SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

July 1996
NSRP 0467

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

A Short Course on Concepts of Modern Ship Production

Course Notes

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

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0467

SHORT COURSE ON

MODERN SHIP PRODUCTION

COURSE NOTES

[VERSION 7/96]

A TRAINING INITIATIVE
OF
THE UNIVERSITY OF MICHIGAN
FOR
THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

FIRST DAY AGENDA

8- 8.30 AM	INTRODUCTIONS
8.30-8.45 AM	WORKSHOP OBJECTIVES
8.45-9.30 AM	SHIP PRODUCTION HISTORY - Video & Discussion
9.30-10.00 AM	BREAK
1O.OO-11.OO AM	MODERN SHIPBUILDING PROCESSES
11.00-11.30 AM	MATERIAL FLOW
11.30 AM - 12.30 PM	LUNCH
12.30-1.45 PM	HULL BLOCK CONSTRUCTION AND ZONE OUTFITTING
1.45-2.30 PM	EXERCISE 1 - Block Breakdown or Zone Coding
2.30-2.45 PM	BREAK
2..45- 3.30 PM	ADVANCED OUTFITTING
3.30- 4.00 PM	EXERCISE 2 - Benefit of Advanced Outfitting

SECOND DAY AGENDA

8- 8.30 AM	FIRST DAY REVIEW
8.30-9.15 AM	PRODUCTION PLANNING & SCHEDULING
9.15-9.45 AM	EXERCISE 3 - CPM
10.00-10.15 AM	BREAK
1O.15-11.OO AM	PRODUCTION CONTROL
11.00- 11.30 AM	MATERIAL CONTROL
11.30 AM - 12.30 PM	LUNCH
12.30-1.30 PM	DIMENSIONAL CONTROL
1.30-2.15 PM	ACCURACY CONTROL
2.15-2.30 PM	BREAK
2.30-3.00 PM	LEARNING AND EXPERIENCE EFFECTS
3.00-3.45 PM	EXERCISE 4 - Team Debate on use of Best Practices
3.45- 4.00 pm	WRAP-UP

SHIP PRODUCTION STRATEGIC FACTORS

I. HISTORY

A. SHIP PRODUCTION TECHNOLOGY SHAPED BY THE FOLLOWING FORCES:

1. Advances in Technology
   --Iron Frame Construction
   --Steel
   --Welding
   --Computer process control

2. Availability of Natural Resources.
   --USA and hardwood forests
   --Great Britain and coal and iron ore

3. Economic and Social Environment
   --USA in 19th century
   --Japan in 1970s
   --Korea today

4. Government Policies
   --USA subsidy
   --Korea today

B. FUTURE TRENDS

1. Integration of design/engineering/production effort.

   -- Japan is leading example in commercial shipbuilding.

   -- US is moving this way in naval shipbuilding, e.g., requirement that bidding efforts have both design agent and shipyards on the team.

2. Computer is facilitating this integration.

3. Standard production systems (i.e., the "standard" ship).

   --Common practice in commercial ships

--Growing trend in military ships

II. SHIPYARD MANAGEMENT CONTROL

1. Production rate varies over time according to stage of completion.

2. Cost estimating is inexact. As production proceeds, production rate has to be adjusted. Reasons are: (1) weather, (2) material flows, (3) design changes, (4) wrong inputs.

III. THE MODEL

A. VARIABLES

1. Not in control of (1) Wage Rates and (2) Material costs.

2. In control of LABOR HOURS. THIS BECOMES THE DRIVING VARIABLE OF PRODUCTION MANAGEMENT DECISIONS, ESPECIALLY IN YARDS WHERE TRADITIONAL ACCOUNTING SYSTEMS PREVAIL.

3. In control of TIME AND THROUGHPUT RATE. THIS BECOMES THE DRIVING VARIABLE OF PRODUCTION MANAGEMENT DECISIONS IN YARDS THAT HAVE ACCOUNTING SYSTEMS THAT FOCUS ON VALUE-ADDED COSTS METHODS.

4. Partially in control of Indirect Costs.

B. OPTIMUM SYSTEM

1. constant work loading/output
2. perfectly trained labor
3. Perfectly located labor
4. Perfect material available at production site, exactly as needed
5. Exact supplies available at right time
6. Ideal equipment to support operation
7. Constant feedback and adjustment to optimum.

C. ONE EXAMPLE: JAPAN

1. Rationalization of the construction process.
   a. Separated the ship into five stages:
      --mold loft
      --fabrication (cutting and shaping).
      --sub-assembly (preliminary joining)
      --assembly (joining)
      --erection (joining at the erection site)
   b. Each stage was independent.
2. Complete design-engineering-production interface.

D. SHIPBUILDING POLICY.

1. Areas of decision needs
   a. Facilities development
   b. Productivity targets
   c. Make, buy, or subcontract
   d. Planning, technical, and production organization

2. Levels of policy development

   a. Strategic--related to type plans, planning units, interim product types, overall facility dimensions, and so on, applied at the conceptual and contract design stages.

   b. Tactical--related to analysis of planning units, process analysis, standard products and practices, and so on, applied at the functional and transition design stages.

   c. Detai1 --related to work station operations, and accuracy tolerances, applied at the detail design stages.

3. Elements of shipbuilding policy (see Figure 1)
   1. Policy overview
   2. Current practice
   3. Productivity action plan

4. Future practice
5. Long term development plan

A. BUILD STRATEGY

1. Company shipbuilding policy is applied in the contract

2. Provide a process for ensuring that design development takes full account of production requirements

3. To utilize production engineering principles that reduce production costs.

4. To create a product-oriented approach to engineering and planning of the vessel.

5. To determine resource requirements, to highlight shortfalls, and to introduce solutions.

6. To provide the basis on which the eventual production may be organized.

7. The build strategy is defined in the "Build Strategy Document."

a. The formal work document that defines the project, and describes the expenditure of resources. The document becomes the basis for all decision-making related to the timely completion of the contract.

b. Table of contents for a typical build strategy document is shown in attached figure.

IV. DISCUSSION TOPICS

1. Perceptions of differences in some yards that you have visited or where you have worked. List the forces that drive each yard's management.

2. Discuss differences in management actions that focus on reducing construction cycle time as opposed to reduction of direct labor man-hours.

3. Describe some instances where a more coherent build strategy would have prevented overruns on some specific ship construction contracts.

FIGURE **SPO-1**
ELEMENTS OF SHIPBUILDING POLICY

Policy Overview

- o policy based on business plan objectives
- o sets objectives for lower levels

Current Practice

- o existing standards
- o “last best” practice
- o procedures to be applied to next contract

Productivity Action Plan

- o covers next twelve months
- O plans improvements in specific areas
- o is a set of projects

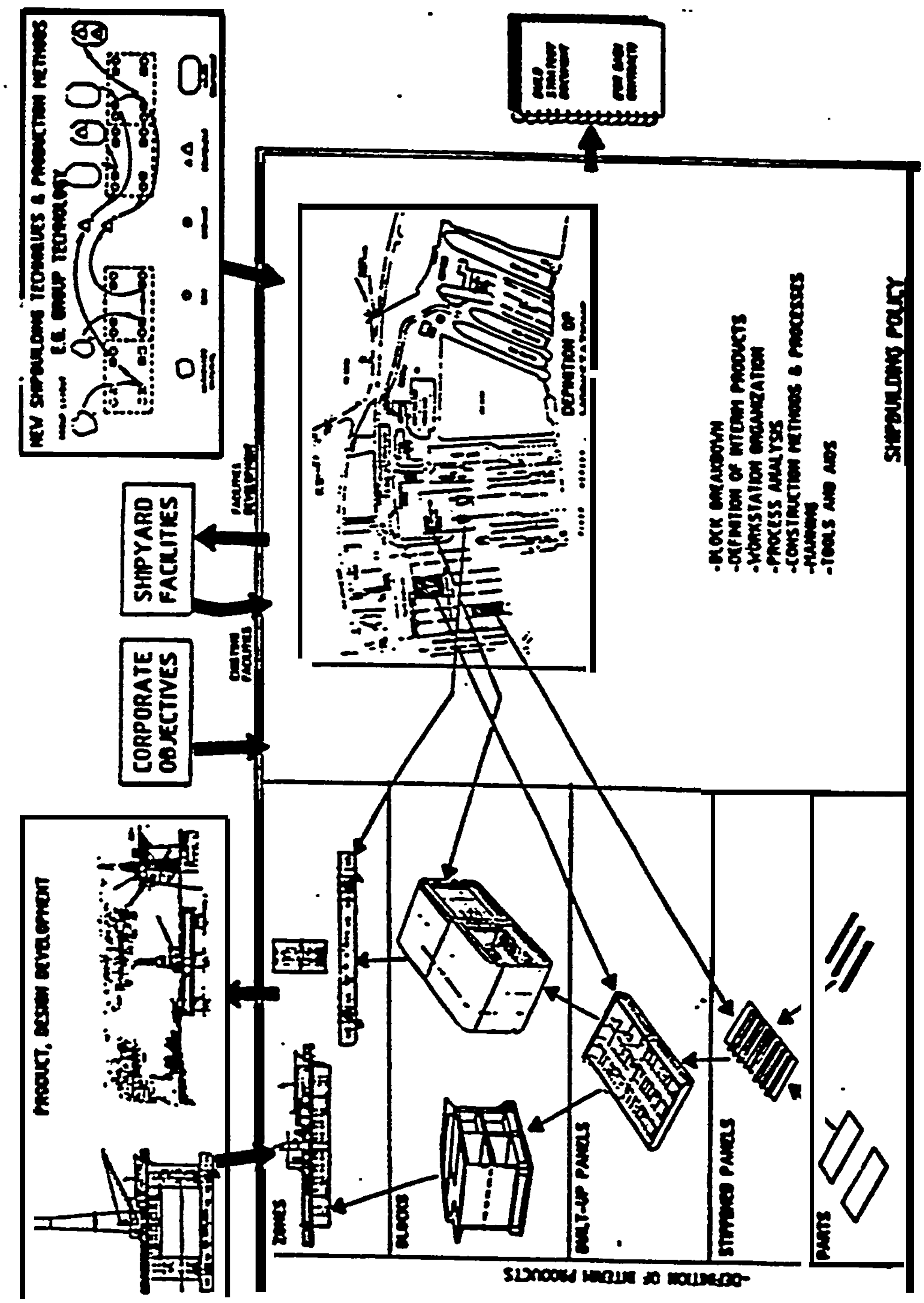
Future Practice

- o developed from current practice
- o incorporates outcome of action plan
- o procedures to be applied to future contracts

Long Term Development Plan

- o covers facilities development
- o covers a five-year period

FIGURE SPO-2
LINKUP BETWEEN SHIPBUILDING POLICY AND THE BUILD STRATEGY DOCUMENT



SPO-7

FIGURE SPO-3

TABLE OF CONTENTS FOR TYPICAL BUILD STRATEGY DOCUMENT

I. Introduction
- -details of vessel
- -details of special features/requircmcnts

II. Main Production Parameters
- -key dates/planned production rate
- -build location/launch rendition
- -productivity targets
- -resource rquircmcnts
- --potential bottlenecks
- --subcontract rquirements

III Build Stratcgy-Hull
- -hull subdivision
- --erection sequence
- -outline of methods

IV. Build Strategy-Machinery
- -identification of installation zones
- --installation sequences
- -identification of outfit assemblies
- -outline of methods

V. Build Strategy-Accommodation
- -accommodation structure subdivisions
- -erection sequence
- -identification of installation zones
- --installation sequence

VI. Planning Framcwork
- -list of planning units
- -building program
- -interim product groups and work stations
- -work station load analyses

VII. Main Purchasing Dates
- -steel
- -high cost/long lead time equipment
- -pipe and fittings
- -electrical cables

UNIVERSITY OF MICHIGAN
DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

SHIPYARD LAYOUT AND EQUIPMENT

L KEY CONCEPTS:

A. The shipbuilding process consists of fabricating raw material into ship parts and assembling them, along with purchased equipment and components (interim products) to produce the finished product, namely the ship

B. All shipyards have the same basic processes

C. Shipyards should be close to and have access to the opens+ and road and/or rail system should be suitable for delivery of equipment, components and raw materials.

D. Shipyards should also be located where there is adequate educated and trained people.

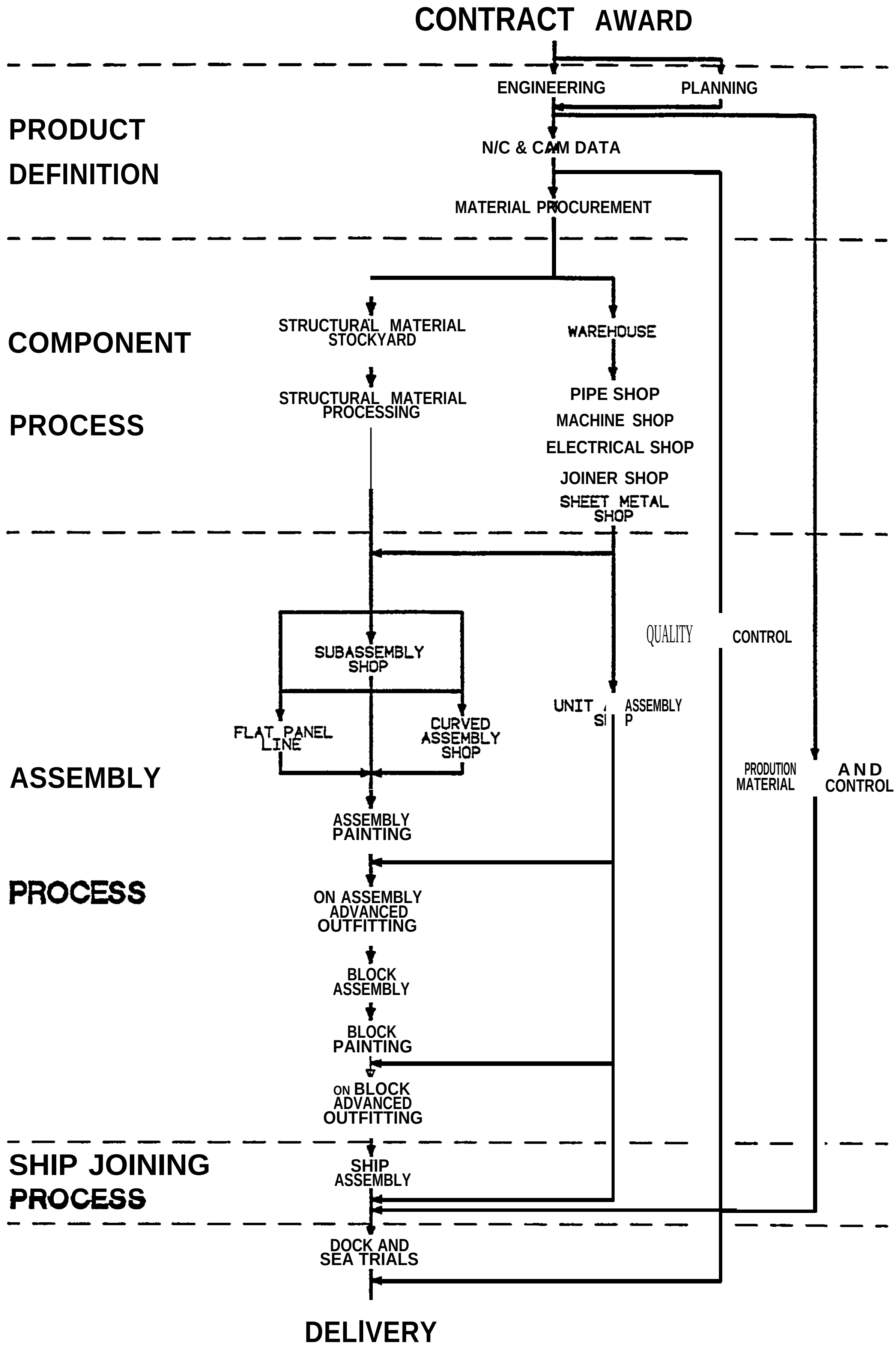
E. At least one boundary should be adjacent to the water.

F. Shipyards require the following attributes:
- Warehouses and raw materiel storage areas
- Shops to fabricate and assemble parts into sub-assemblies, assemblies and even Outfitted blocks
- Building berth and system of transferring ship to water - launchway, drydock, floating dock
- Pier(s) to secure the ship after launch

G. Goals of facility layout that must be considered are:
- optimizing material and work-in-process inventory
- minimizing buffer storage consistent with uniform flow through-out the yard
- minimizing the number of lifts and reducing the distance material and interim products must be transferred.

H. Block Construction and Advanced Outfitting require greater life capacity cranes. 200T Whirleys and 1000 T+ Gantrys.

I. Most U.S. shipyards have been in existence for many years and are constrained by existing plant boundaries and layout.


CONTRACT AWARD
ENGINEERING
PLANNING
PRODUCT DEFINITION
N/C & CAM DATA
MATERIAL PROCUREMENT
COMPONENT PROCESS
STRUCTURAL MATERIAL STOCKYARD
WAREHOUSE
STRUCTURAL MATERIAL PROCESSING
PIPE SHOP
MACHINE SHOP
ELECTRICAL SHOP
JOINER SHOP
SHEET METAL SHOP
QUALITY CONTROL
SUBASSEMBLY SHOP
UNIT ASSEMBLY SHOP
FLAT PANEL LINE
CURVED ASSEMBLY SHOP
ASSEMBLY PROCESS
PRODUTION MATERIAL AND CONTROL
ASSEMBLY PAINTING
ON ASSEMBLY ADVANCED OUTFITTING
BLOCK ASSEMBLY
BLOCK PAINTING
ON BLOCK ADVANCED OUTFITTING
SHIP JOINING PROCESS
SHIP ASSEMBLY
DOCK AND SEA TRIALS
DELIVERY

AVONDALE SHIPYARDS, INC.
MAIN PLANT

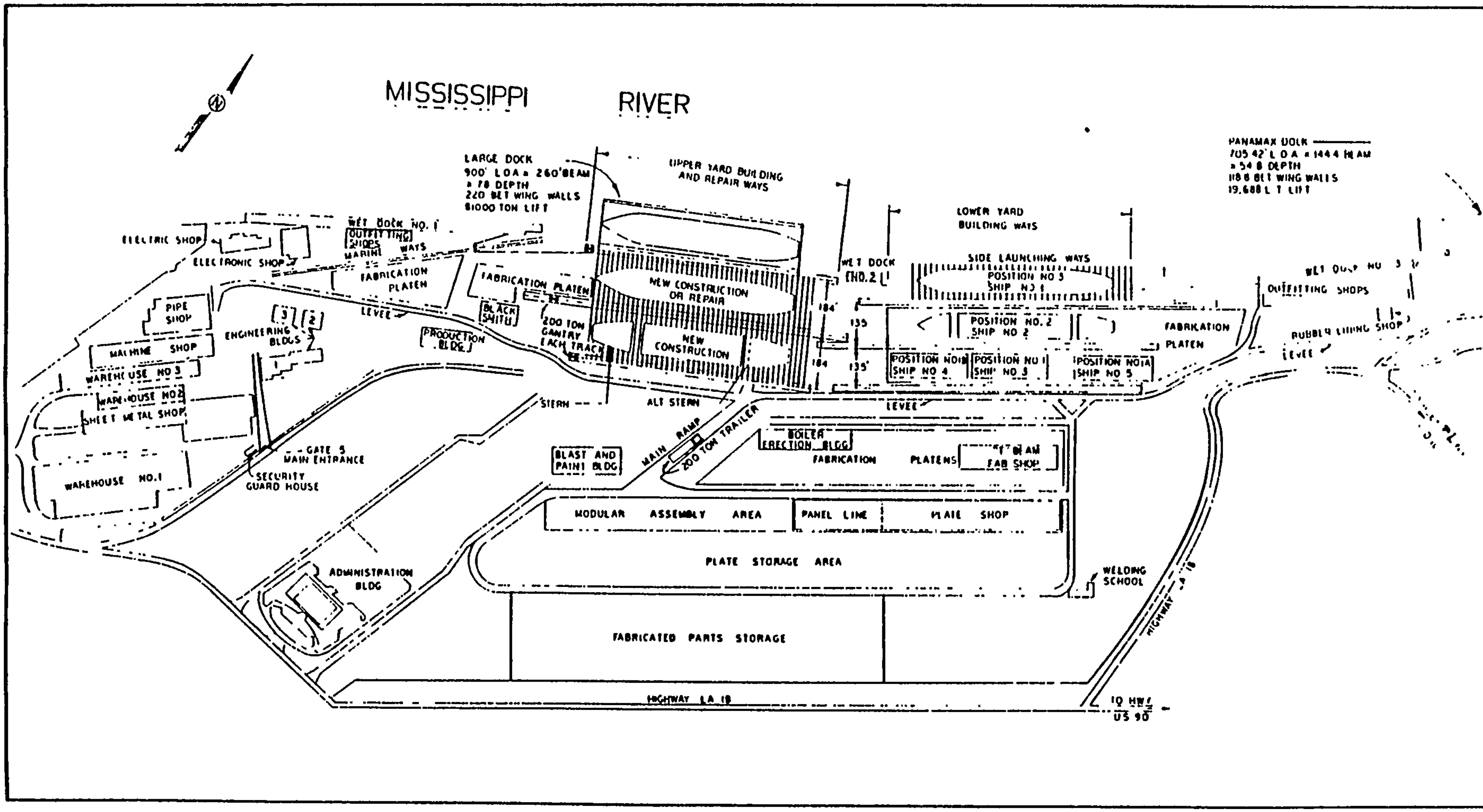
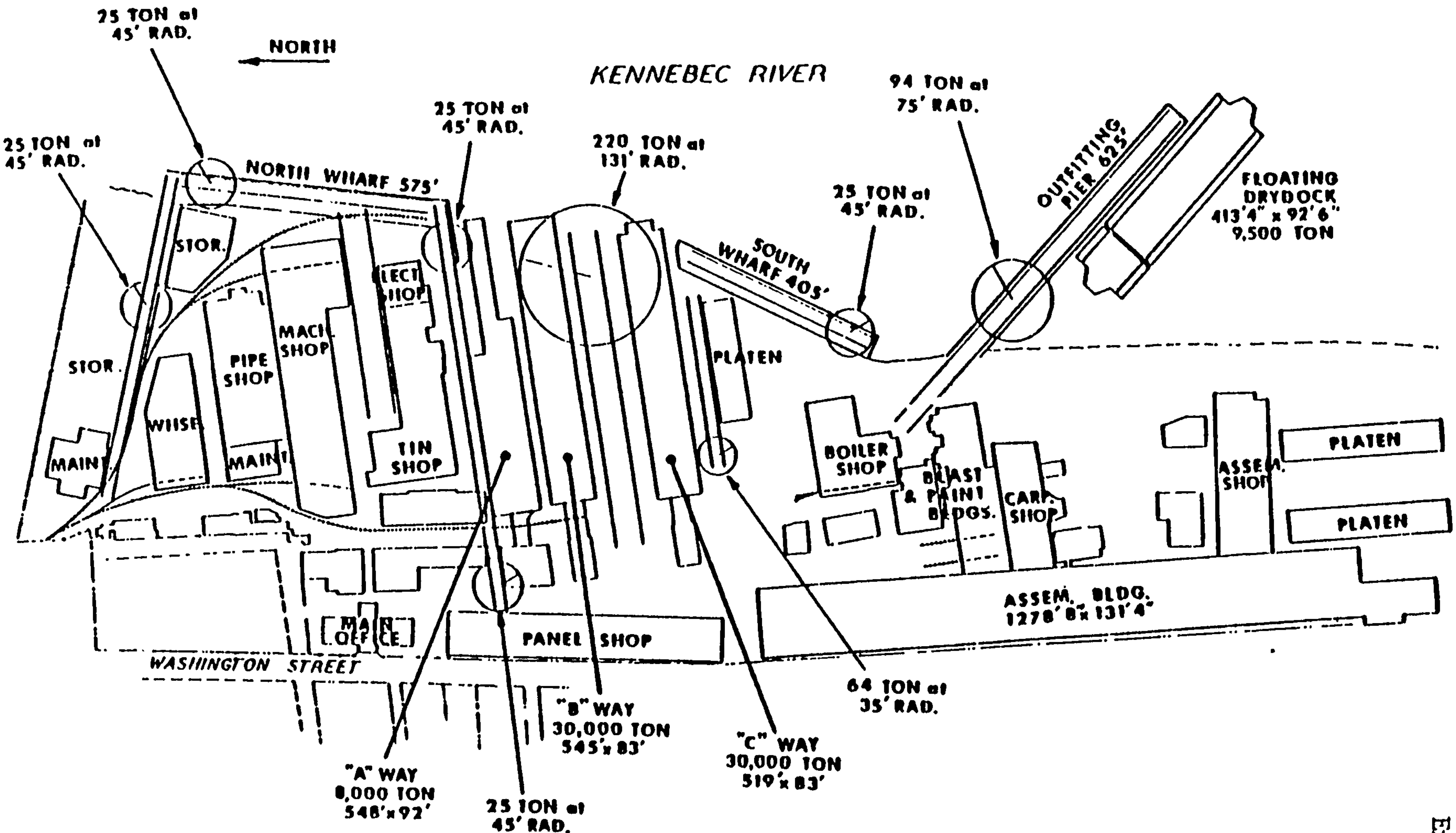


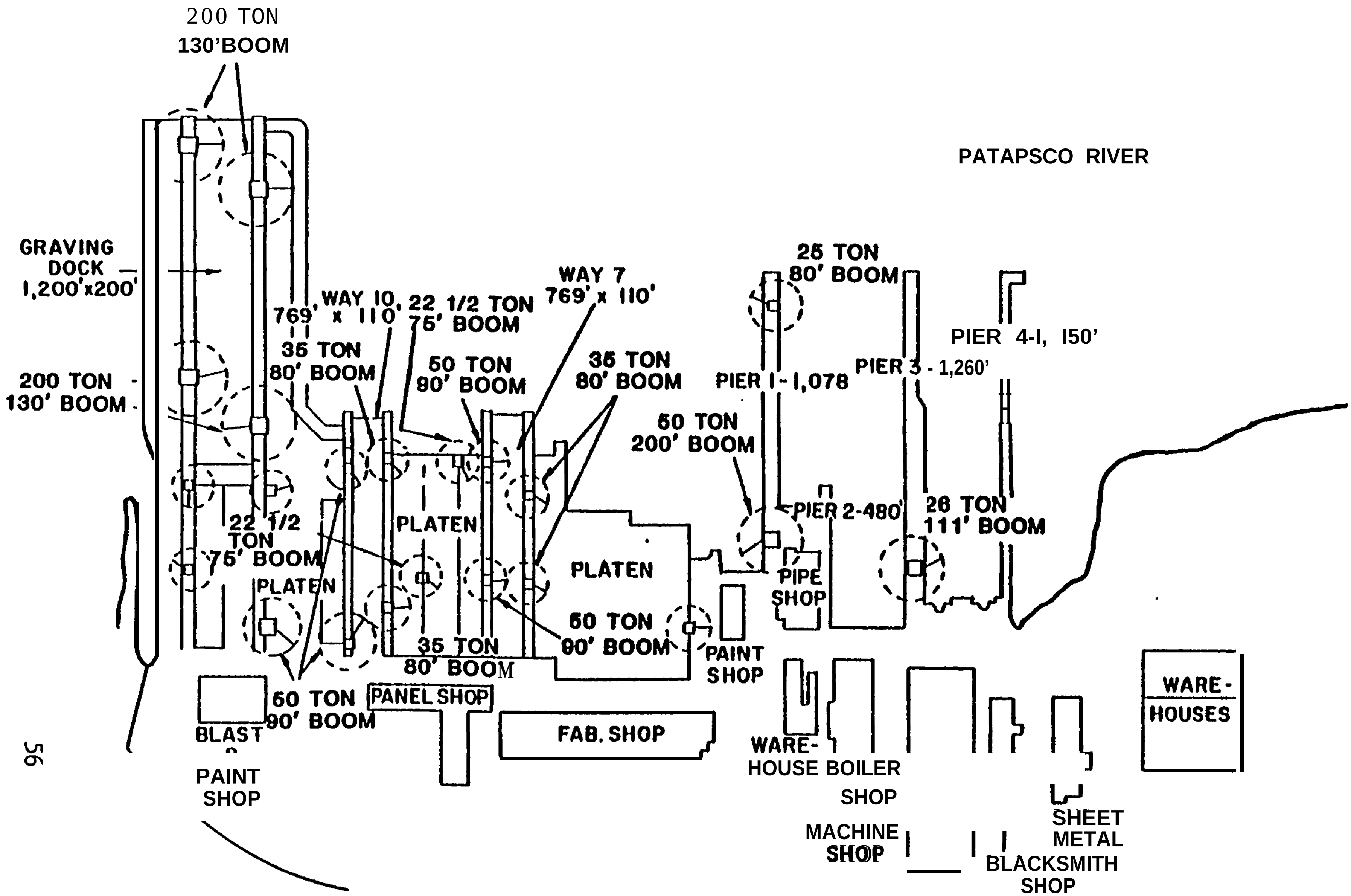
Exhibit 4



BATH IRON WORKS CORP.

Exhibit 5

Exhibit 9

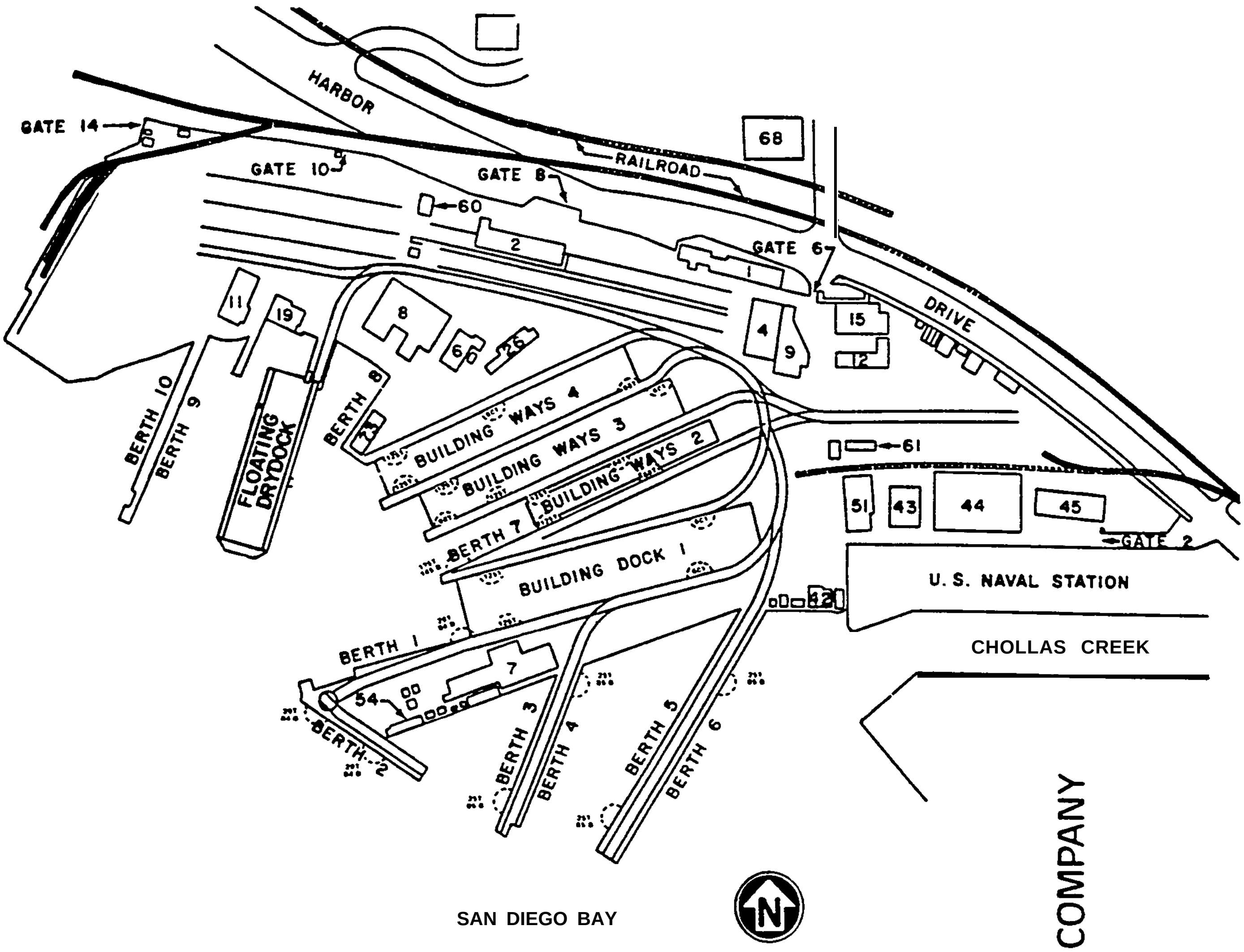


BETHLEHEM STEEL CORPORATION

SPARROWS POINT YARD

Exhibit 23

NATIONAL STEEL AND SHIPBUILDING COMPANY



BUILDINGS

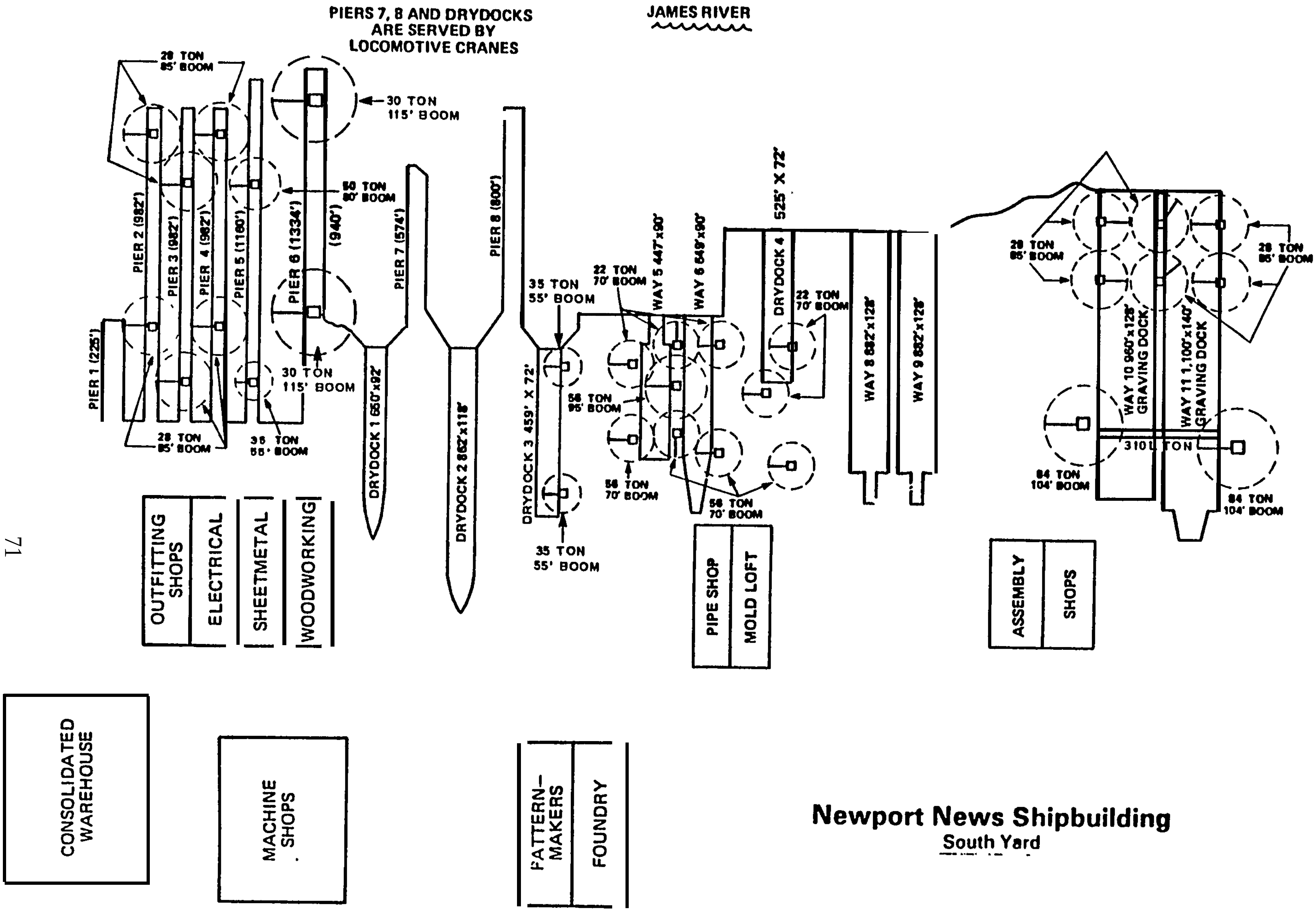
1 ADMINISTRATION BUILDING
2 PLATE SHOP
4 PIPE SHOP
6 ELECTRIC SHOP
7 SHEETMETAL SHOP
8 PRODUCTION OFFICES
PLANNING MACHINE SHOP
9 FOUNDRY
11 STOREROOM
12 MAINTENANCE
15 ADMINISTRATION ANNEX
19 CARPENTER SHOP
26 PLATEN OFFICE
42 YARD CONFERENCE ROOM
43 WAREHOUSE
44 WAREHOUSE
51 ENGINEERING
54 QUALITY ASSURANCE
60 FLAME PLANER SHED
61 WELDING OFFICE
68 INFORMATION SYSTEMS
72 WAREHOUSE
73 BOILER SHOP

DOCKS AND WAYS

BUILDING DOCK 1
1000 X 176
BUILDING WAYS 2
675 X 96
BUILDING WAYS 3
906 X 115
BUILDING WAYS 4
905 X 115
FLOATING DRYDOCK
585 X 170
(140 CLEAR BETWEEN WINGWALLS)
(OPERATIONAL 12 83)

BERTHS

BERTH 1
620 X 30 DEEP
BERTH 2
900 X 30 DEEP
BERTH 3
540 X 30 DEEP
BERTH 4
625 X 31 DEEP
BERTH 5
965 X 35 DEEP
BERTH 6
1090 X 35 DEEP
BERTH 7
350 X 23 DEEP
BERTH 8
300 X 23 DEEP
BERTH 9
825 X 25 DEEP
BERTH 10
775 X 25 DEEP



Newport News Shipbuilding
South Yard

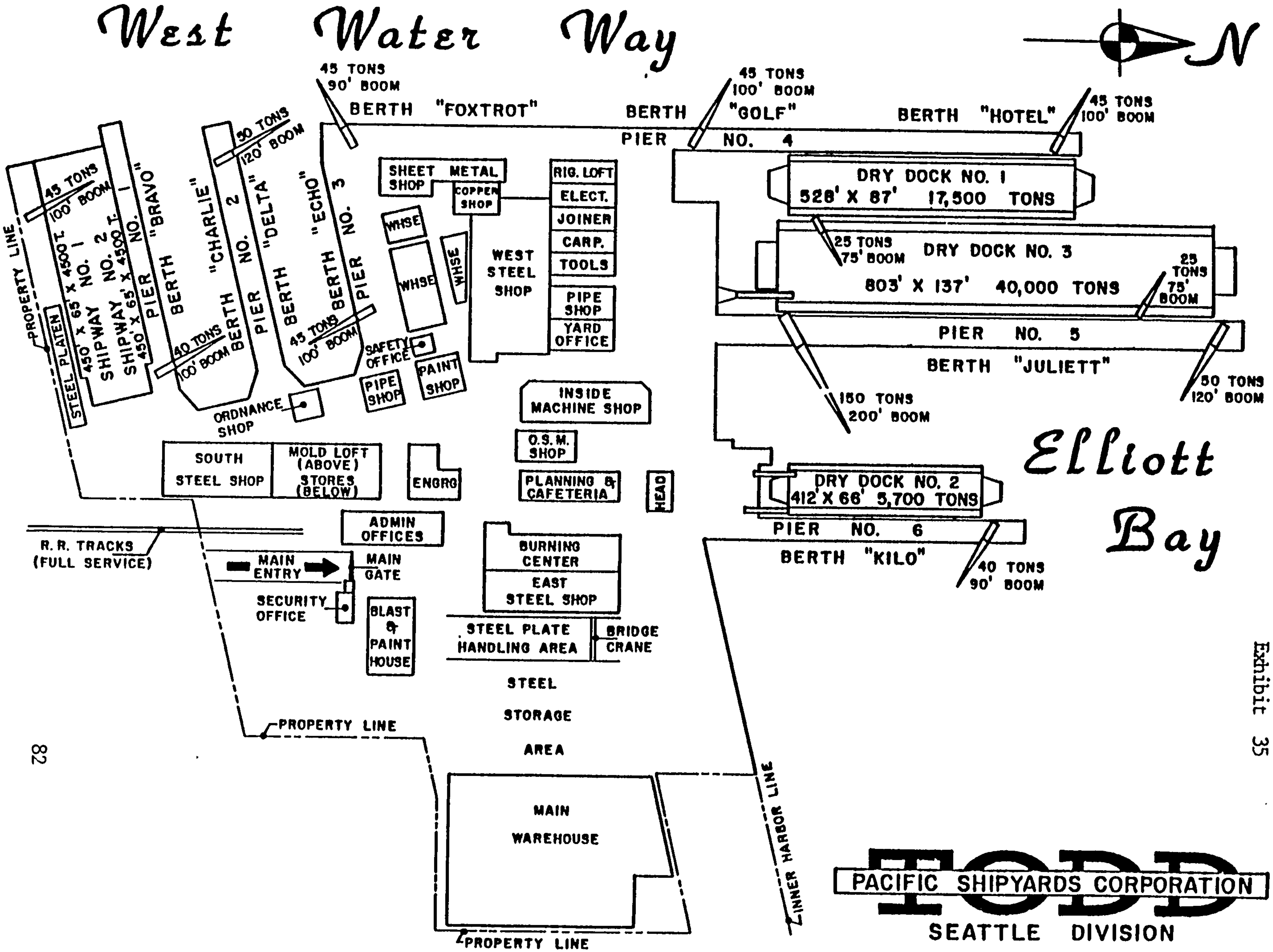
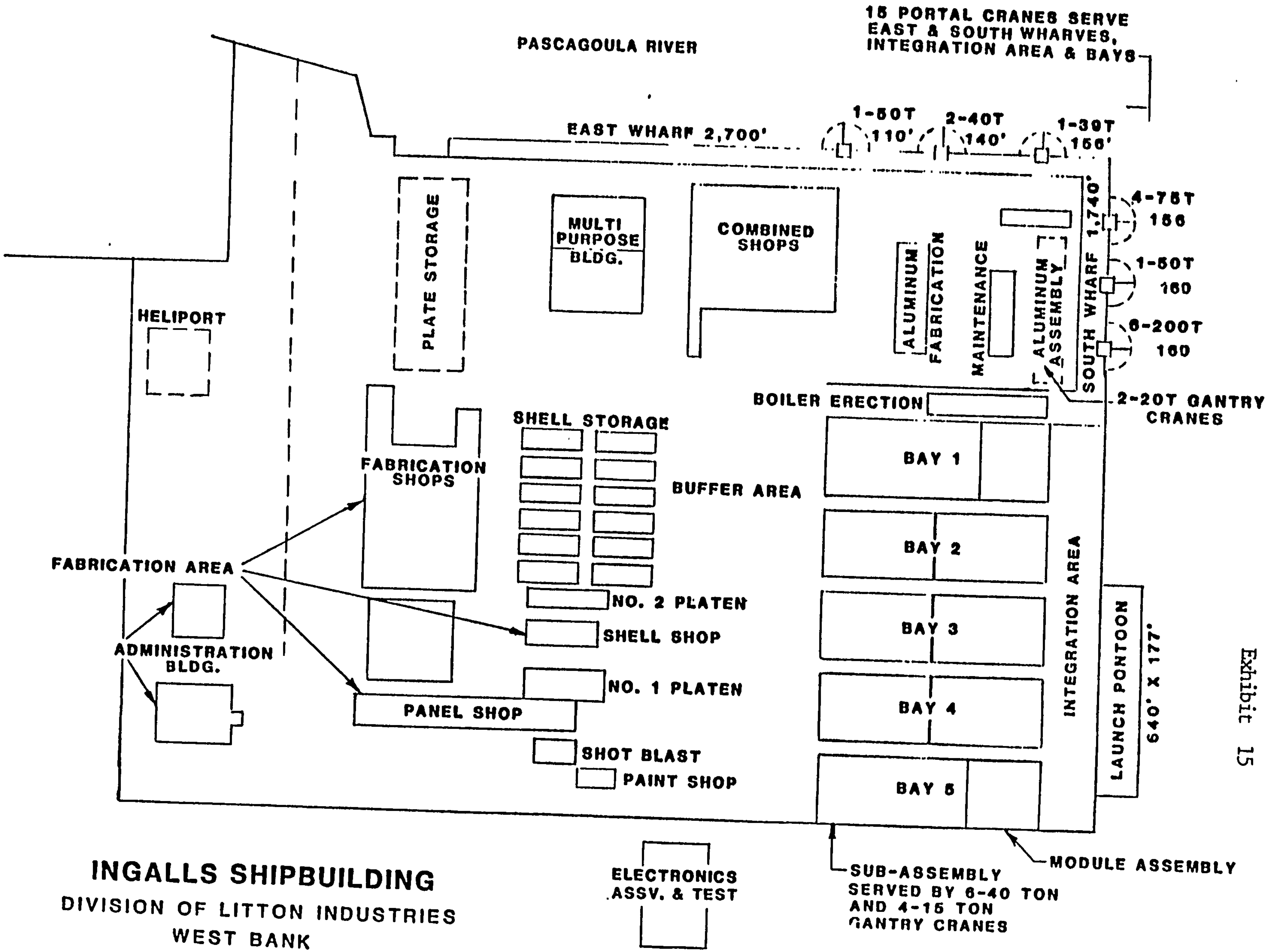

West Water Way
N
45 TONS
90' BOOM
BERTH "FOXTROT"
BERTH "GOLF"
45 TONS
100' BOOM
BERTH "HOTEL"
45 TONS
100' BOOM
PIER NO. 4
DRY DOCK NO. 1
528' X 87' 17,500 TONS
25 TONS
75' BOOM
DRY DOCK NO. 3
803' X 137' 40,000 TONS
25 TONS
75' BOOM
PIER NO. 5
BERTH "JULIETT"
50 TONS
120' BOOM
150 TONS
200' BOOM
Elliott Bay
DRY DOCK NO. 2
412' X 66' 5,700 TONS
PIER NO. 6
BERTH "KILO"
40 TONS
90' BOOM
PROPERTY LINE
45 TONS
100' BOOM
STEEL PLATEN
450' X 65' X 4500 T.
SHIPWAY NO. 1
SHIPWAY NO. 2
450' X 65' X 4500 T.
PIER NO. 1
BERTH "BRAVO"
BERTH "CHARLIE"
50 TONS
120' BOOM
BERTH NO. 2
PIER NO. 2
BERTH "DELTA"
BERTH "ECHO"
BERTH NO. 3
PIER NO. 3
40 TONS
100' BOOM
45 TONS
100' BOOM
SHEET METAL SHOP
COPPER SHOP
WHSE
WHSE
WHSE
WEST STEEL SHOP
RIG. LOFT
ELECT.
JOINER
CARP.
TOOLS
PIPE SHOP
YARD OFFICE
SAFETY OFFICE
PIPE SHOP
PAINT SHOP
ORDNANCE SHOP
INSIDE MACHINE SHOP
O.S.M. SHOP
SOUTH STEEL SHOP
MOLD LOFT (ABOVE)
STORES (BELOW)
ENGRG
PLANNING & CAFETERIA
HEAD
ADMIN OFFICES
R.R. TRACKS (FULL SERVICE)
MAIN ENTRY
MAIN GATE
SECURITY OFFICE
BLAST & PAINT HOUSE
BURNING CENTER
EAST STEEL SHOP
STEEL PLATE HANDLING AREA
BRIDGE CRANE
STEEL STORAGE AREA
PROPERTY LINE
MAIN WAREHOUSE
PROPERTY LINE
INNER HARBOR LINE
TODD
PACIFIC SHIPYARDS CORPORATION
SEATTLE DIVISION

Exhibit 35

Exhibit 15



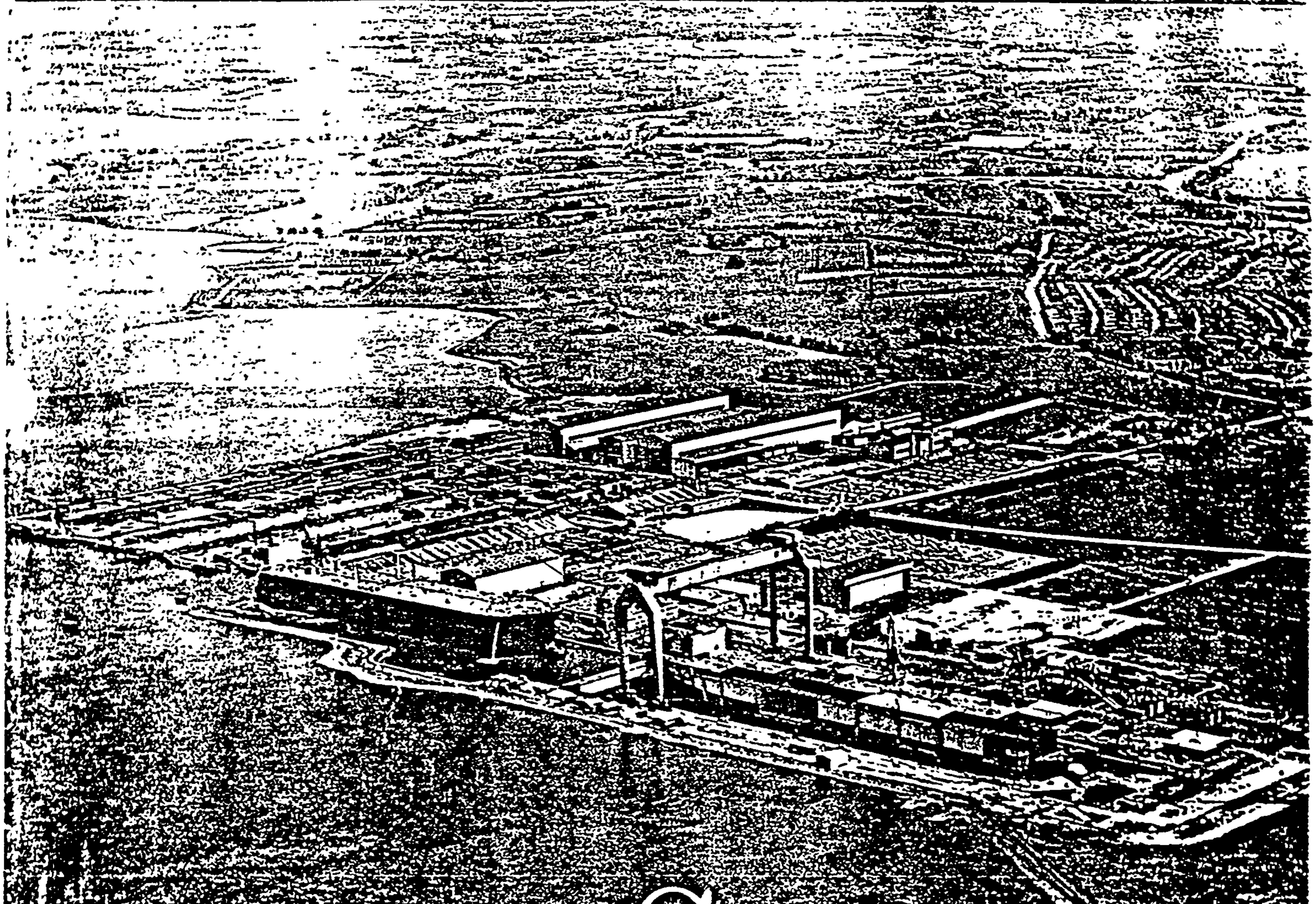
INGALLS SHIPBUILDING

DIVISION OF LITTON INDUSTRIES

WEST BANK

THE LINDØ SHIPYARD

PREPARED BY SHIPBUILDING & SHIPPING RECORD/MARINE WEEK 1974



A FLOWLINE SHIPYARD

SETTING OUT from Funen's ancient city of Odense and travelling some 10 miles towards the small residential and fishing village of Kerteminde on the shores of the Great Belt strait, one does not expect a giant gantry crane 300ft in height surrounded by enormous fabrication shops to suddenly appear in the middle of a green field, with a new supertanker almost ready to steam away.

