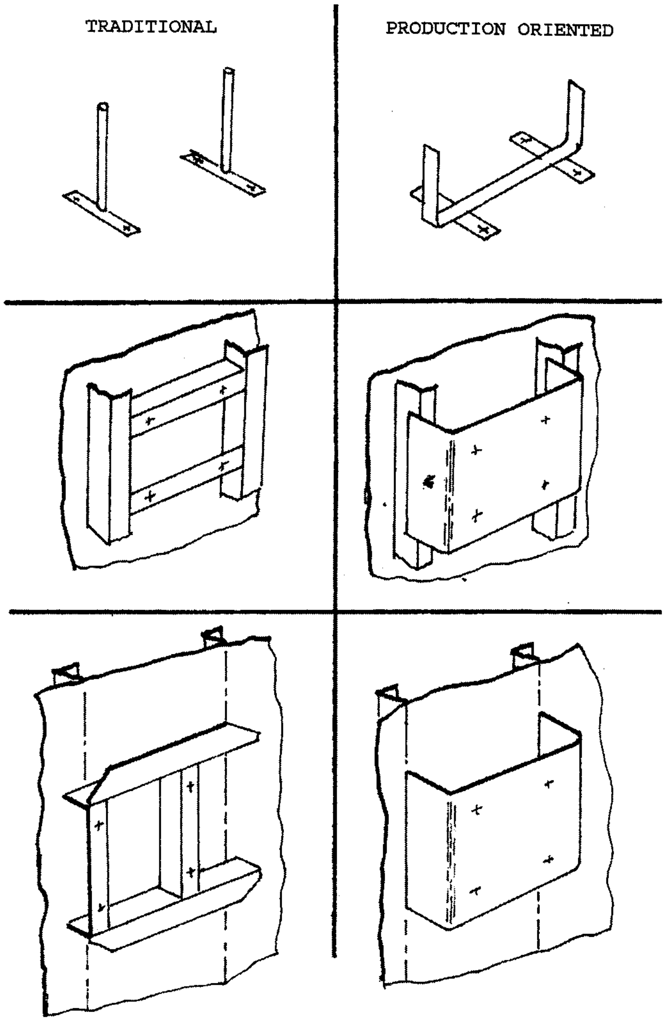


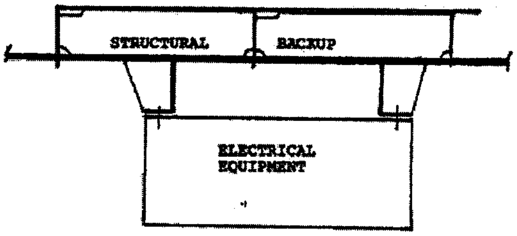
[A] TRADITIONAL CLIP HANGER

[B] PREFERED CHANNEL HANGER

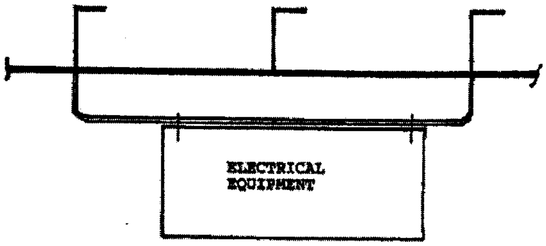


SUPPORTS SPACED TO SUIT BEAM/
FRAME/LONGITUDINAL SPACING





TYPICAL ELECTRICAL FOUNDATION WITH BACKUP



FLANGED PLATE FOUNDATION ELIMINATING NEED FOR BACKUP

**Figure 14.84** Typical DFP for Electrical

## 14.3.4 Application Examples of DFP

To assist in the application of DFP a number of examples are presented. They range from the use of simple comparisons to the use of sophisticated computer-based decision-making tools.

### 14.3.4.1 Part reduction

The first example considers part variation reduction. Figure 14.85 shows a typical midship section for a product tanker. It has 21 longitudinals on the shell, side longitudinal and centerline bulkheads. As the section modulus of each longitudinal depends on the head above it to the tank overflow, each longitudinal could be different in size. To reduce the number of different parts ship designers have grouped to 21 longitudinals into 4 to 5 groups of the same size. As the longitudinals in a group have to all be sized based on the lowest longitudinal in the group there is a small weight increase, but any additional material cost is insignificant compared to the man-hour savings resulting from the part reduction.

Another solution would be to make all the longitudnals the same size as the lowermost one, vary the longitudinal spacing and increase the plate thickness so that the global and local structural requirements were met. This would have a significant weight increase associated with it but this is moving in the direction of the longitudinal less ship or advanced hull structural design (48).

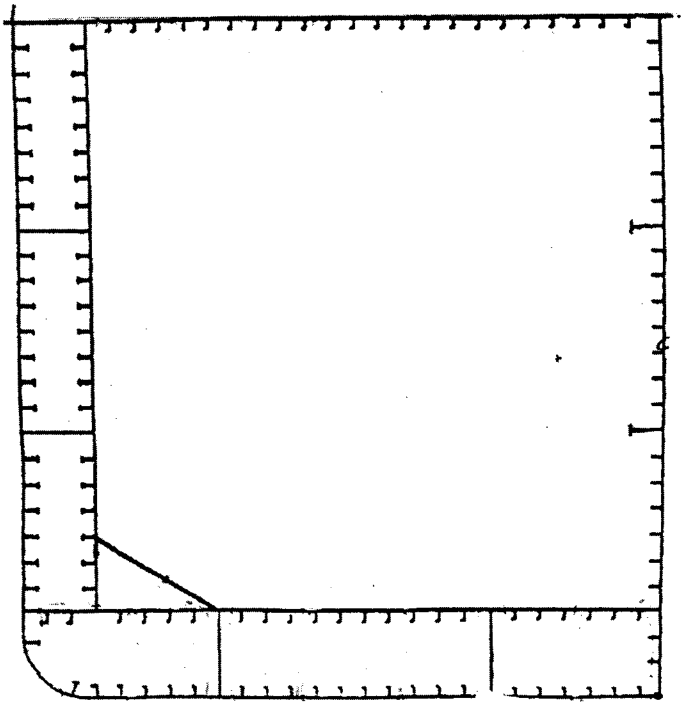


**Figure 14.85** Product Tanker Midship Section

### 14.3.4.2 Block breaks

This example shows how the type of framing impacts the decision On-block breaks. Figure 14.86 shows how in a longitudinally framed ship, it would be better to have long blocks, whereas for a transversely framed ship wide blocks would be better. This is because the above choices would eliminate section joints and leave only plate joints.

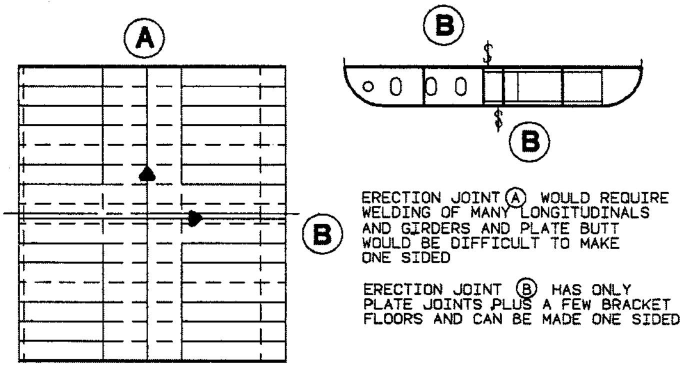
### 14.3.4.3 Tranvsverse versus longitudinal framing

This example examines whether man-hour savings cam be achieved by changing from longitudinal to transverse framing on normal commercial ships such as container, tanker, bulk carrier, etc., by focusing on the double bottom as shown in Figure 14.87. The dimensions of the double bottom block are:

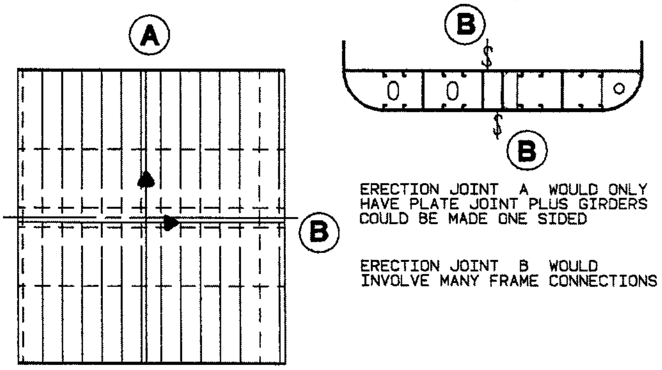
| | |
|---|---|
| Length | 12 800 mm |
| Breadth | 12 000 mm |
| Depth | 2000 mm |
| Frame spacing | 800 mm |
| Longitudinal spacing | 800 mm |

(Note this will give 12 longitudinals rather than the 7 shown in the sketch.)

Table 14.III shows the comparison and that transverse

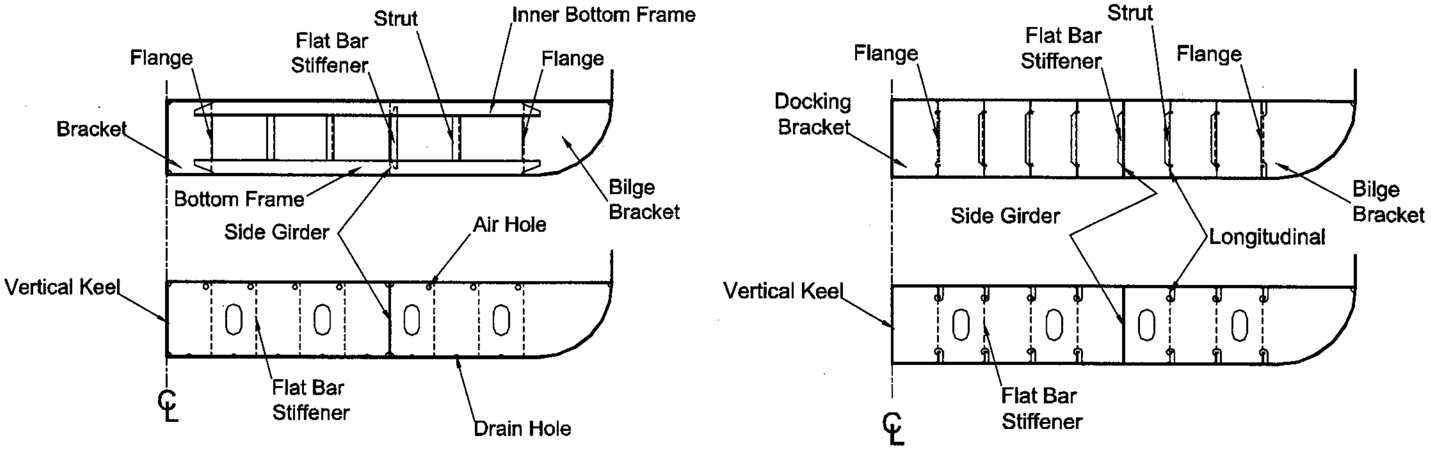


**LONGITUDINAL FRAMING**



**TRANSVERSE FRAMING**

**Figure 14.86** Block Break DFP



a) Transverse Framing b) Longitudinal Framing

**Figure 14.87** Transverse Versus Longitudinal Framing in Double Bottom

framing can reduce the number of parts by 40%, the number of unique parts by 31% and the joint weld length by 17%.

### 14.3.4.4 Man hole cover

Many shipyards have standard parts and Figure 14.88a shows one shipyard's standard for man hole covers. It can be seen from the figure that the actual cover is different for each man hole type. Figure 14.88b shows the DFP solution to standardize the actual cover.

### 14.3.4.5 Slits and notches with chocks

This example uses the computer-based simulation to evaluate alternative designs for double bottom floor longitudinal/floor intersections by deriving the outcomes.