The situation of the Lindo Yard, in what appears as a green meadow and with little if any other industry within sight, is certainly surprising. The meadow is actually mostly reclaimed land bordering the Odense Fjord.

Some people have formed the impression that in 1957 the Lindo yard arrived in the minds of its originators as a vision in strict accordance with its present 1974 layout, complete with gantry crane and a 330 000 tonner taking shape below its 480ft span.

Nothing could be further from the truth.

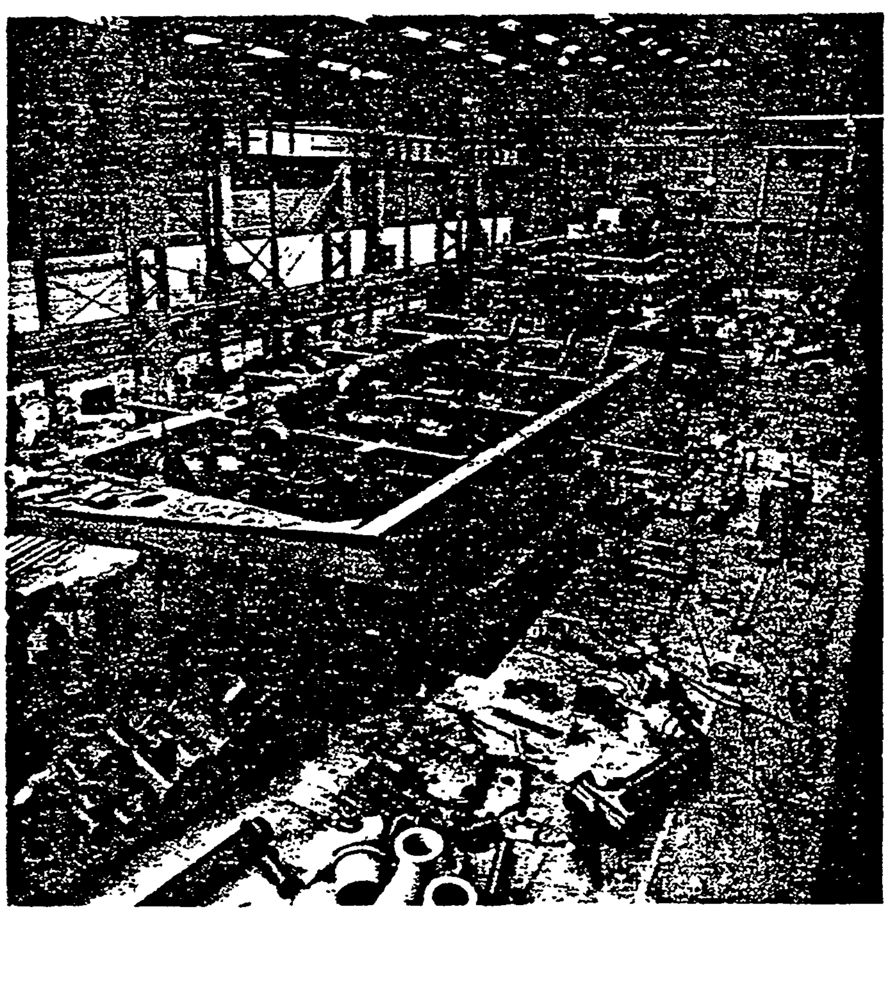
The need for a yard capable of building somewhat larger ships than the "parent" Odense yard's maximum of 45 000 tonners was seen and had to be faced. The vision which emerged in 1957 was to have an area large enough for a major shipyard with room for further expansion, and still have plenty of land on all sides to avoid being hemmed in by other industries, harbour facilities and the like.

The shipyard layout originally arrived at filled only a fraction of the space available. As a matter of policy, plenty of space was left between each facility to permit development.

Lindo, as the reader will realise, has changed a lot over the years and keeps changing.

In the following article, the original layout is merely treated in passing and the emphasis is on the present.

Fitting of machinery components into hull block units



In 1959 production started at the then brand new Lindo Yard. The facilities consisted from the beginning of two shops for preparation and assembling of steel, two building docks, an outfitting basin, and outfitting shops together with canteen and office buildings.

A new large assembly shop of 10 000m^2 and shops for preparation of stiffeners and for marshalling components were inaugurated in 1965. A new stockyard with magnetic cranes, fully-automatic conveyor-lines, and surface preparation plant for plates was then also established.

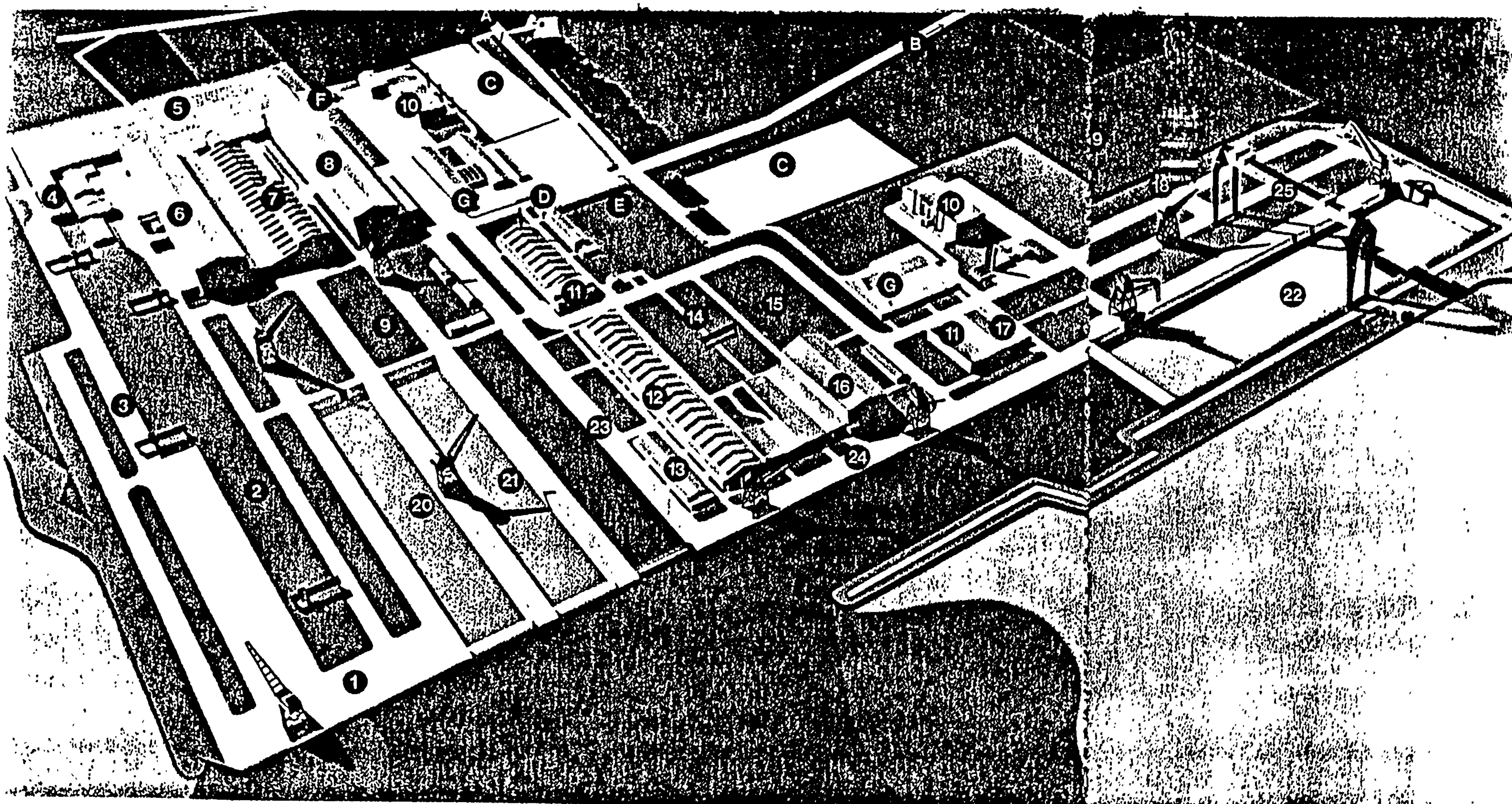
In 1967 a unique new surface preparation shop with two cabins was added, its purpose being to permit the blasting and spray painting of large block units in an air conditioned atmosphere. However, about that time it became clear that with the very rapid growth in tanker size, a building dock capacity for about 200 000 dwt tankers would soon be too small, and it was decided to start a major expansion programme of the production facilities. The main points in this expansion were a building dock for ships up to 500 000 dwt or more, a gantry crane with about 800t lifting capacity spanning the dock, yet another assembly shop of 10 000m^2, and a special line for surface preparation of stiffeners. In addition new cafeterias and so on were constructed, and this phase of expansion was finished in 1969.

In 1971 new and larger shops for preparation of plates and stiffeners were ready to start production together with a bigger blasting/painting shop and enlarged stockyards for plates and rolled sections. A specialised shop mainly for pre-outfitting of engineroom blocks was established in 1972, and in 1973 a panel line and two block assembly lines were installed in one of the already existing assembly shops.

The flow-line shipyard

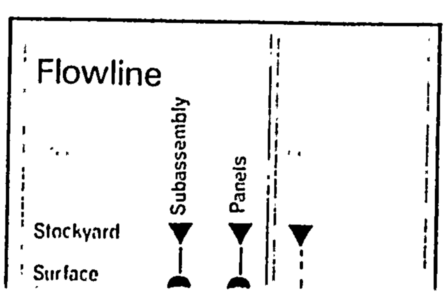
The basic concept for the Lindo Yard has been the flow-line philosophy. This does not mean that the materials are all flowing on conveyor lines, and, for a guest visiting the yard, the pattern of flow may not be immediately apparent.

Flow-line at Lindo means that the assembly procedures take place as a



smooth progress from the material stockyards to the finished ship, each process being carried out in shops or areas specially organised to suit their individual purposes. The principle is schematically shown in the diagram on the right.

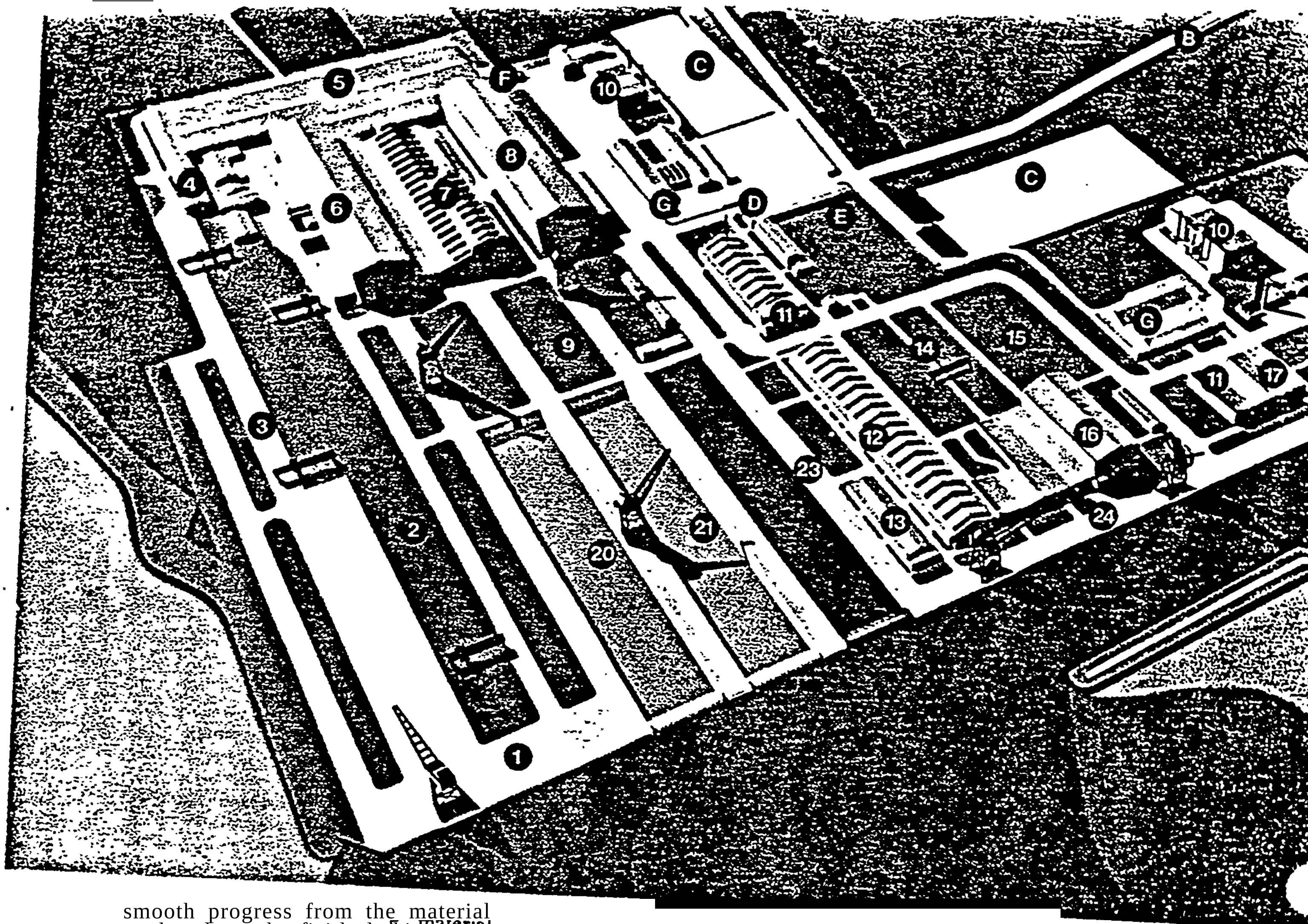
Physically, the result of this philosophy is that there is a very clear separation between individual areas of manufacture and that each manufactur-



first the block manufacturing area, which has the task of delivering blocks pre-outfitted and painted, and second the erection and outfitting area including the building dock and final outfitting/testing.

The purely producing departments would be unable to obtain their high output without close and efficient support from service departments, i.e.

Above, bird's-eye view of the Lindo shipyard 1974



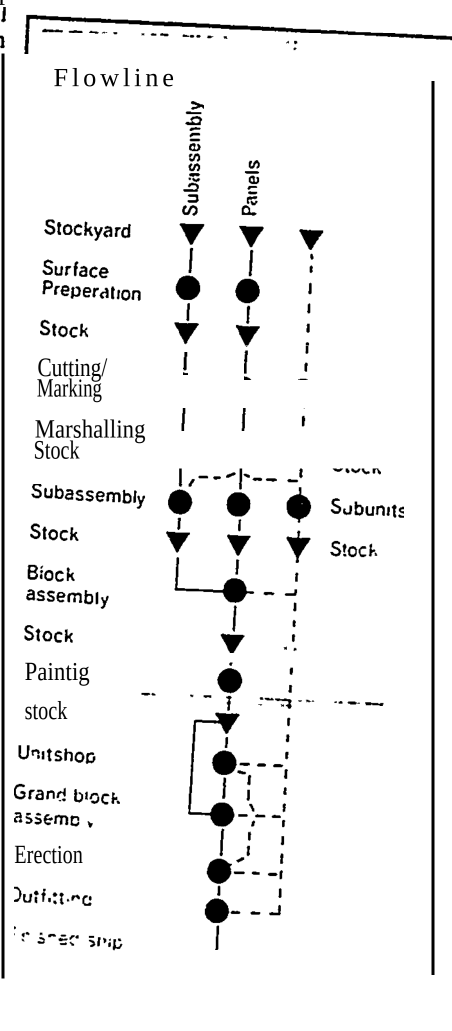
smooth progress from the material stockyards to the finished ship each process being carried out in shops areas specially organised to suit the individual purposes. The principle schematically shown in the diagram on the right.

Physically the result of this philosophy is that there is a very clear separation between individual areas of manufacture and that each manufacturing area has a buffer stock in front of it. The resulting layout means that the production facilities cover a large area.

One of the principal demands of the "flow line philosophy" is for careful control of the many intermediate stock: so that they are minimised just to the point where they are able *to* fulfil theit mission. to regulate the production process and secure an even work load inside the manufacturing areas.

Previously it has been normal practice in shipbuilding to distinguish clearly between steelwork and outfitting work. This way of thinking was abandoned at the Lindo Yard years ago. The philosophy at Lindo is now that every part of the ship is a complex system consisting of steel structure as well as outfitting.

Following this concept, the assembling of steel. i.e. sub-assemblies. blocks and outfitting items. takes place *in* the earliest possible phase as seen from the diagram. Thid mesn. that the yard lay-out consists of two main areas.



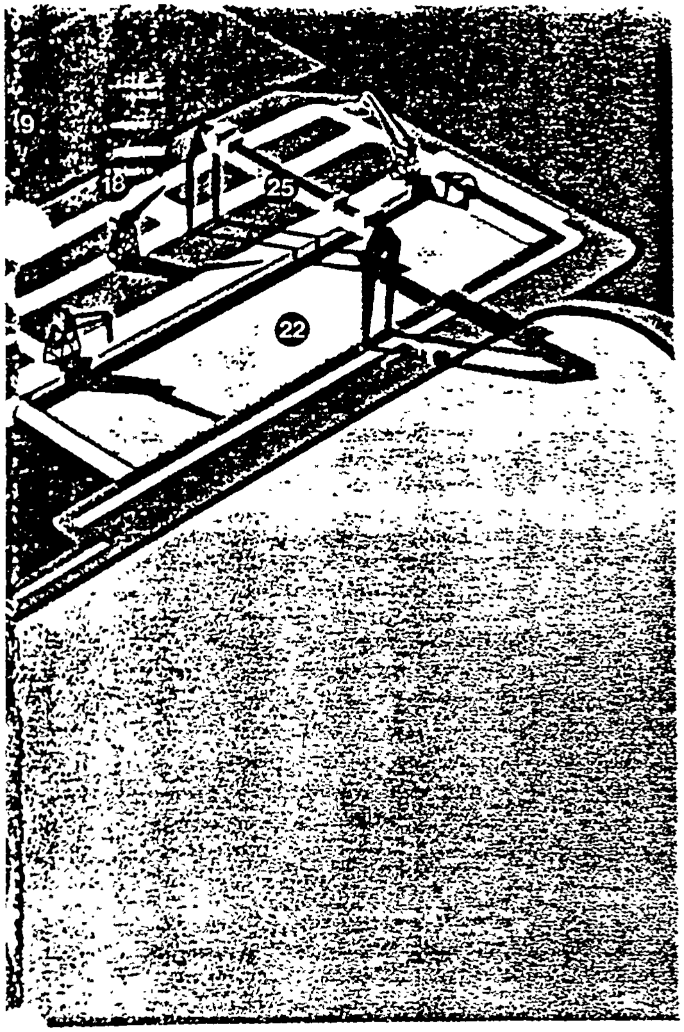
first the block manufacturing area, which has the task of delivering blocks pre-outfitted and painted, and second the erection and outfitting area including the building dock and final outfitting testing.

The purely producing departments would be unable to obtain their high output without close and efficient support from service departments, i.e. dcpartments such as maintenance. general stores. transportation, logistics. and staging. To achieve this, the philosophy has been to allocate the necessary urea.. for the different kinds of support centres as close as possible to the main manufacturing areas.

Design for production

The basis for optimum utilisation of the production facilities is efficient co-operation between the design and production departments. Only then is it possible to maintain from the earliest design phase a process of finding optimum solution in which the production parameters are included. optimisation generally takes place in two steps.

The first step is a rough analysis of the mutual influence between main dimensions, hull form, structure and engineroom arrangement and the production facilities. This results in outline proposals for ...



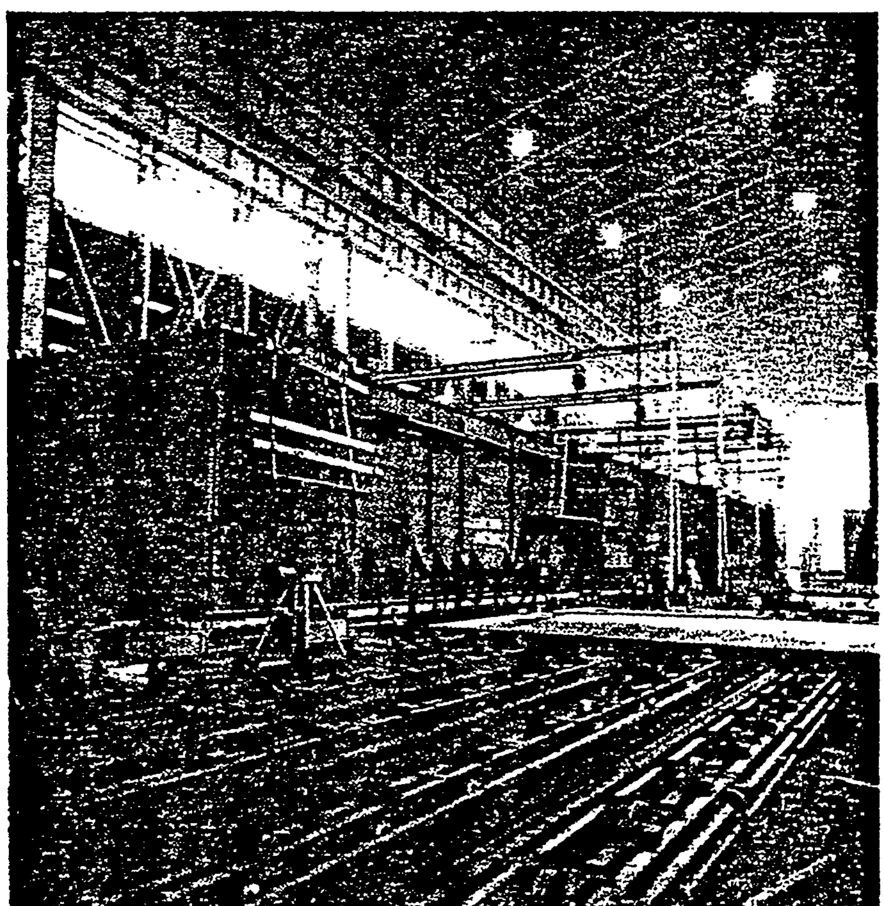
KEY

1 Material Receiving Quay
2 Plate Stockyard
3 Section Stockyard
4 Surface Preparation
5 Edge Preparation
6 Assembly of straight Hull Block Units
7 Assembly of Hull Sub-assemblies
8 Assembly of curved Hull Block Units
9 Storage of Hull Sub-assemblies
10 Surface preparation of Hull Block Units
11 Goods reception and store
12 Outfitting shops
13 Services (water, compressed air, oxygen, gas, etc)
14 Pipe stockyard
15 Storage of outfitting components
16 Fitting of machinery components into Hull Block Units
17 Dock Office
18 Storage of Hull Block Units
19 Staging Assembly and Stockyard
20 Building Dock I
21 Building Dock II
22 Building Dock III
23 Outfitting Basin
24 Outfitting Quay
25 Gantry Crane

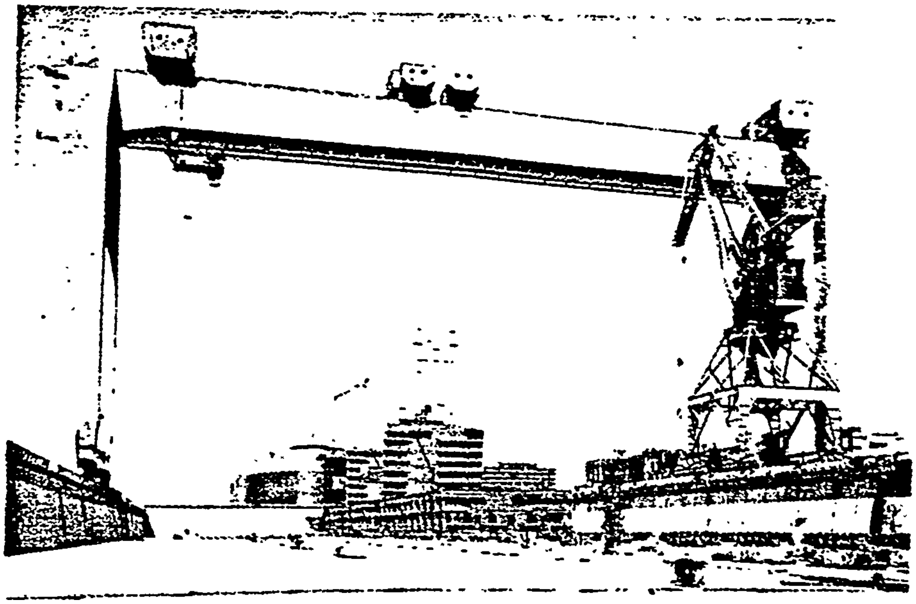
A To Munkebo Village
B To Odense
C Car Park
D Main Gate
E Administration
F Maintenance Shops
G Canteens, Baths, etc

Above, bird's-eye view of the Lindo shipyard 1974

Below and right: Panel and block unit assembly line. Specialised stations. each with its own clearcut purpose, are the keynote



From keel laying to delivery in sixteen weeks



Week 1

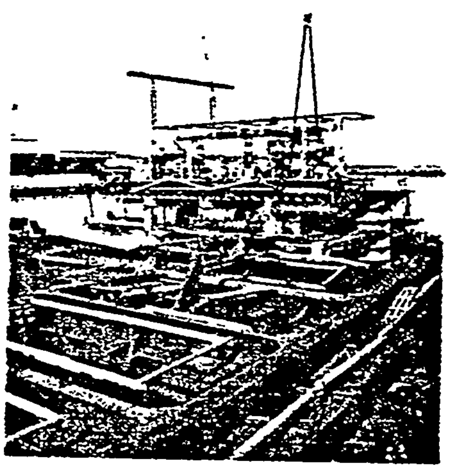
The second step comprises a detailed analysis of a more final design and the relevant production areas. and may result in extensive proposals for re-adjustments in production and or facilities. This step covers in time a period of approximately two years and one of the main targets of the pro duction departments will be 10 reduce the number of elements.

While the final result of the analysis will. of course, always be a cons-promise between design and produc-tion criteria. there is no doubt that the described procedure is a valuable tool in the creation of a design which has a high product quality and at the same time is well suited for production.

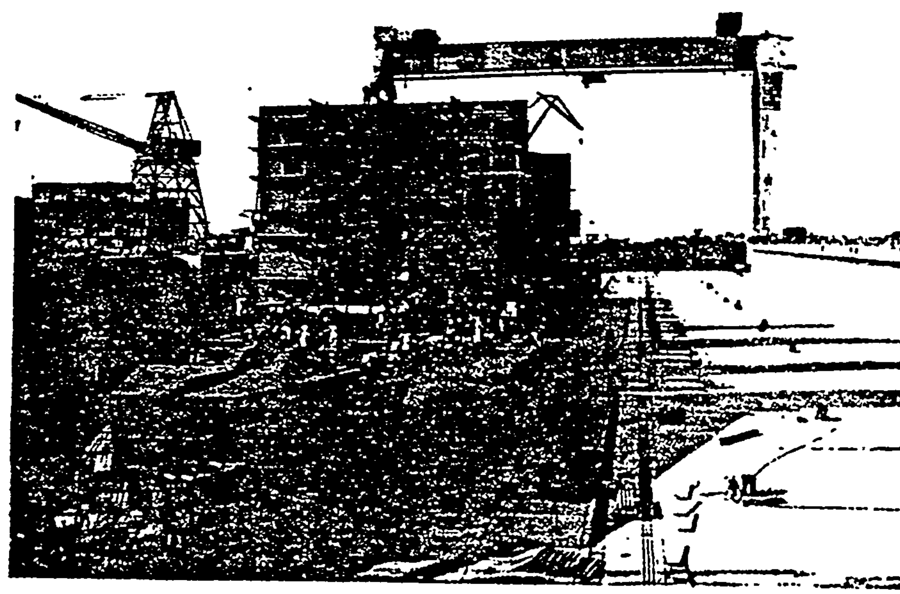
it should perhaps be said that the Lindo policy is to build hulls suited to the production plant and in not too small while while trying to remain flexible to meet owners requirements in important details such as machinery and accommodation.

Planning and control

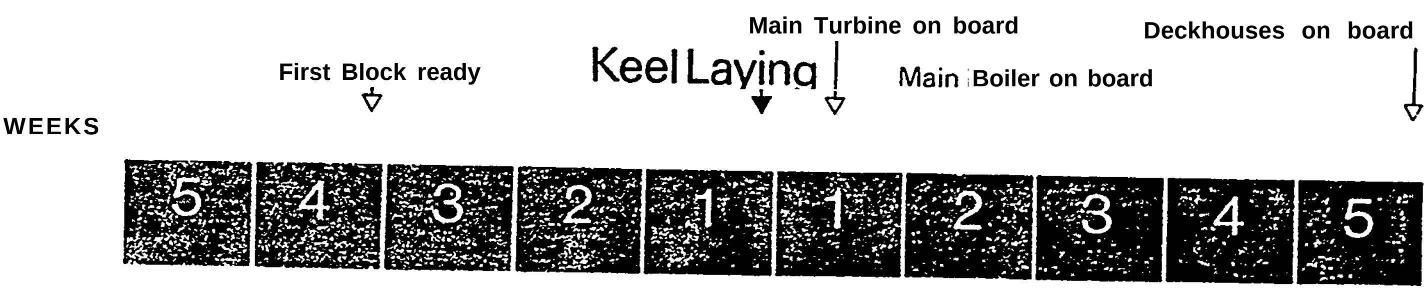
Planning and control are key points for a yard which wants to assemble large tankers as fast as Lindo is doing. The philosophy behind the systems at the Lindo Yard is that planning and control can only operate with success if the communication lines are short and direct. Following this concept, the



Week 2



Week 3



planning and control operatuibs are decentralised to a very largc extent and consist of small groups placed very close to the production and to the problems.

This, of course. does not prevent the yard from using computerised methods for planning and control. and the yard is continuously working on the improvement of such systems and development of new ones at every level.

Capability in Performing a good quality-control is essential in modern shipbuilding to reduce costs and building time. Quality control work has been intensified at Lindo during the last couple of years with the aim of establishing control specifications for the products in the different phases of manufacture. The control function embraces outfitting as well as steel work.

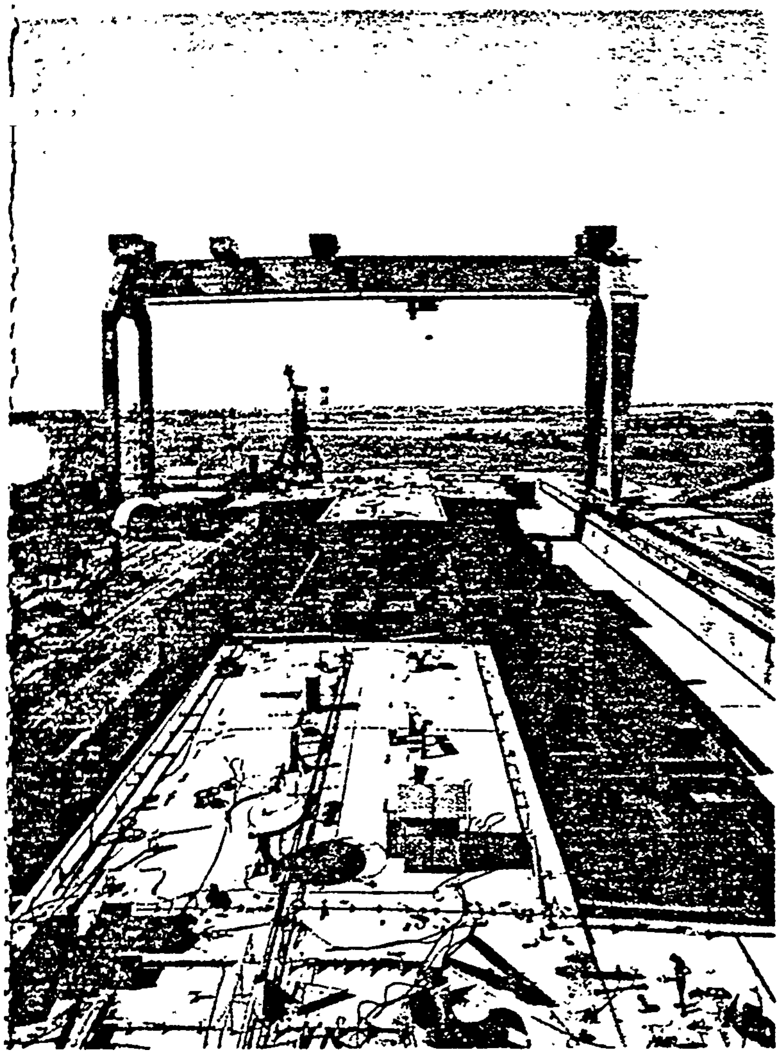
Mechanisation and automation

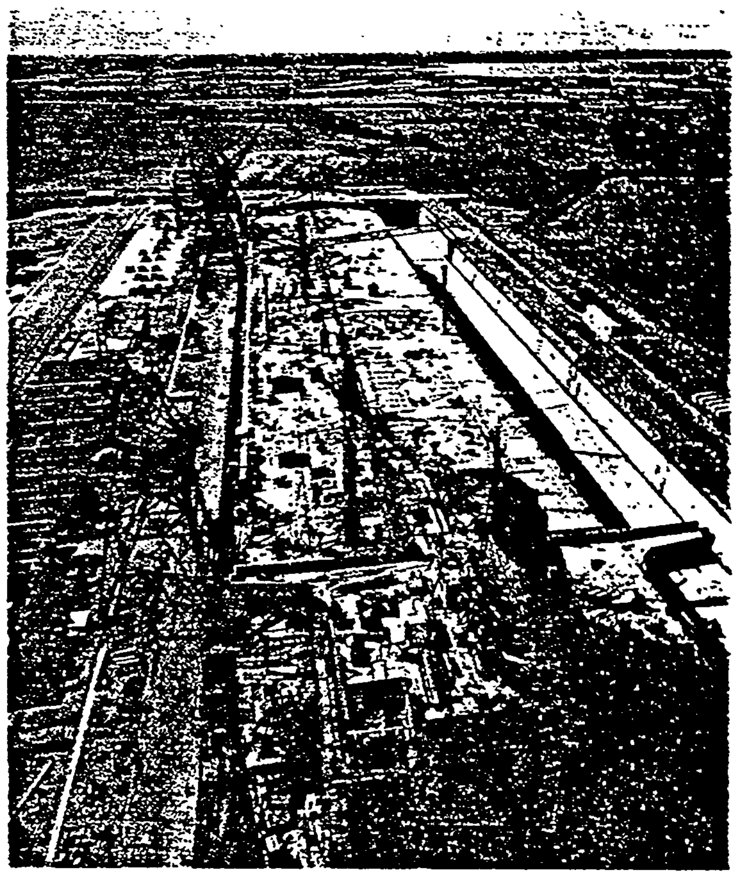
Like many other shipyards in the world today. and Lindo has been faced with the problems of labour shortage and rapidly increasing wages. The only remedy seems to be mechanisation and automation.

Demands for advanced equipment in a shipyard are. beyond functional requirements. reliability and a certain degree of flexibility. These demands very often result in equipment which is very capital-intensive. Therefore it seems as yet unrconomnic to carry out a too extensive mechanisation and automation in every area of production

However. there arc fields. such as cutting. welding and panel fabrication. where advanced equipment is found to be advamtageous not only because of the direct labour savings. but also because of indirect savings resulting from better quality and accuraacy.

Developments in corrosion control systems and the requirements of classification societies have resultcd in more strict painting Specification for large tankers. Weather conditions in Denmark are rather unstable and only seldom give the right conditions for applying advanced paint systems for ships. Therefore. the Lindo Yard was the first company to establish special





Week 6 Week 9

Erection last Block — Floating — Fire on boilers — Start machinery trials — Departure — Delivery

6 7 8 9 10 11 12 13 14 15 16

Production Facilities

Fabrication area

Stockyards

A1most all steel materials arrive at the yard by ship. After unloading. the materials are stored in specialised stockyards, one for plates and one for rolled sections. Plates are carried from the quay to the appropriate storage area by fast magnetic overhead cranes while the rolled sections are carried partly in trestles and partly by special cranes.

From the stockyards, plates and sections are conveyed by automatic conveyor lines through surface preparation plants to the edge preparation shops.

Preparation **shops**

The preparation shops are divided for plates and stiffeners. In the plate shop all activities concerning flame cutting and marking of plates are concentrated and the largest cutting machine in this shop is numerically controlled.

The stiffener shops undertake activities such as marking, cutting and bending. Materials handling in all shops is carried out by trolleys and magnetic overhead cranes.

Assembly shops

In the sub-assembly area transvere and webs ***are*** assembled in permanent jigs with built-in alignment stops.

The specialised panel block assembly shop includes a panel line with two welding carriages each with two banks of three electrodes. For the butt welds of the flat panels two-sided welding is invariably applied. After the panel line. assembly is completed in dual block lines of assembling and welding of blocks. The other assembly shop specialises in fore and aft end blocks and here lifting capacity of up to 320 tons is available.

Painting-shops

The **next step** in the "flow-line". is the painting shop with equipment for shotblasting and spraying with all types of paints. Air temperature and humidity are controlled by air conditioning plants.

Prefabrication area

This area includes a series of smaller and bigger shops such as machine shop, pipe shop, carpenter and blacksmiths shops.

Erection area

Unit shop

The new block unit **outfitting shop** provides excellent conditions for the assembly of all kinds of units. It is big enough to permit outfitting of engineroom blocks and assembling of big pipe units.

Welding area

Alongside the building dock is the grand assembly area where single blocks we joined to make double blocks with weights of 500-600 tons and where. at the same time, as much outfitting work as possible is carried out.

Building dock

The main dimensions of the building dock are 415 x 90m. The dock. which may be lengthened if necessary without difficulty. is served by an 800-ton gantry crane and several tower cranes with lifting capacities from 50 to 100 tons.

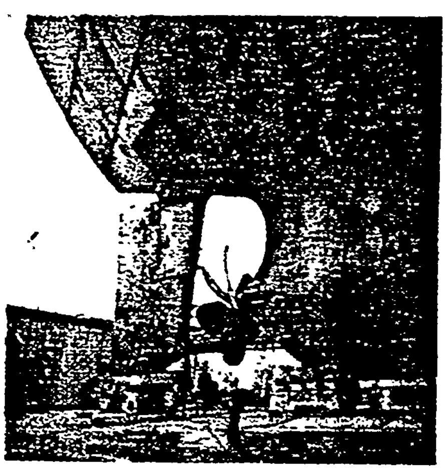
Powerful dock pumps empty the dock in approximately 14 hours after floating and undocking each new hull.

Services

The services area comprises workshops for maintenance. logistics and warehouses.

blasting and painting shops, where painting of entire blocks up to 320 tons in weight is carried out under temperature and humidity control. These shops form a very important part of the production flow and ensure paint work of the highest quality.

Staging has increased tremendously with the larger tankers due to bigger dimensions and increased number of tanks. The reaction at Lindo is to incorporate staging design and layout in each new **design. Important** savings have been achieved, partly by the choice of suitably sized hull **block divisions** and partly by designing parts of the steel structure to function as permanent work platforms, thus replacing staging. In addition, a very inten**sive** programme is continually being carried out at the yard with the purpose of reducing staging costs while increasing safety in all areas.



Pre-outfitting units

As previously described in this article, fitting-out activities are gradually being spread out over the building process and hence over the entire assembly area to meet the requirements of pre-outfitting at the earliest possible time.

Most important of all was to develop the unit principle, i.e. smaller units consisting of only two to three outfitting components, which join up to form bigger machinery units and are finally united into heavy and complex platform and engineroom units. Application of this concept has made it possible to avoid or greatly reduce the unfavourable concentration of work during final outfitting. and in turn has made possible a considerable reduction in total building time.

The requirement for a short dock cycle is that a minimum number or blocks are to be handled. i.e. maximum block weights in relation to crane capacity. A suitable hull block subdivision has been the solution to achieve this goal.

In the tank section the yard applies the panel block system as panels have been found to give the best possible utilisation of production facilities and at the same time give the easiest joints in the budding dock. At the :ore and aft ends the hull is divided in the largest possible three-dimensional blocks.

One of the characteristics of the Yard is the application of the " one-dock ". system with only one ship in the dock at a time.

lnvestigations have proved that the steps taken to ensure the spreading of the activities have given the necessary balance in work load and so the yard has found no great attrac**tion** in the semi-tandem-system. Further. it is found that the development towards bigger ships is **in favour** of the one dock system. In the building dock itself the activities are spread out by using a four-point erection system. i.e. erection is carried out starting from the pumproom and simultaneously starting from the clean ballast tanks, hence permitting ***work*** to proceed in four directions.

Future **possibilities**

In conclusion it may be stated that the production facilities at the Lindo Yard constitute a \vell balanced and flexible production unit. suited also **for its future tasks. Already the dctailed planning of** the necessary adjustments for the next generation of tankers, Of around 500 000 dwt is well underway.

However. ii is important never to forget that a shipyard is a complex system consisting of both men and facilities. The facilities alone are nothing but a tool.

RECENT DEVELOPMENT IN METHODS OF PRODUCTION

The large scale achievements mentioned briefly above which are localized in Europe and Japan, are the products of recent development in shipbuilding techniques; the first achievements of this new generation only appeared at the beginning of the present decade (ARENDAL and CHIBA, 1963). A few years previously, the idea of prefabrication began to spread, the first significant manifestation of the new priority given to economic construction methods over considerations concerning the intrinsic quality of the individual ship which had hitherto prevailed. This process of development was to culminate in the I Present transformation of production facilities and in the realization of the importance of rationalization and modernization problems.

The new importance given to economy in construction has been directed into the following two main channels:

. Mass production by introducing highly specialized facilities with very high capacities.

l Optimization of production by research into the most economic methods at all stages" of fabrication.