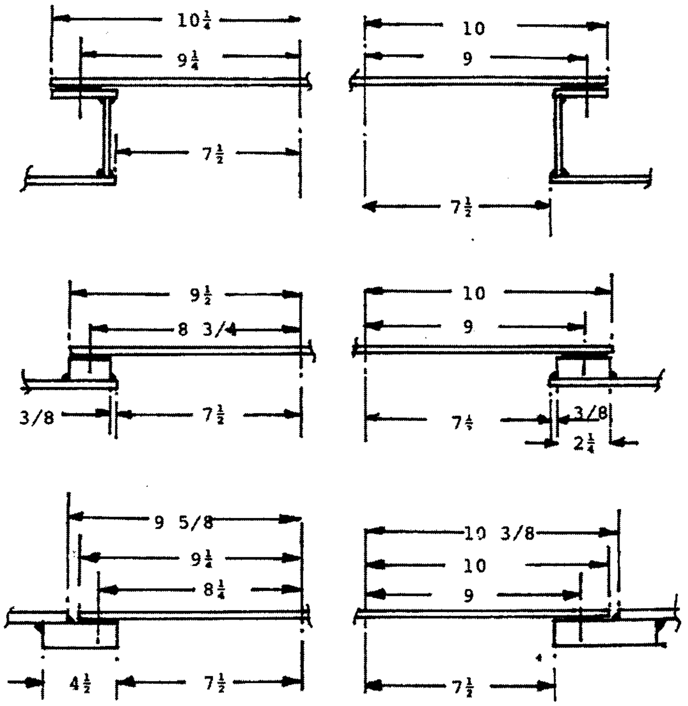
Computer-based simulation systems such as DELMIA, can be used to model the product, processes and resources for both cases and run to determine the cycle time and man-hours for each case, and the outcomes can be compared.

A double bottom structure for a container ship is used as an example. It consists of two stiffened plate assemblies; tanktop and the bottom, and eight subassemblies; 3 floors and 5 girders. Two different longitudinal notch shapes are considered, as shown in Figure 14.89.

Case I longitudinal notch shape design has several advantages and disadvantages over the Case II design, such as:

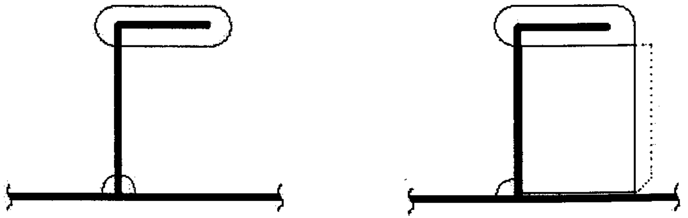
*Advantages*

- collar plates are not required resulting in less number of parts
- less welding length especially for the chocks that are difficult to access, and
- less cutting length.s