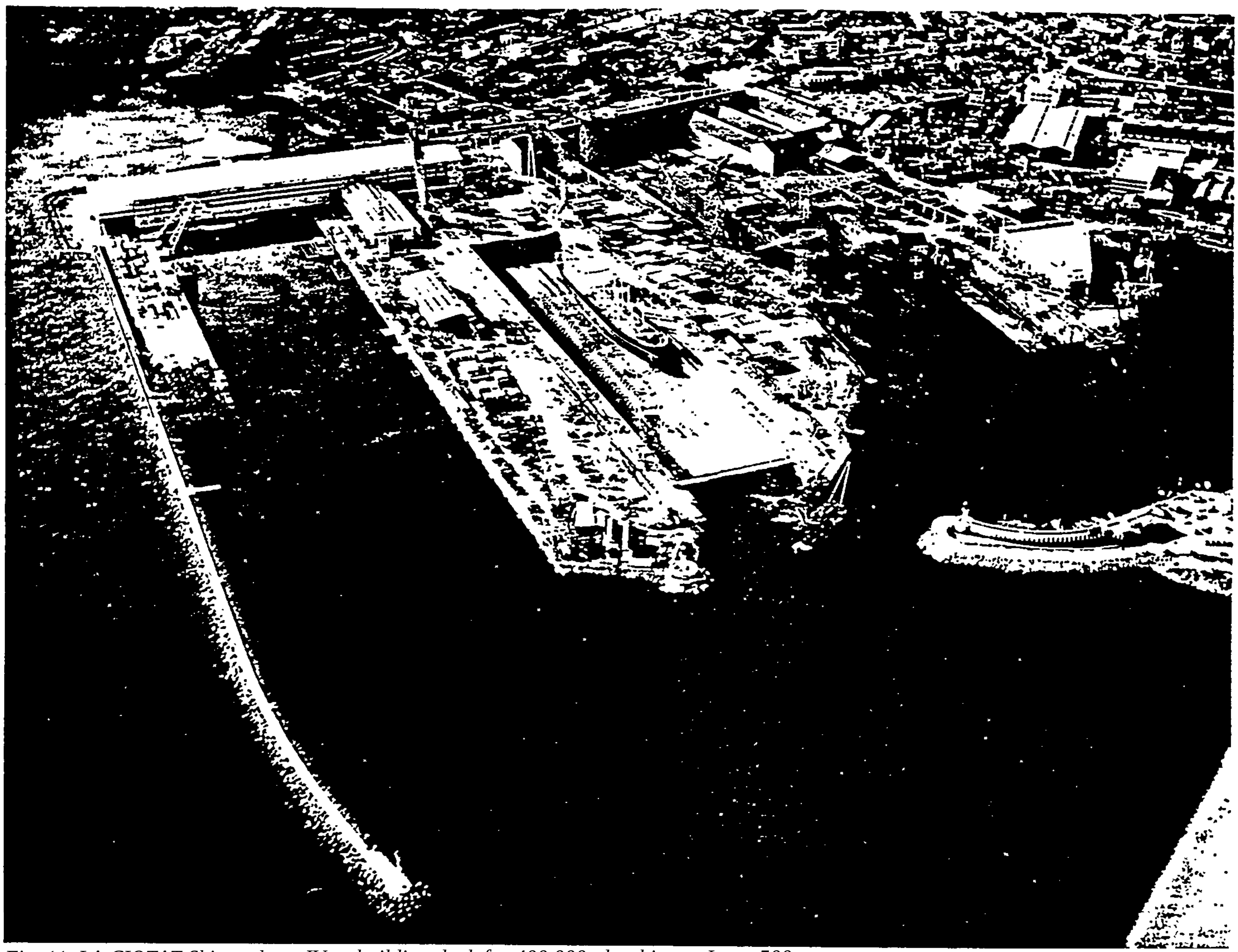
The turn towards mass production is simply the expression of the necessity to produce on a very large scale in order to be competitive; it has had the following Important repercussions on shipyard design and equipment:

l Appearance on the scene of new shipyards Specialized in the construction of giant ships (CHIBA. I. H. I.. YOKOHAMA. SAKAI, SAKAIDE in Japan. ARENDAL in Europe)

l Increase in production capacity by introducing new specialized units into an existing shipyard (NAGASAKI and KURE in Japan; in Europe. SAINT-NAZAIRE. LA CIOTAT. MONFALCONE, BELFAST, BREMEN, MALMO) (figure 11).

l Breaking down of the construction process into unit fabrication sequences in specialized shops or locations (materials preparation, prefabrication, fitting out. pre-assembly, painting, etc.).

l Development of pre-assembly in large tonnage units in order to reduce final assembly operations which form bottle-necks and limit productivity.



Fig, 11. LA CIOTAT Shipyards — IVew building dock for 400,000 tdw ships. usIng a 500-ton gantry crane.

- Utilization of large capacity production equipment mainly in the field of oxy-cutting, welding and handling (gantry cranes, bridge cranes, conveyor systems).

The optimum utilization of production facilities, which has become more essential since the introduction of high capacity equipment with high amortization costs, has led to developing rationalization and forecasting methods.

The breaking down of the process of construction into units mentioned above has been accompanied by sequence work preparation based on workload equalization research at all stages of production and by performance of the operations on the basis of a precise schedule.

This is why development took place both in shop fabrication to eliminate hazards inherent in outdoor work and the scheduling and workload equalizing difficulties associated with it, and in mechanization, which reduces fabrication irregularity caused by numerous manually performed operations and discontinuous handling.

This rationalization drive bears mainly on the following items:

- Reduction of requirements regarding stocks of raw materials and products at the various stages of fabrication.

- Optimum utilization of automatic machines for marking off and cutting raw materials.

- Development of pre-prefabrication. i.e. the rational preparation of subassemblies for feeding the prefabrication lines and facilitating the pre-assembly work.

- Introduction of prefabrication lines where the assembly of the prefabricated units is effected rationally and automatically.

- Development of pre-fitting out operations. i.e. optlmum breakdown in sequence of fitting out operations. making pre-assembled units, assembly at the hull prefabrlcation and pre-assembly stages.

- Simplification of the final hull assembly work. by use of automatic machines. improvement of the sizing accuracy of the pre-assembled units, workload. scheduhng and equalization, extensive preparation of final fitting out operations.

Finally, another feature which can be ascribed to the optimization of production facilities is the recent introduction of digital computers in the following fields:”

- Checking of production shop by shop, including production basic data analysis. aim setting. process follow-up and performance check. The production checking integrates production facilities as they exist and the data resulting from the examination of the following points.

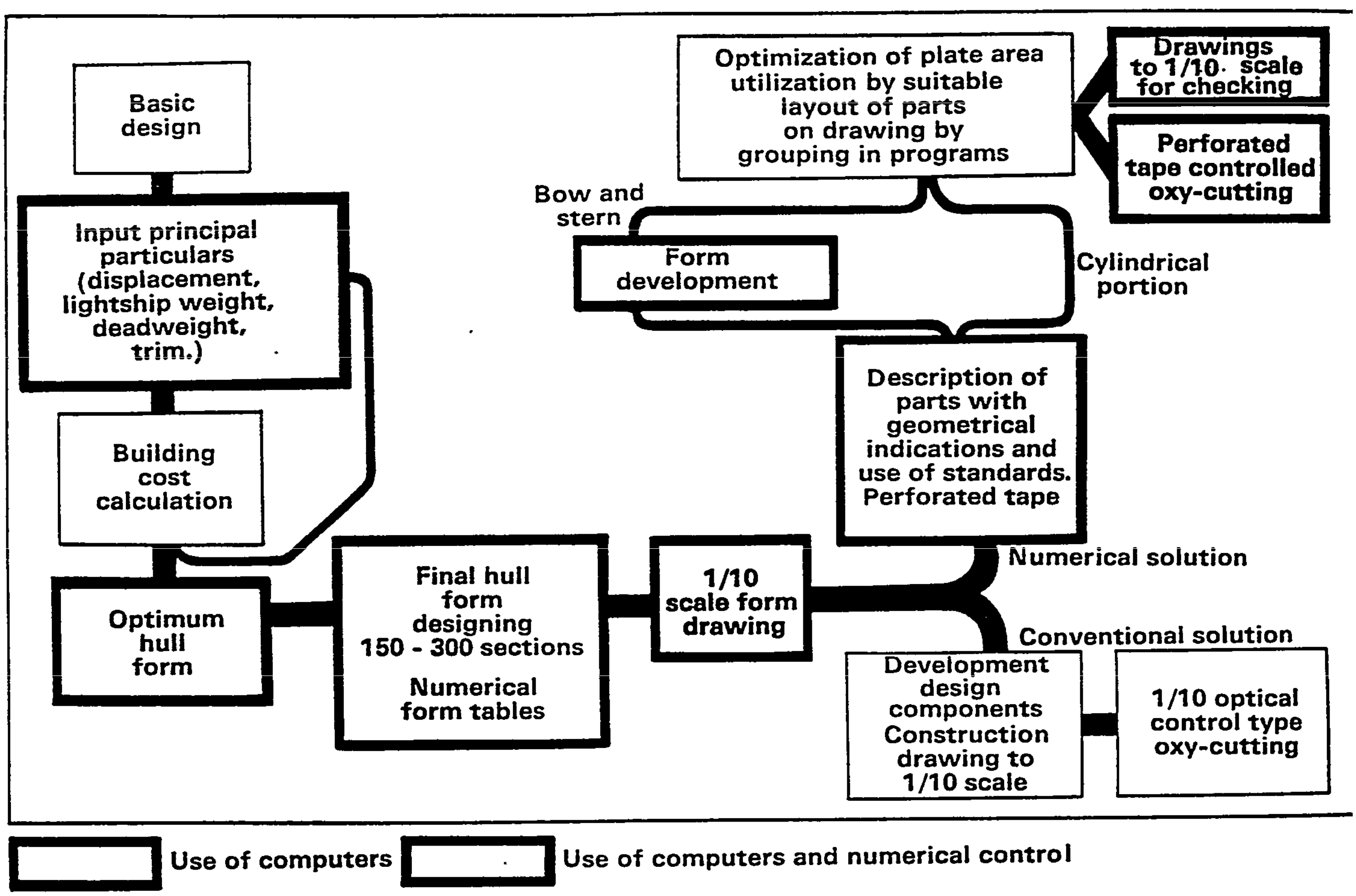


Fig. 12. Use of computers for hull form designing and numerical control of oxy-cutting machines.

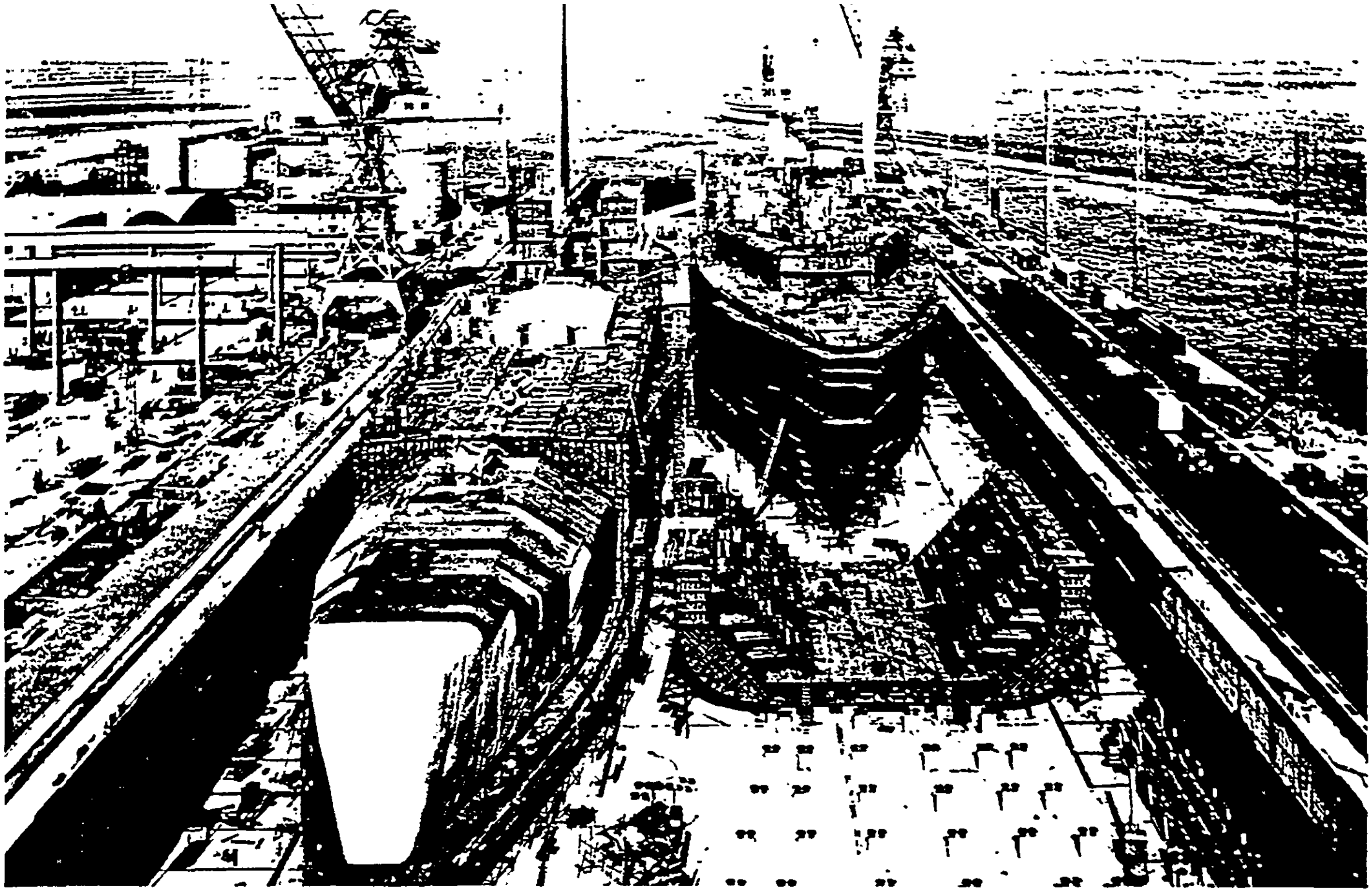


Fig 13 Building three gas carriers in the KOCKUMS building dock

● Preparation of the program and the completion procedures for each ship.

● Direct control of production equipment (confined for the time being to cutting machinery).

It should also be noted that the use of computers in large modern shipyards is not confined to production but developed initially at the engineering stage, for scientific calculations (optimization of vessel and hull characteristics, structure calculation, etc.). hull design (strake fixing), scaling shop drawings to 1/1O (using an automatic drawing table for the last two operations) (figure 12).

It is probable that in the next few years the use of computers in shipyards will extend to other fields: for example numerical control will be generalized, optimization procedures will develop and checking will be reinforced.

HULL ASSEMBLY - GIANT DOCKS AND PRE-ASSEMBLY IN UNITS

At the end of 1969, 31 installations will be capable of building vessels of over 200,000 tdw. one-third being located in Japan and two-thirds in Europe Twenty of them will be building docks (8 in Japan. 12 in Europe]

In spite of the difficulties encountered when laying down the first 200,000 tdw vessels, a good many shipbuilders contemplate continuing this method of laying down for ships of this slze. Some of them, it is true, get round the difficulty by laying down ship halves and then assembling them afloat or in the dock (NAGASAKI. NDSM, AG WESER VEROLME).

The development of building docks and the disappearance of slipways. at any rate for the construction of very large vessels are linked to the question of the greater facility In construction and the saving of time they afford.

The buildlng dock however represents a very heavy Investment which must be rendered an economic proposition by building as many vessels in it as possible (figure 13). The objective of the shipyard is then to reduce the null assembly time to the greatest possible extent by putting extremely heavy prefabricated elements into the building dock. These elements are panels or blocks, assemblies of several panels, which are handled

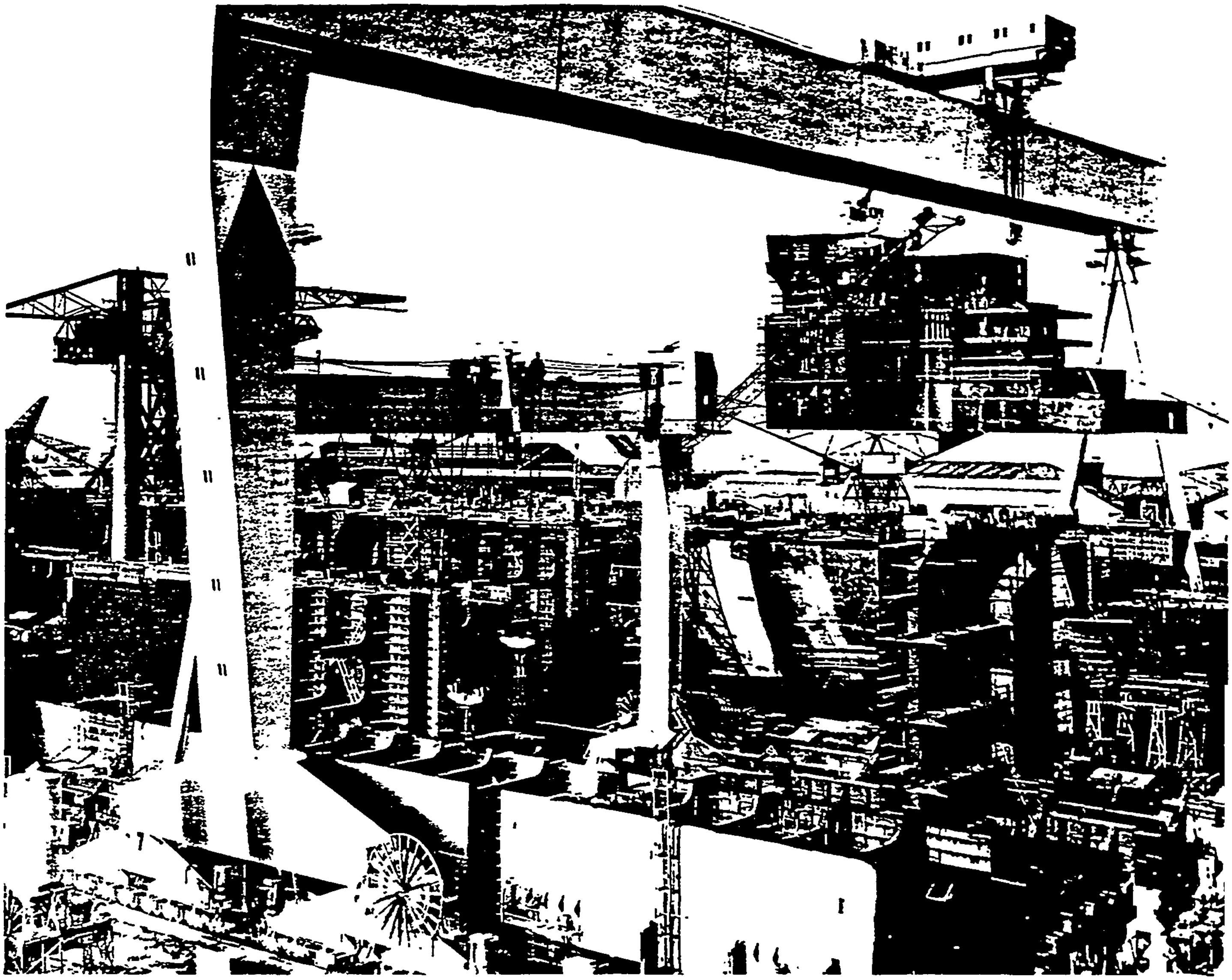


Fig 14. Block assembly is carried out at Saint- Nazaire by a 240-ton gantry crane in the block pre-assembly zone located alongside the building platform The 750-ton gantry crane is used to transfer the blocks to this platform.

by means of very powerful handling equipment, usually gantry cranes, which now have capacities as high as 1.000 tons (O DENSE) and even have spans of 140 meters (BELFAST, CHIBA). Twenty or so building docks and berths will be equipped with these in 1969.

The time saved in hull construction will make it possible. for instance, to complete the assembly of a 200.000 tdw class vessel representing a throughput of over 30,000 tons of steel in 75 days.

The problem of optimum panel and block size determination is a complex one which involves prefabrication and hull assembly costs, investment in handling facilities and shops, the size of the ships to be built, etc. The recent installations in Japan and Europe have a maximum panel size ranging from 100 to 250 tons and the weight of the blocks is between 400 and 1,000 tons. In the case of a shipyard building vessels in the 200,000 to 250,000 tdw range, the maximum weight for the optimum panel/block assembly would be 200 to 600 tons, i.e. approximately twice the average figures for the 250 panels and the hundred or so blocks forming the hull.

Some building docks have a length which is designed fo using the semi-tandem type construction method (SAINT. NAZAIRE, HARLAND & WOLFF, SAKAI, CHIBA). Ar entire ship is built at the same time as the stern of the nex which is floated into position when the first vessel i! launched. The dock building capacity is therefore increased (figure 15). An alternative to this method is to be used by the Japanese shipyard at Tsu which is

** The SAKAIDE shipyard has announced a period of 70 days for 200.000 tdw vessel hull assembly, the stern being pre-assembled in t. repair dock. Five tankers of this size can thus be produced per year by the building dock.*

to have an elongated building dock with a gate at each end and an intermediate gate handled by gantry crane which can be put in several different locations to form isolated enclosures variable in size.

Unit pre-assembly is most frequently effected in the open air adjacent to the building docks, alongside and at the head of the dock, and is performed by the gantry crane or one of the two cranes used for the dock, by an auxiliary crane (NAGASAKI, SAKAI, SAKAIDE, LA CIOTAT), or else by an auxiliary gantry crane (SAINT- NAZAIRE) (figure 14). At ODENSE, the only gantry crane is to have four trolleys, two of which will be specialized in block pre-assembly alongside the building dock, the two others being assigned to transferring and holding loads in the dock, which in principle makes it possible to economize an item of handling equipment specialized in block assembly.

At KOCKUMS, block assembly is also effected in tne shops the blocks being evacuated through the roof try the docn gantry crane; an original solution has been found a: ARENDAL. where the building docks are extended into the assembly shop. and the vessels are advanced horizontally in the docks by means of hydraulic jacks as thelr construction progresses.

Another new channel is being explored in the United States by LITTON INDUSTRIES in their new. PASCAGOULA shipyard which is under construction. Complete ship sections (including outfitting) are to be assembled on prefabrication lines and then moved horlzontallv by conveyors to a final assembly area: the traditional conception of hull construction in dock on the basis of units or panels has been completely abandoned in this case

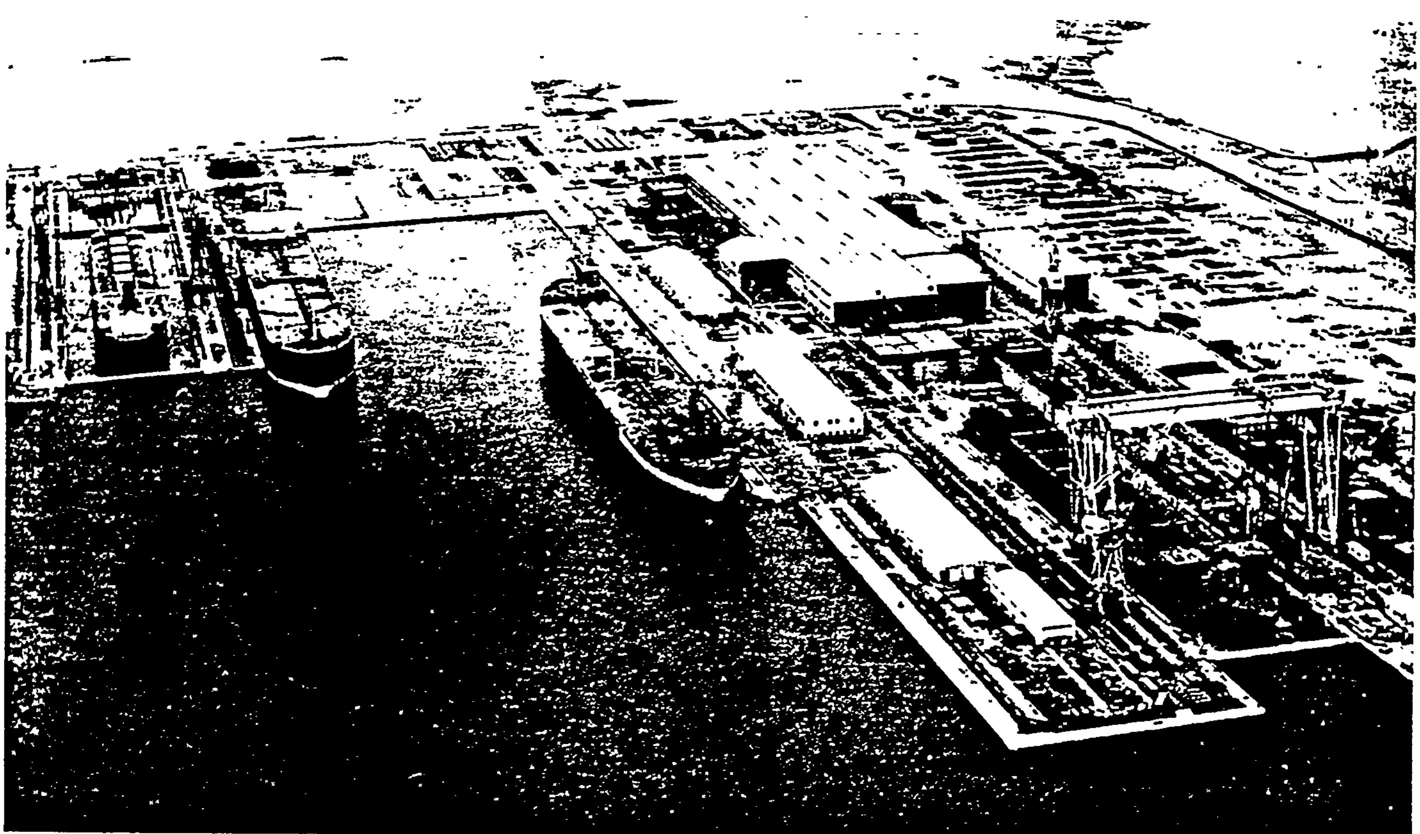


Fig 15 KAWASAKI Dockyard shipyard at SAKAIDE. Building dock for 400,000 tdw vessels, using two 200-ton gantry cranes. The beginning of assembly of a tanker stern in the 600,000 tdw ship repair dock can be seen.

DEVELOPMENT OF PREFABRICATION -

INTEGRATED SHOPS AND PREFABRICATION LINES

Originally, the idea of prefabrication was touched off by the necessity to reduce space requirement for berth assembly and to eliminate open-air work hazards. The prefabrication shops were primarily assigned the task of providing space and a roof. The panels were prefabricated on the spot, the supply of materials and the evacuation of the assemblies being carried out by bridge crane.

The advent of mass production, which transferred the center of gravity for assembly from the berths or building docks and located it in specialized shops, gave rise to totally different thinking as regards the latter. The new criteria were high output, production flexibility, improvement of sizing performances and of welding quality in order to prepare final assembly operations efficiently and therefore improve the shipyard's overall productivity.

The prefabrication stage, which in its present conception covers ship section assemblies as complete as possible, represents the converging point of a multitude of components, hull components such as plates, sections and stiffeners or fitting-out components such as piping, valves, ladders, etc. The location of this stage is determined by the position defined for specialized work stations and conveyor systems between stations composing a continuous assembly line, and also takes account of easy routing of the components. This is the reason why the new Japanese shipyards include integrated fabrication shops (figure 16), where all the preparation operations for the components and the assembly of the subassemblies and assemblies are performed (SAKAI, SAKAIDE, CHIBA, YOKOHAMA). The layout of the specialized work areas is designed in a rational manner in order to reduce materials routing distances (figure 17).

The European shipyards have on the contrary opted for setting up independent units: the fact that they have had to design their extensions on the basis of existing ins. tallations is certainly not unconnected with this choice. To revert to the hull component fabrication process, the following specialized units are involved:

- Materials storage yard (plates, sections. pipe)
- Plate preparation shop
- Preparation line for secondary fittings (webs)
- Prefabrication line for flat panels
- Prefabrication line for curved panels
- Piping preparation shop
- Painting shop for prefabricated elements.

In a shipyard specialized in building giant tankers and ore carriers, the proportion of prefabricated components giving rise to the largest number of repeat operations, i.e. the flat panels, is high, as it represents two-thirds of the total steel hull tonnage.

The flat panel shop is thus the center of production around which the assemblies serving it gravitate.

We crive below some figures which are characteristic of a typical large shipyard*, designed for building four 200,000 tdw tankers in a year:

● Annual tonnage of hull steel produced	110,000 tons
including a plate tonnage of	77,000 tons
Nr. plates	20,000
Section tonnage included	33,000 tons
Nr. sections	52,000
● Annual tonnage of flat panels prefabricated	73,000 tons
Nr. flat panels	660
● Annual tonnage of curved panels prefabricated	37,000 tons
Nr. curved panels	400
● Annual tonnage of webs (secondary fittings)	22,000 tons
Nr. of webs	2,500
● Annual tonnage of reinforcing and miscellaneous parts	14,000 tons
Nr. parts	45.000

** This shipyard would have a tonnage expressed in gross registered tons of approximately 450,000 grt. It would be fifth in the 1968 worl classification for shipyards according to vessels launched. Its annual turnover would be in the 65 million U.S. dollars range.*

Fig 17 Plate preparation in the IHI Shipyard at YOKOHAMA.

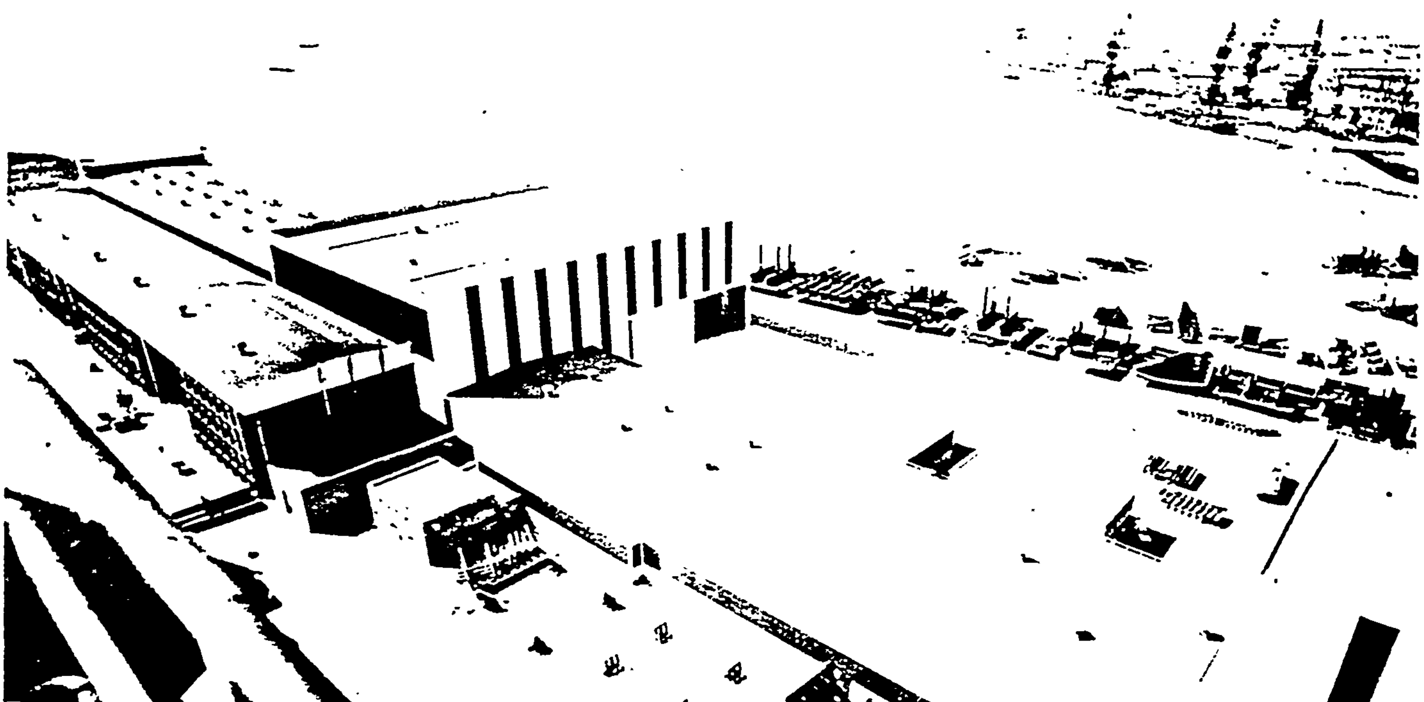


Fig 18 Chantiers de l'Atlantique flat panel shop at SAINT-NAZAIRE

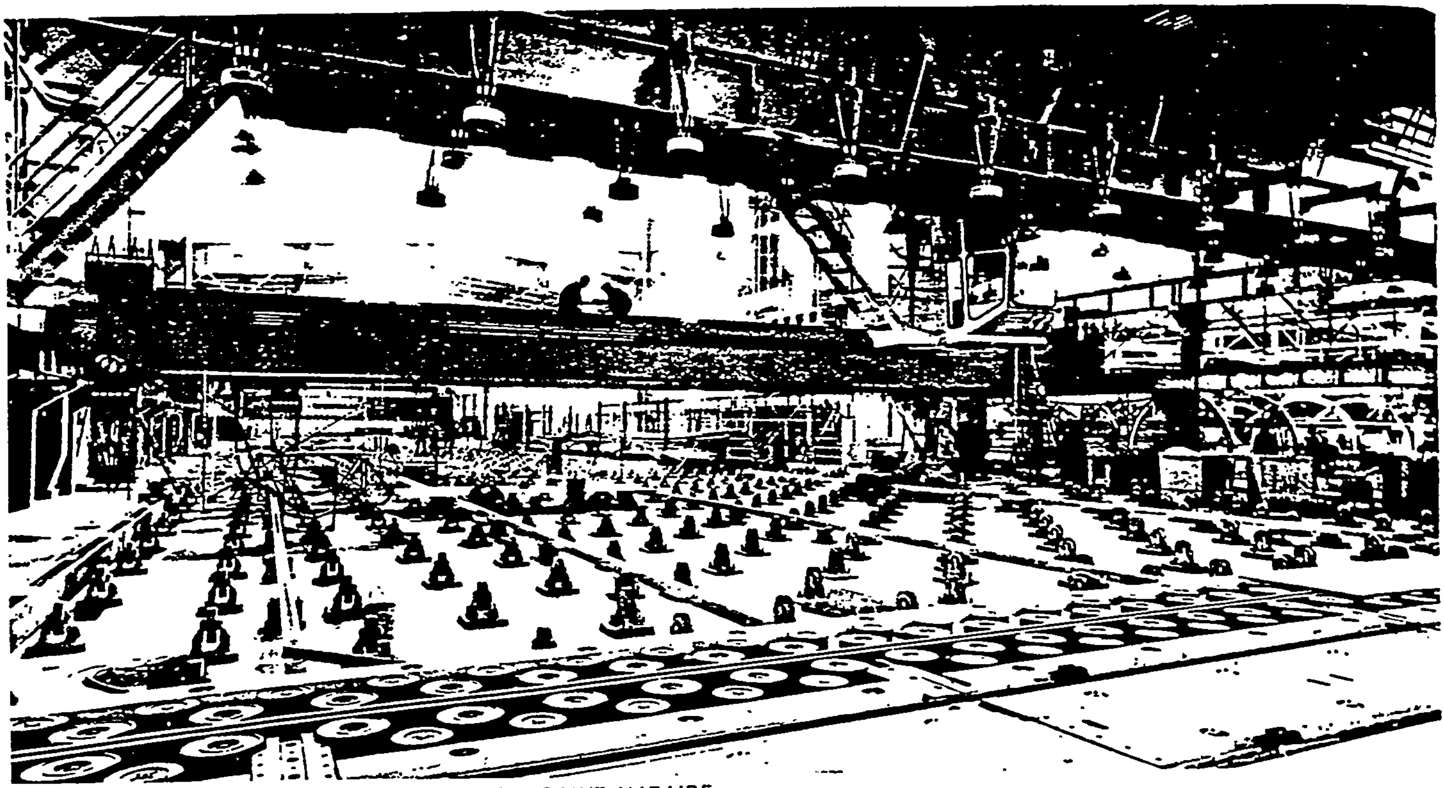


Fig. 19. Flat panel line — Plate assembly station SAINT-NAZAIRE.

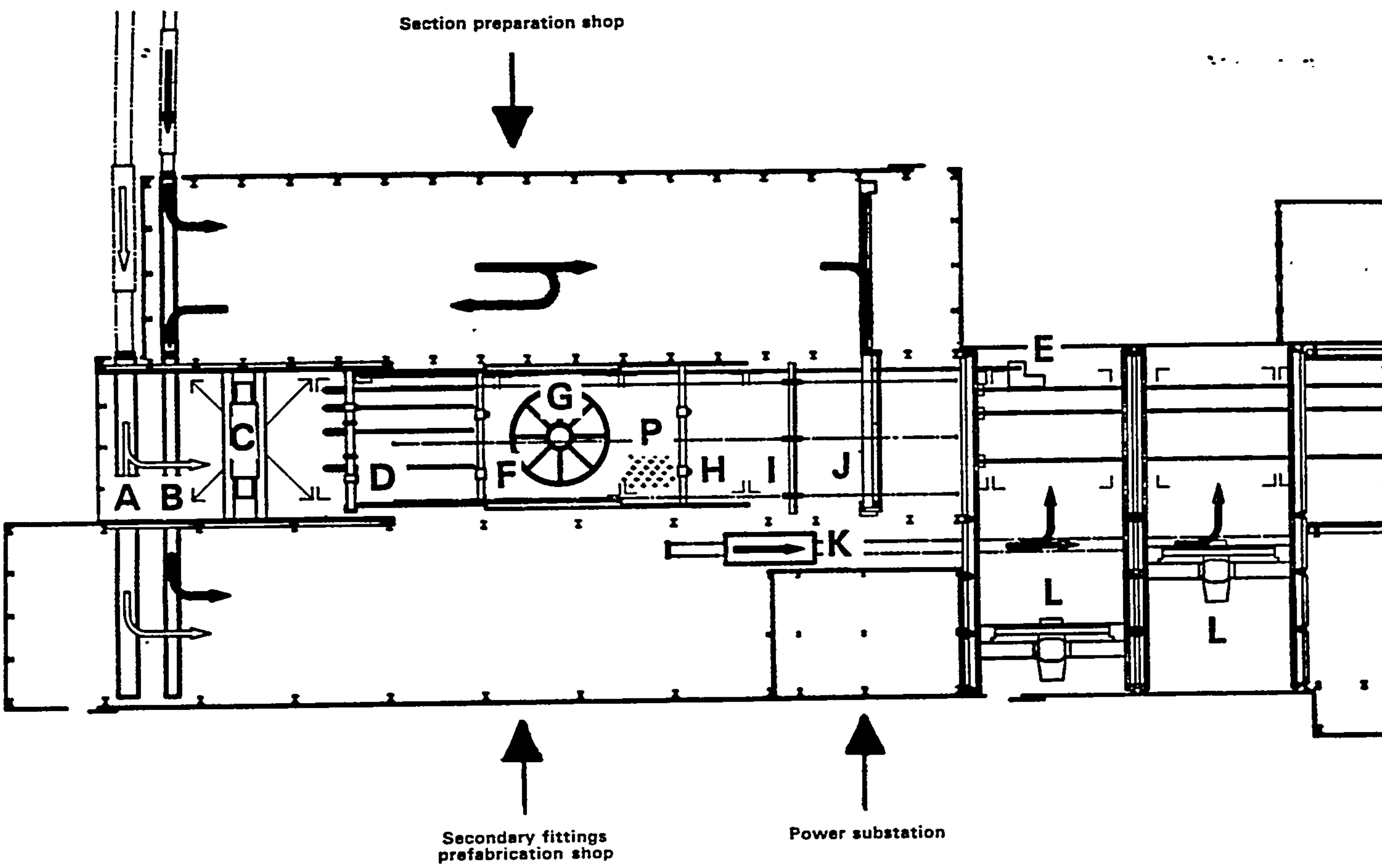


Fig. 20. Flat panel preparation shop

FLAT PANEL SHOP

The flat Panel shop is the specialized area where the flat prefabricated hull parts are made by mechanized operations. We have seen that in a Japanese shipyard, this flat panel shop would in fact be completely integrated in a fabrication shop grouping together all the shipyard preparation and prefabrication operations. while in Europe the trend has been to set UP independent shops (figure 18).

The flat panel shop is basically composed of a ground-based conveyor system forming a flat bed of rollers on which the panel advances as it is assembled. The fabrication operation: are divided up according to type, and each operatlon is performed at a specialized work station (figure 20).

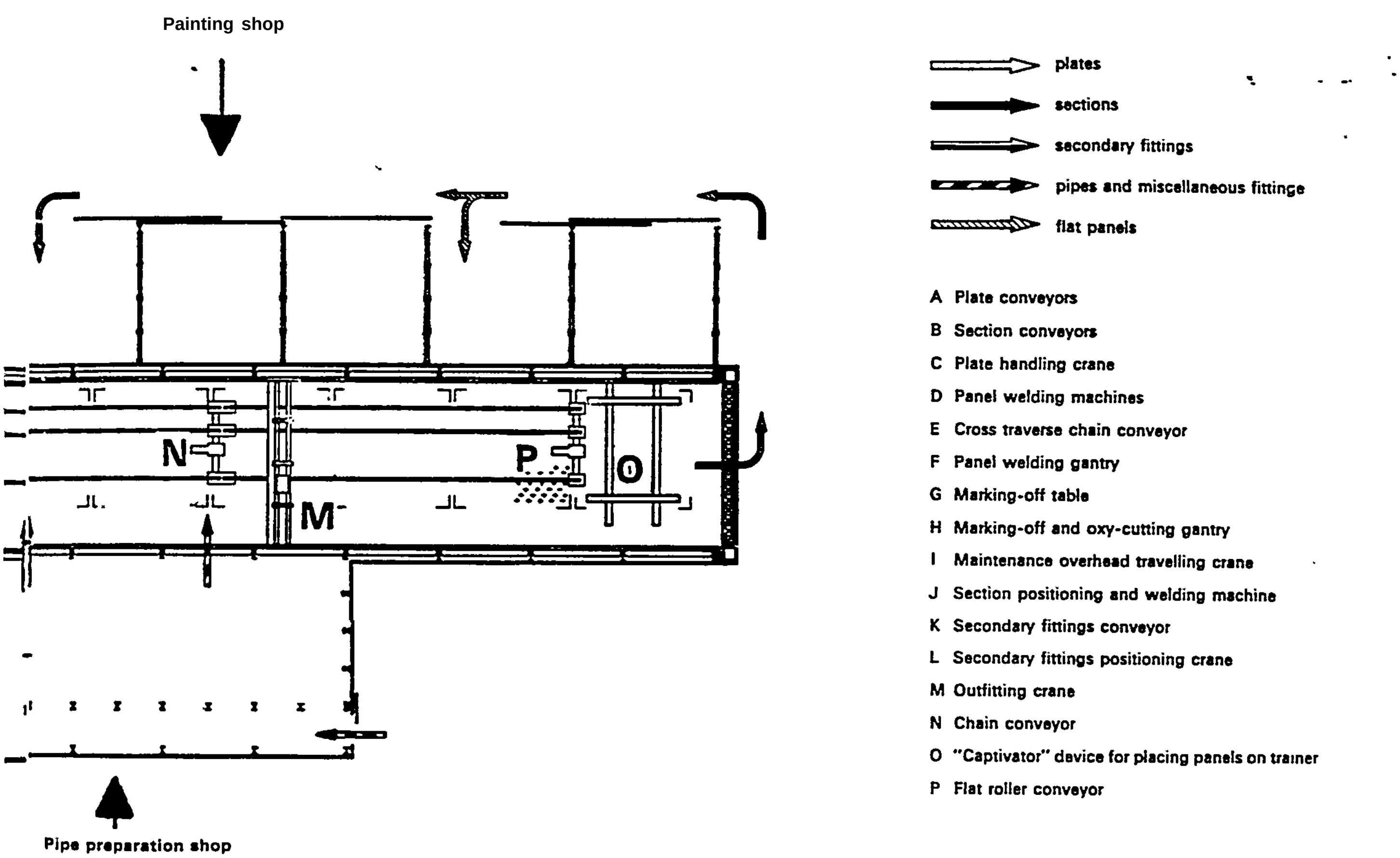
- Welding plate assemblies from single plates. The work station includes mechanical devices allowing accurate positioning of plates and usually a magnetio clamp type table for keeping the plates stable while they are being spot welded (figure 19).

. Panel welding at one or two work stations (according to whether the welding is done on one or both sloes. the second station being in that case for turning the panel over and welding it on the other side. The welding is performed by an automatic welding machine (figure 22).

- Rotating, panel edge preparation and section position marking. The purpose of the rotating operation is to allow for positioning the primary stiffeners perpendicular to the plates in certain cases. The oxy-cutting of the edges and the marking of sections may be effected by an automatic numerically controlled machine.

. Section positioning and welding. The sections are placed on the plate. held in place and welded by a machine which performs these operations automatically (figure 21).

· *In Japan. all the new shipyards are equipped for performing exclusively one-side welding (OSW). In Europe. the welding equipment manufacturers are perfecting various processes which are being closely watched by the shipyards. AKERS in Norway is the only firm using one-side welding. according to a Japanese process (developed by KOBE STEEL).*



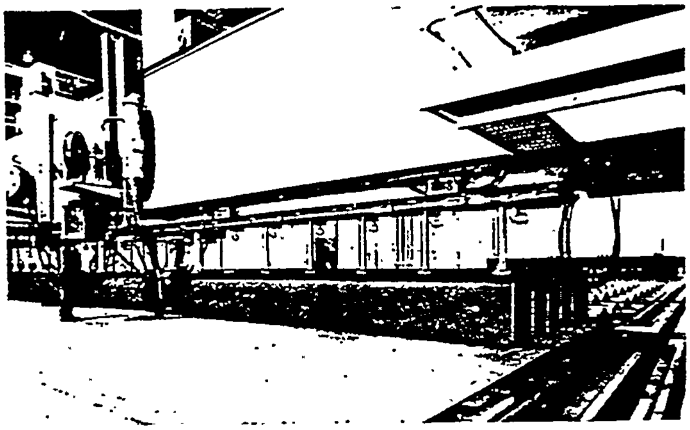


Fig. 21. Flat panel line — Positioning and welding the sections SAINT-NAZAIRE.

- Positioning the secondary fittings by means of bridge cranes.
- Fitting-out of panels, i.e. putting in place the pipes valves, motorized pump sets, ladders, supports, reinforcing, etc.
- Removal of panels. This may be effected by trailer, transfer car or direct by the dock hoisting equipment.

The method of assembly usually used in Japan is rather different from this process, as the primary stiffeners and webs are previously assembled in "eggbox" form before they are placed on the panels.

The production capacity of a flat panel line is determined by the maximum size of the panels which can be assembled on it and the maximum number of panels produced per day.

At present the existing flat panel shops can make up to four panels a day, with the following maximum dimensions - 20 to 25 meters in length, 15 to 20 meters in width weight up to 250 tons (CHANTIERS DE L'ATLANTIQUE).

The first shops of this type were those set up in 1964 by KOCKUMS at Malmö and MITSUBISHI at Nagasaki.

Other installations of the type have since been made in Europe (AG WESER, CHANTIERS DE L'ATLANTIQUE), sometimes in a simplified form (VEROLME, N.D.S.N.), or are under construction (HARLAND & WOLFF). In Japan, the flat panel lines form part of integrated shops (I.H.I., TOKOHAMA, CHIBA, SAKAI, SAKAIDE).

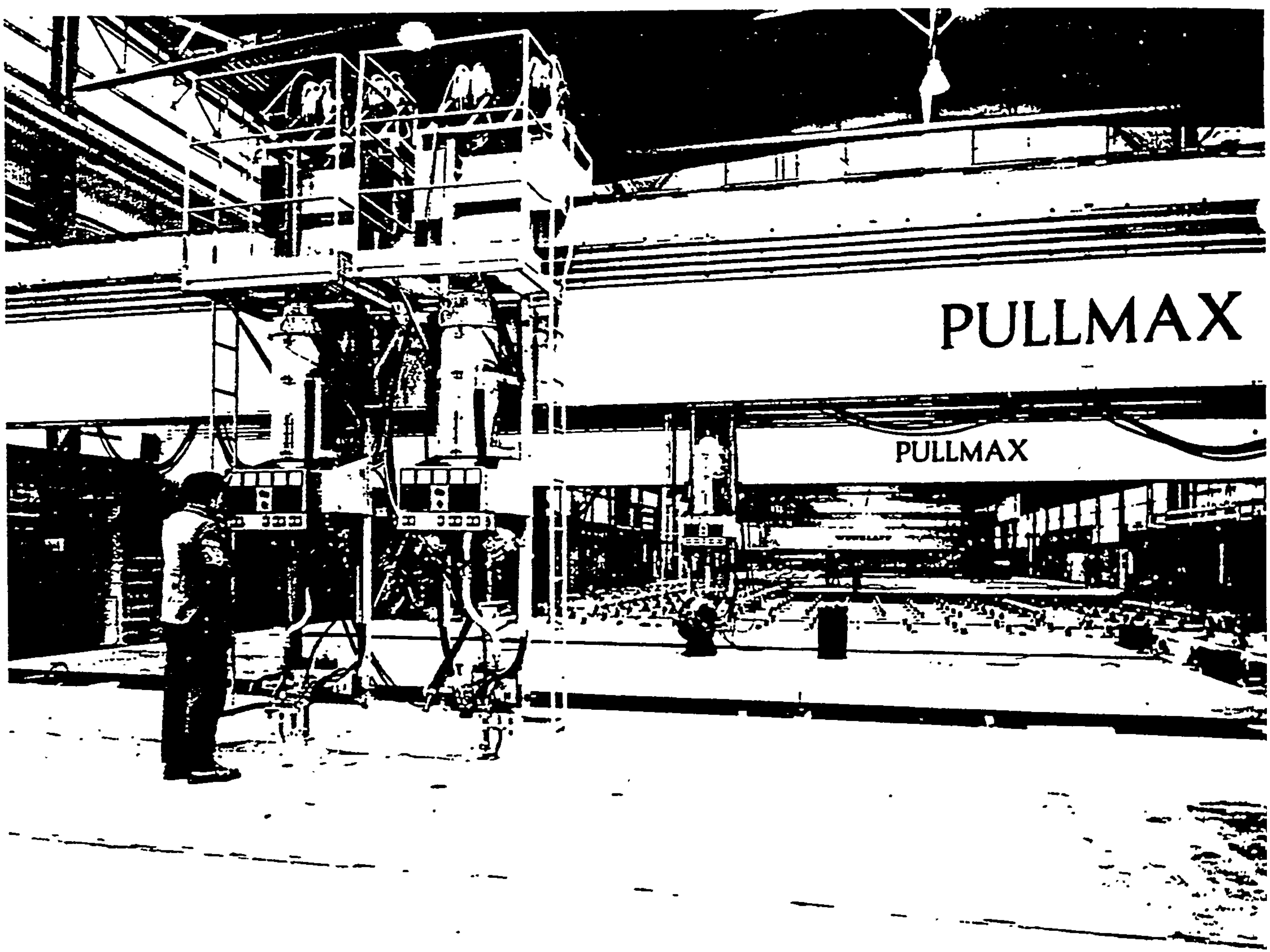


Fig. 22 Flat panel line — Welding the plates making up the panels SAINT-NAZAIRE.

SECTION PREPARATION SHOP

This shop is specialized in the preparation of the sections required for stiffening the ship's frame, both for direct utilization on the primary panel system and for constituting the secondary fittings.

In the case of the shipyard used as example, which produces four 200,000 tdw vessels per year, 52,000 rough sections are cut and machined per year to make the 109,000 or SO sections integrated into the frame of the ships built.

The huge production capacity of such a shop involves maximum mechanization and automation for handling and transfer as well as for the machining operations themselves. The sections from stock undergo all or part of the following operations, after being shot-blasted and painted:

● Cutting the sections to length, by sawing — or using guillotine shears — or by oxycutting. In both cases, the required length is obtained accurately by a mobile stop system, the stop being located downstream of the cutting equipment used (this stop can be manually controlled, but currently numerical control is used for it'..

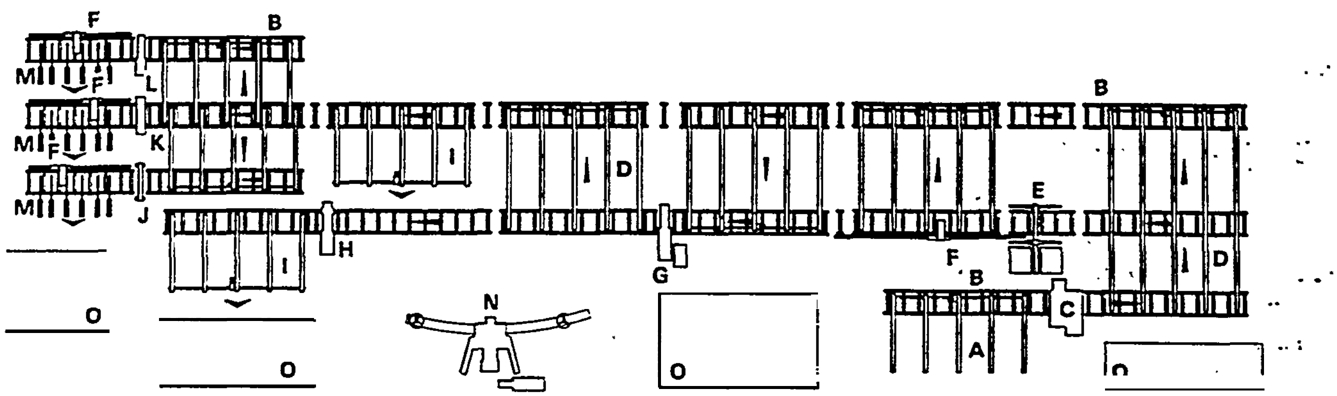
● Machining the ends, the chamfers required for butting being obtained by semi-automatic oxy-cutting.

● Scalloping and drilling of the limbers either by punching on a press (with automatic feed of the section in certain cases) or by oxy-cutting on templets for example (with possible use of length stops to position cutouts).

● Straightening the sections either at the beginning of the line to allow machining of sections which have been deformed during transportation or storage operations. or after punching, to offset any deformation arising from that operation.

● Bending curved sections on a press.

Station-to-station transfers are effected by gravity roller conveyors and transfer table conveyors for moving the sections sideways (figure 23). Loading at the start of the line" and discharging at the end of the machining operations are carried out by the magnetic overhead traveling crane equipping the shop. The transfer table



A Cross traverse input conveyor, buffer storage
B Gravity roller conveyor
C Straightening machine
D Cross traverse conveyor
E Automatic edge oxy-cutting gantry
F Automatic shop for cutting to length
G Limber punching machine
H Straightening machine
I Cross traverse evacuating conveyor, buffer storage
J Automatic oxy-cutting and cutting gantry
K Guillotine shears
L Saw
M Shunt-out ejector
N Bending machine
O Stockyards

Fig 23 Section preparation line.

conveyors located at the beginning and end of the line to allow for intermediate stacking of the sections and for " flexibility in the use of the traveling cranes (figure 24).

Finally, it should be pointed out that the weight and geometric dimensions of the sections have increased along with the size of vessels: this has led the shipyards, which until recently used rolled sections, to equip their shops with special machines to produce the sections they cannot obtain on the market. As a result, installations for making large tee sections from universals are being developed.

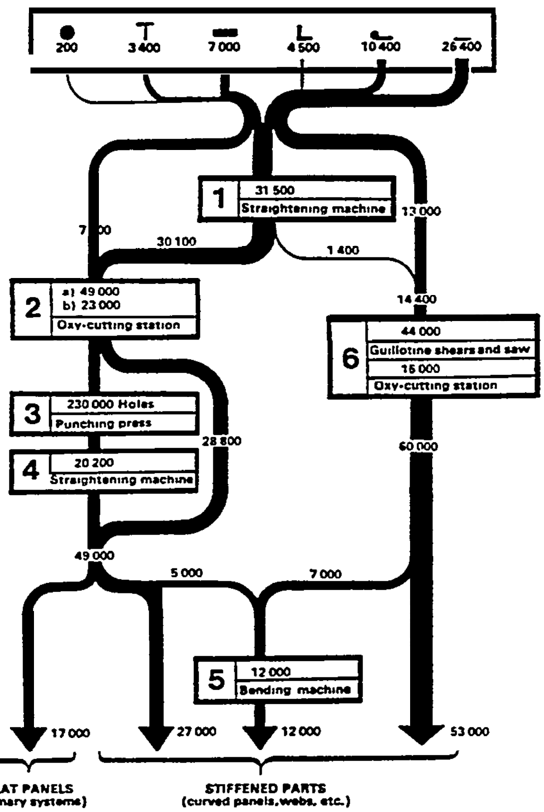


Fig. 24. Product flow in a section machining line.

TREND TOWARDS A NEW GENERATION OF SHIPYARDS?

The present phase of construction and modernization of shipyards undeniably represents an important stage in the development of shipbuilding. Under the effect of the transformation of methods and of mass production equipment, the industry has just lived through a period of mutation caused by" the huge rise in the demand for ships and the sharp increase in vessel size. It is probable that the fairly near future will bring market stabilisation, both as regards the number of vessels built and the types and size of the ships.

investments in shipbuilding which have been made at a rate hitherto unknown in the industry have given rise to a great increase in production capacity: the large new modernized installations are the best fitted to stand UP to competition, and their share in production will rise. to the detriment of long-established small shipyards which will either disappear or reconstruct. As in all other industrial sectors, the competitive nature of production will come into play in the following fields:

● At the level of the size of the production unit in the direction of an increasingly high production rate per shipyard.

● On the productivity level, in the direction of increasingly extensive organization of work schedules and methods and towards greater mechanisation and shop prefabrication.

. On the specialization level, by directing shipyard production towards units very similar in size and type and orientating research towards a type of vessel standardization conducive to repeat operations at fabrication level.

● Recent investments have above all been centered on the construction or modernization of large shipyards for building giant tankers or ore carriers. Still more progress will be made as regards mechanizing. simplifying materials routing and the use of numerical control and computers; more radical changes will probably come about in the case of shipyards building small and medium-size vessels, but whatever the present size of the ships being built, these changes will only take place within the framework of the trend towards strict specialization according to types of ship and a large increase in the number of vessels built per shipyard.

The influence of the market for ships will be decisive at that time. Although the shipping market is still dominated by "custom-made" building, it is not unreasonable to think that in a more distant future its structure will be closer to that of the aircraft market, which is characterised on a world scale by a very small selection of commercialized types and very large series of the same types, producer by a very limited number of builders.

Production Technology

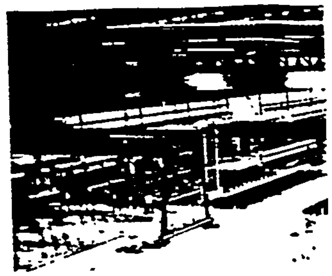
TTS has since its involvement in shipbuilding developed production systems which substantially increase shipyard profitability and competitiveness through improved productivity, quality, and increased capacity.

TTS offers complete production systems for cutting, welding and assembly of steel sections. All TTS production lines utilise highly efficient integrated material handling systems in order to optimise the production process.

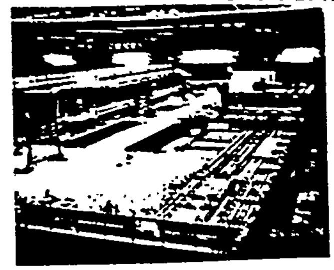
Since TTS introduced one-side welding technology based on submerged arc welding nearly 30 one-side welding stations have been delivered. TTS welding experts are continuously working at the TTS Test Centre to further increase one-side welding productivity.

TTS production lines are customised according to individual customers' steel throughput, cost and technology level. These range from efficient and reliable mechanised production lines to advanced and highly productive CIM production lines utilising state-of the-art robot technology.

TTS is continuously developing new ideas and solutions for shipyard steel fabrication in order to further reduce production costs. Comprehensive after-sales service programmes secure high performance and low maintenance costs for all TTS production lines.

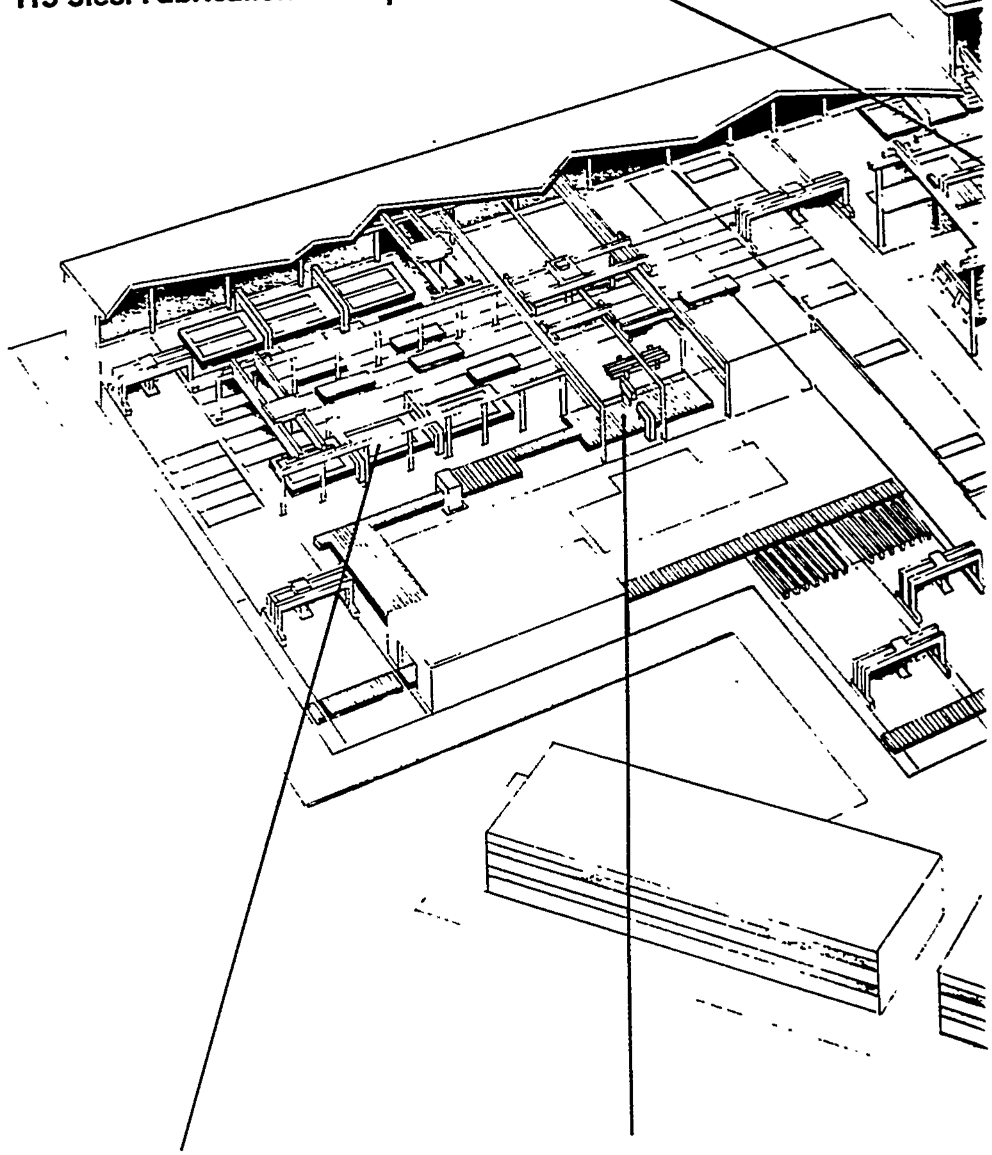


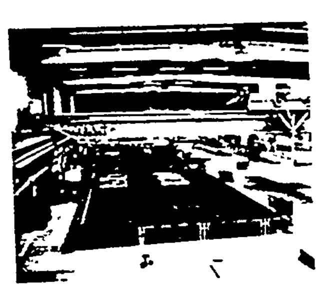
Eggbox and block production lines.



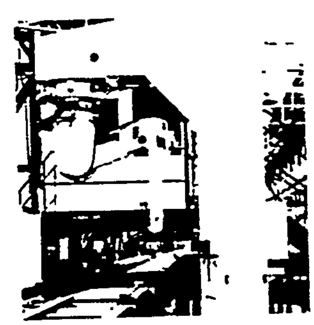
Large panel production lines.

TTS Steel Fabrication Concept

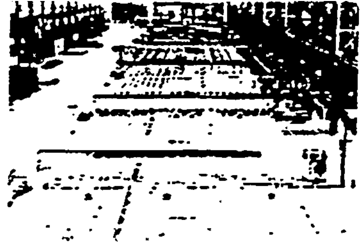




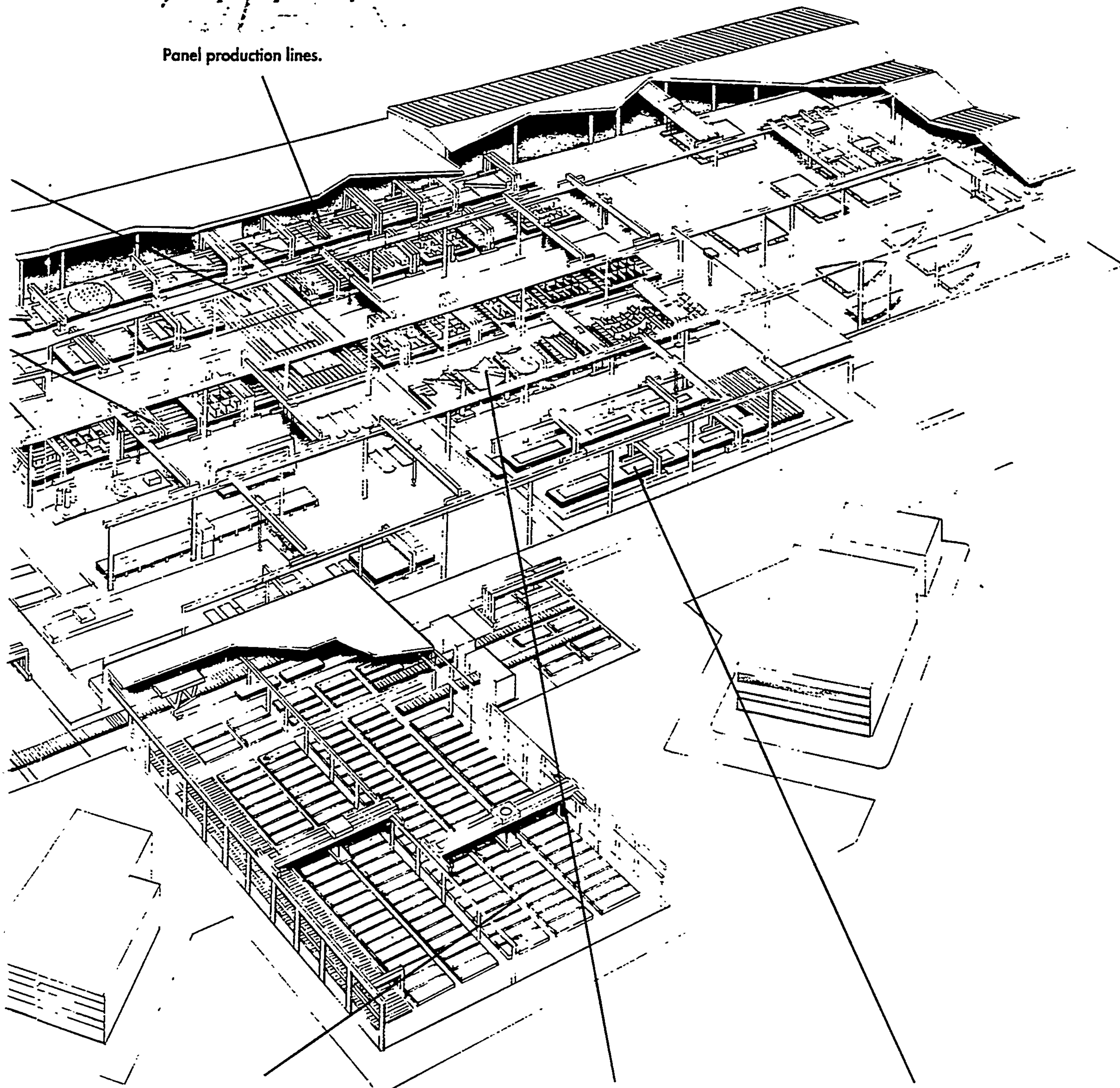
Automated material handling system for steel cutting shop.

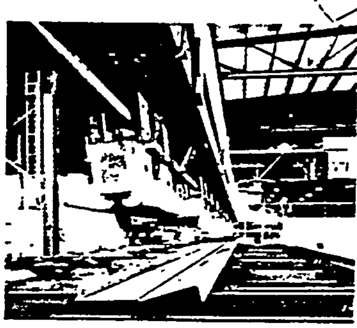


Profile processing lines

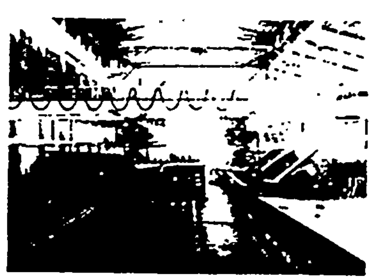


Panel production lines.





Automated material handling

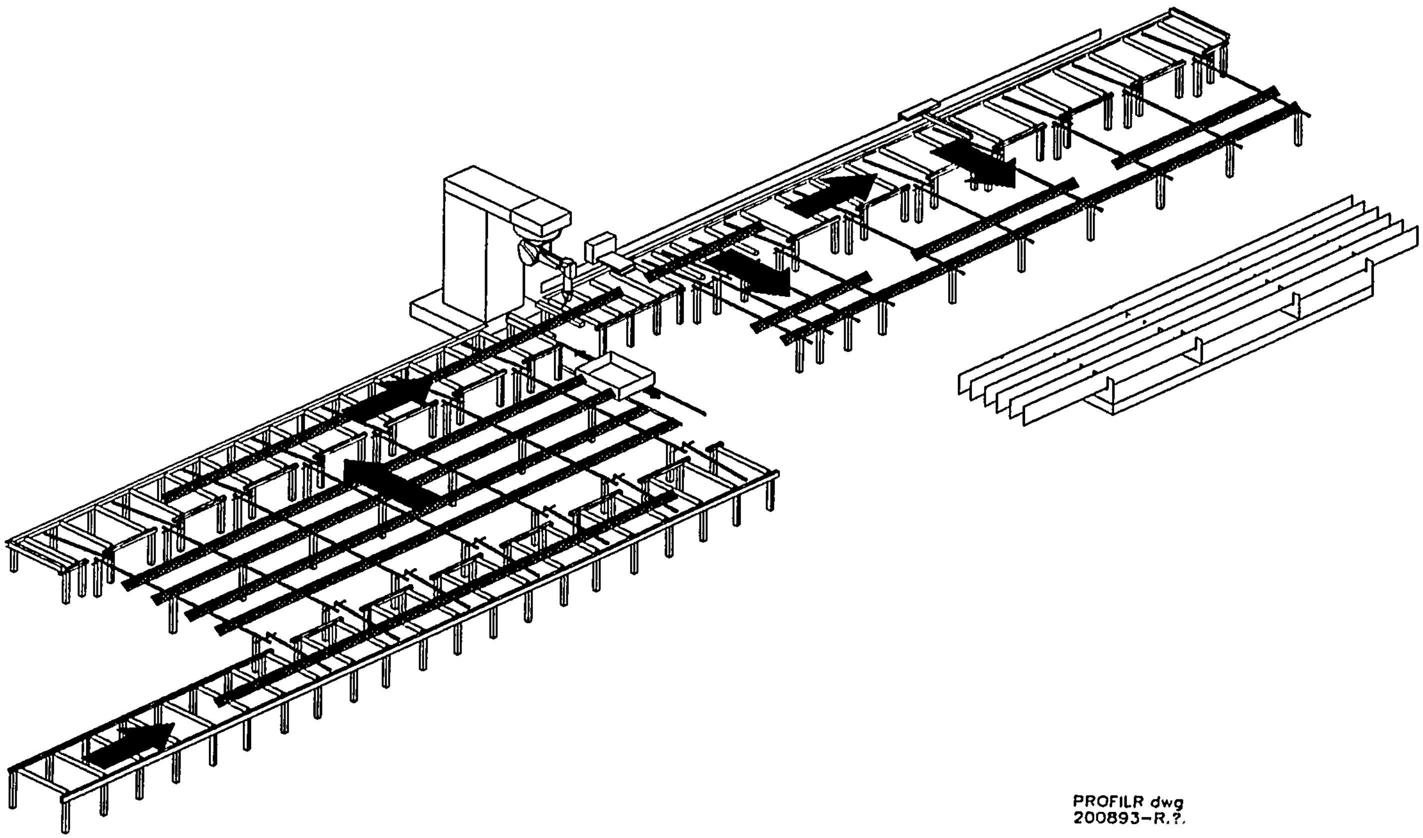


Curved block production lines.

Web and component production lines.

TTS Robotic Profile Line

Your Technology Partner

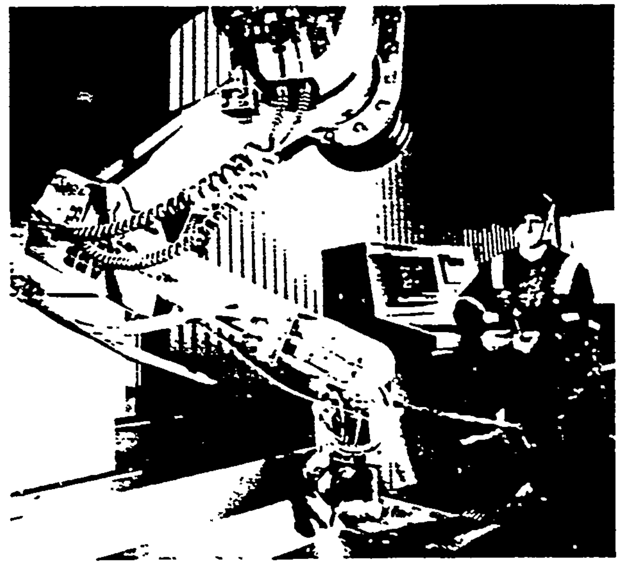


introducing robotics and CIM (Computer integrated Manufacturing) in shipbuilding is technologically challenging. The main challenge is the small production series produced from parts and subassemblies with low degrees of dimensional accuracy.

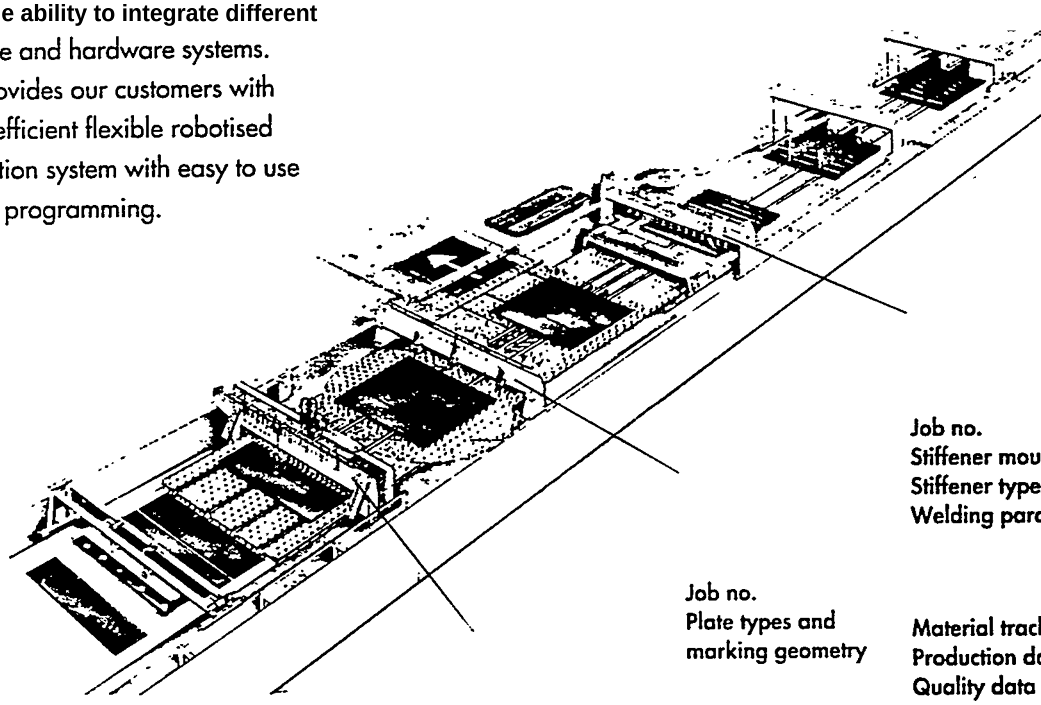
TTS has developed and delivered a wide range of fully CIM integrated production systems for steel cutting and assembly.

Extensive knowledge in technology integration is a competitive advantage for ITS in the design and supply of robotised CIM production systems. ITS provides system interfaces between existing yard software systems, such as the CAD, and planning systems.

TTS robot and CIM technology have the ability to integrate different software and hardware systems. This provides our customers with a cost-efficient flexible robotised production system with easy to use off-line programming.



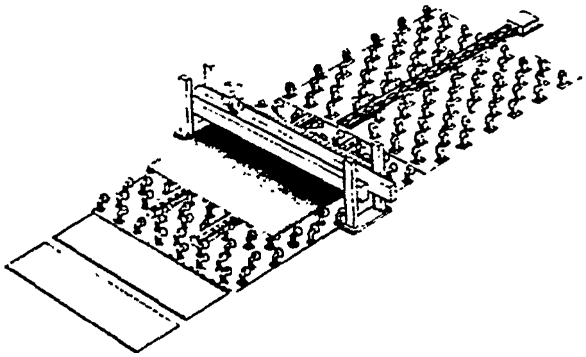
TTS Robot Test Centre.



Information flow computer integrated panel production line.

Investing step-by-step in productivity improvement

STEP 1



Step 1 consists of infeed conveyors, a one-side welding station and a station *for* additional processing.

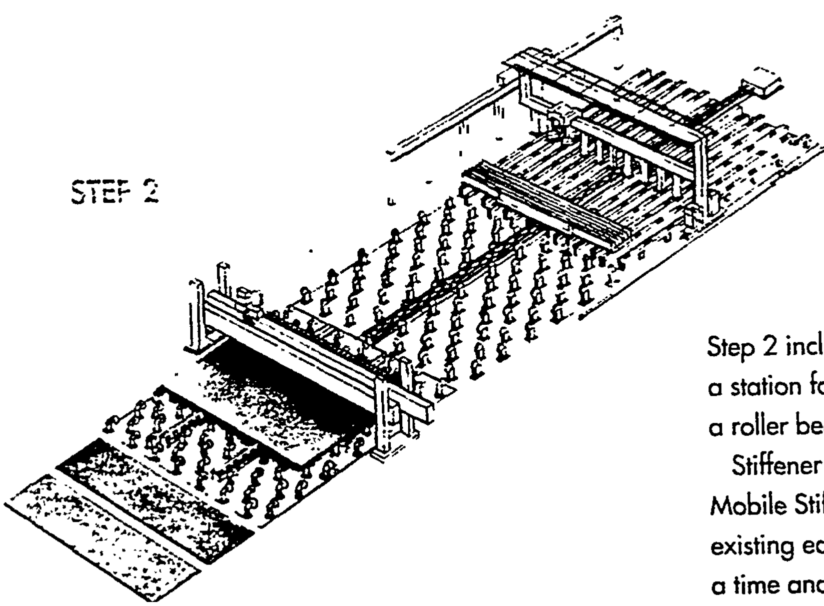
Steel plates are positioned in the one-side welding station and tack welded.

After clamping, the plates are butt welded by a submerged arc, one-side welding process against a flux-covered, water-coaled copper-backing. The one-side welding station permits single-pass butt welding far plates up to 15 mm thick.

The TTS one-side welding process is approved by all major classification societies far all commonly used steel qualities. One operatar is required.

The station far additional processing is used to clean, mark and cut the panel to prepare it for the mounting and welding of stiffeners and webs. The number of operators working on this station depends an the actual work load; in most cases, one operator is sufficient.

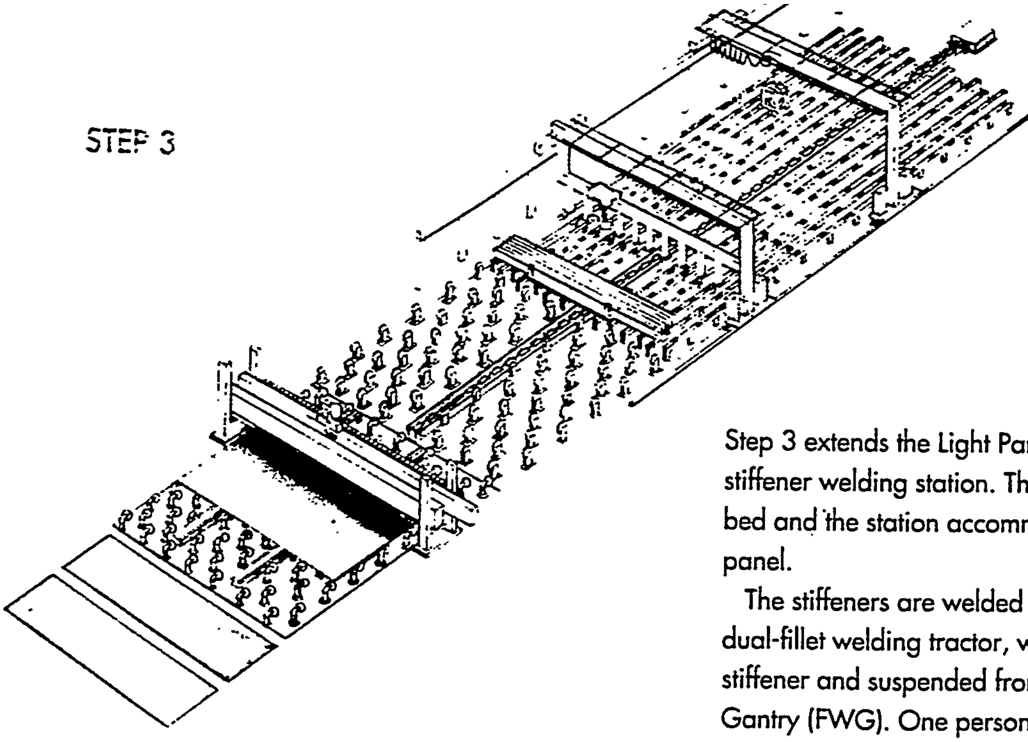
STEP 2



Step 2 includes an extension of the line by introducing a station for stiffener mounting. The station consists of a roller bed to accommodate one full-size panel.

Stiffener mounting is done automatically by using a Mobile Stiffener Gantry (MSG) or manually by using existing equipment. The MSG picks up one stiffener at a time and positions each stiffener at pre-marked locations on the panel. Semi-automatic welding equipment is mounted on a clamping trolley to tack weld the stiffeners. The MSG can be controlled by one person.

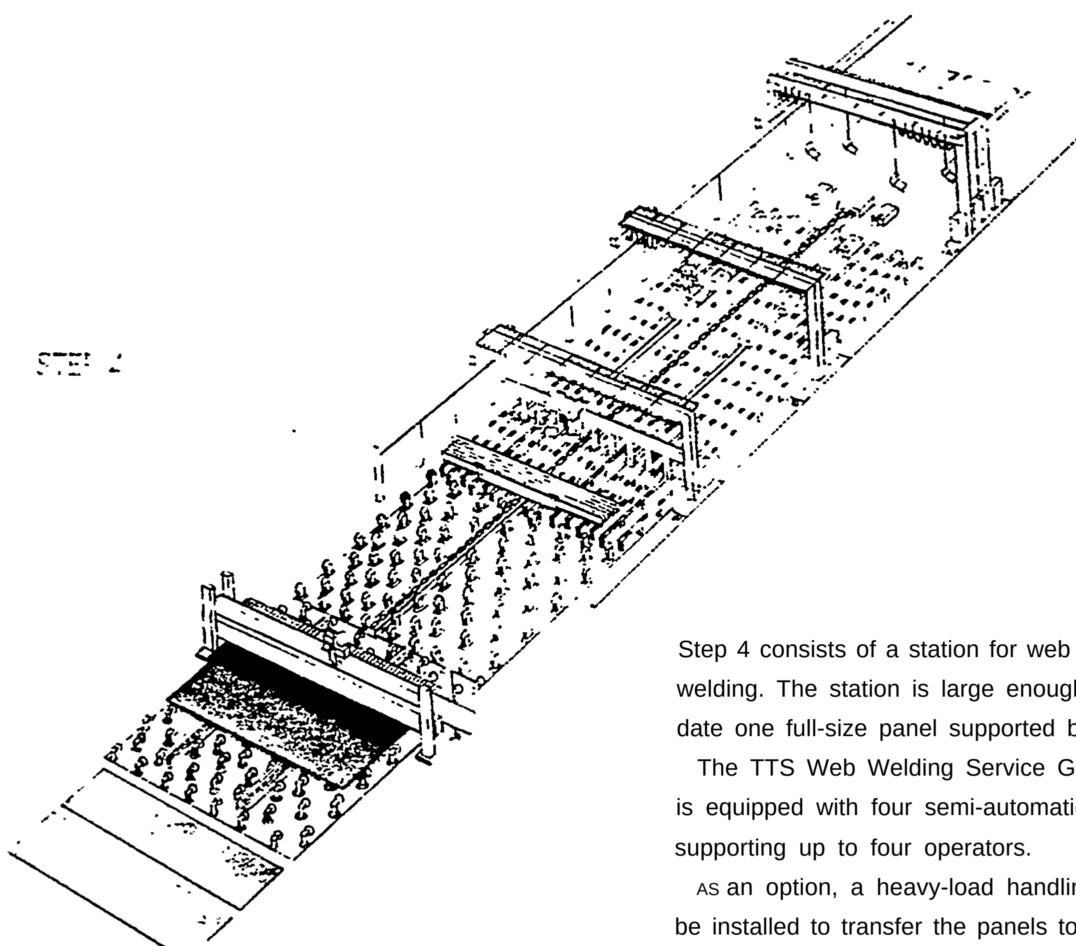
STEP 3



Step 3 extends the Light Panel Line by adding a stiffener welding station. The panel rests on a roller bed and the station accommodates one full-size panel.

The stiffeners are welded by a semi-automatic dual-fillet welding tractor, which is guided by the stiffener and suspended from the Fillet Welding Gantry (FWG). One person is needed to operate the FWG. Alternatively, the welding can be done manually using existing equipment.

STEP 4



Step 4 consists of a station for web mounting and welding. The station is large enough to accommodate one full-size panel supported by a welding floor.

The TTS Web Welding Service Gantry (WWSG) is equipped with four semi-automatic welding units, supporting up to four operators.

AS an option, a heavy-load handling system can be installed to transfer the panels to any additional stations.

File: shtcrse.d/p2/11/dp/yardlayout

SHIPYARD LAYOUT

I. INTRODUCTION

A. Aim of layout is good flow:

1. Minimum movement of material

2 Work at most efficient site

Labor
Equipment

3. Minimum time in process

Often times above are opposite force.

a. Of the two, latter is MOST important

c. This is a major change in shipyard philosophy. Many reasons. Most important is realization that tasks can be done away from the site.

B. Minimum of inventory

1. No disruption for lack of parts

2.. Costs of inventory

II. SPECIFIC FLOWS IN SHIP CONSTRUCTION

A. Material flow pattern

1. Oveview

a. Three cutting lanes
** flame planning
** profile cutting
** guillotine

b. Three forming lanes
** press

** rolls
** flanges-(same as press)

2. The Flow is Simple

a. Over **70%** do not need further processing
b. Major expansion in parts, especially from profile cutting and the guillotine
c. A tanker (55 ton) will have about 7,000 cut plates.
d. Most plates are less than 3m x 2m

B. Treatment Plant

1. Shot blasting

2. Primer

3. Straightening.

C. Thermal Cutting

1. Flame Planning for use in non-complicated cutting and edge preparation straight line. can be used in slight curve cutting.

a. Used for plates on hull, and panels, docks, tank tops, etc.
b. Consists of three beams one for trimming sides other tow for trimming ends.

2. Flame profiler for cutting complicated shapes. generally have automatic control

a. 1:1 template
b. 1/10 drawing or 1/100 negative control
c. N.C.

D. Mechanical Cutting

1. Guillotine

2. Bandsaw

E, Forming

1. Cold frame

    a. Use hydraulic rams to bend plate
    b Spring back is problem
    c. Tough to do two-axis bending

2. Furnace

3. Line heating

F. Assembly

1. Use of flow lanes based on group technology

2. Utilize both real flow and virtual flow

    a. Real flow is movement of material by the worker.
    b. Virtual flow is movement of the worker by the material.

G. Erection

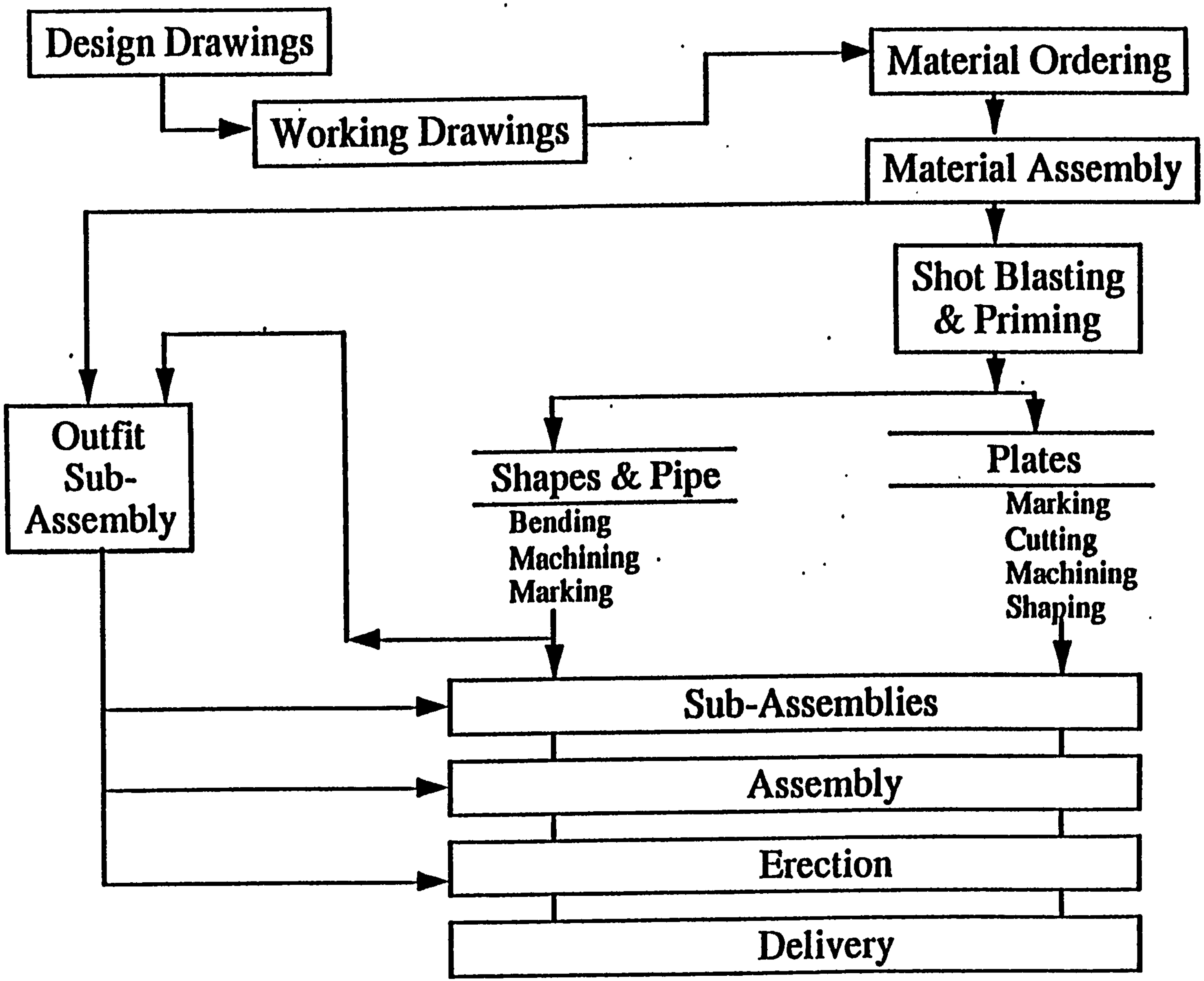
1. Attempt to minimize erection time

2. Minimum scaffolding

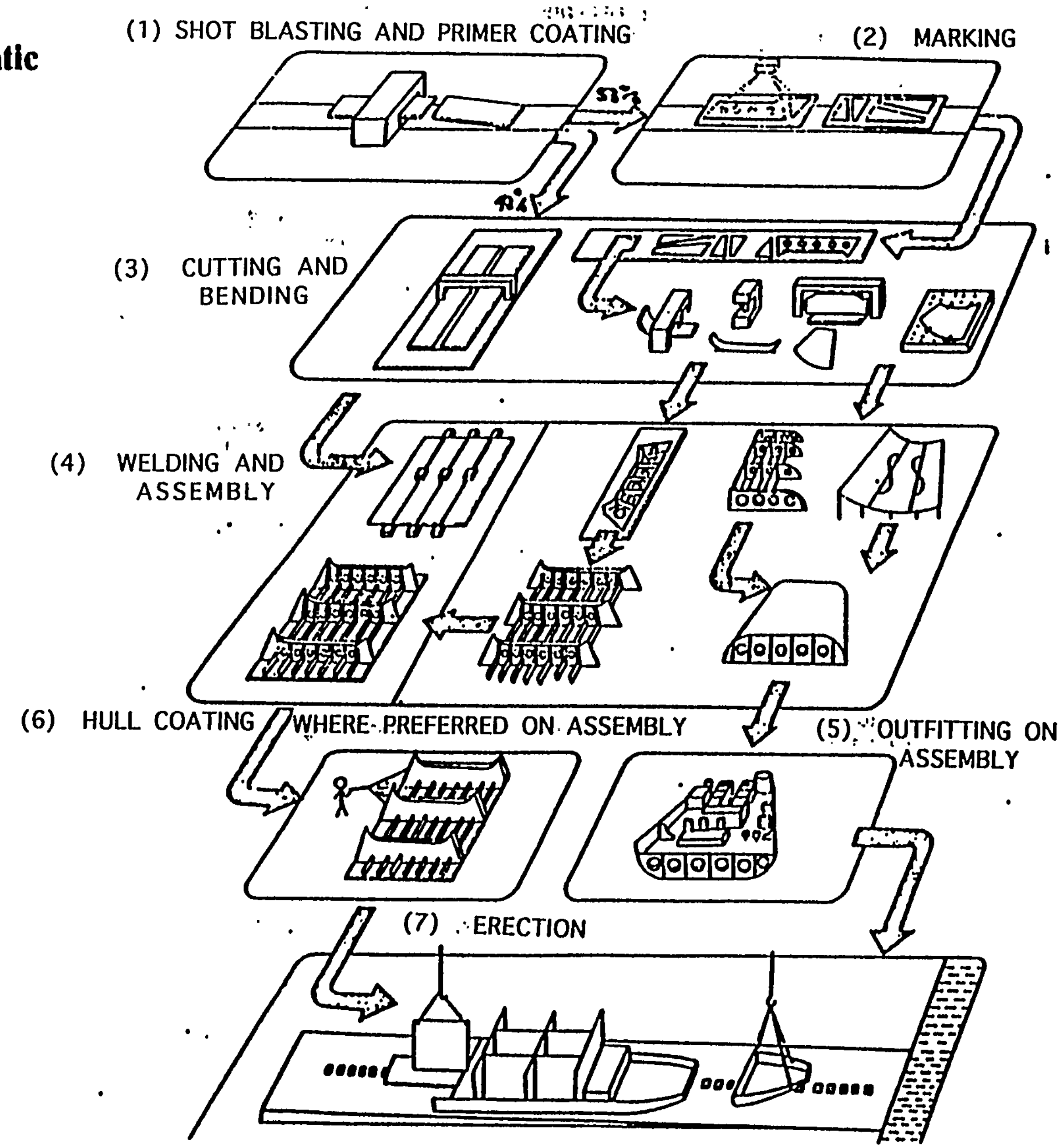
3. Optimium block size has been found to be less than 350 tons, in most production settings.