a) Original Standard Design b) DFP Standard Design

**Figure 14.88** Standard Man Hole Design



Case I Case II

**Figure 14.89** Two Longitudinal Connections

**TABLE 14.III** Tranvsverse versus Longitudinal Framing

| | *NOP* | *NOUP* | *JWL m* | *WELD PROCESS* |
|---|---|---|---|---|
| **TRANSVERSE FRAMING** | | | | |
| Plate Floor | 3 | 1 | 168 | Panel |
| Plate Floor Stiffeners | 24 | 1 | 77 | Subassembly |
| Bulkhead Floor | 1 | 1 | 56 | Panel |
| Bulkhead Floor Stiffener | 12 | 1 | 39 | Subassembly |
| Docking Bracket | 12 | 1 | 86 | Manual |
| Docking Bracket Stiffener | 12 | 1 | 38 | Subassembly |
| Bilge Bracket | 12 | 1 | 120 | Manual |
| Bilge Bracket Stiffener | 12 | 1 | 38 | Subassembly |
| Inner Bottom Frame | 12 | 1 | 216 | Panel |
| Shell Frame | 12 | 1 | 216 | Panel |
| Girder Stiffener | 12 | 1 | 48 | Subassembly |
| Weld Frames to Brackets | — | — | 82 | Manual |
| **TOTALS** | **124** | **11** | **1184** | — |
| **LONGITUDINAL FRAMING** | | | | |
| Plate Floor | 3 | 1 | 168 | Panel |
| Plate Floor Stiffeners | 36 | 1 | 115 | Subassembly |
| Bulkhead Floor | 1 | 1 | 56 | Panel |
| Bulkhead Floor Stiffener | 12 | 1 | 39 | Subassembly |
| Docking Bracket | 12 | 1 | 86 | Manual |
| Docking Bracket Stiffener | 12 | 1 | 38 | Subassembly |
| Bilge Bracket | 12 | 1 | 120 | Manual |
| Bilge Bracket Stiffener | 12 | 1 | 38 | Subassembly |
| Inner Bottom Longitudinals | 12 | 1 | 307 | Panel |
| Shell Longitudinals | 12 | 1 | 307 | Panel |
| Girder Stiffener | 12 | 1 | 48 | Subassembly |
| Girder Stiffener Brackets | 24 | 1 | 38 | Manual |
| Inner Bottom Longitudinal Collars | 24 | 2 | 19 | Manual |
| Shell Longitudinal Collars | 24 | 2 | 19 | Manual |
| Longitudinal Connection to Floors | — | — | 29 | Manual |
| **TOTALS** | **208** | **16** | **1427** | — |
| Compared to Longitudinal Framing Difference | 84 | 5 | 243 | 17% |

NOP – Number of Parts JWL Panel Line 656; NOUP – Number of Unique Parts JWL Subassembly – 240; JWL – Joint Weld Length JWL Manual – 288

*Disadvantages*

- subassembly alignment is more difficult taking more time and man-hours to assemble by sliding floors over longitudinals, and
- high accuracy is required.

On the other hand, Case II longitudinal notch shape design uses chocks and thus has more parts, more joint weld length where hard to access, and more cutting length, but the alignment is easier than the other design.

In this example model, the production process consists of five workstations:

1. fabrication – cutting,
2. fabrication – bending,
3. subassembly,

**TABLE 4.IV** Man-hour Differences Between Case I and II, with Respect to Workstations

| | *Case I* | *Case II* | *Difference*[1] | *Percent*[2] |
|---|---|---|---|---|
| Fabrication – cutting | 56.2 | 57.7 | 1.4 | 2.4 |
| Fabrication – bending | 2.0 | 2.0 | 0.0 | 0.0 |
| Sub-assembly | 222.9 | 222.9 | 0.0 | 0.0 |
| Assembly | 397.9 | 578.0 | 180.0 | 31.2 |
| Block construction | 199.4 | 279.4 | 80.0 | 28.6 |
| Total | 878.5 | 1139.9 | 261.4 | 22.9 |

**TABLE 14.V** Man-hour Differences Between Case I and II, with Respect to Processes

| | *Case I* | *Case II* | *Difference* | *Percent* |
|---|---|---|---|---|
| Manufacturing | 326.3 | 687.8 | 361.4 | 52.6 |
| Cutting | 33.0 | 34.4 | 1.4 | 4.1 |
| Forming | 2.0 | 2.0 | 0.0 | 0.0 |
| Edge milling & Misc | 43.1 | 43.1 | 0.0 | 0.0 |
| Welding | 248.3 | 608.3 | 360.0 | 59.2 |
| Material handling | 552.2 | 452.2 | –100.0 | –22.1 |
| Lift/turn-over | 150.0 | 50.0 | –100.0 | –200.0 |
| Aligning | 382.2 | 382.2 | 0.0 | 0.0 |
| Move/Transport | 20.0 | 20.0 | 0.0 | 0.0 |
| Total | 878.5 | 1139.9 | 261.4 | 22.9 |

4. assembly, and
5. block construction workstations.

And the shipyard model has NC plasma marking/cutting machine, semi-automatic edge beveling machine, profile NC marking/cutting machine, plate edge milling machine and rolling machine transfer conveyor in fabrication, two gantry cranes in subassembly, two gantry cranes, a hydraulic jack, automatic stiffener feeder in assembly, and two overhead bridge cranes and a transporter in block construction.