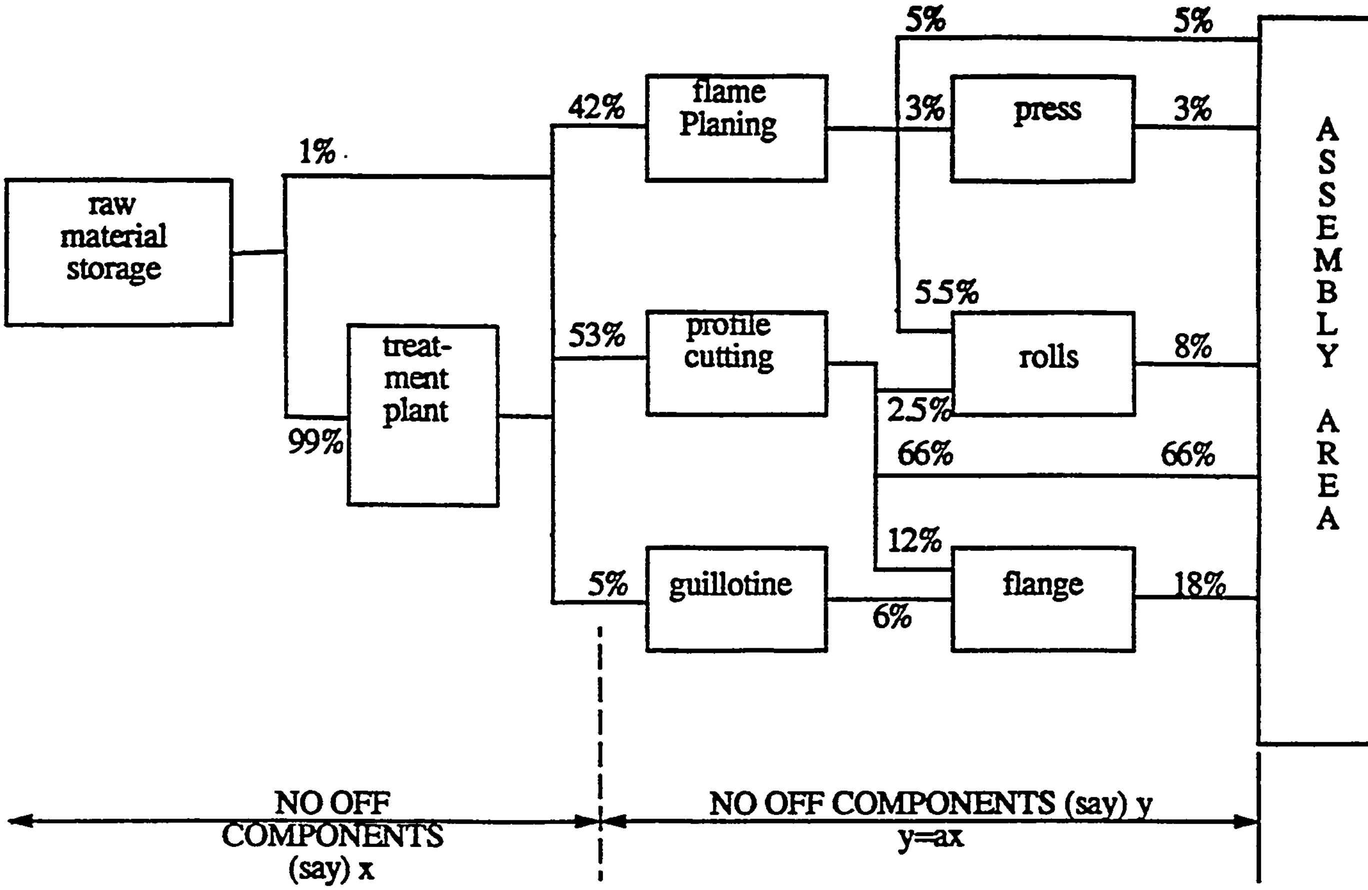
4. Major benefit in erecting in a basin or land-level facility.

Material Flow

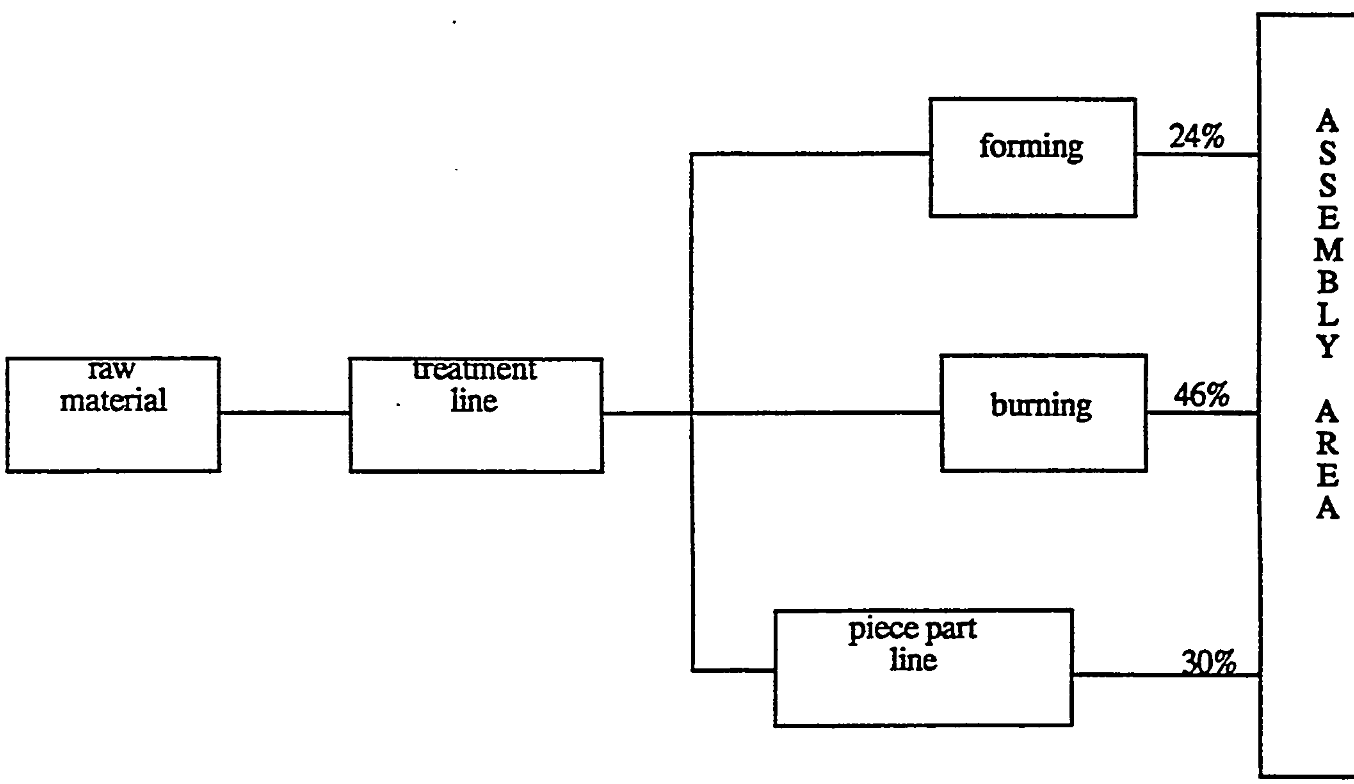


Building Process Schematic



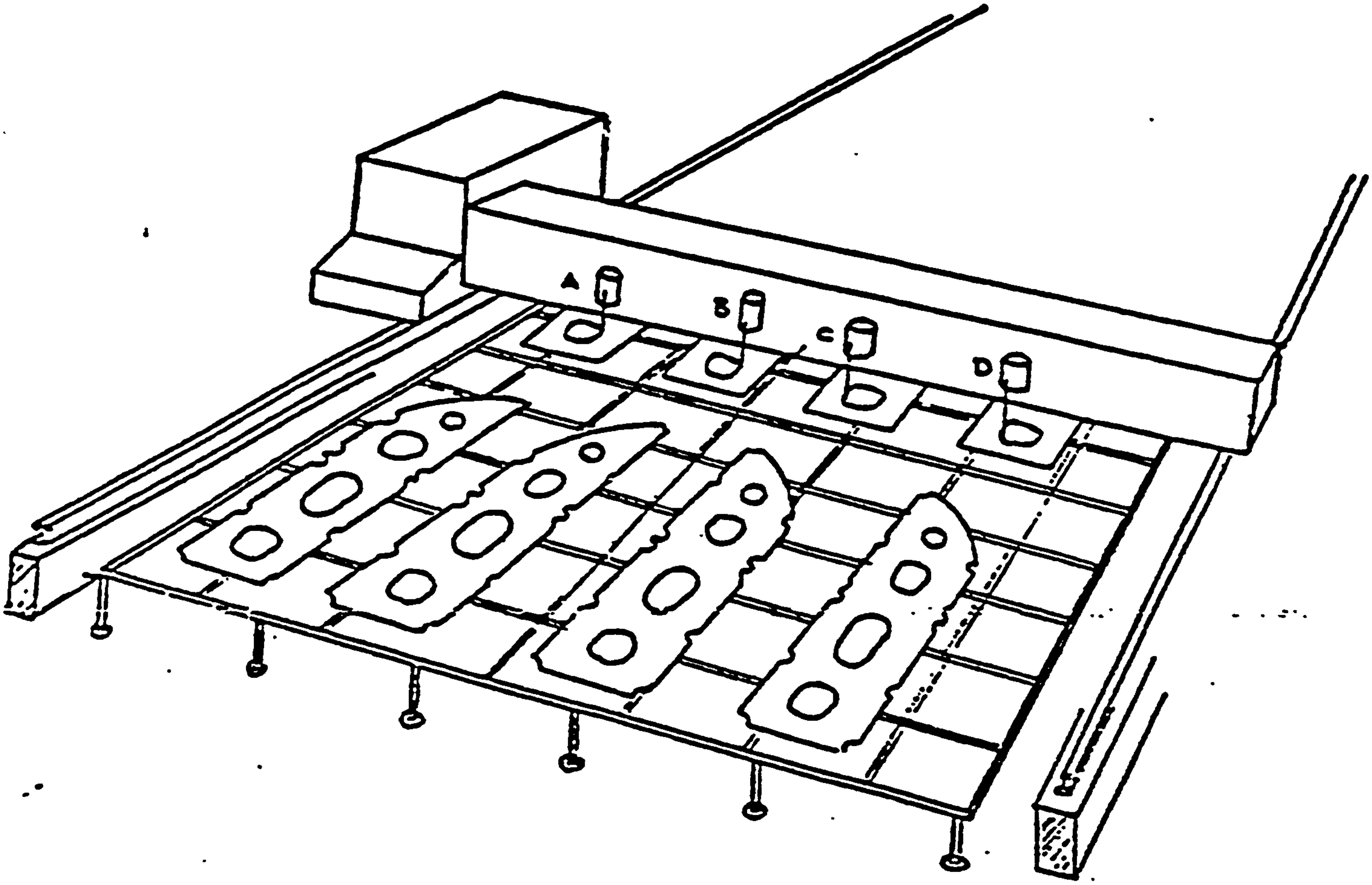


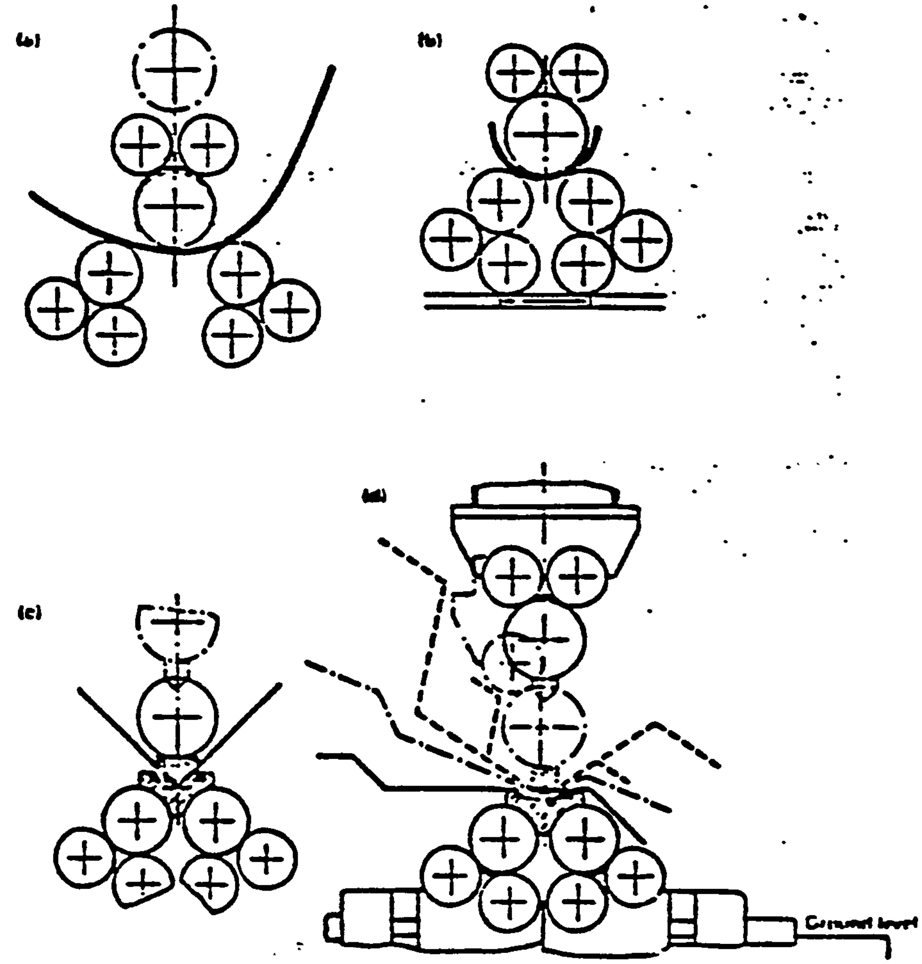
MATERIAL FLOW PATTERN (plate parts)

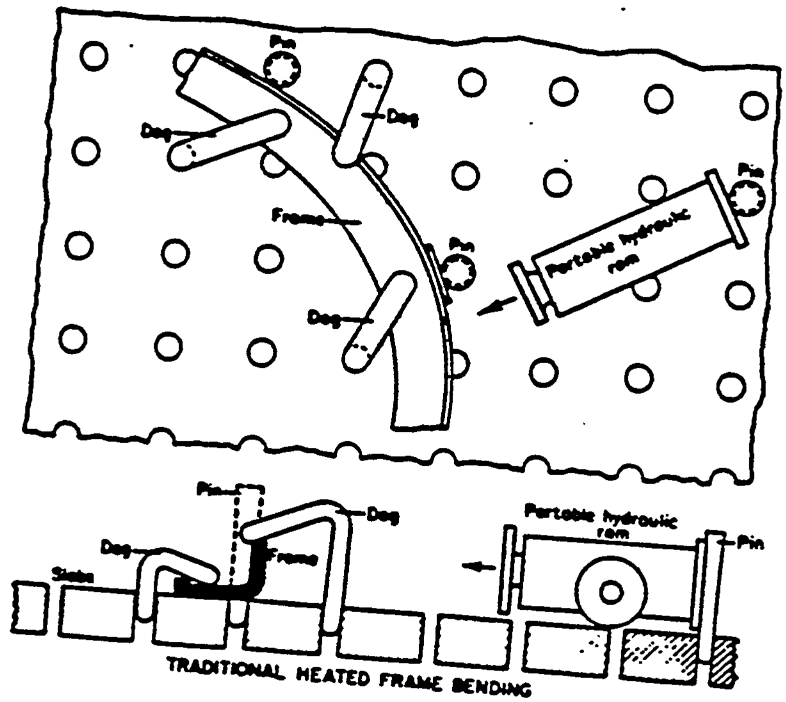


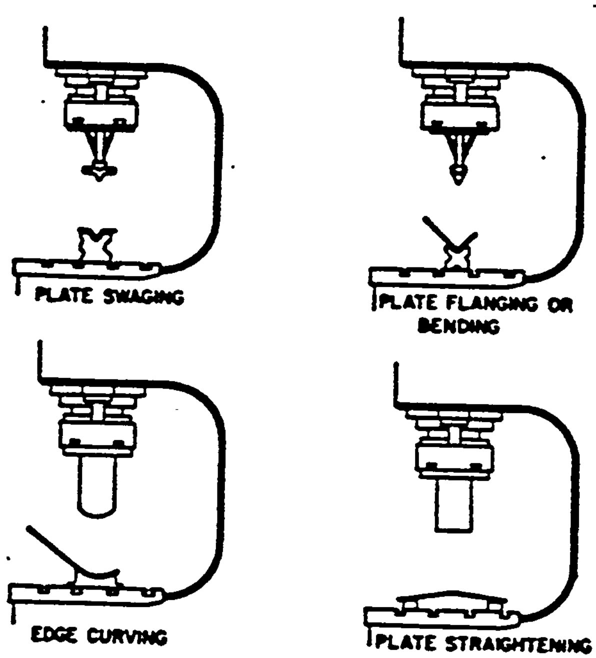
MATERIAL FLOW PATTERN (section parts)

YL-6


A
B
C
D

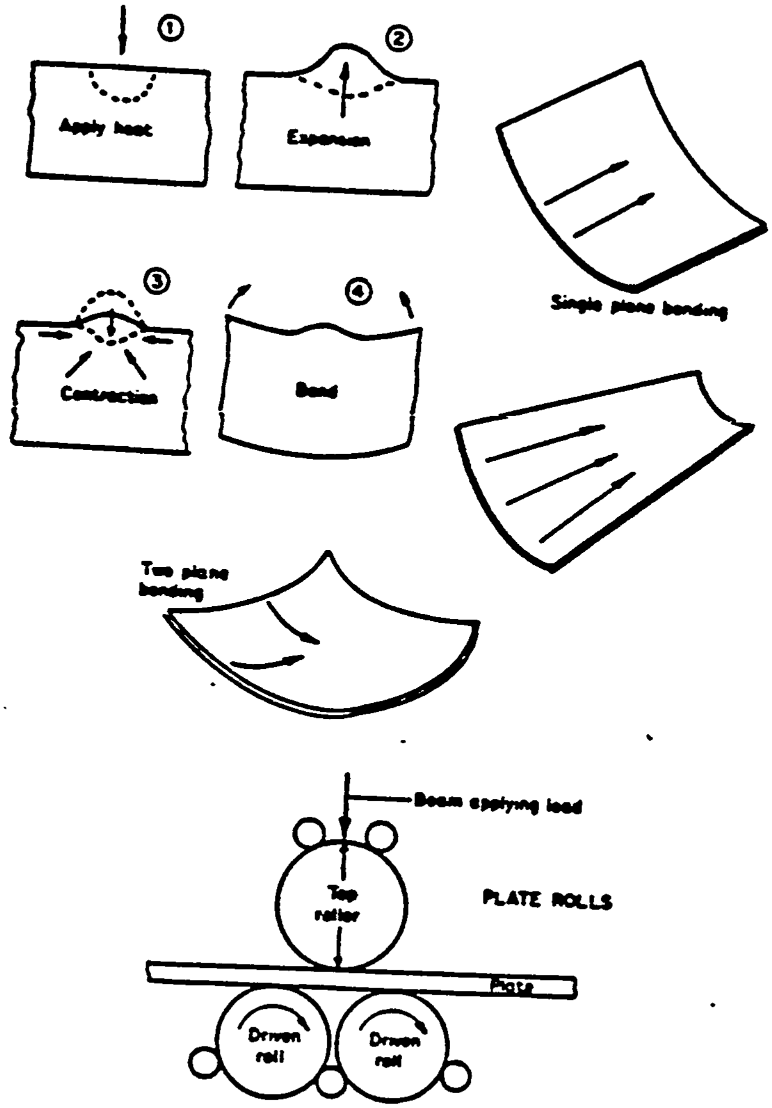

(a)
(b)
(c)
(d)
Ground level





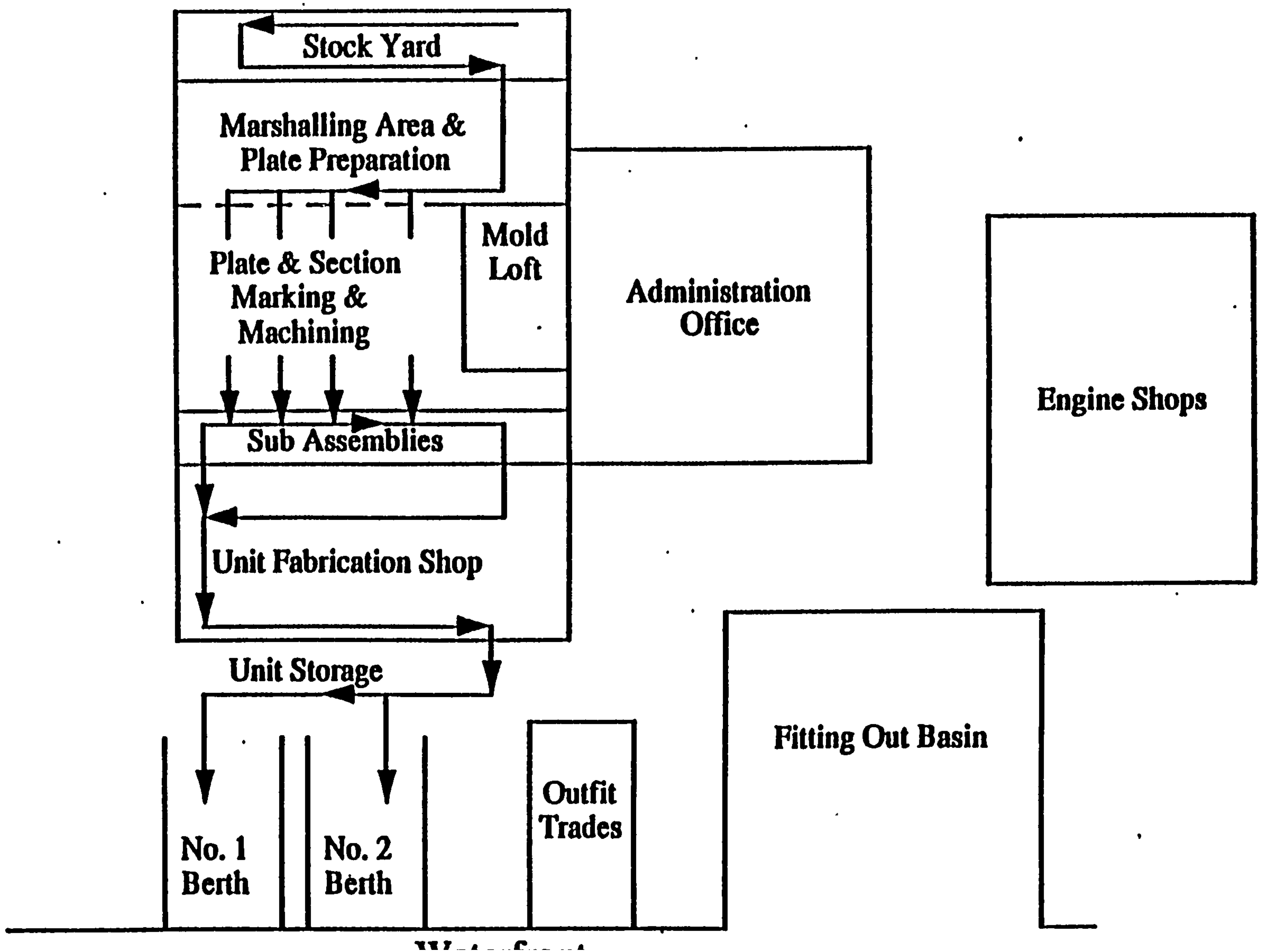
Gap presses

YL-8

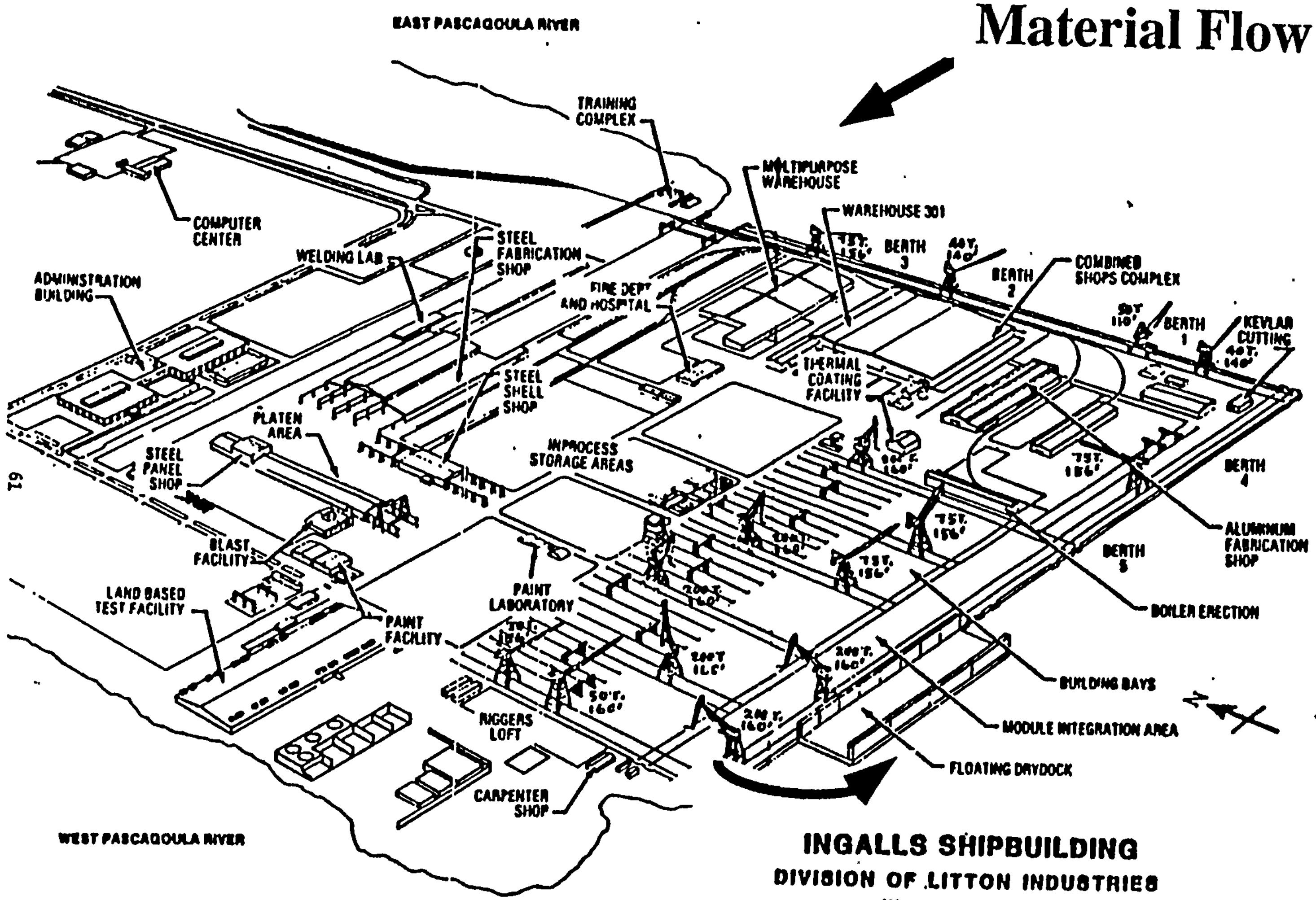


Heat line bending principle

Modern Shipyard Layout



Material Flow



INGALLS SHIPBUILDING
DIVISION OF LITTON INDUSTRIES
WEST BANK

COMPUTER INTEGRATED SHIP PRODUCTION -

FANTASY OR REALITY ?

CIM DEFINITION

ITS
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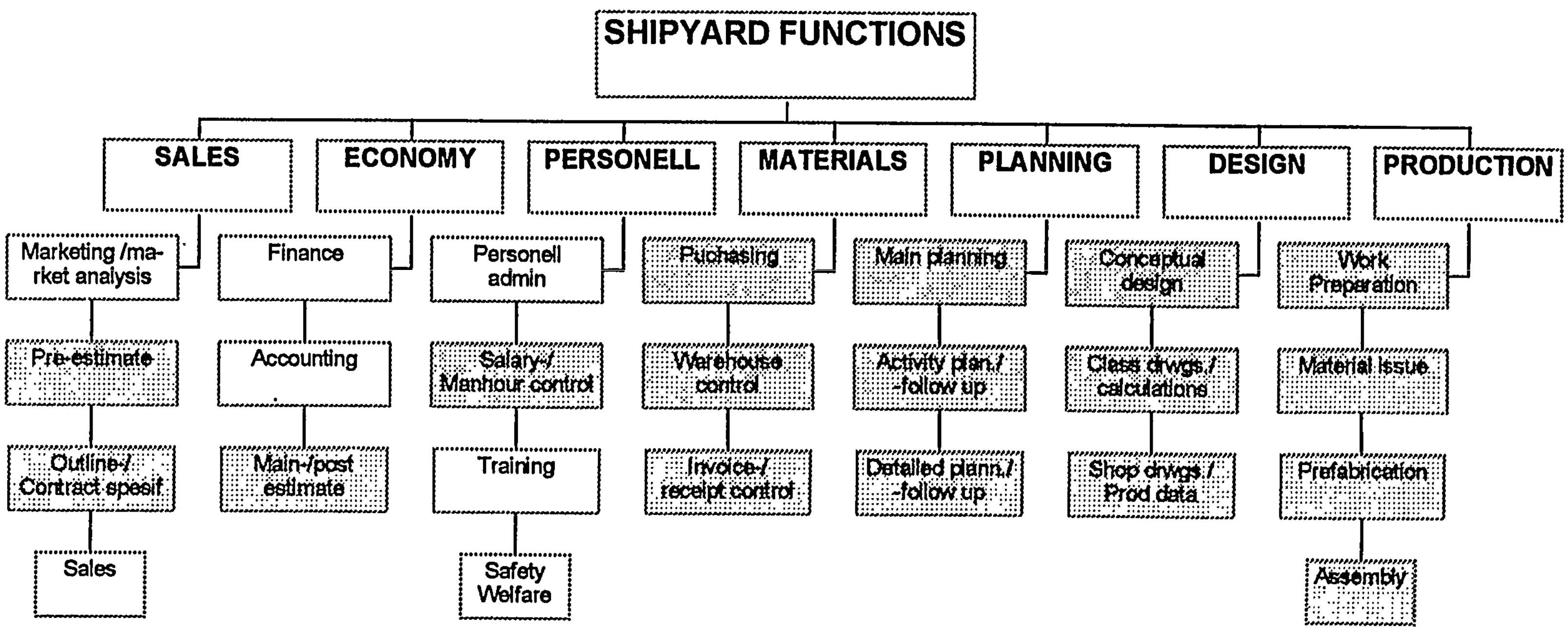
CIM means application of computer based, integrated information systems in shipyard functions directly related to the ship definition and building process

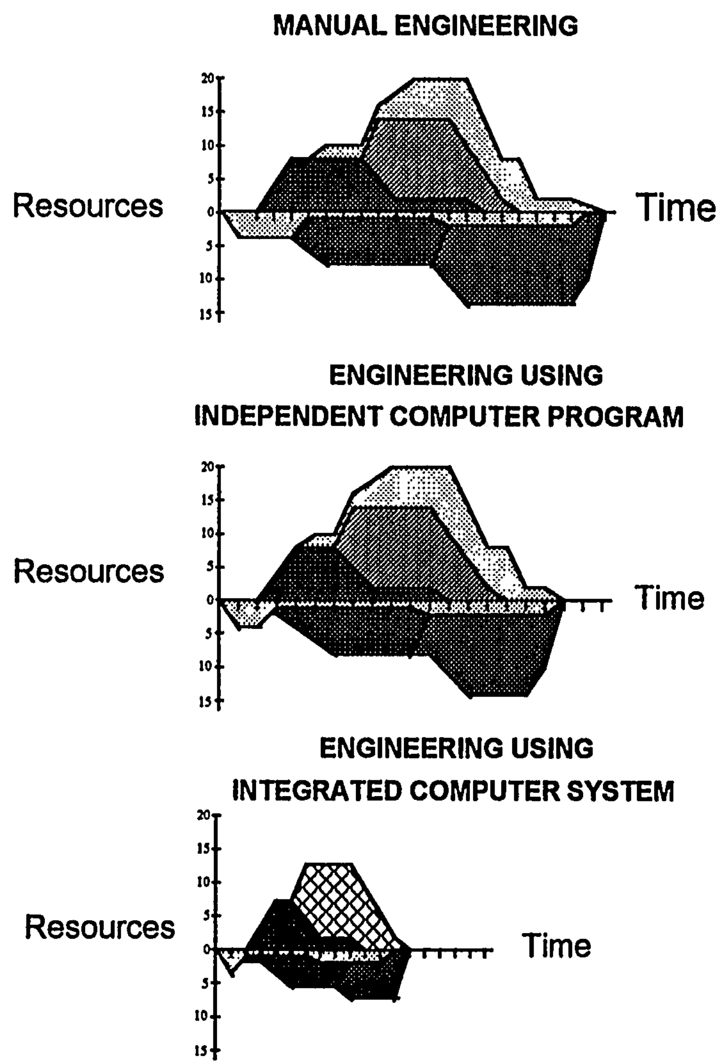


What makes the shipbuilding industry special when it comes to the use of CIM ?

- The mass production industry has used CIM and off-line programming of robots and other production equipment for a long time
- The time of programming one robot is not an issue in the mass producing industry
- The nature of the problem in shipbuilding is different
  - ✓ 'One off' production (or small series)
  - ✓ Multi discipline products
  - ✓ Large number of different work tasks
  - ✓ High degree of manual work

ITS
Your Technology Partner

Possible benefits in CIM



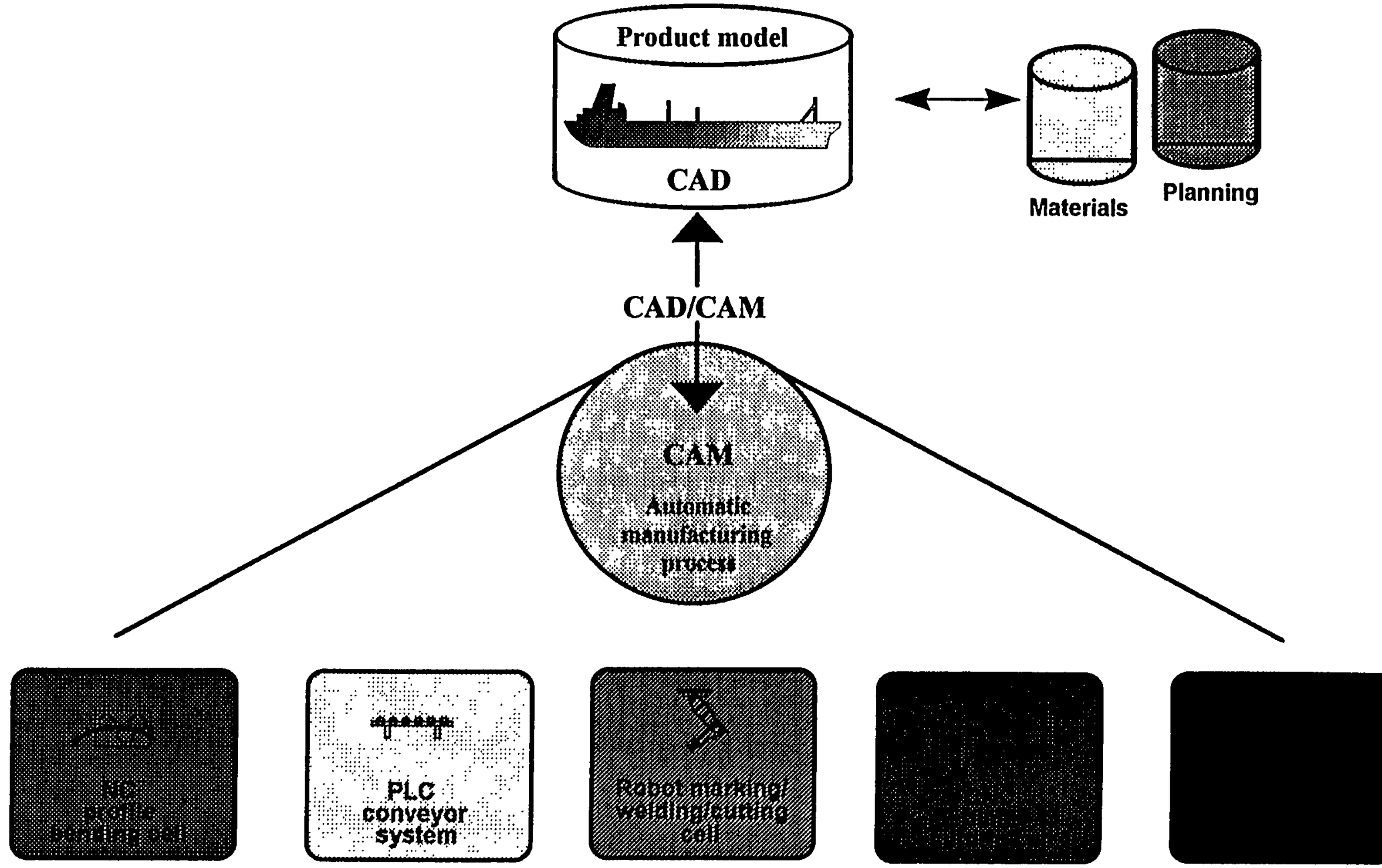
KEY

- Basic Ship Design
- Hull Class Dwgs
- Hull Assembly Dwgs
- Hull Fabrication
- Outfit Class Order
- Outfit Fabrication

Ref : Paper in Naval Architect, April 1991

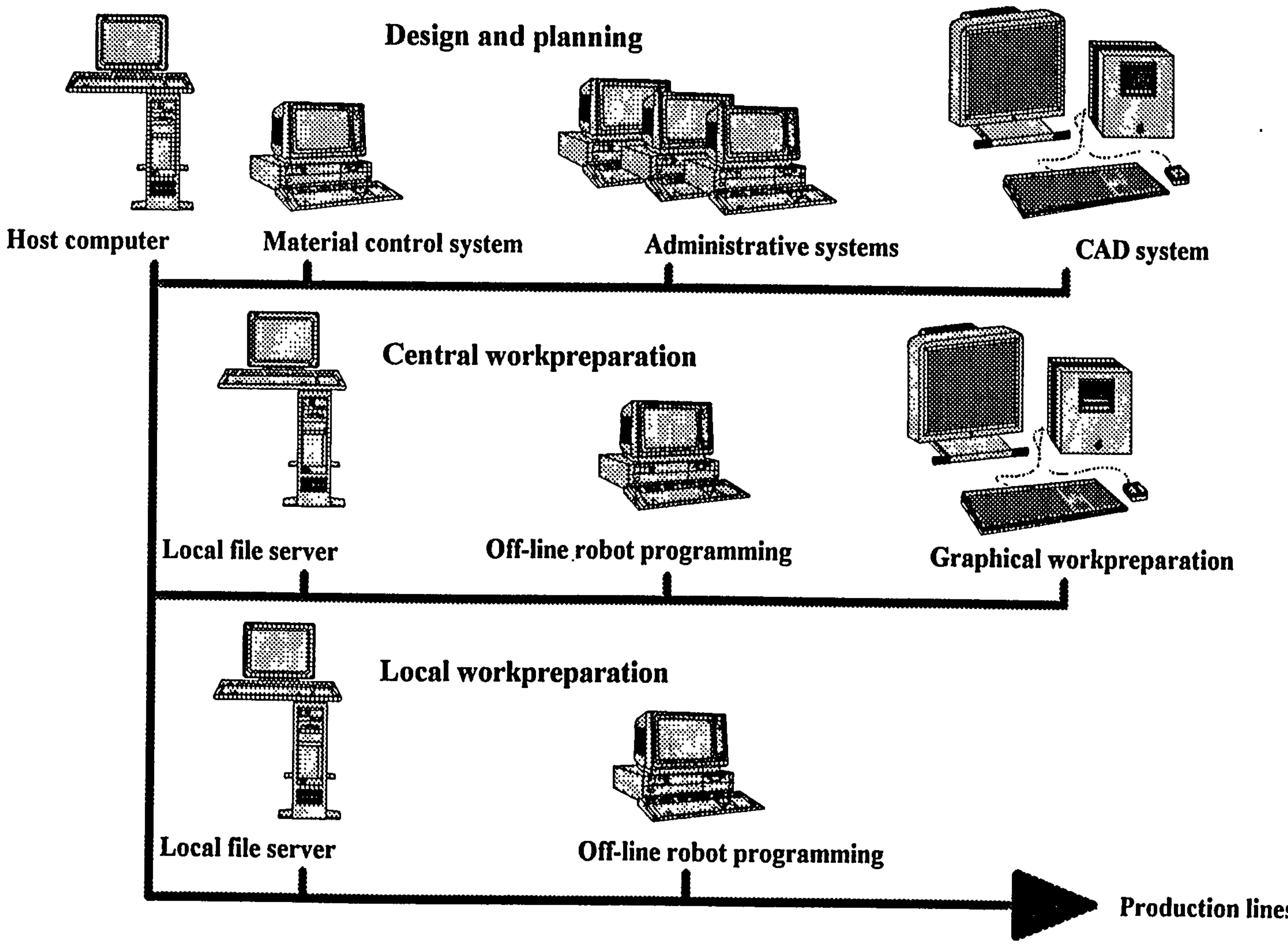
Link between the CAD and CAM systems

Your Technology Partner



Overall CIM principals

Your Technology Partner



Kvaerner Warnow Werft

ITS
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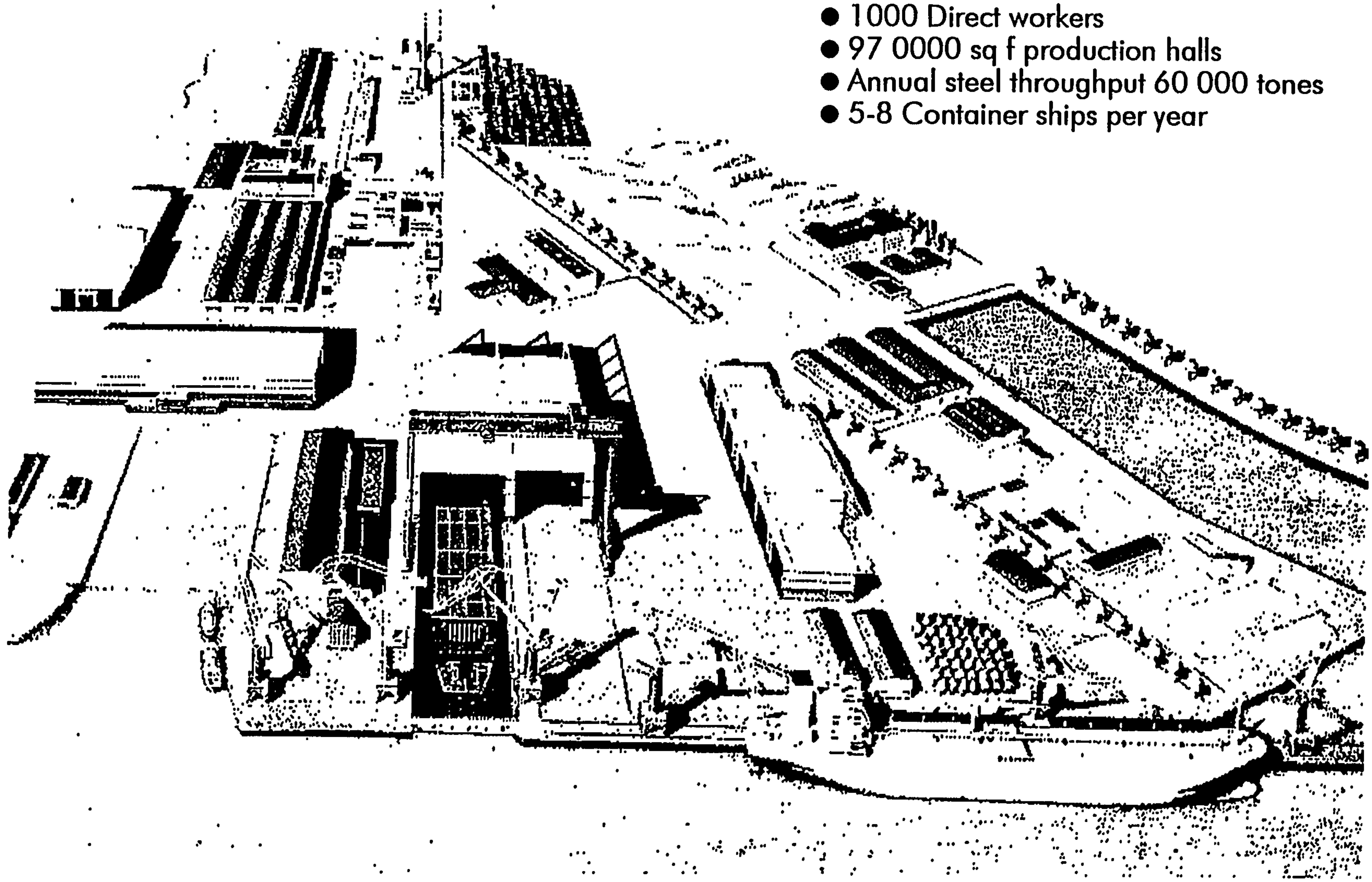
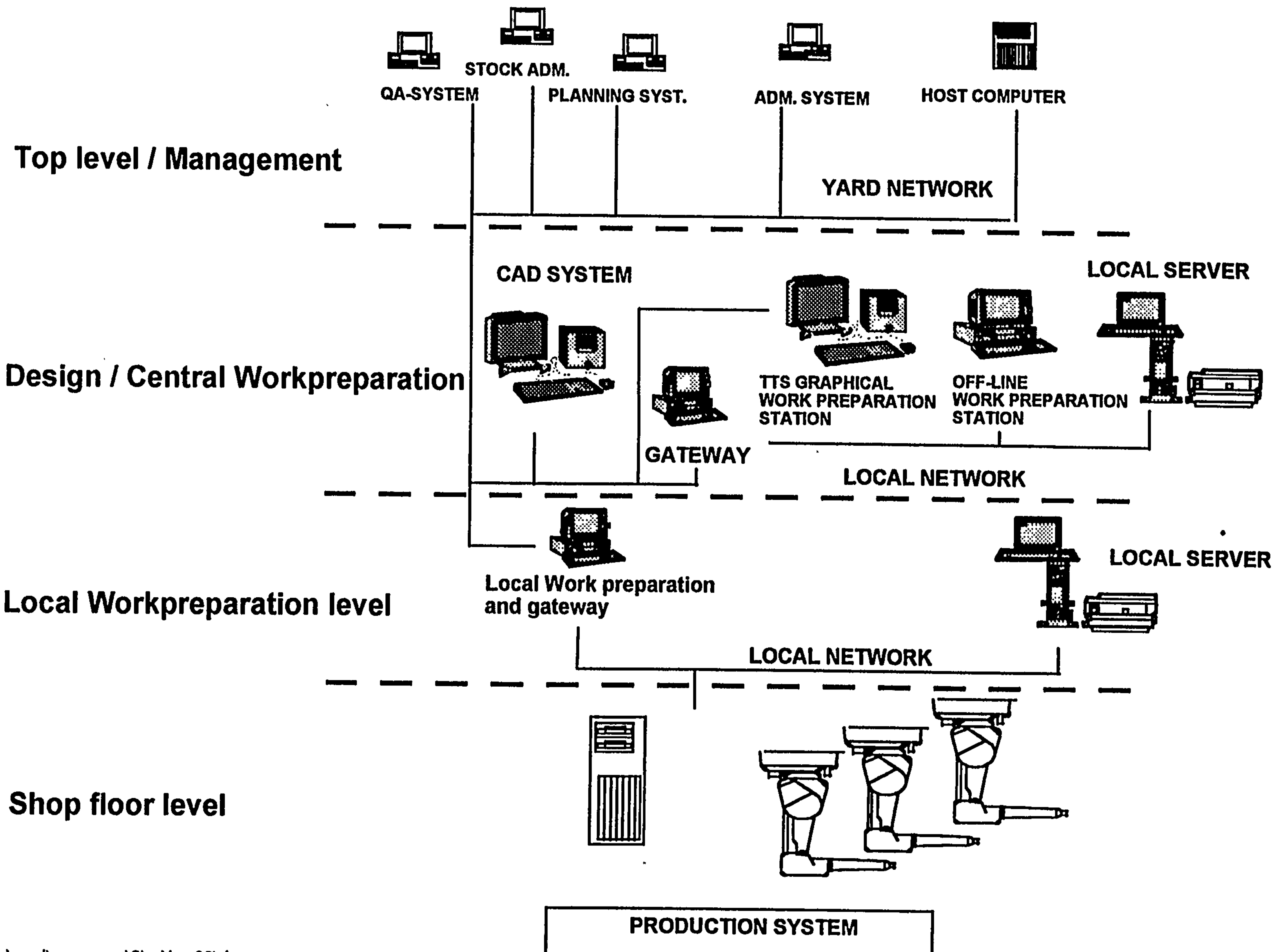
- 1000 Direct workers
- 97 0000 sq f production halls
- Annual steel throughput 60 000 tones
- 5-8 Container ships per year



Principal CIM Set-Up at KWW

Your Technology Partner



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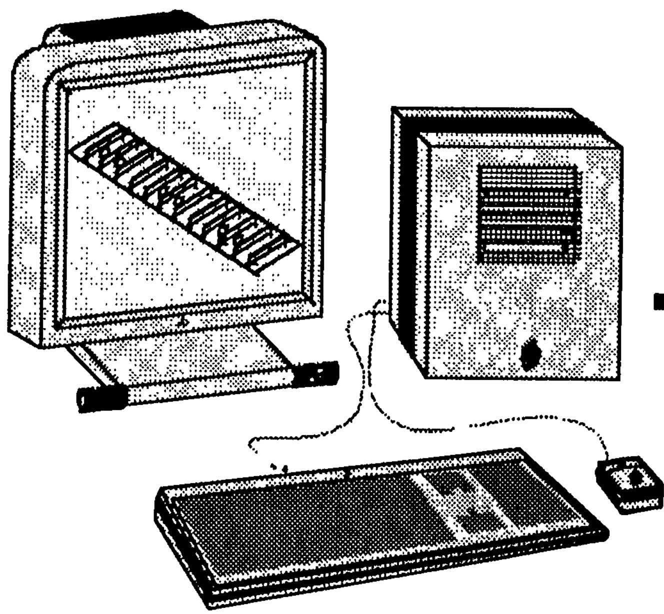
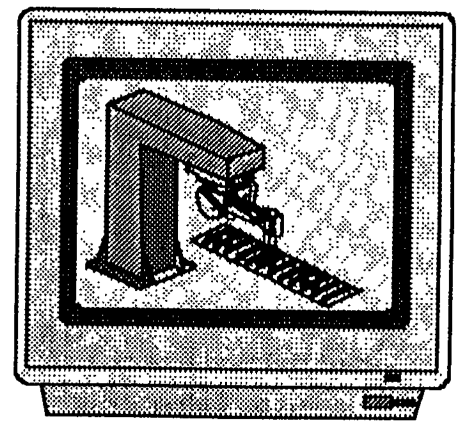
Simulation of pre-programmed off-line robot executable code

Off- line programming



Visual CAD robot Interface system

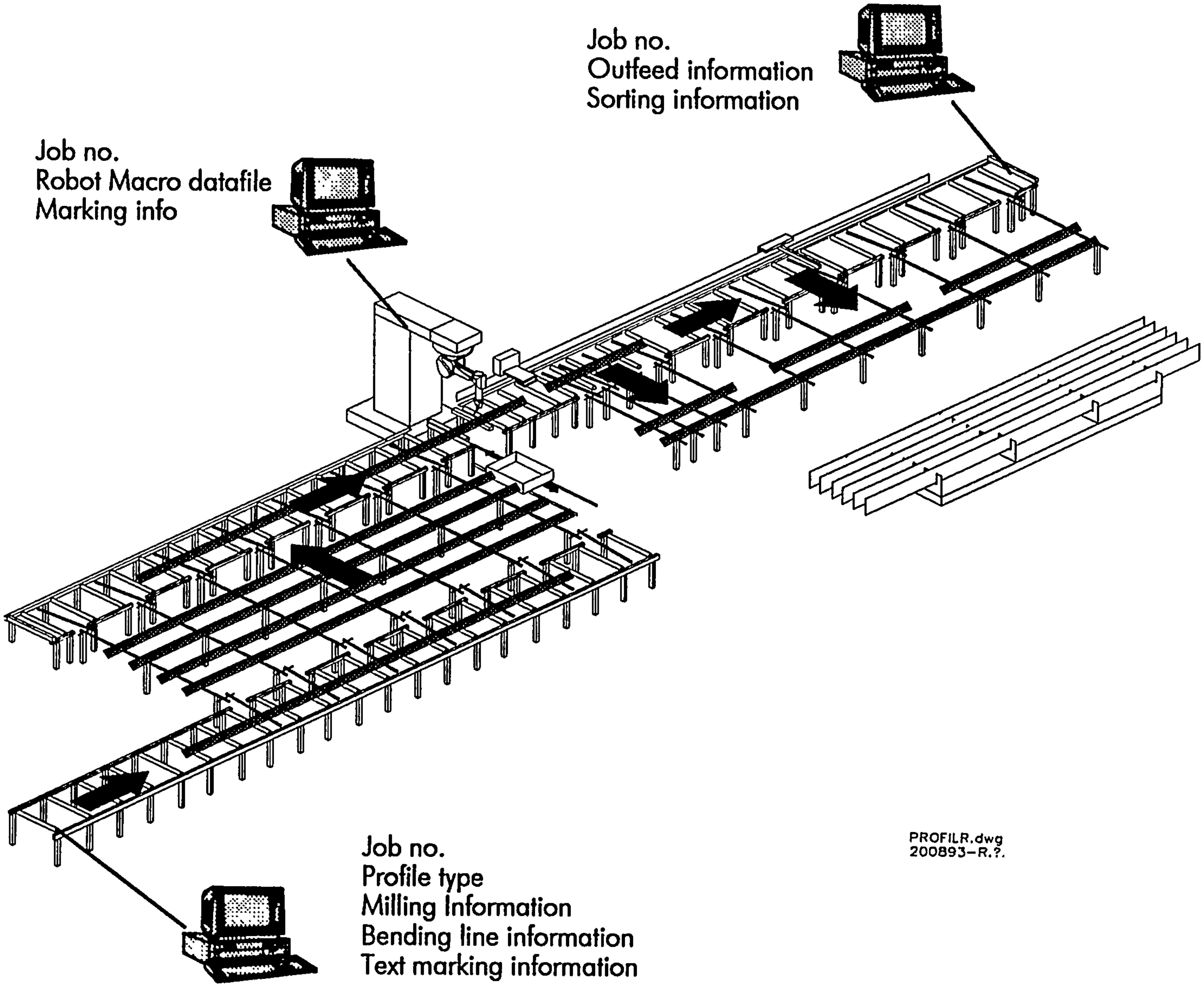
Simulation



Robot simulation

TTS Robotic Profile Line

TTS
Your Technology Partner



TTS WEB LINE

TTS
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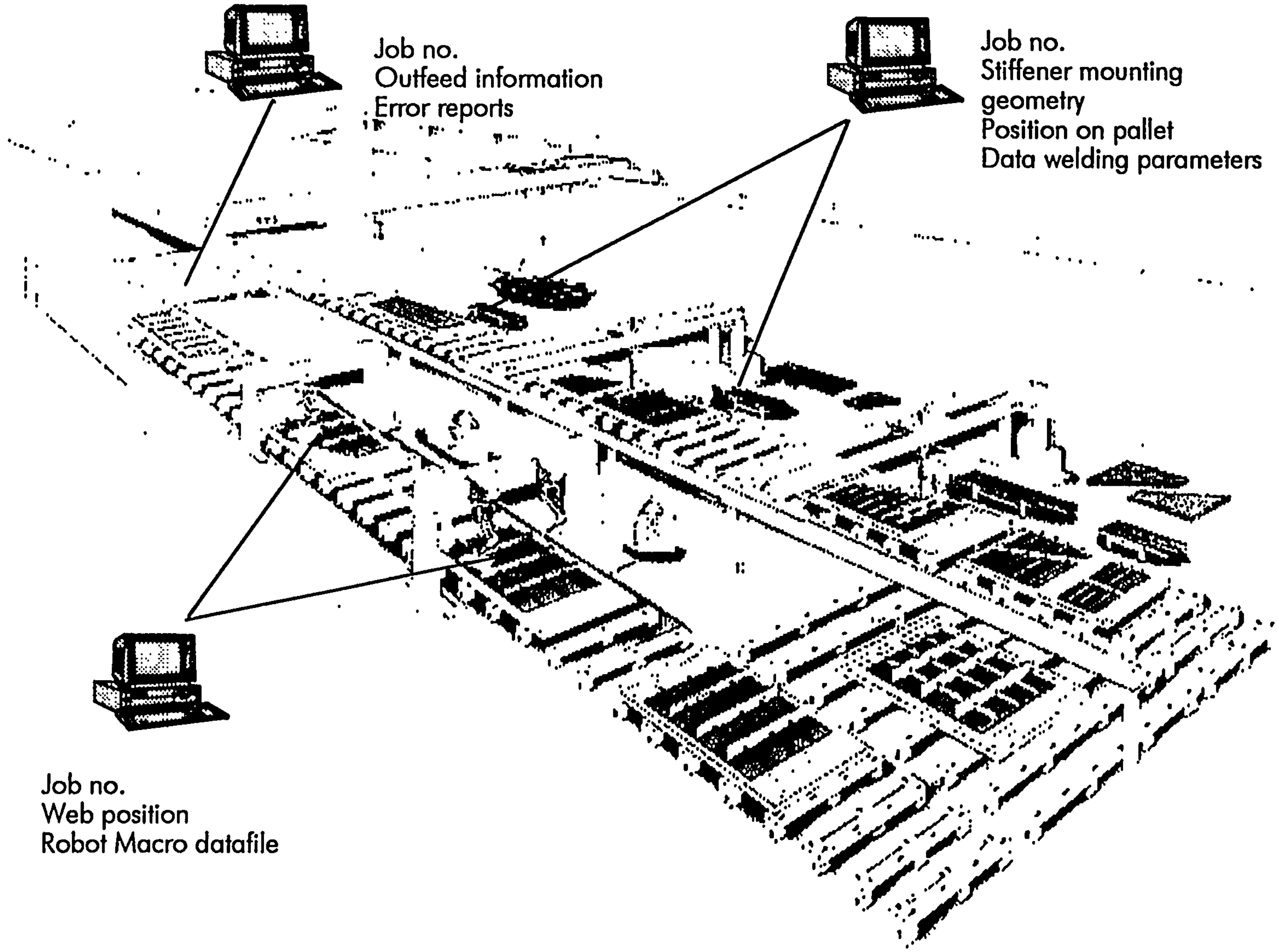

TTS Panel Line

TTS
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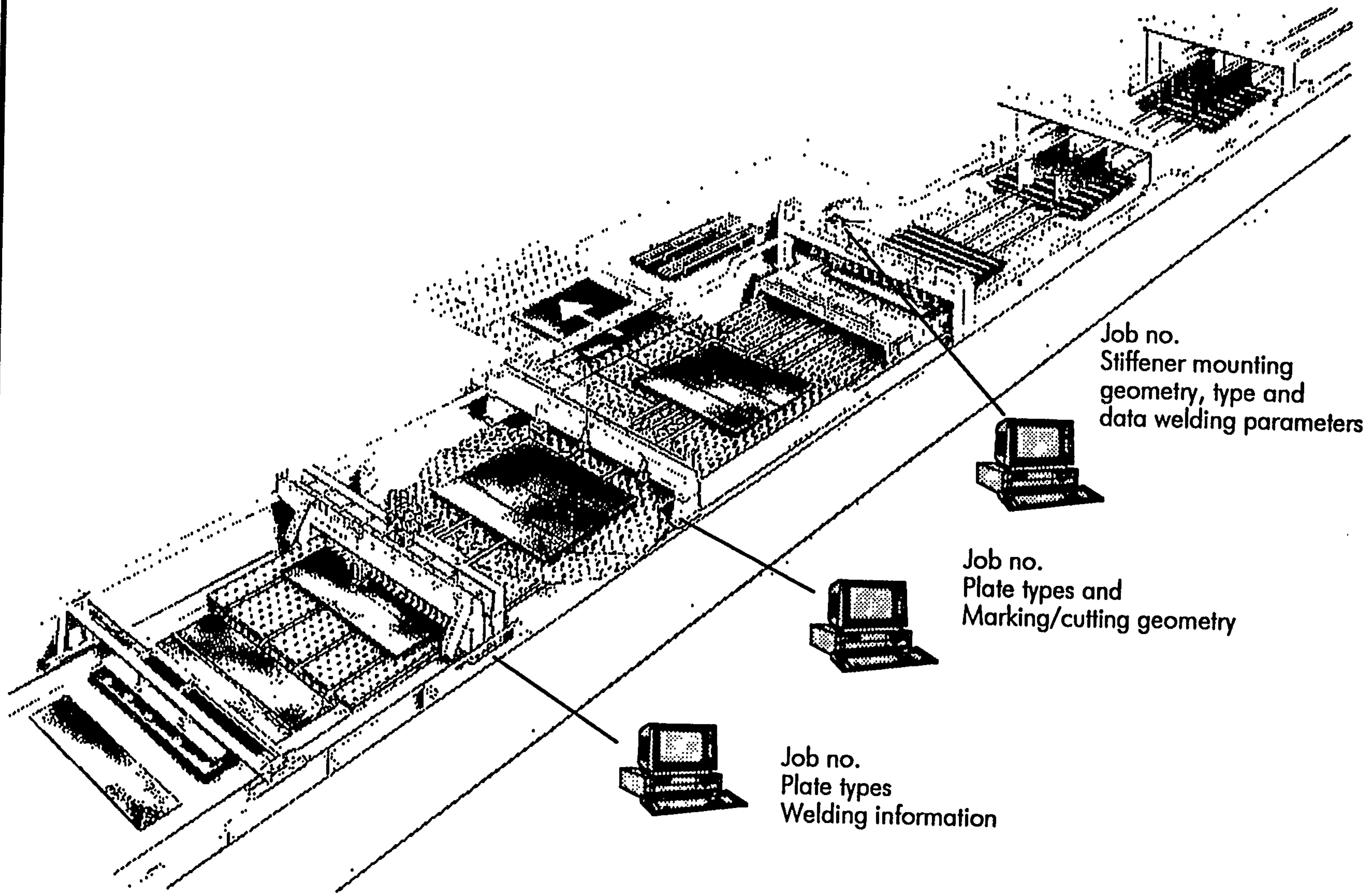
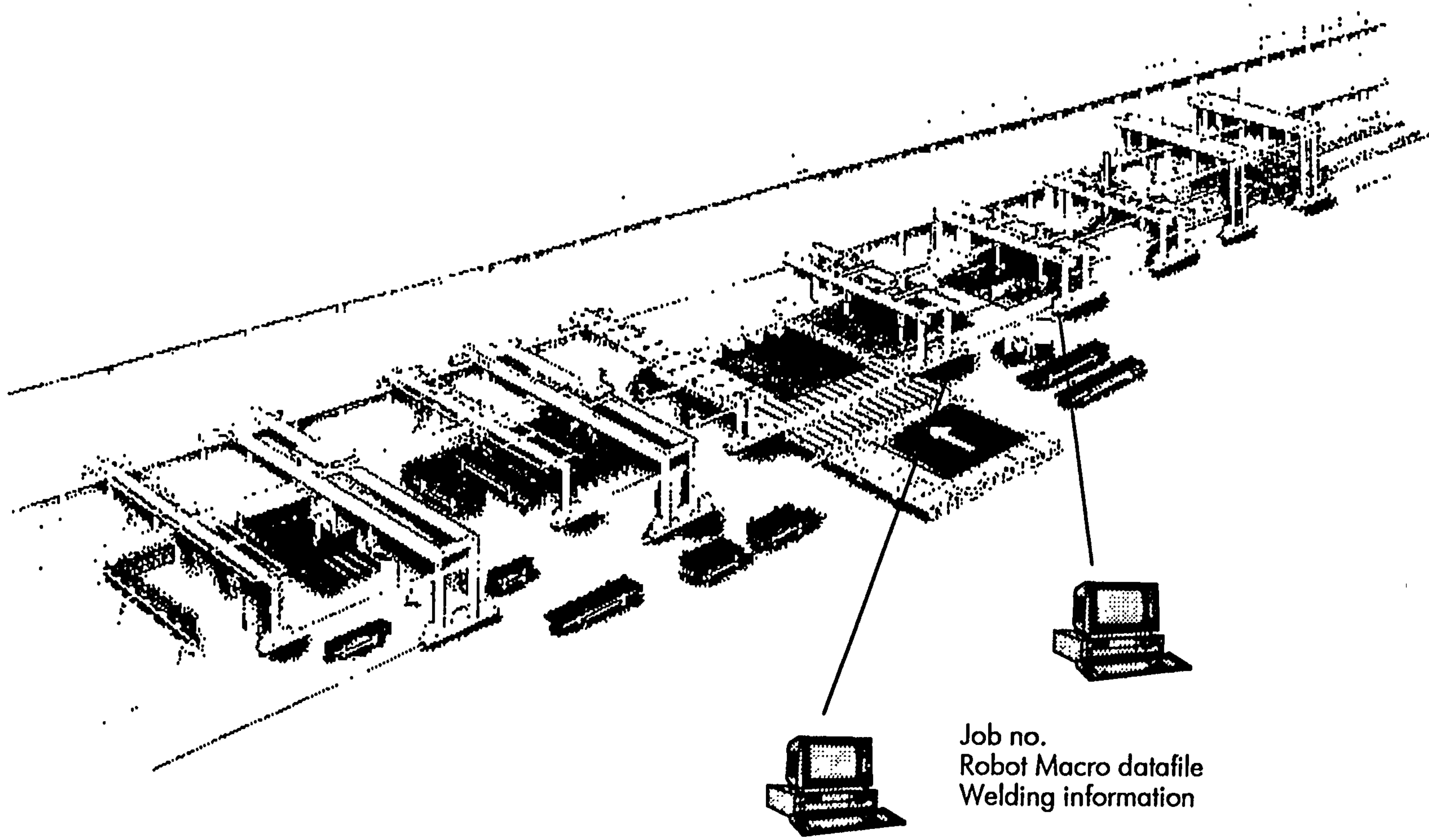


TTS Double bottom line



Implementation experiences

Your Technology Partner

- The initial phase of the project can be crucial outcome
- The whole organisation must be reorganised to fit the new situation
- Motivation and education of workers must be focused
- The implementation and start-up can be a lengthy process with a large learning potential
- Time and Cost for a CIM system is high, but a comfortable payback period can be expected
- Benefits are not easily to quantified, but they will mainly be the result of :
  - ✓ Shorter building period
  - ✓ Better control of the production
  - ✓ More detailed planning structure

- ✓ A fully utilized and specialized simulation software package can be a very good management decision tool for layout planning and daily production planning.
- ✓ Continued development and use of production simulation will make it easier to utilize the potential benefits found in CIM.

❑ **Computer technology and networks**

- ✓ Further development of workstations and X-terminals in integrated LAN solutions
- ✓ More powerful Database technology

❑ **Production technology**

- ✓ Production equipment will be developed to further facilitate and prepare for computerized links
- ✓ Design and standardization of ship constructions and parts will also improve the use of CIM

Conclusions

ITS
Your Technology Partner

- **We have now been though a period of early users with large and expensive CIM installations and are now moving into a new era**
- **The development and implementation of CIM systems will become**
  - ✓ Less costly
  - ✓ More accessible for smaller shipyards
  - ✓ More profitable on a smaller scale
- **The development will also continue within :**
  - ✓ Advanced production systems and equipment
  - ✓ Production simulation and planning
  - ✓ Product model model technology and standardization
  - ✓ Computer technology and network communication

Status on CIM - Today

ITS
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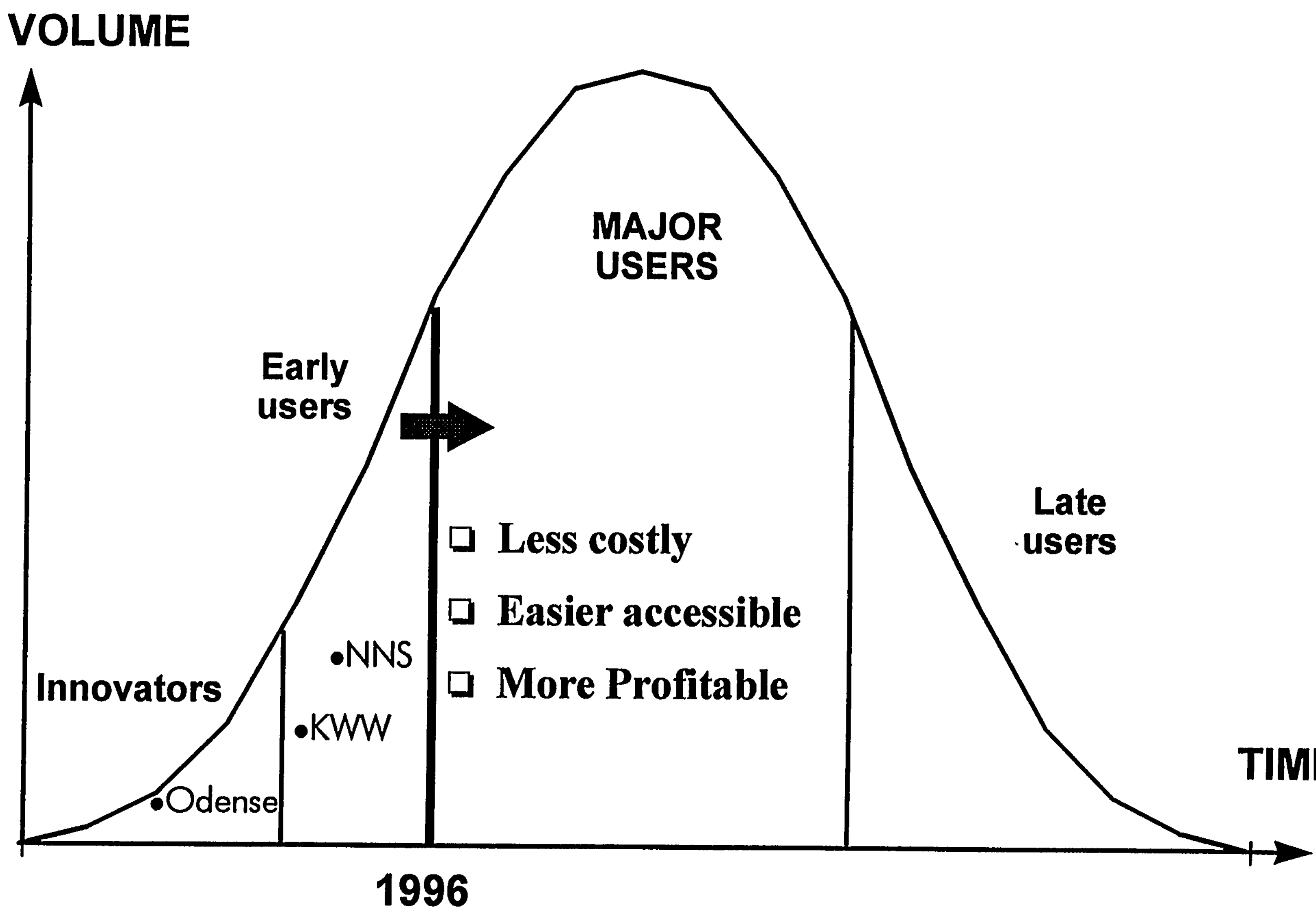

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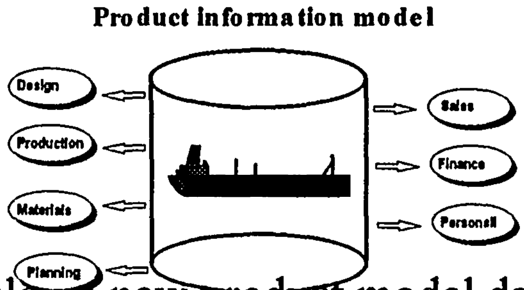
Future Development

❑ Product information models

- ✓ The product information model is the focal point in the CIM environment



- ✓ STEP is an ISO activity to develop a new product model data exchange standard which will be a big step forward for further development and use of CIM in shipyards.

❑ Production simulation and planning

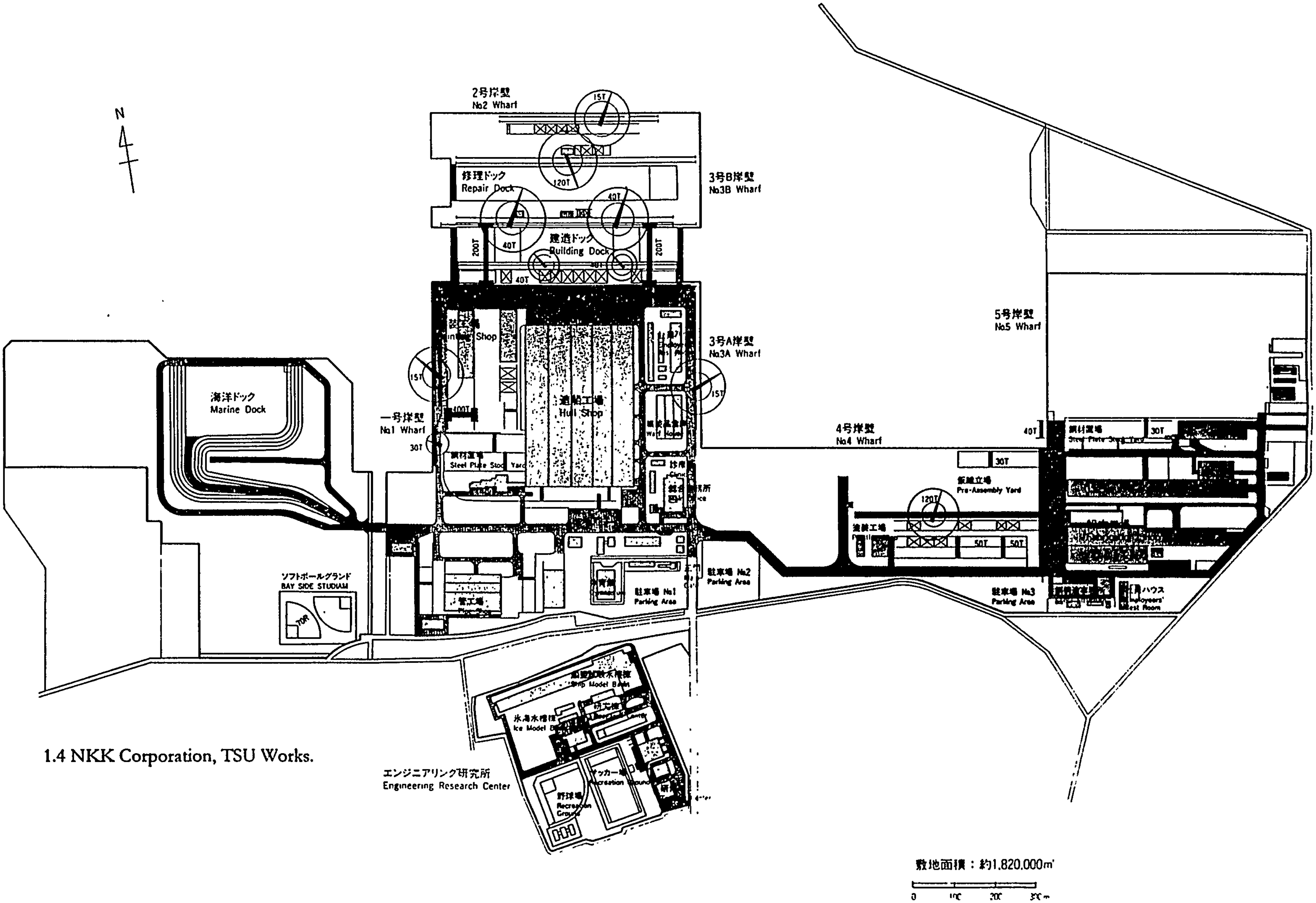
- ✓ The growing complexity and interrelationships in the production facilities and surrounding systems requires new techniques and tools to cope with the management problems.
- ✓ Production simulation is such a tool

Conclusions

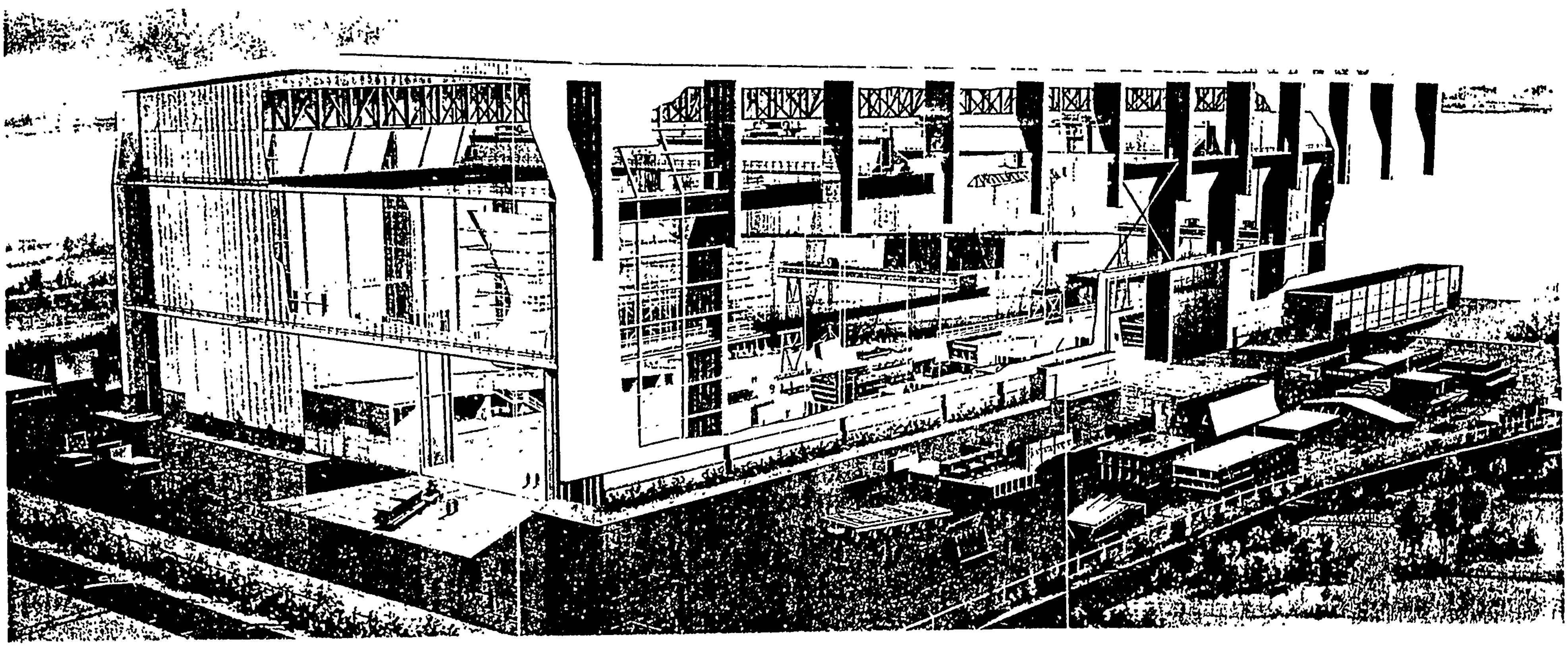
Your Technology Partner

- **We have now been though a period of early users with large and expensive CIM installations and are now moving into a new era**
- **The development and implementation of CIM systems will become**
  - ✓ Less costly
  - ✓ More accessible for smaller shipyards
  - ✓ More profitable on a smaller scale
- **The development will also continue within :**
  - ✓ Advanced production systems and equipment
  - ✓ Production simulation and planning
  - ✓ Product model model technology and standardization
  - ✓ Computer technology and network communication

➔ **Computer integrated ship production is not a fantasy but reality, as demonstrated in this presentation**



1.4 NKK Corporation, TSU Works.



1.5 Van der Giessen-de Noord Shipyard

Cut Systems

I Gas Cutting (Flame Cutting)

1. The ignition point of the ferro alloy must be lower than the melting point.

2. The resulting oxide of the ferro alloy must have a melting point sufficiently low so that the oxide can be moved out of the area by the oxygen jet.

3. Conditions exist for

   a. Mild steel
   b. Lower alloy steels.

4. Conditions do not exist for

   a. High alloy steels
      ** stainless steel
      ** high heat resistant steels
      ** most anti-magnetic steels
   b. Most cast-iron

5. Certain steel must be pre-heated and cooled to decrease the temperature gradient Avoids surface Hardening

6. Powder cutting is applied to produce a cut. (cast iron, stainless) but Qualitv is not as good.

   a. Silicon oxide powder is used to produce increased kinetic energy form cutting kerf.
   b. Iron powder is injected into oxygen to keep oxides liquid.

7. Oxygen cutting process can be used

   a. From lmm to 3000mm. (up to 100 inches)
   b. Auto cutting from 1/4 inch up to 10 inches

8. Fuel Gases

a. Acetylene (very hot, also used for welding)
b. **LPG**
   ** cheaper, but not as hot
   ** C_2H_6 or C_3H_8
c. Natural Gas (CH_4)
d. Hydrogen (used for underwater)

9. Portable systems are available

a. Low capital costs
b. Other

III. Plasma Arc Cutting

1. Mechanism

a. Plasma is iodized gas that will conduct electricity
b. Electrode is connected to a negative DC supply
c. A nozzle restriction exists, causing a higher temperature than open arc
d. Arc is established by the ionized gas. Plates are cut by the high-temperature, concentrated arc.

2. Theoretically all metals may be cut. is especiallv appropriate for stainless and nonferrous metals.

3. Process is endothermic, i.e., all heat energy is brought in.

4. Impressive speeds: 4 to 8 meters/minute on thin plate (say 1/16 to 3/16" thick.) Speeds go down rapidly with plate thickness because of endothermic character of process.

5. Recess limitations

a. **Thickness/speed**
b. Quality of cut kerf
c. Toxic fumes generated

6. Applications

   a. Used for high alloy steels
   b. Aluminum
   c. Found in countries where electricity is relatively cheap.

   ** Norway.

IV. Arc-Air Gouging

1. A combination of arc and oxygen supply. A gas cutting torch is supplies with extra nozzles that allow gouging.

2. Used as a gouging Process- not as an original cut.

V. Laser Fusion Cutting

1.Useful only in materials that absorb large amount of have energy

2. Application
   a. Mild steel
   b. Stainless
   c. Some non ferrous metals (cannot cut aluminum or nickel.)
   d. Leather
   e. Wood (high absorption. Cut in inert gas to eliminate oxidation of material.)

3. Limitations requires high focus, there are limitations to thickness
   Steel: up to 1/4”
   a. Wood up to about 1“
   c. Plexiglass about 3“

3. Benefits
   a. High accuracy
   b. Thin kerf width (2 mm)
   c. Nonexistent heat distortions.

VI. Water cutting

1. Water is pumped at pressures up to 60,000psi and expelled through a sapphire nozzle to form a fine cutting stream.

2. The jet is about .008" dia. Common diameters for cutting applications range between .003" and 0.020".

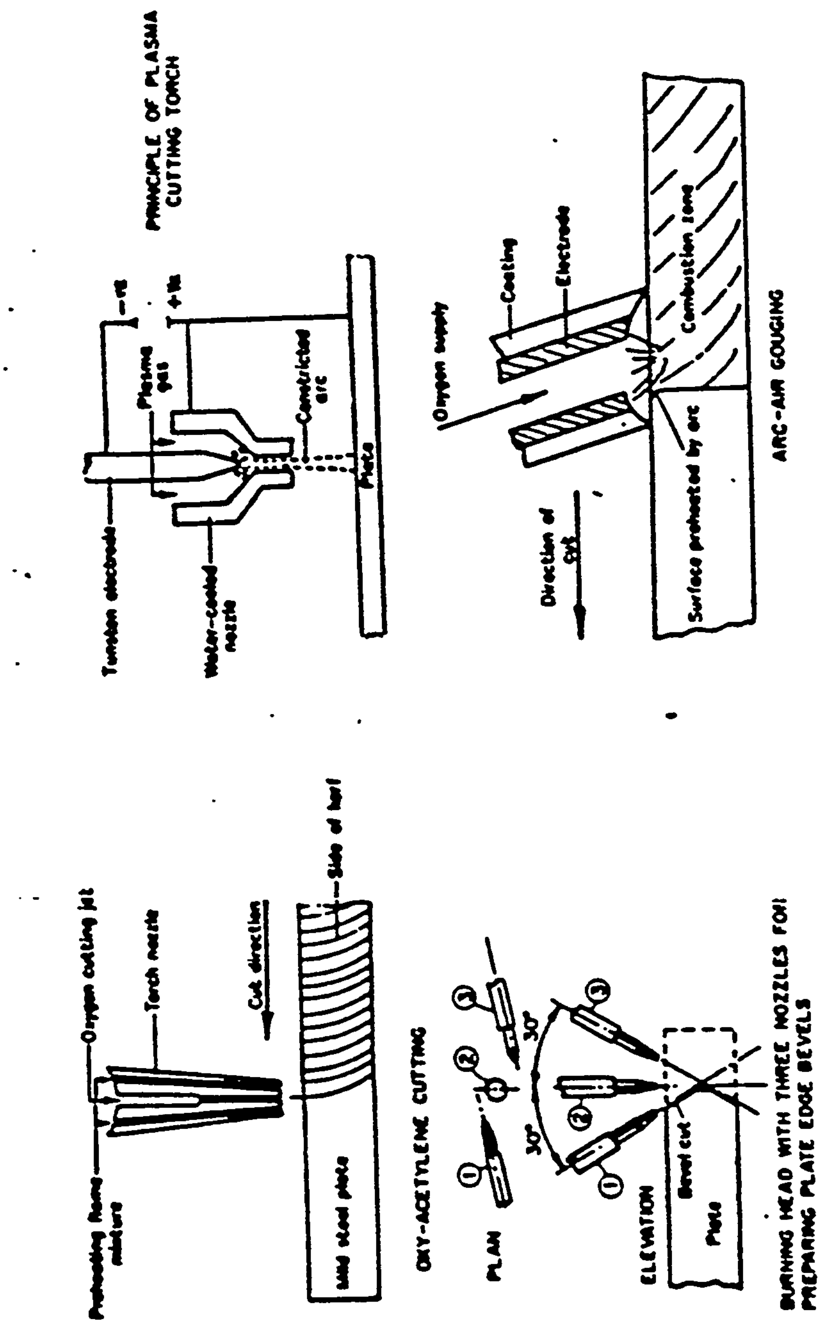
3. Wide range of materials can be effectively cut by system.

4. Advantages are
   a. No airborne dust
   b. High cutting speed on certain materials
   c. Ease of shape cutting
   d. No dulling of the cutting tool
   e. Quality kerf

5. Disadvantages are
   a. Specialized equipment required that has limited portability
   b. Can initiate localized rusting because of moisture
   c. Endothermic, and has thickness Imitations

FIGURE CS-I
METAL CUTTING PROCESSES

I



Welding Systems

I GENERAL

A. Welding is a process whereby two metals are melted and resolidified to form a solid connection

B. Welding lends itself to prefab techniques

C. Joints are produced more quickly

D. Less skilled labor is required

E. Easier to obtain water tightness

F. Basic types in shipyards (three): Gas and Electric Arc and 'E1ectro-Slag (Resistance).

II GAS

A. Most common is acetylene-oxygen flame to 3000^{00}c

B. Slow, limited to thin metal (about 1/4" plate)

C. Heat must be transferred from flame to plate.

D. Shipbuilding limited to 1/4" and less (HVAC, accommodations, etc).

III. ELECTRIC ARC WELDING (SEE FIGURES I-III)

A. A wire (or electrode) is connected to a source, ground tied to plates to be welded. A gap causes a high temperature arc. This melts the plate edges and end of electrode.

B. Types are:

1. Slag shielded-flux produces a shield that permits an easier are by consuming of the surrounding oxygen and by protecting the molten metal

2. Inert gas shielded

C. Shielded metal arc (covered electrode); see Figure IV.

1. Universally used for manual welding when semi-automated processes are not used because of

   a. Lack of equipment
   b. Operator skills
   . c. Or where versatility of process is desired

2. Most common types of Electrodes are

   a. Rutile– have high titanium
   ** general purpose
   ** easily controlled
   ** good weld finish

   b. Low hydrogen (called "basic")--have higher lime content and low moisture content.
   ** superior mechanical properties
   ** high tensile strength steels
   ** needs an experienced operator.

3. Can be used in down-hand. vertical. or overhead.

   a. Requires different electrode, current, and technique
   b. Very easy to change

D. Submerged Arc--Arc is maintained in a blanket of granulated flux (see Figure V)

1. Consumable filler wire is employed.

2. Flux breaks down around arc providing gases and protective thermal blanket. Results in high concentration of heat

   a. Very efficient
   b. Suitable for high deposits of fast speed.

3. Only intended for down-hand.

4. Where used in a single pass, a backing bar is generallv employed because of large puddle.

5. Is most frequently used automatic process in ship production.

6. Is usually employed undercover using clean plates.

7. There is a semi-automatic process portable system marketed.

E. Flux-Cored Arc Welding

1. can be used on relatively dirtv plates

2. Semi-automatic process

3. Some variants use C02 DIUS argon shielding

4. Used as semi-automatic system for steel alloys.

F. Stud Welding (See Figure VI)

1. Arc is drawn between stud and date: classified as shielded arc process

2. Each stud is inserted into a stud welding gun chuck—a ceramic ferrule is slipped over it and placed against surface.

3. On triggering stud is lifted from plate, an arc is established, melting end of surface.

4. Stud welding is often useful in shipbuilding for
   a. Fastening stud bolts
   b. Insulation to bulkheads.

G. Tungsten Inert Gas Welding--Arc is drawn from a non- consumable tungsten electrode (Figure VII)

1. Fill metal is added as required

2. Ignition is obtained by means of a high frequency discharge across the gap

3. Only plate thicknesses of less than one-fourth inch are welded by this process

4. Also may be used for root pass

5. Also used with aluminum.

H. Gas-Metal Arc (Figure VII)

1. Used for automatic and semi-automatic welding of stainless steels, aluminium, and other non-ferrous alloys.

2. Occasionally used for low-alloy steal.

3. Can be used on very thin plates with "dip transfer technique"

1. EIectroslag/Electrogas (Figure VIII)

1. Electroslag is resistance welding: an arc is struck, then welding is achieved by resistance path heating through the flux

2. Used for welding thicker steel plate (up to 16"]

3. Weld should be continuous: stopping/starting produces discontinuities

4. Vertical weld only

5. Greater interest is the electrogas.
   a. more suitable for welding in the 3/8" to 1-1/8" size range with square or v-edge preparation.
   b. Produces a better weld because of the arc process.