Table 14.IV shows the differences in man-hours between Case I and II, with respect to workstations. The total man-hours required to produce a double bottom block using Case I design is about 23 % less than that of Case II. The difference in man-hours ranges from 0 % in bending and subassembly to a high of 31 % in assembly workstation. The Case II using collar plates requires by far more man-hours in assembly and block construction, which could be reasonable due to the welding of collar plates in assembly and block construction workstation.

Although the longitudinal notch has more cutting length, Case I requires less man-hours in cutting. This is because Case II requires collar plate cutting as well as longitudinal notch cutting.

Table 14.V shows the man-hour differences between Case I and II, with respect to process. As can be seen, Case I requires more material handling man-hours, especially aligning, while Case II requires more manufacturing man-hours, especially welding. Although case II requires 22 % less man-hours in material handling processes, total man-hours are 23 % more than that of case I, due to the by far more man-hours in welding process for Case II.

The total man-hours, required to produce the double bottom block with Case I notch shapes, is about 23 percent less than that of Case II notch shape. The difference in man-hours ranges from zero percent in bending and subassembly to a high of 31 percent in block construction workstation. Case II requires more man-hours in assembly and block construction, which is due to the welding of collar plates in assembly and block construction workstations. Case I requires more material handling man-hours, especially aligning.

As in the example in subsection 14.3.4.2 the savings will be multiplied in way of transverse bulkheads.

#### 1.1.3.6 Designing out the need for high accuracy

Many structural details, especially those used in naval ship design, have connections that use butt weld connections. This type of connection requires high accuracy and significant man-hours for fitup. This can be avoided by using overlapping connections, such as the butted longitudinal connections by lapped connections as shown in Figure 14.55 and Figure 14.56 and the frame/beam brackets shown in Figure 14.62. Also the replacement of butt weld connections by fillet weld connections, as shown in Figures 14.54

## 14.4 BUILD STRATEGY APPROACH

All shipbuilders plan how they will design and build their ships. The plan may be only in someone's head or a detailed and documented process involving many people. Often different departments prepare independent plans, which are then integrated by a *Master Plan/Schedule*.

The *Build Strategy Approach* is much more than the normal planning and scheduling and a description of how the Production Department will build the ship.

Many shipbuilders use the term *Build Strategy* for what is only their Production Plan. This is incorrect. The term Build Strategy as originally developed in Britain and subsequently in the U.S. has a special, specific meaning. It is also recognized that some shipbuilders have a process very similar to the Build Strategy approach but do not call it such. The recent U.S. Navy/industry promoted *Design and Build Plan* has a lot of similarity to a *Build Strategy,* although it still allows the shipbuilders to ignore the important *Shipbuilding Policy* part of the Build Strategy Approach.

### 14.4.1 What is the Build Strategy Approach?

It was A&P Appledore that conceived and developed the formal Build Strategy Approach in the early 1970s. It developed from the ideas and processes generated to support the A&P Appledore associated *Ship Factories* at Appledore and Sunderland, in the U.K. The detailed work breakdown, formalized work sequencing and very short build cycles associated with these ship factories required the communication, coordination and cooperation that are inherent in the Build Strategy Approach.

*British Shipbuilders* adopted the Build Strategy Approach for all their shipyards (49,50) and A&P Appledore consulting group continued to develop the approach as a service to their clients.

The Build Strategy Approach was introduced into the U.S. by A&P Appledore's participation in IREAPS conferences, as well as through presentations to individual shipbuilders and the SP-4 Panel (14).

A&P Appledore consulting to NORSHIPCO, Lockheed Shipbuilding Company and Tacoma Boat introduced the use of the Build Strategy Approach to U.S. shipbuilding projects. The author was involved in a project to implement the Build Strategy Approach into U.S. shipbuilding (15). Finally, the Build Strategy Approach was described in the DESIGN FOR PRODUCTION Manual, prepared by A&P