6. Navy has been reluctant to permit electroslag/electrog as process because of concern with finish hardness.

IV. WELD DISTORTION

A. Introduction

1. Question: What causes distortion?

2. Answer: Restraints to the expansion contraction process that occurs during heating and cooling. See Figure IX.

B. Control of Weldment distortion

1. Do not overweld

2. Use intermittent welding

3. Use few weld passes as possible.

4. Place welds near neutral axis

5. Use back-step welding

6. Anticipate the shrinkage forces.

7. Plan the welding sequences.

8. Remove the shrinkage forces after welding

9. Minimize welding time.

C. HOW PROPERTIES OF METALS AFFECT DISTORTION

1. Coefficient of Thermal Expansion-Hi~h Thermal Expansion Yields Greater Expansion/Contraction

2. Thermal Conductivity-High conductivity yields low shrinkage

3. Yield Strength–High Yield Strength yields High Distortion

4. Modules of Elasticity--High Modulus yields High Distortion Resistance

5. Examples of material properties:

	Modulus (10psi)	Yield (10^3psi)	Coefficient Expansion (in/in/degF)	Thermal Conduct'v (cal/cm^2/cm^0/c/sc)
Steel, Carbon	30	38	7	.12
Steel, Stainless	29	45	10	.04
Aluminum Alloy	10	20	12	.50
Copper Alloy	15	10	9	.90

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FIGURE W-I
ELECTRIC ARC WELDING PROCESSES

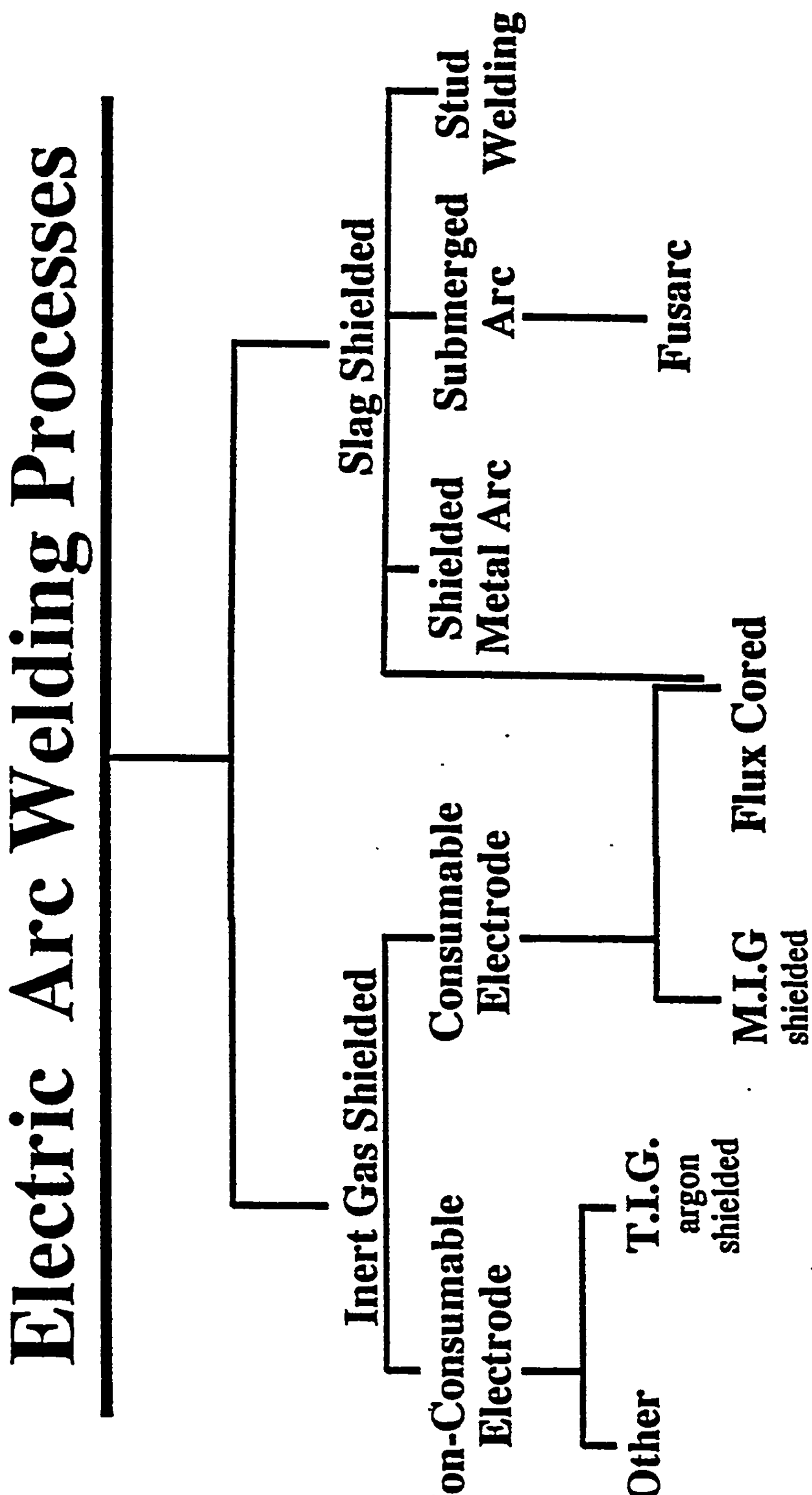

FIGURE W-II
COMPARISON OF WELDING METHODS

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	Covered Electrode	Covered Elect rode w/ Iron Oxide	Gravity	Submerged Arc (SAW)	Electro Slag & Electro Gas	Gas Metal Arc (GMAW)	Gas Tungsten Arc (GTA)
Production Rate	5	4	3	2	1	4	6
Price of Equipment	1	1	2	5	6	4	3
Welding Position	All	H	H	H	V	All	All
Automation Potential	6	6	3	1	4	2	1
Charpy-V Impact	2-4	4	4	5	6	2	1
Cold or Hot Welding	3	4	4	5	6	2	1

1 = Best, 6 = Worst	H = Horizontal, V = Vertical

FIGURE W-III
APPROXIMATE USE OF WELDING PROCESSES

Type	USA Navy	USA Commercial	Japan Commercial
Shielded or Stick A.W.	60 - 70 %	50%	< 30%
Gas Metal Arc	20 - 30%	30-35%	> 70% (Gas Metal Arc through Electro - Slag)
Submerged Arc	5 - 10%	15-20%	
Stud	< 1%	< 1%	
Gas Tungsten (Manual)	1%	--	
Electro - Slag	--	3-5%	

FIGURE W-VII
METAL INERT GAS WELDING

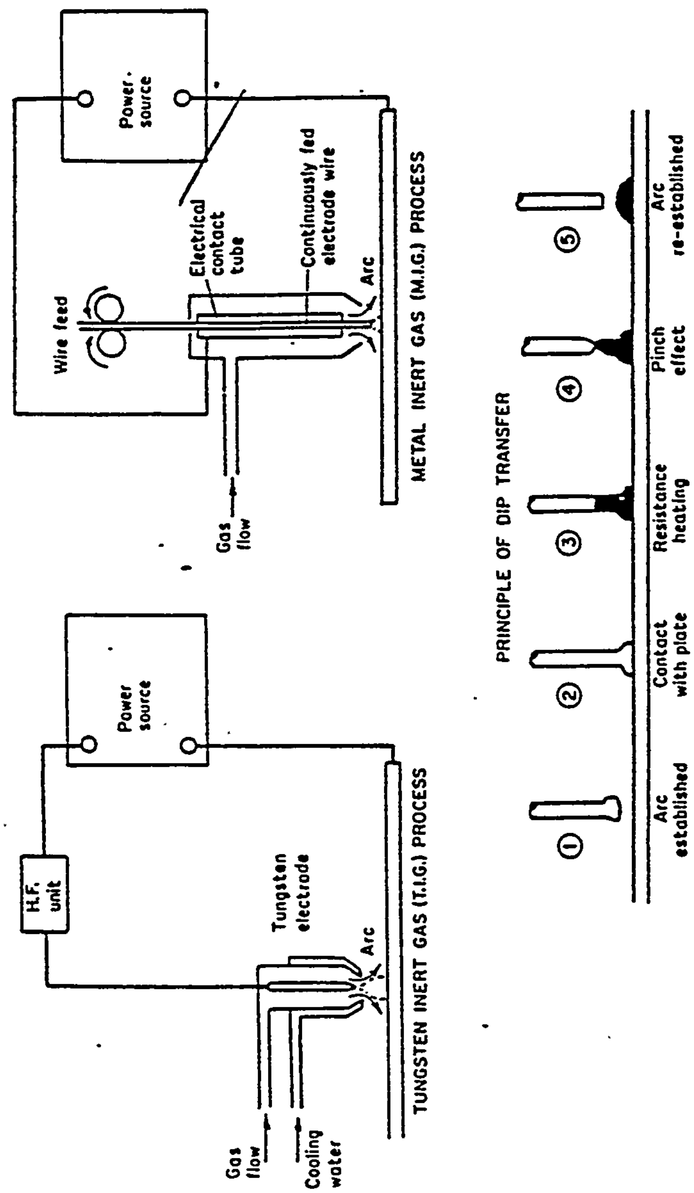

FIGURE W-V
AUTOMATIC ARC WELDING

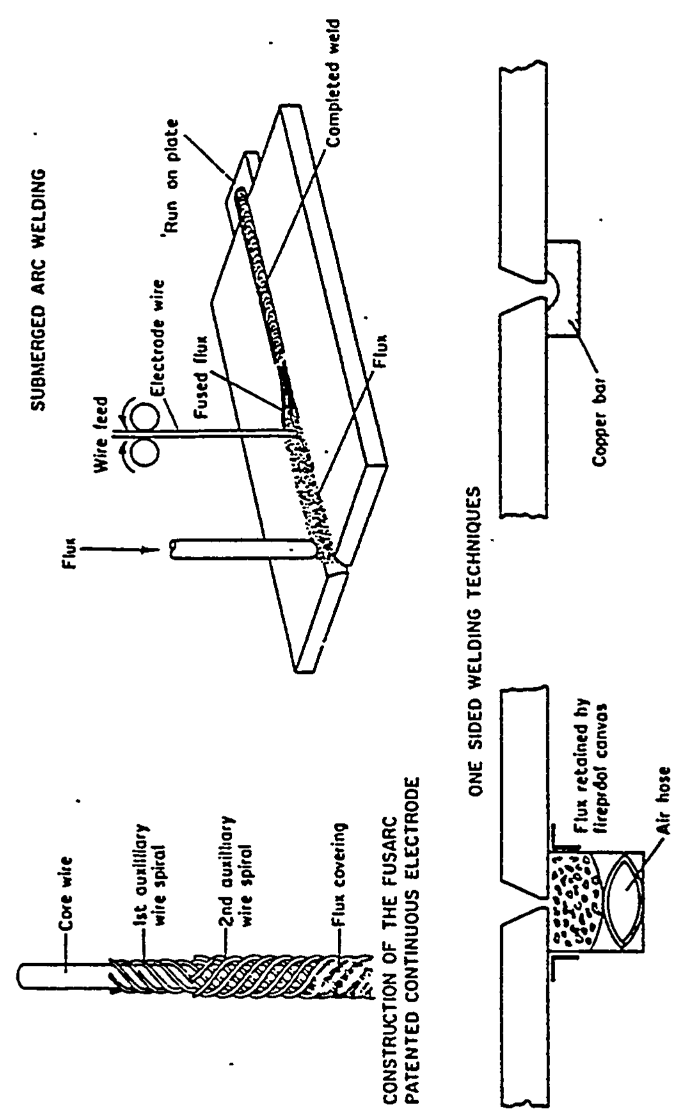

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FIGURE W-VI
STUD WELDING

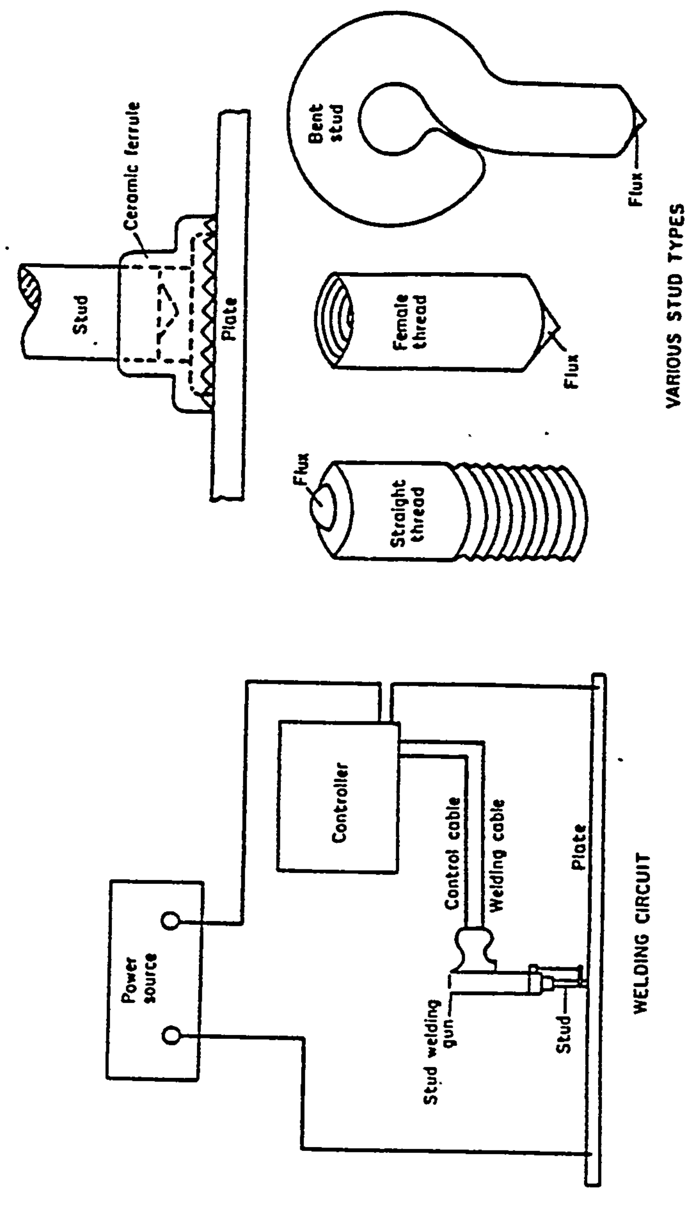


FIGURE W-VII
METAL INERT GAS WELDING

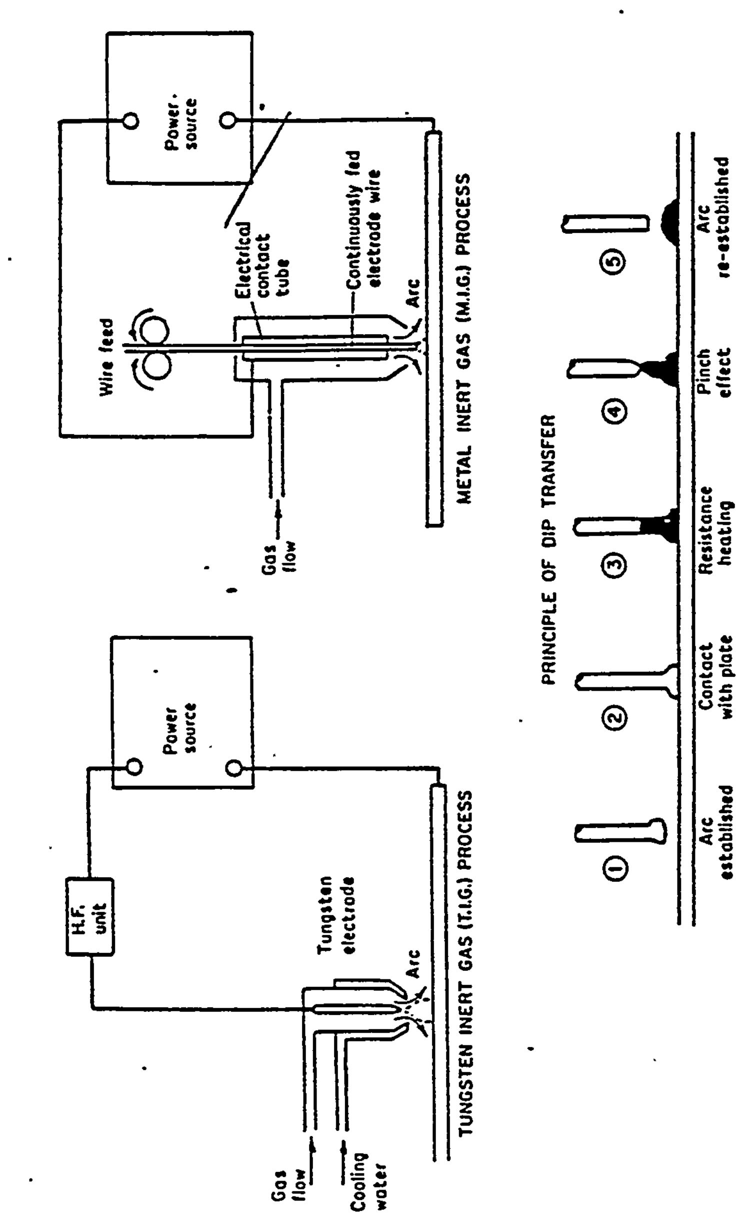
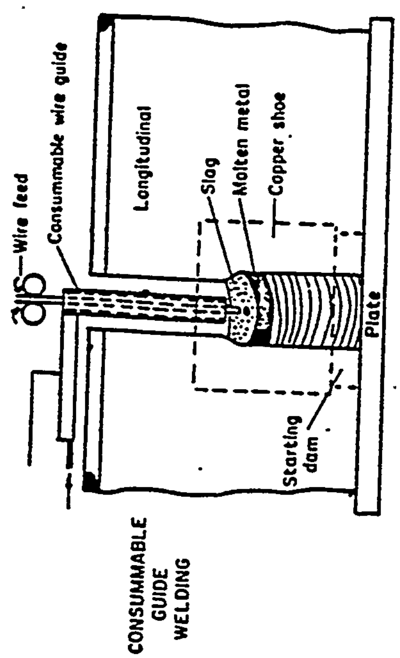
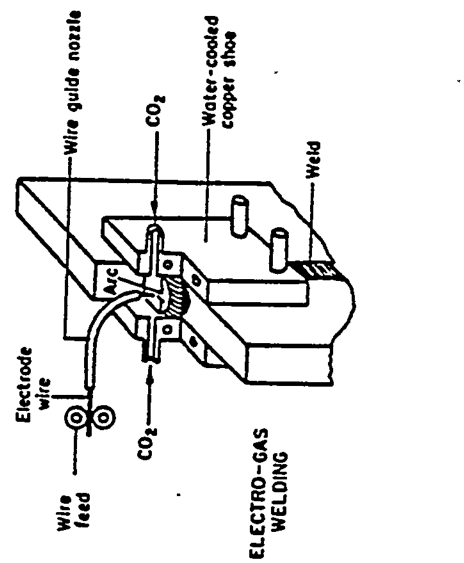
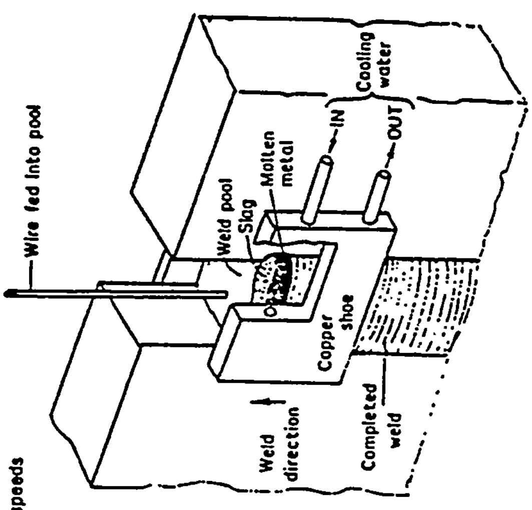


FIGURE W-VIII
ELECTRO-SLAG WELDING







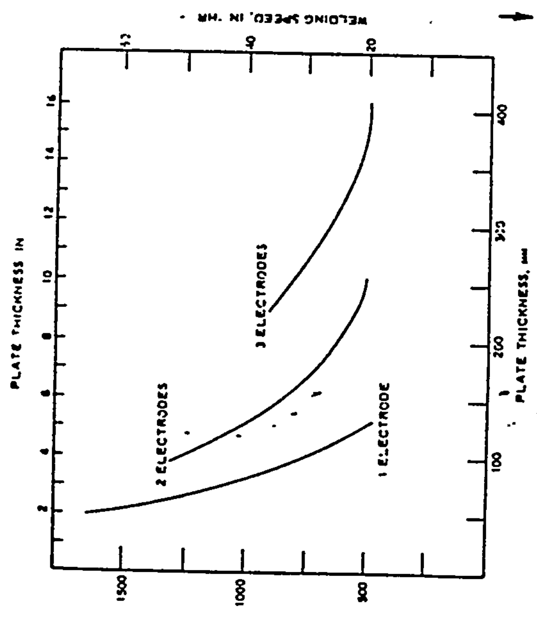
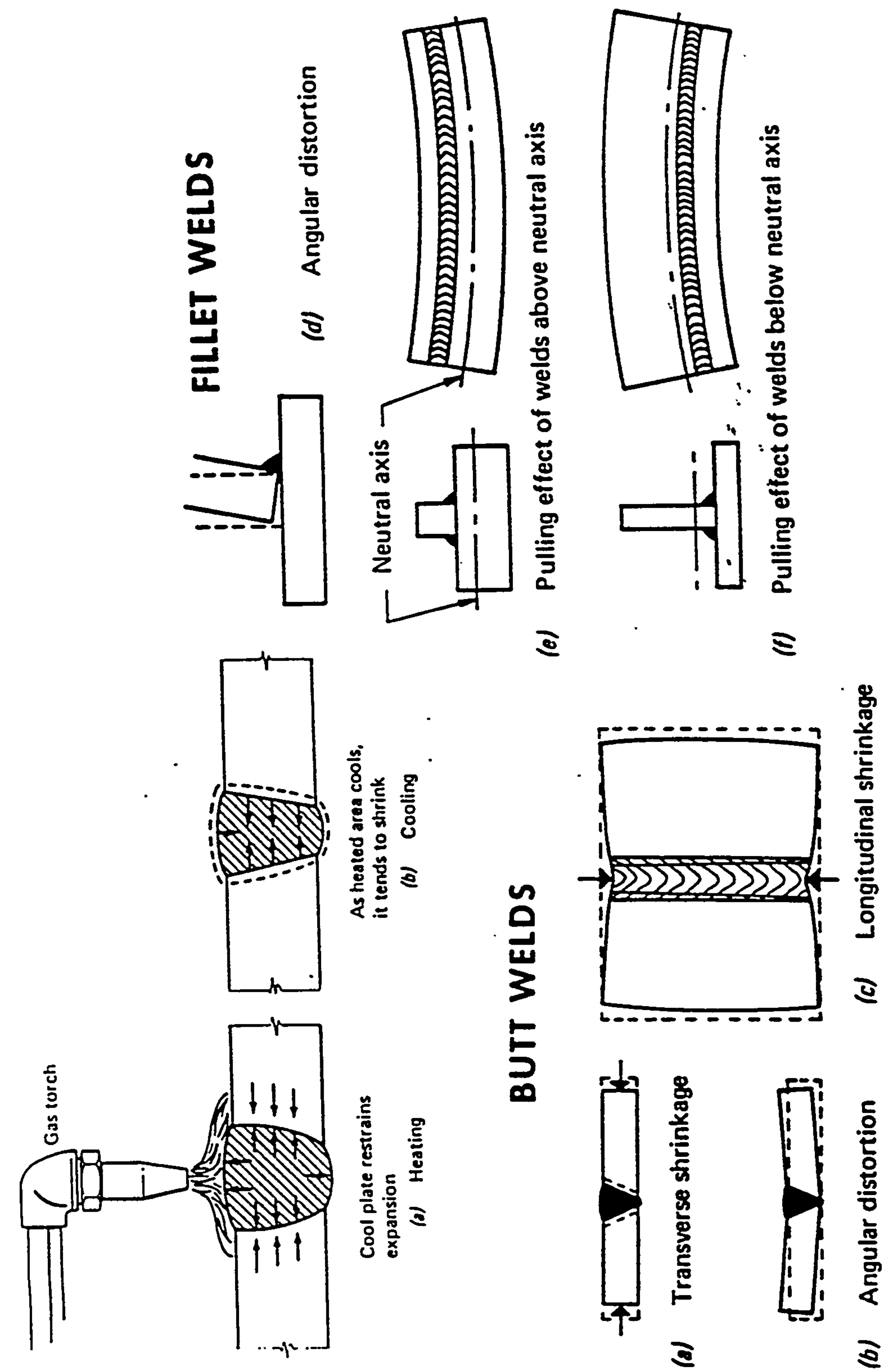


Fig. 15 Electroslag welding speeds

FIGURE W-IX
WELDING DISTORTION



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GROUP TECHNOLOGY APPLIED TO SHIP PRODUCTION--HULL BLOCK

L HULL BLOCK CONSTRUCTION METHOD

A. Construction Objectives

1. Assign material to work package grOUPS that consider similarities in problem areas
2. Still be stable configurations
   Sized for optimum space
3. Group by similarities in volume. space, and shape,
5. Optimum production positions
   -down-hand welding
   –distribute work to best facility locations

II. PLAN FOR HULL CONSTRUCTION

A. Seven levels (Figure I)

B. Part fabrication: level #1 (Figure II)

1. First manufacturing level
2. Produces components that cannot be further subdivided
3. Work packages are grouped by zone and by area
   -parallel parts from plate
   –nonparallel parts from plate
   –internal parts from plate
   –parts from rolled shape
4. By stage
   –plate joining
   -marking & cutting
   –bending
   --universal press
   –press with die
   –line heating

C. Part assembly: level #2 (Figure III)

1. Outside the main work flow
2. Typical work packages are
   -built up parts (e.g. tees not rolled by mills)
   –sub-block parts

D. Sub-block assembly level #3 (Figure IV)

1. A number of Job related/and or assembled parts groupings by area for
   - -similar work content in large quantities (can be mass produced.)
   - --similar work content in small quantities (require job shop approach)
2. Generally on main flow path

E. Semi-block and block assembly and Ground-block joining: levels #4, #5, #6

1. **This is the key manufacturing level**
   - -only the block assembly is in the main flow. The other levels provide planning alternatives.
   - -divided by area using
     - features of the panels need as a base
     - uniformity of working time
   - -typical area divisions are:
     - ** **flat**
     - ** **special flat**
     - ** **superstructure**
     - ** **curved**
     - ** special **curved**
2. Examples of hull block construction method used by two US yards
   - --Avondale Shipyards (Figure V)
   - –Bath Iron Works (Figure VI)
3. Comparison Avondale/Hudong/Kawasaki (Figures VII and VIII

F. Erection: level #7

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FIGURE HBCM-1
TYPICAL MANUFACTURING LEVELS FOR THE HULL BLOCK CONSTRUCTION METHOD

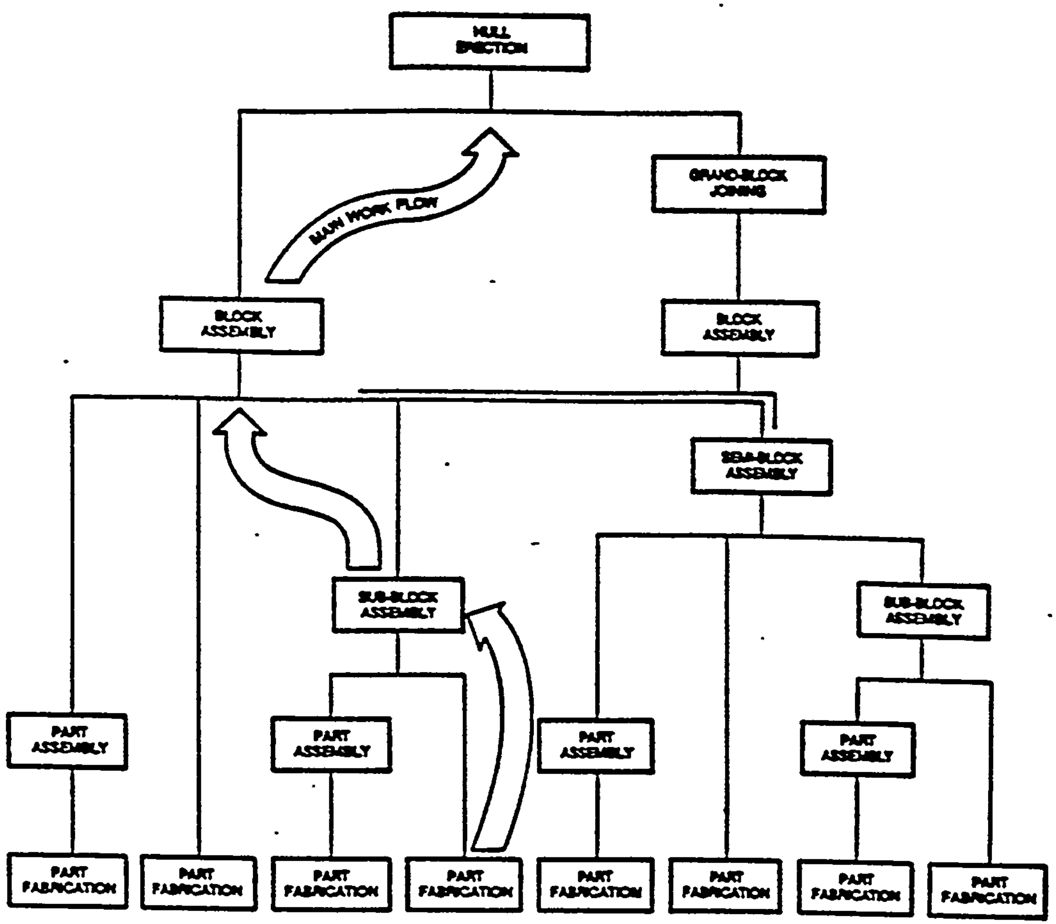

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FIGURE HBCM-2
PART FABRICATION LEVEL

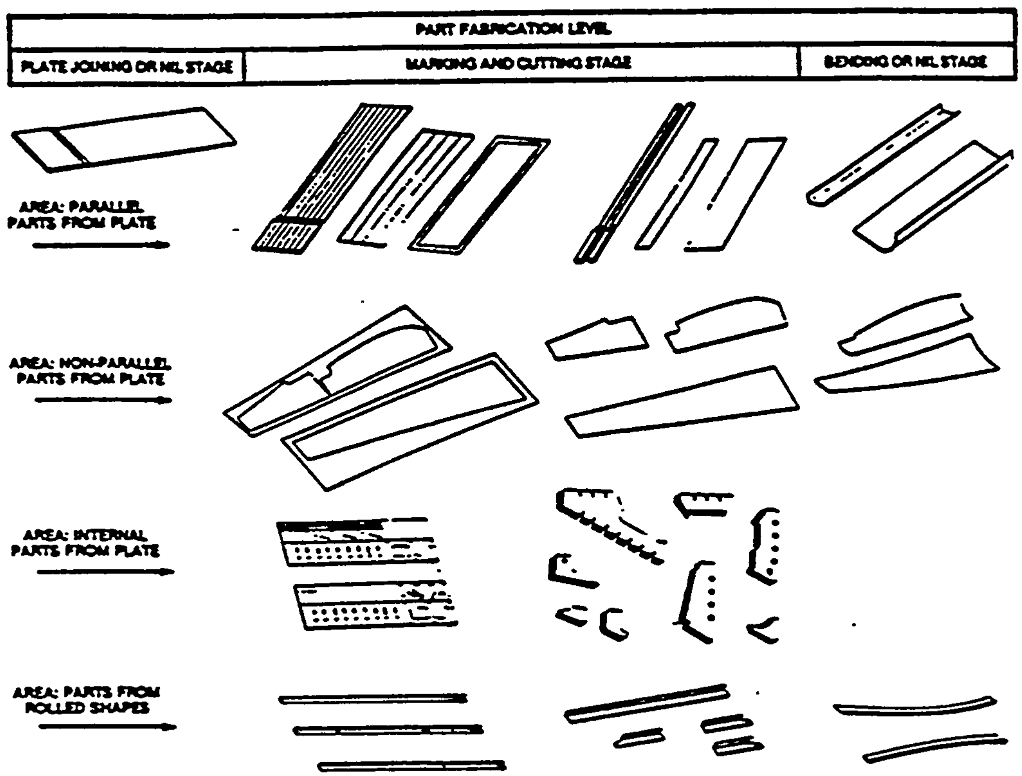

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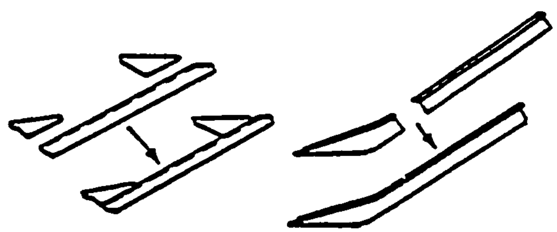
FIGURE HBCM-3
PART ASSEMBLY LEVEL

PART ASSEMBLY LEVEL
ASSEMBLY STAGE



AREA: SUB-BLOCK PART

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FIGURE HBCM-4
SUB-BLOCK ASSEMBLY LEVEL

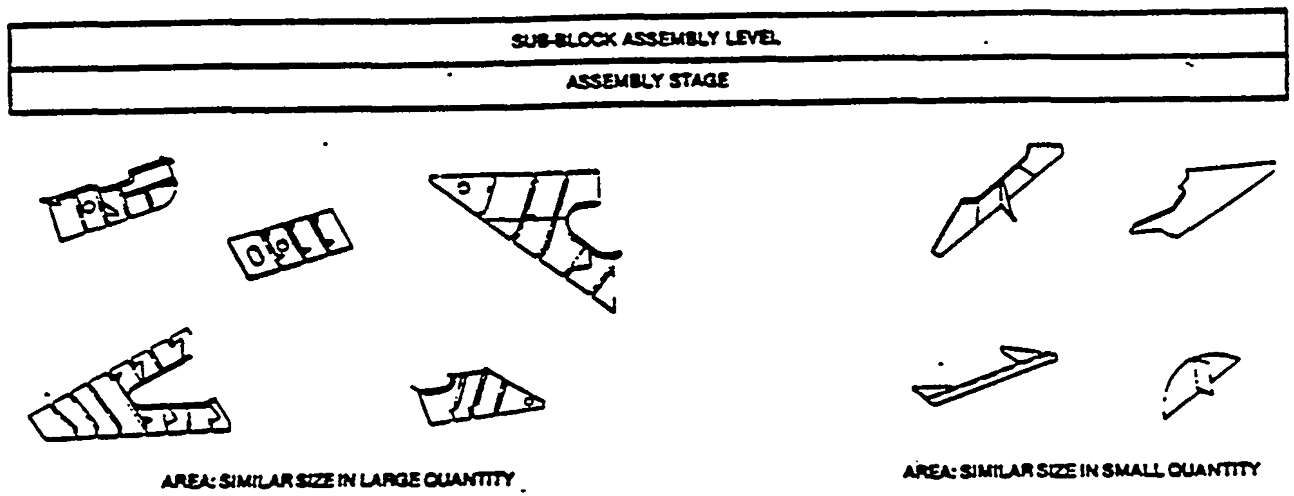

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FIGURE HBCM-5
AVONDALE SHIPYARD BLOCK CATEGORIES

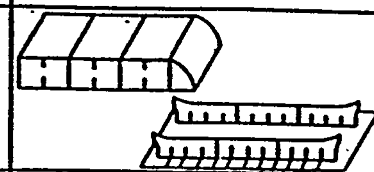
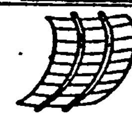
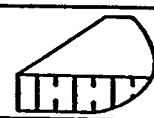
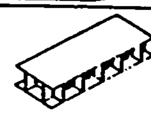
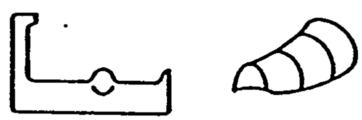
CATEGORY	UNIT NAME	PLATEN SUPPLYING FABRICATED PARTS	SHAPE	ASSEMBLY PLATEN
No. 1 FLAT PANEL UNIT	MID PART DOUBLE BOTTOM SIDE SHELL LONG BHDS	23 24		20
No. 2 CURVED SHELL UNITS	AFT & FORE PART SIDE SHELLS	16		17
No. 3 SUPERSTRUCTURE UNITS	DECKS FLATS BULKHEADS HOUSES ETC.	16		8 9 11
No. 4 FORE PEAK AFT PEAK	LARGE AND VERY HEAVY 3 DIMENSION UNITS	16		10 13 307
No. 5 ENGINE ROOM INNER BOTTOMS	LARGE AND HEAVY INTRICATE UNITS	16		14 307
No. 6 SPECIAL UNITS SKEGS RUDDERS ETC.	BULBOUS SHAPES STERN CASTINGS	16		19

FIGURE HBCM-6
BATH IRON WORKS BLOCK ASSEMBLY FLOW

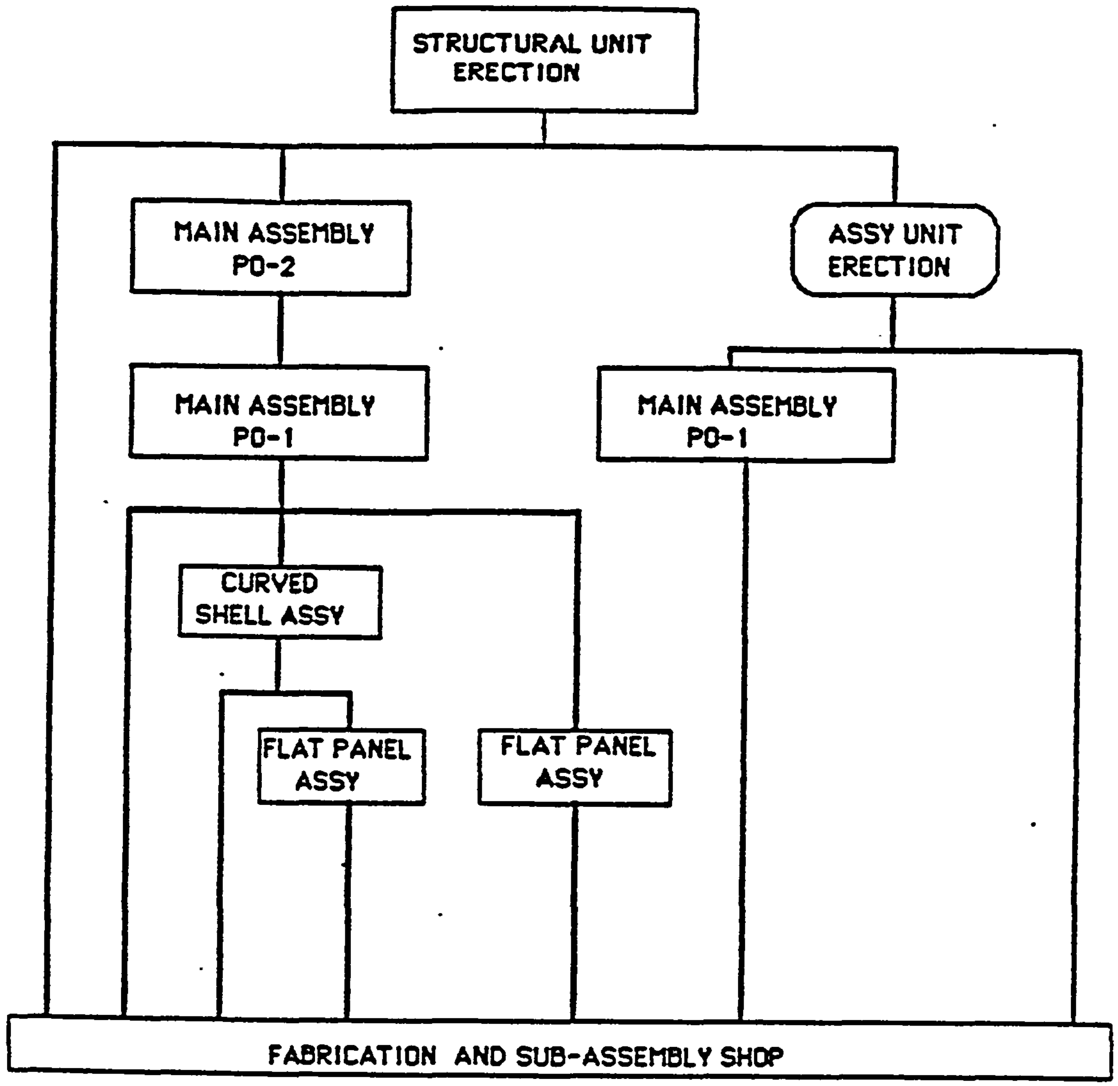
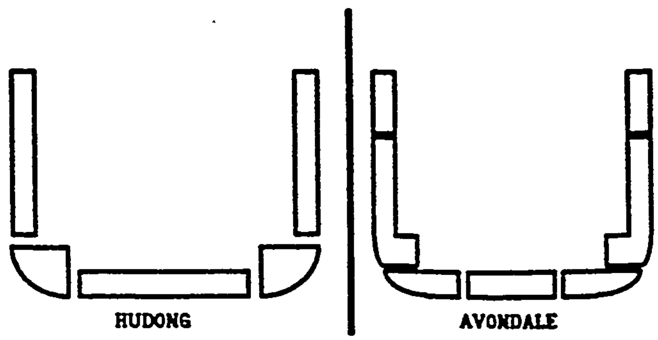


FIGURE HBCM-7
HULL BLOCK COMPARISONS



Schematic of block divisions at midship section for Hudong and Avondale Shipyards

Block production categories, Hudong and Avondale

HUDONG SHIPYARD								
	Count		Weights (short tons)					Process Path
Block Category	#	%	Range	Sum	% of Total	Avg.	Sigma	Distance (ft)
A.--Flat (cargo area double bottoms bilge, decks, and ramps.)	51	26.3	4.9–143.5	3,498	31.7	68.6	39.4	7,870
B.--Flat Special (3-dimensional side-shell, decks with side-shells.)	63	32.5	21.9–155.7	5,023	45.5	79.8	35.3	7,870
C.--Carved (Engine room double bottoms.)	2	1.0	50.7–142.9	194	1.8	96.8	46.2	7,550
D.--Carved Special (Bow and Stern)	15	7.7	13.2–138.9	1,191	10.8	79.4	31.1	8,350
E.--Superstructure	20	10.3	25.1–31.1	541	4.9	27.0	3.8	6,250
F.--Other (hatch, transverse and horizontal beams)	43	22.2	2.8–41.7	588	5.3	13.7	7.3	7,400–8,050
TOTALS	194	100.0	2.8–155.7	11,035	100.0	56.9	27.2	7,800

AVONDALE SHIPYARD								
	Count		Weights (short tons)					Process Path
Block Category	#	%	Range	Sum	% of Total	Avg.	Sigma	Distance (ft)
1.--Flat Pannel Units (mid part, double bottoms, side-shells, longt blkheads)	97	46.2	9.7–123.9	6,814	61.6	70.2	29.0	7,050
2.--Carved Shell Units (Aft & Fore Part Units, side shell.)	31	14.8	19.3–100.6	1,630	14.7	52.6	24.6	2,900
3.--Superstructure	19	9.0	23.1–71.2	807	7.3	42.5	14.6	2,850
4.--Fore Peak and Aft Peak Units (large & very heavy 3D curved)	13	6.2	13.1–97.2	778	7.0	59.5	34.9	2,900
5.--Engine Room Inner Bottoms (large and Heavy, intricate, flat units)	6	2.9	31.0–97.2	292	2.6	48.7	22.2	4,600
6.--Special Units (skegs, rodders, bulbous shapes, stern castings)	44	21.0	8.6–130.6	749	6.8	17.0	18.8	3,050
TOTALS	210	100.0	13.1–140.0	11,070	100.0	52.7	20.5	5,500

File: sht crse.navy/3.31.D/P/ HBCM

FIGURE HBCM-8
COMPARISON OF MATERIAL FLOW AND SIZE OF FACILITIES FOR TWO SHIPYARDS

Description of production facilities at two shipyards

ASI Area/Shop	ASI Square Feet	KHI Area/Shop	KHI Square Feet
	FABRICATION		
Plate shop	178,000	Shop #2P	42,910
T-beam shop	27,700	Shop #3P	23,000
Platen 23	32,500	Shop #4P	17,600
Platen 24	32,500		
Platen 16	48,100		
Sub-Total	318,800		83,510
	SUB-ASSEMBLY		
Platen 8	6,750	Shop #2P	18,390
Platen 9	8,000	Shop #3P	23,000
Area 307	14,400	Shop #4P	26,400
Platen 17	51,350		
Platen 20	32,200		
Sub-Total	112,700		67,790
	ASSEMBLY		
Platen 8	20,250	Shop #10K	11,800
Platen 9	24,000	Shop #1B Mid	23,700
Area 307	43,200	Shop #3B Mid	17,200
Platen 10	50,600	Shop #3B Fore	8,600
Platen 13	48,400	Shop #3B Aft	17,200
Platen 14	48,100	Yard Fore	14,000
Platen 19	33,800	Yard Aft	23,700
Platen 20	104,800	Shop #5K	11,800
Platen 25	38,000	Shop #5B	11,800
Platen 26	30,000		
Sub-Total	441,150		139,800
	ERECTION		
Upper yard	421,800	Berth #4	140,800
		Berth #7	89,600
Sub-Total	421,800		230,400
SHIPYARD TOTALS	1,294,450		521,500

Travel distance (ft) for production blocks at two shipyards

Production Unit Classification (ASI definition)	ASI	KHI
Flat Panel Units (Category #1) Mid Parts Double Bottoms Side Shell Longitudinal BHDS	7040	420-1120
Curved Shell Units (Category #2) Aft & Fore Parts Side Shells	2880	430
Superstructure Units (Category #3) Decks Flats Bulkheads Houses, etc	2840	650-740
Fore Peak and Aft Peak Units (Category #4)	2880	430

GROUP TECHNOLOGY APPLIED TO SHIP PRODUCTION--OUTFIT

I. ZONE OUTFIT

A Background

1. Results from HBCM
2. Use of ZOFM will cause you to use HCBM
3. HBCM starts with zone. divide into sub blocks. until basic part is obtained nature of any zone associates it with a specific manufacturing level. Regenerated Process. Size increases as manufacturing progresses
4. ZOFM-Divides into zones that best suit the work at hand. Only generically associated with HCBM zones.

B. Types of Zones/Stages

1. On Unit--independent of hull structure
2. On Block--associated with hull structure. before erection
3. On Board--Associated with hull structure. after erection.

c. Objectives

1. Rationalized work flows that facilitate intimation with HBCM and ZPTM.
2. Identify interim product costs
3. Identify in-house customers
4. Enhance productivity, e.g.. down-handed welding. etc.
5. Enhance safety. e.g., open, spacious. low work sites.

D. Stages (Figure I)

Operation and test

E. Component Procurement

1. Same as fabrication in HBCM
2. Includes decision on procurement Posture
   a. Inside MFG
   b. Outside MFG
   c. Purchase

F. On unit

1. Key element (like block in HBCM
   a Work toward balance in assembly M/H, weight, # of components:
   b. Sub classification
   1. Machinery unit
   2 Pipe unit
   3. Other (hatch covers)
2. Grand Unit
   a. Provides for reducing time needed for fitting on board and on dock.
   b. Provides stable entities

G. On B1ock (Figure II)

1. Associated with a block zone: however keyed to a specific work station.(el.g. before or after turn-over]
2. Classified by basic product orientation
   a. Deck
   b. Accommodation
   c. Machinery
   d. Electrical

H. On Board

1. Should be limited to
   a. fragile components
   b. too large and too heavy
   c. connecting components between HBCM Blocks
2. Two types:
   a. Open sky-performed before the area is enclosed.
   b. Enclosed--performed after the area is enclosed. Most expensive.

I. Costs (Figure III)

1. On unit = 1—-->3
2. On block= 2—>5
3. On board= 5--->15

II. BENEFITS AND COSTS

A. Group Technology can result in productivity gains of 50% or better when properly applied.

B. Cost Required

1. greatly increased planning of all resources
2. greatly increased attention to accuracy control
3. greatly increased attention to material management

FIGURE ZOFM-I
MANUFACTURING LEVELS FOR ZONE OUTFITTING

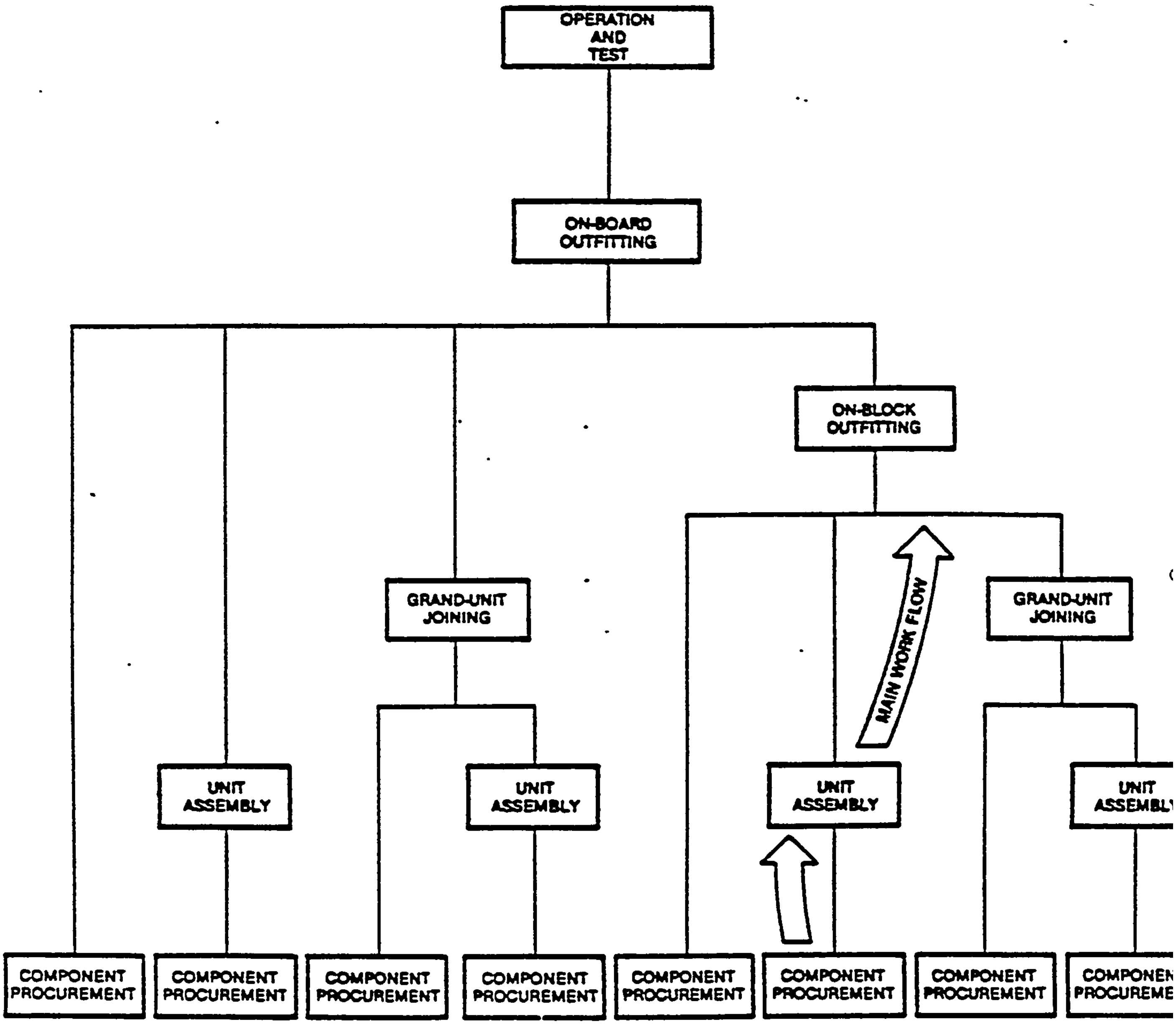


FIGURE ZOFM-II
BASIC PRODUCT ORGANIZATION

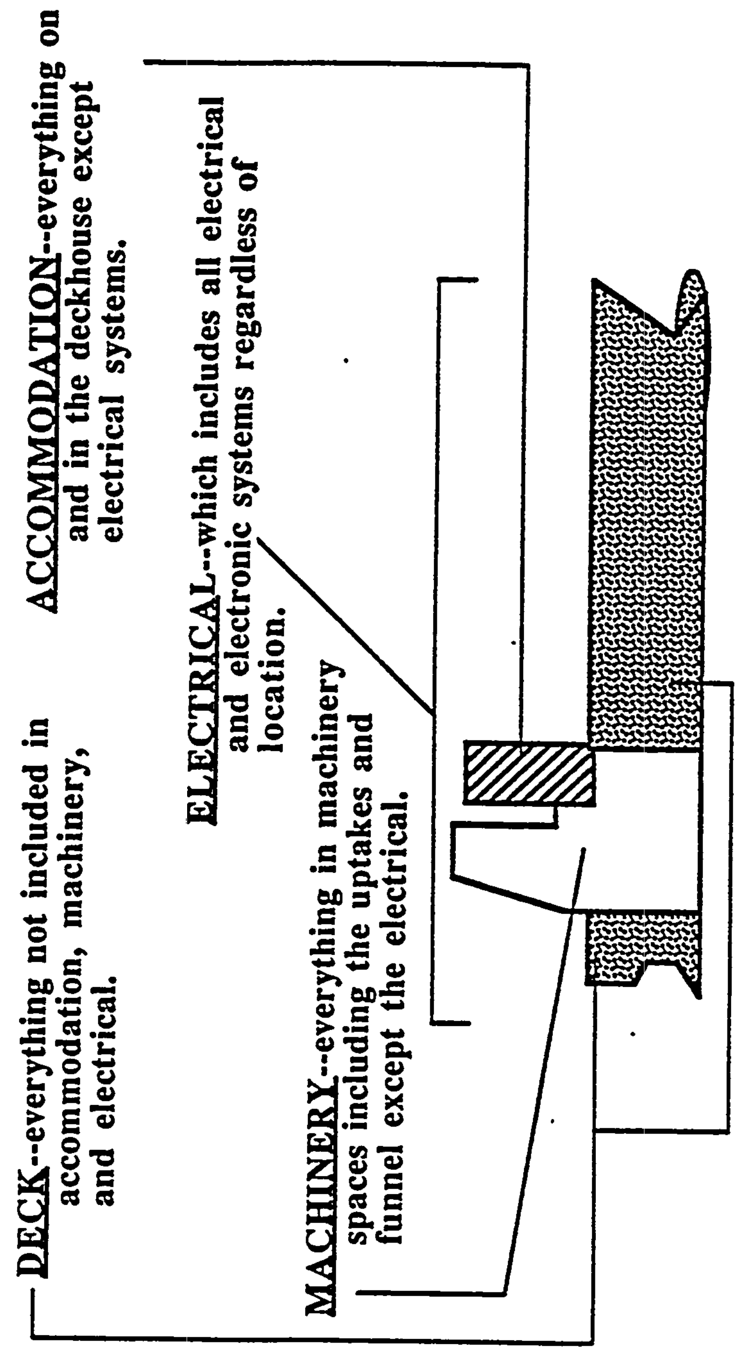
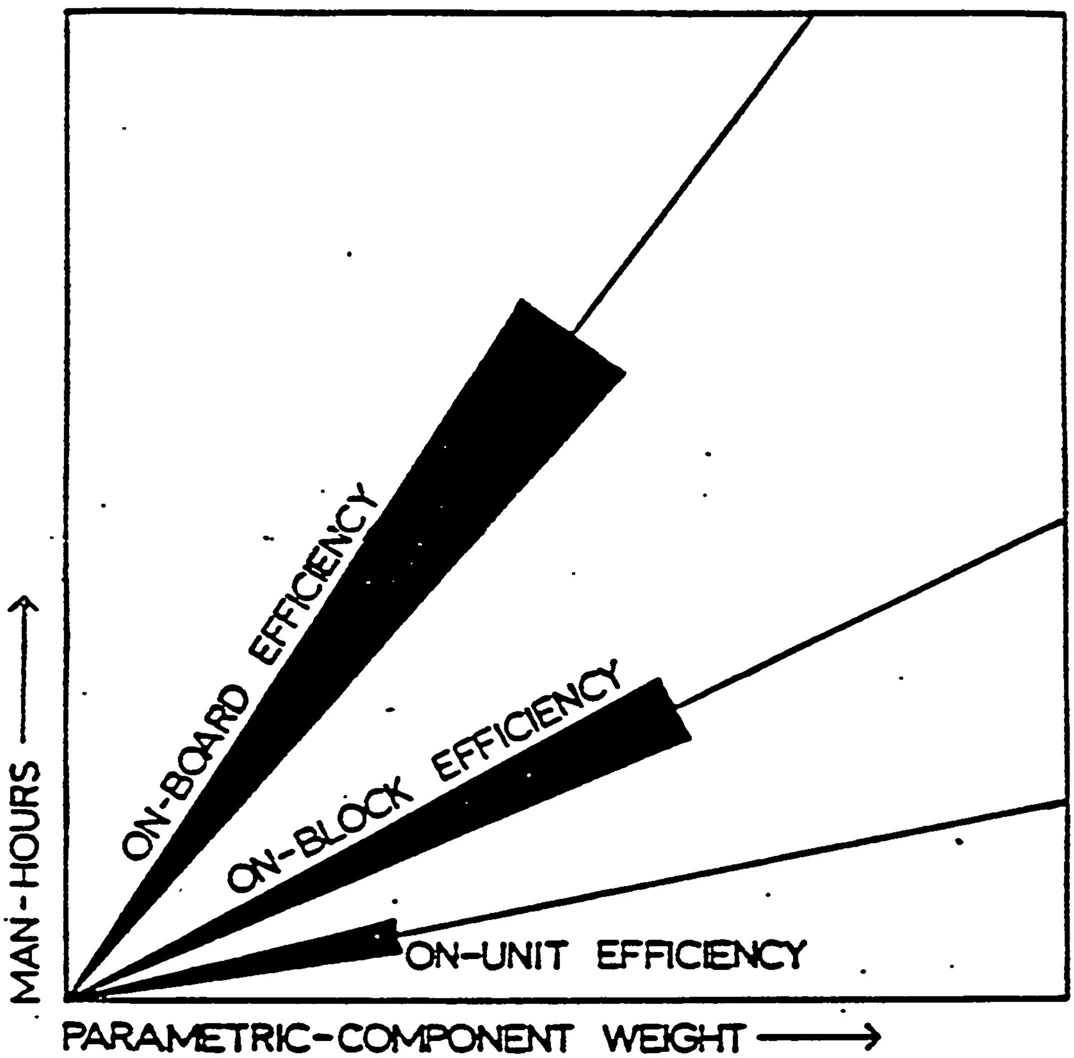


FIGURE ZOFM-III
OUTFIT STAGE EFFICIENCIES



1.12 Advanced Outfitting

1.12.1 WHAT IS ADVANCED OUTFITTING. Advanced outfittig can be regarded simply as the fitting to ship structure, before and after it is erected on the building berth, of outfit items at a significantly earlier time in the building sequence than is traditionaL

Advanced outfitting is normally subdivided into three types, namely:

- On Unit
- On Block
- on Board

"On-unit" advanced outfitting consists of constructing packages of equipment or bundles of pipe and other systems on a common foundation. The work is usually performed in a shop environment instead of onboard the ship. The packages incorporate unitized foundations and/or support bases, equipment small tanks, pipe, fittings, controllers, electric cable, etc., and are completely painted except perhaps for a touchup coat. Where required and possible, the package is tested before installation "on block" or "on board." Typical examples of 'on-unit" advanced outfitting are shown in Figures 1.1.127 and 1.128.

"On-block" advanced outfitting consists of installing "units" (equipment modules), pipe bundles, foundations, etc., on a structural assembly or module before it is erected on the building berth. Structural assemblies may be erected as assemblies or joined to other assemblies or modules to form an "erection module." Typical examples of 'on-block" advanced outfitting are shown in Figures 1.129 and 1.130.

"On-board" advanced outfitting consists of installing "units" or 'individual pieces of equipment pipe. etc., into the ship as it is on the building berth or once it is afioat. Typical examples of "on-board" advanced outfitting are shown in Figures 1.131 and 1.132. A special approach to 'on-board" advanced outfitting is "open deck" or "blue sky" advanced *outfitting. In this* approach a complete compartment such as a machinery space is left open (deck off) until all the equipment is installed. It is normally used by shipyards which have covered building berths, especially for warship (frigate and destroyer) construction as shown in Figure 1.133.

1.12.2 WHY USE ADVANCED OUTFITTING. Traditionally, shipbuilding engineering attempts to complete all design and material procurement before commencing actual construction. In the past, shipbuilding companies in Japan and Europe had large order books, and were able to do this. This approach is illustrated in Figure 1.134(a). This has generally not been possible in most U.S. shipyards due to both commercial and naval ship procurement methods. It is quite usual for a U.S. shipyard to obtain a new ship construction order with no other ongoing work in the yard. The objective then is to get production started as soon as possible, and this causes an overlap of design, material procurement and production activities, as shown in Figure 1.134(b). It is this overlap coupled with the traditional approach to both design and production which causes the extensive rework and equipment delay problems normally experienced in U.S. shipbuilding.

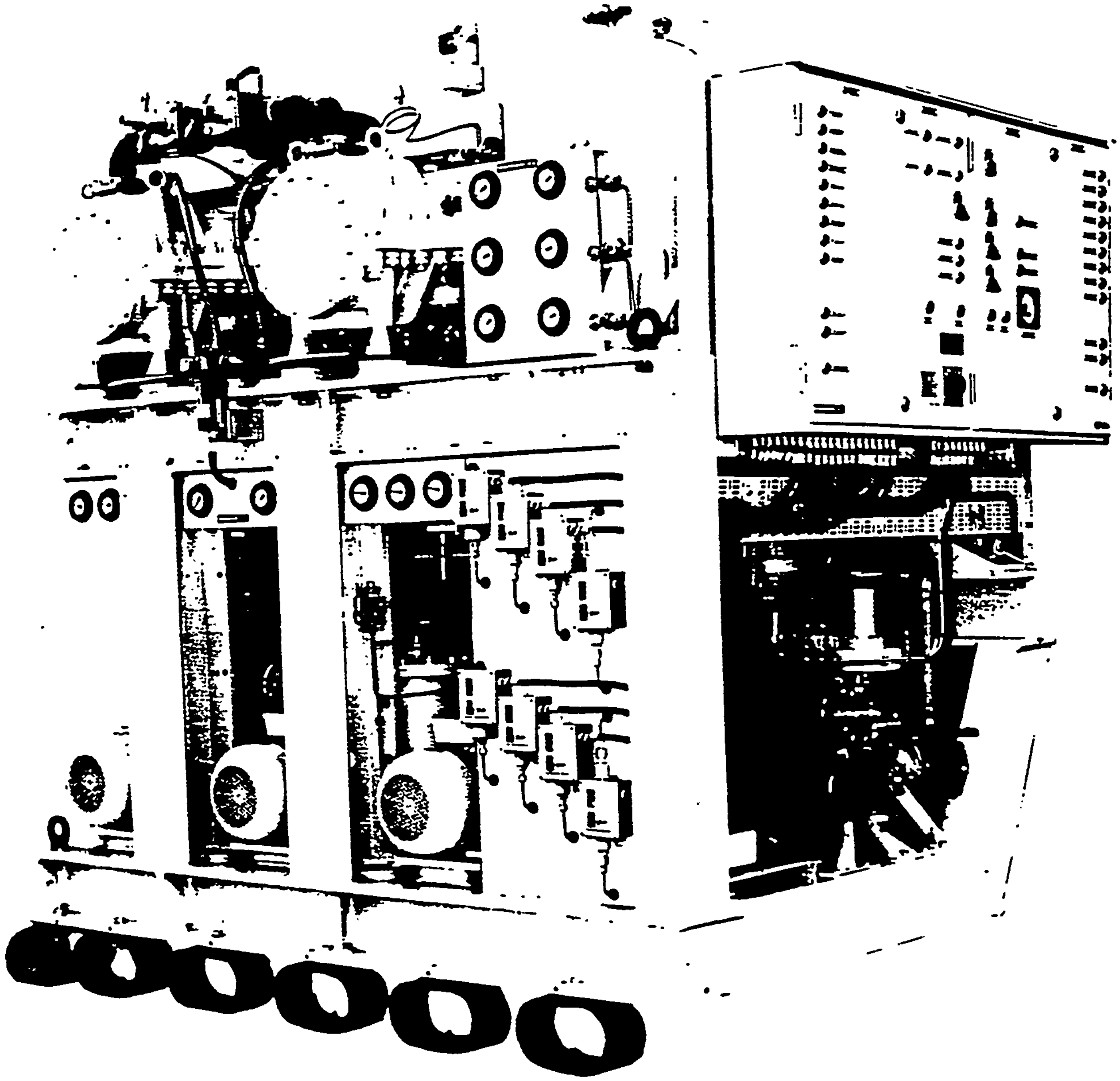


FIGURE 1.127 Typical "on-unit" advanced outfitting.

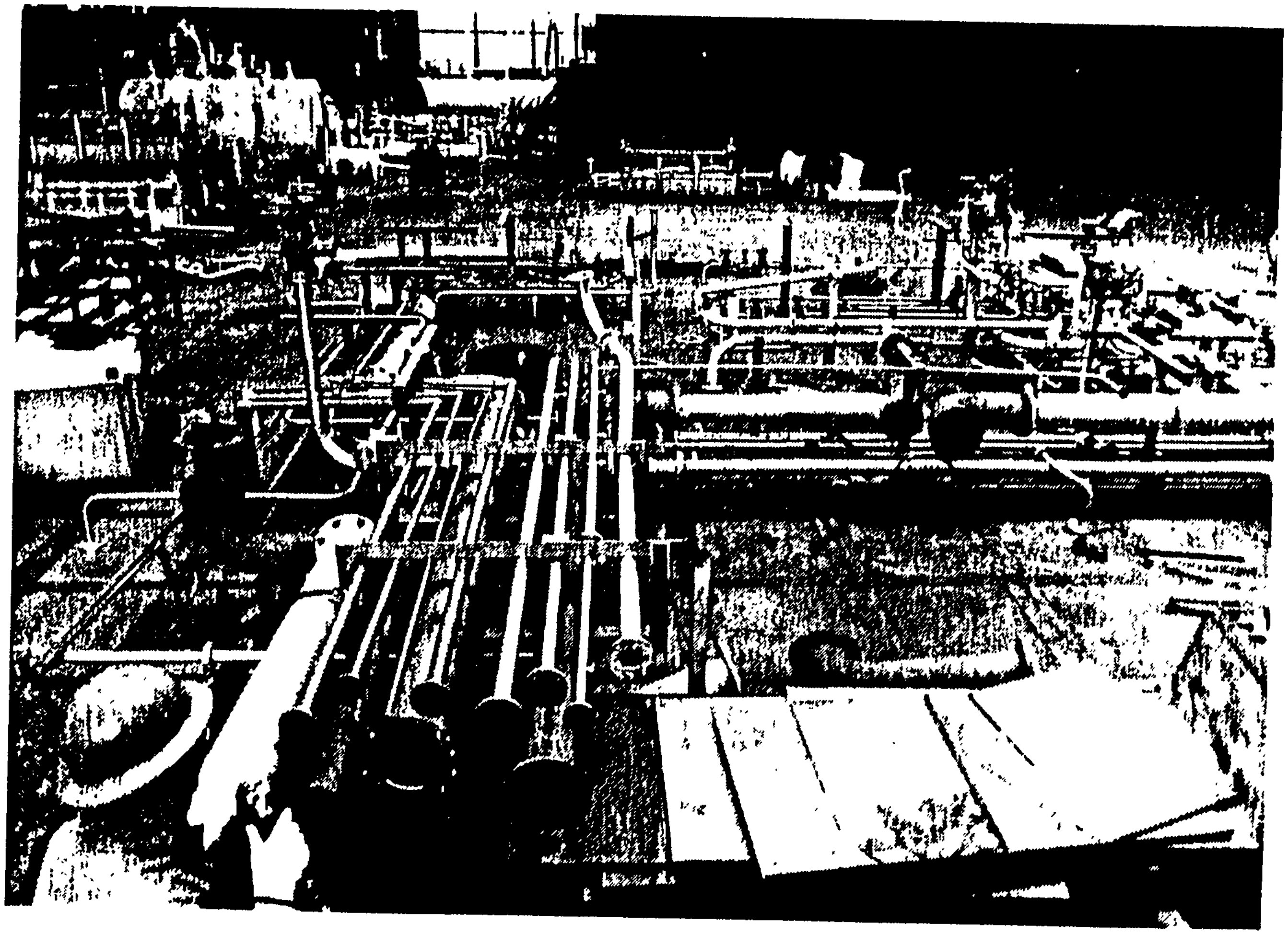
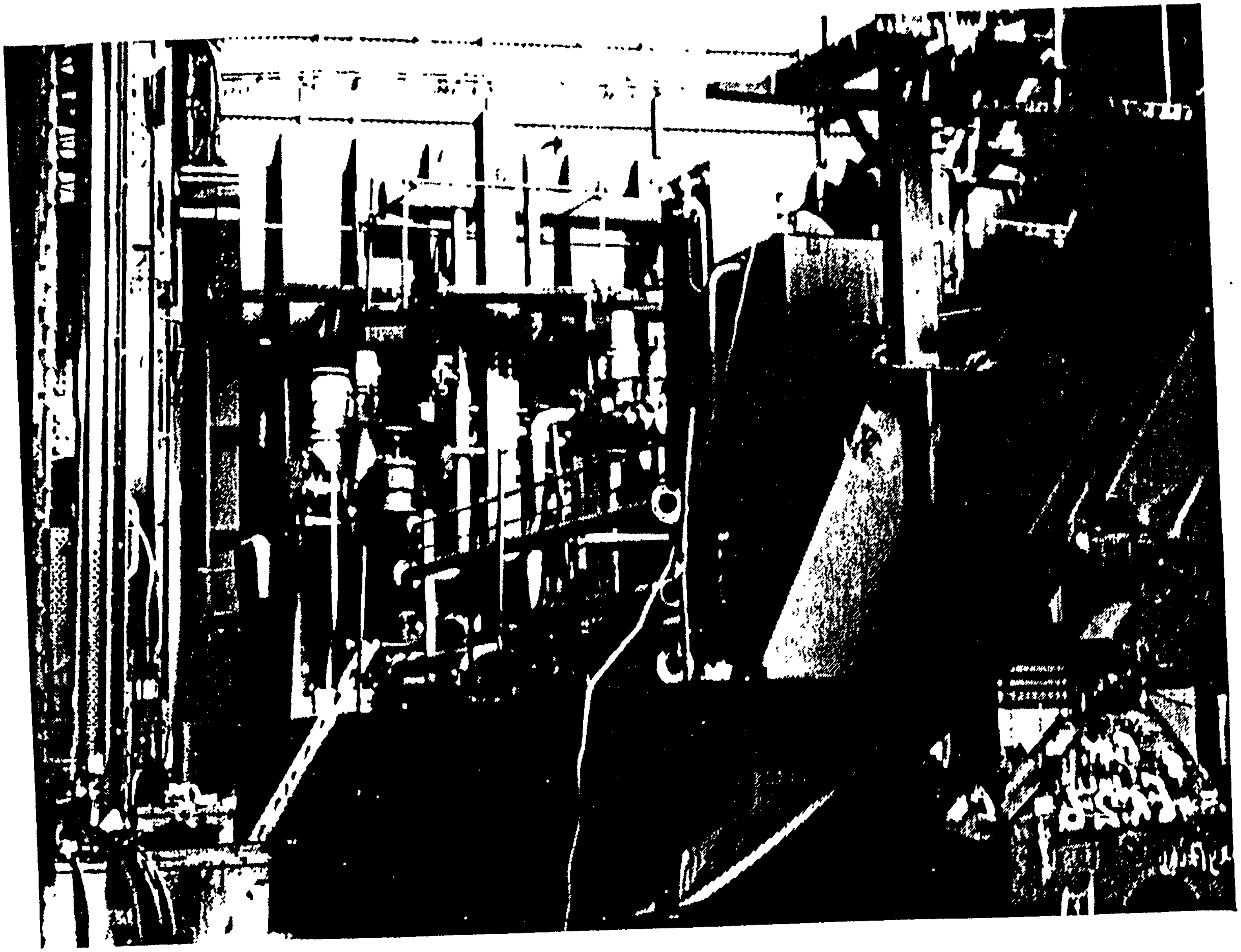


FIGURE 1.128 Piping bundle "on unit" under construction.



·FIGURE 1.129 "On-block" advanced outfitting.

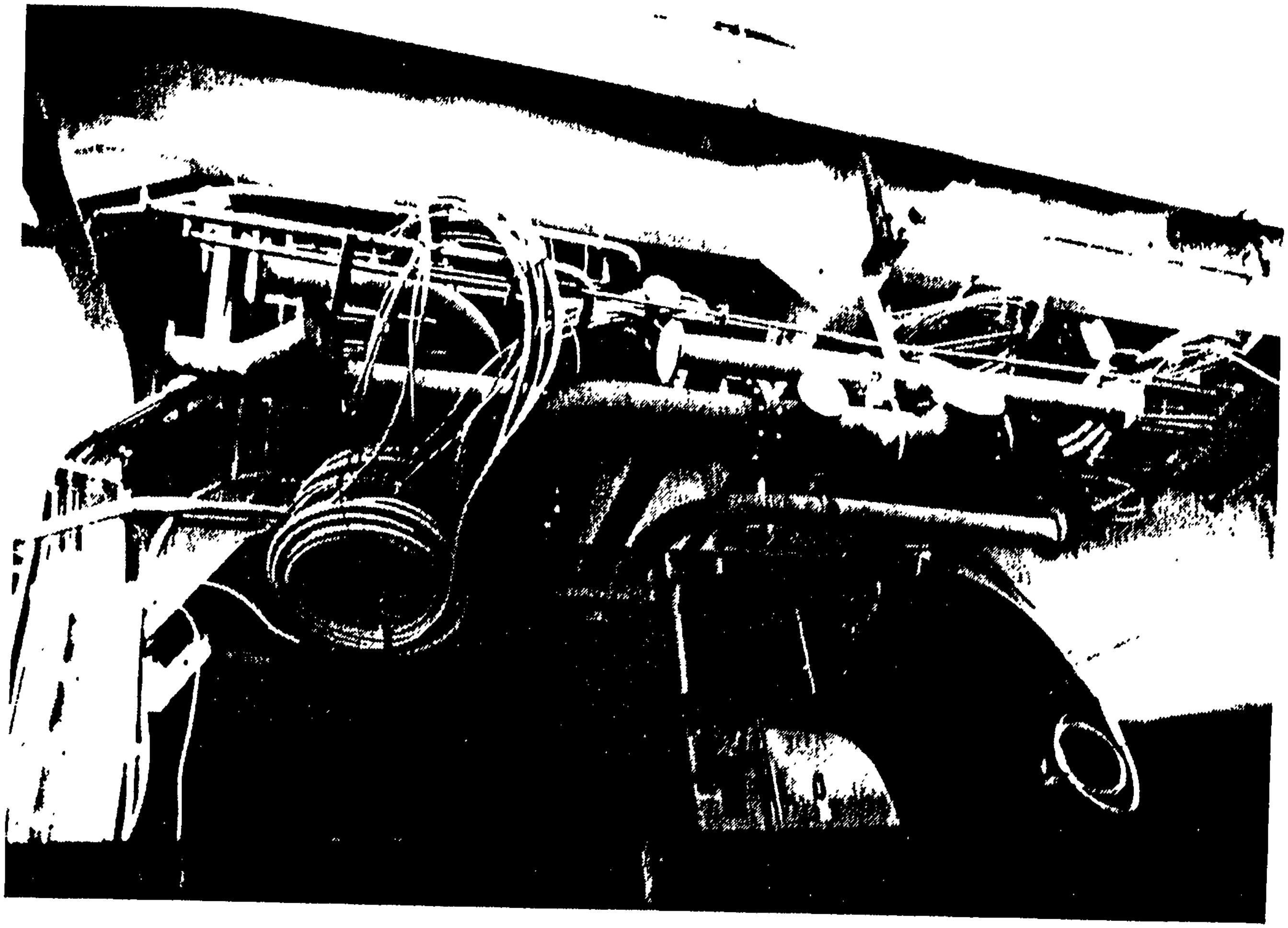


FIGURE 1.130 "On-block" advanced outfitting.

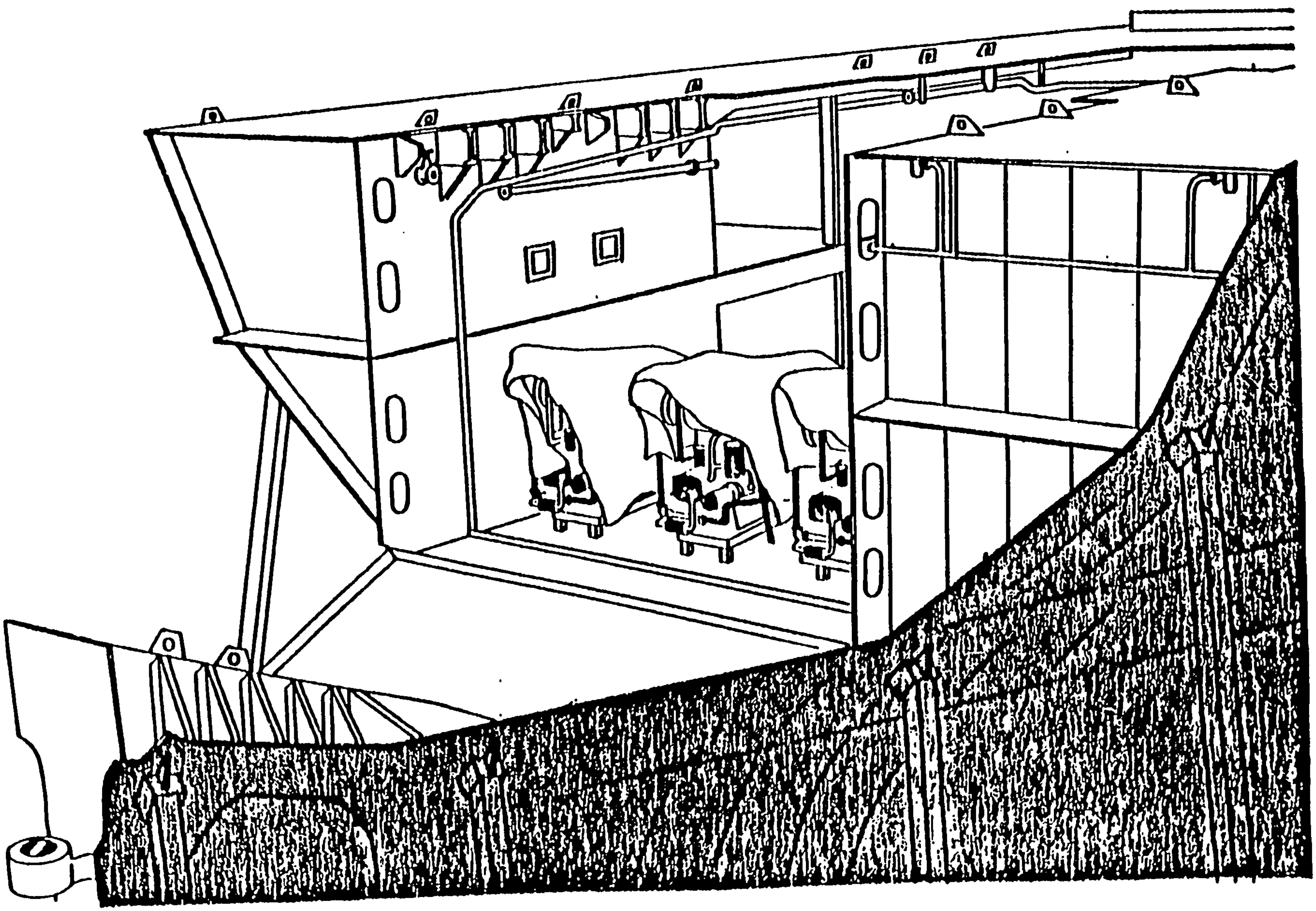


FIGURE 1.131 "On-board" advanced outfitting.

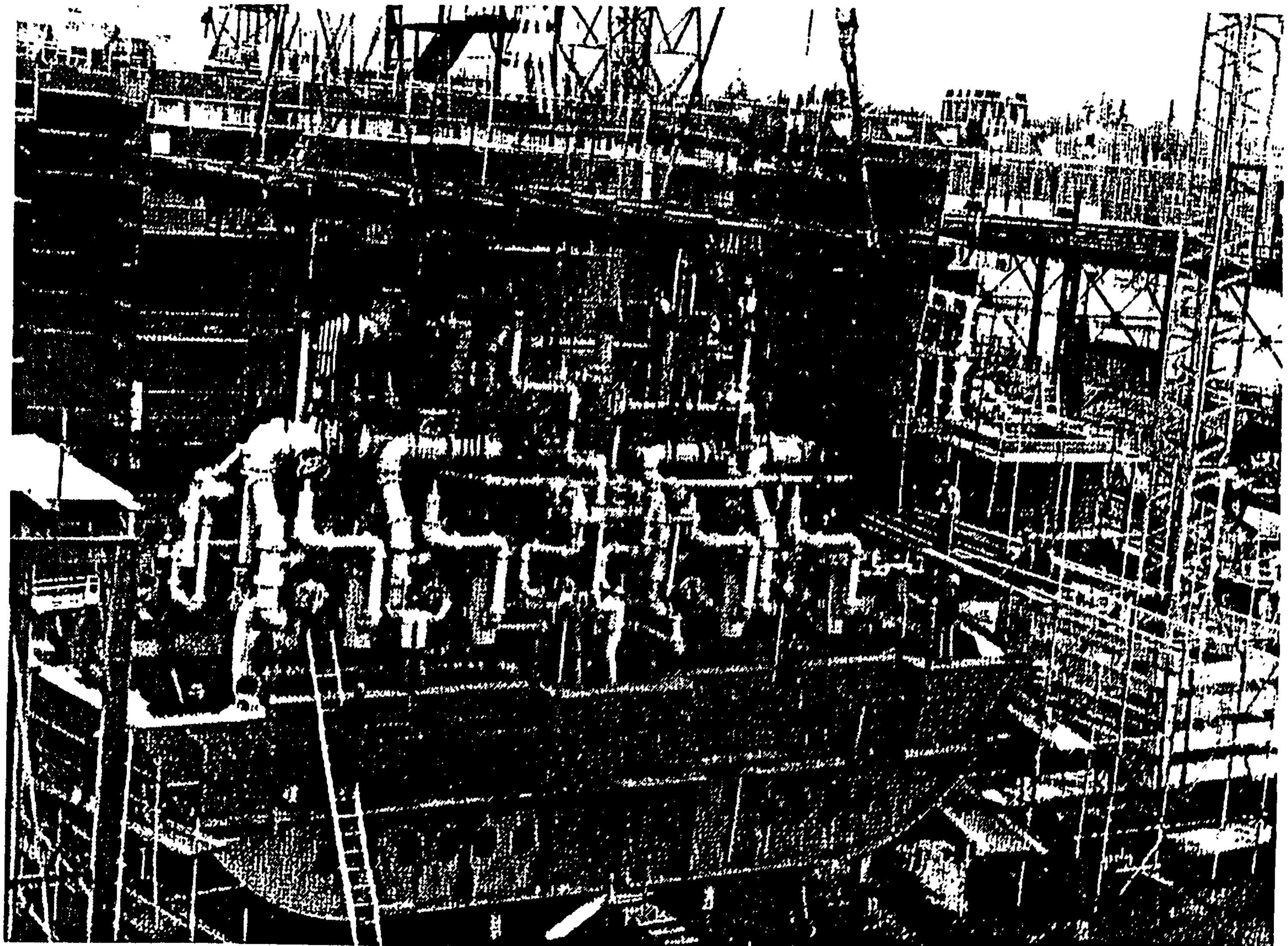


FIGURE 1.132 "On-board" advanced outfitting.

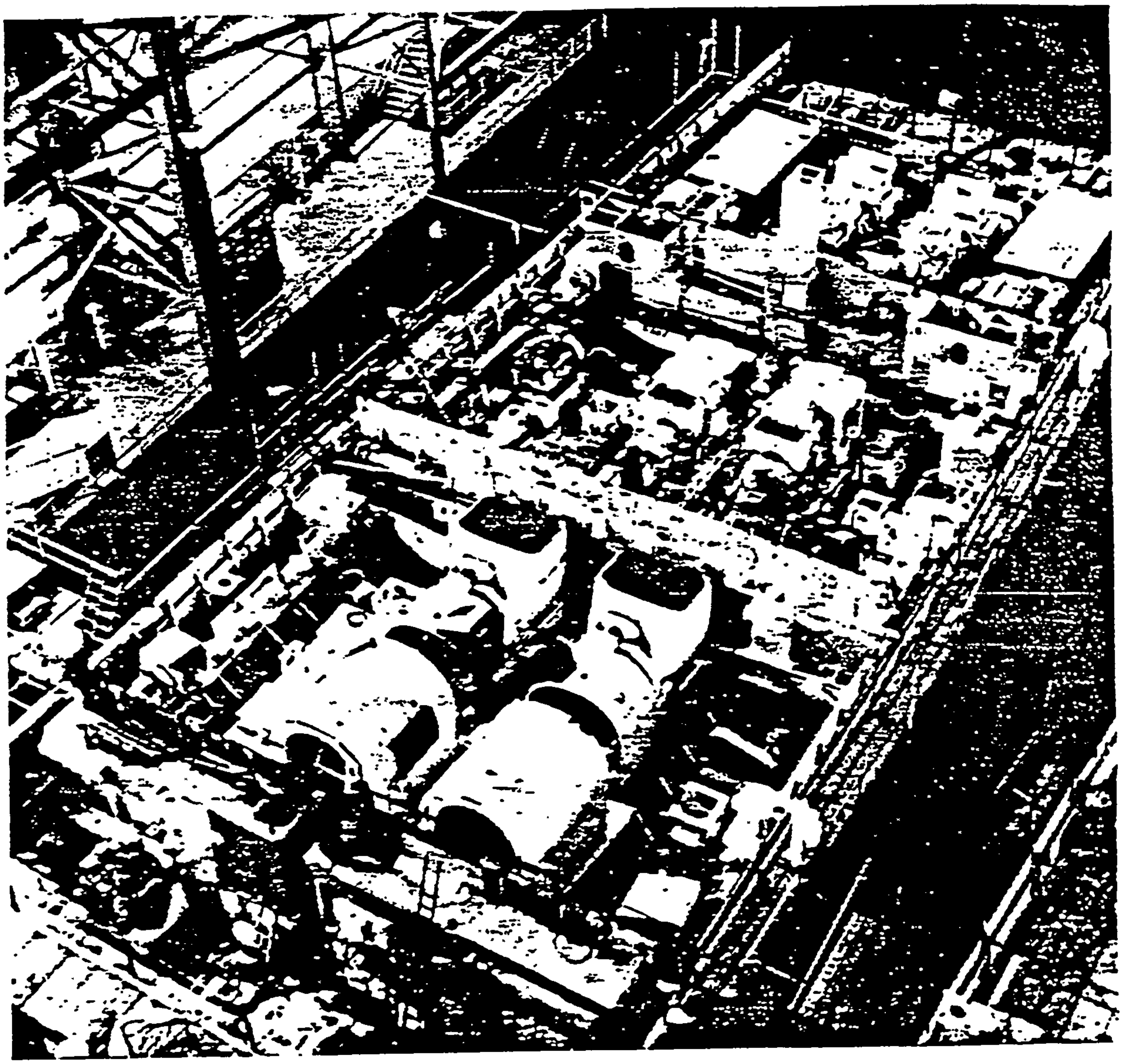


FIGURE 1.133 "Blue–sky" or "open–air" advanced outfitting.

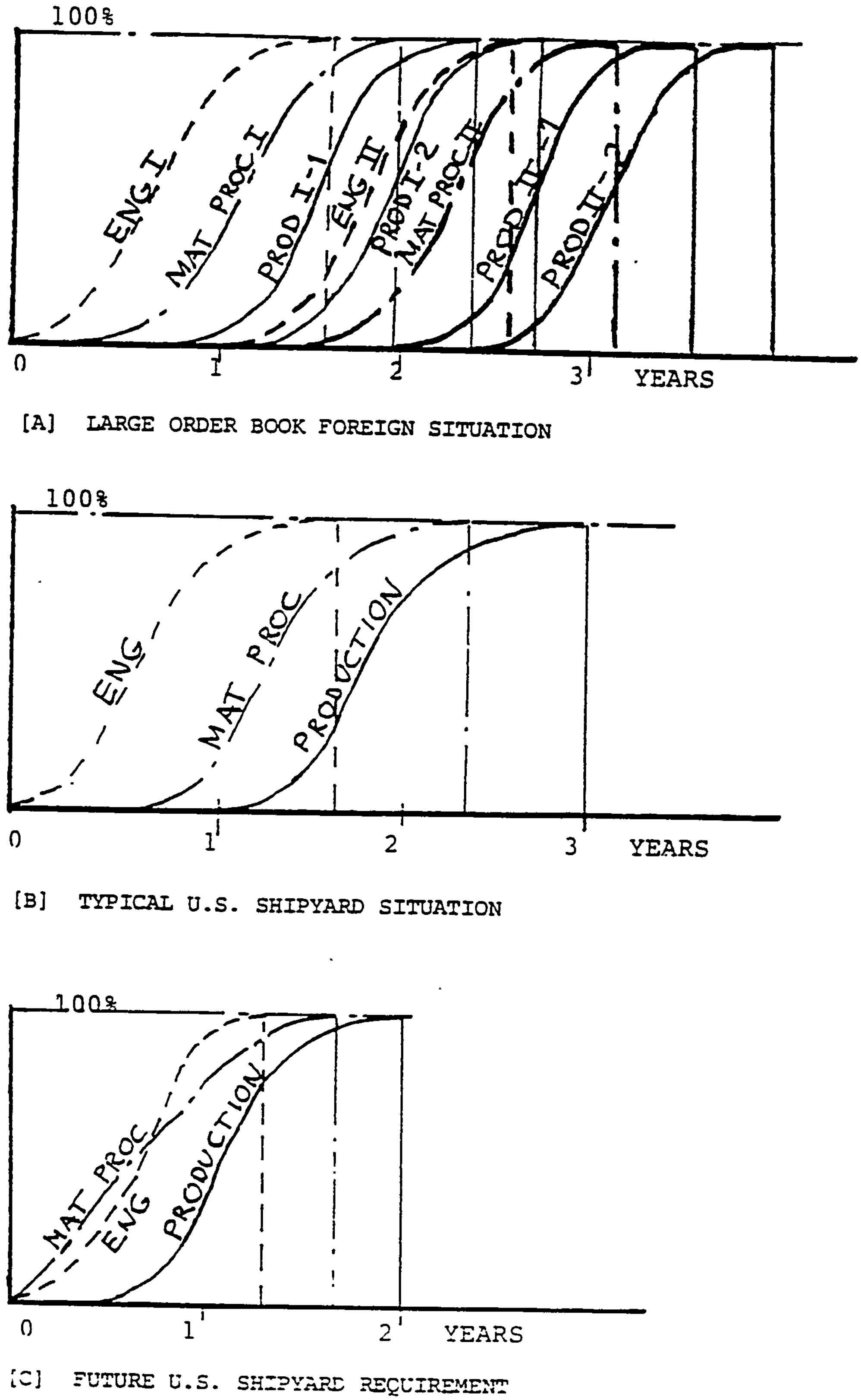


FIGURE 1.134 Required change in contract performance time.

In today's competitive shipbuilding situation, it is not enough to make the existing overlap work successfully. It is necessary to reduce the performance time, and at the same time increase productivity. Obviously, any reduction in performance time increases the overlapping of the activities as shown in Figure L134(c). This has been successfully done by a number of foreign shipyards, and they have presented the requirements based on their experience to accomplish both reduced contract performance time and increased productivity. The essential requirements are:

- A completely integrated planning function
- A planning, scheduling, and control system which is adequate for the task
- Maximum practical use of advanced outfitting
- Maximum use of industry standards for equipment
- Maximum use of company standards for system design and fabrication details
- An engineering approach that is compatible with production requirement, and the way the ship will actually be constructed
- A material procurement approach which is compatible with production schedule. This requires ordering and receiving material on a zone basis

The direct benefits of advanced outfitting are increased productivity and shorter building schedules. Increased productivity is possible as the workers' efficiency for "on-unit" versus "on-block* and "on-board" advanced outfitting is one half and one quarter, respectively. This can be seen from Figure 1.135 which is taken from NSRP publication, *Product Work Breakdown Structure.* This results from the following benefits:

- Earlier start to outfit fabrication and installation,. thus better utilization of outfit crafts throughout the duration of construction rather than the heavy concentration near the end
- Logical sequencing of work
- Improved worker safety throughout easier access, better ventilation, better lighting, easier material delivery, etc.
- Simpler outfit planning and scheduling
- Installation of outfit in the best position and worker attitude
- Shop environment allowing cleaner work and better quality (less rework)

Figure 1.136 gives en overview of the goals and benefits of advanced outfitting as modified from a similar figure in the National Shipbuilding Research program publication, *Outfit Planning.*

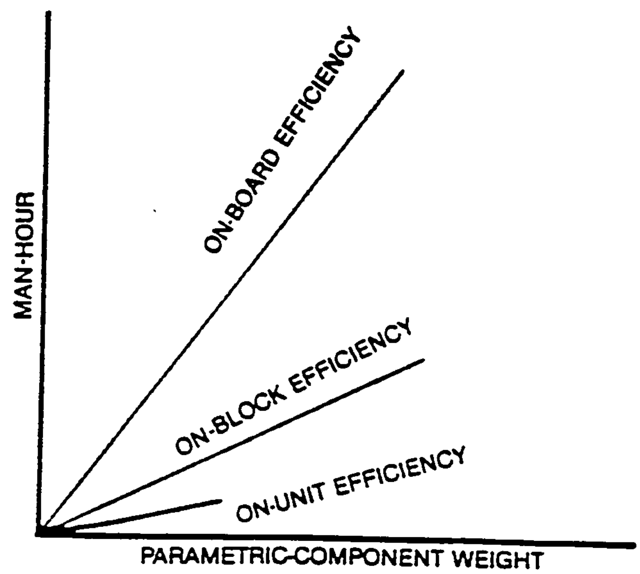


FIGURE 1.135 Productivity improvement through advanced outfitting.

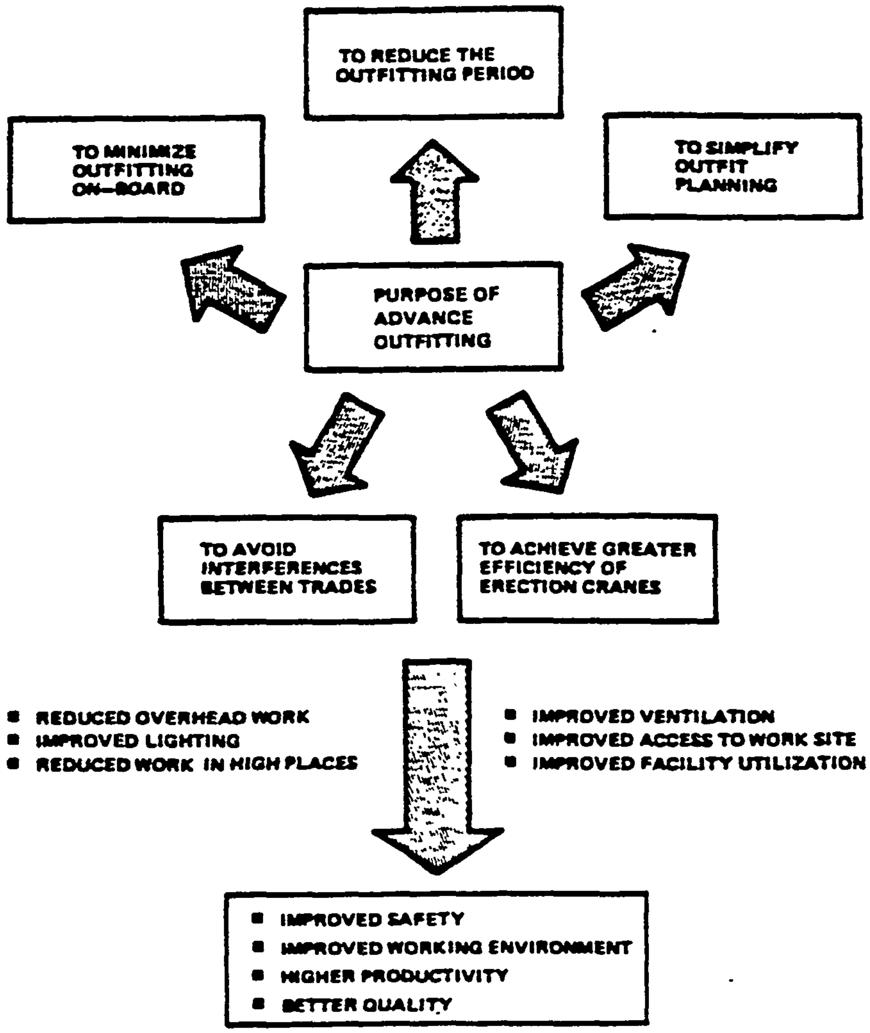


FIGURE 1.136 Goals and benefits of advanced outfitting.

NATIONAL SHIPBUILDING RESEARCH PROGRAM

PLANNING AND SCHEDULING

PLANNING AND SCHEDULING

- PLANNING IS THE "HOW". SCHEDULING IS THE "WHEN"
- PLANNING FOCUSES ON THE FUTURE, WHAT IS TO BE ACCOMPLISHED AND WHEN
- THE PLANNING FUNCTION INCLUDES THOSE MANAGERIAL ACTIVITIES THAT DETERMINE OBJECTIVES FOR THE FUTURE AND THE APPROPRIATE MEANS FOR ACHIEVING THEM
- PLANNING OCCURS AT ALL LEVELS IN AN ORGANIZATION
- THERE ARE THREE LEVELS OF PLANNING; STRATEGIC, TACTICAL AND DETAILED (OPERATIONAL)
- TOP MANAGEMENT HANDLES THE STRATEGIC PLANNING, MIDDLE MANAGEMENT THE TACTICAL PLANNING AND THE DETAILED PLANNING SHOULD BE HANDLED AT THE LOWEST APPROPRIATE LEVEL IN THE ORGANIZATION

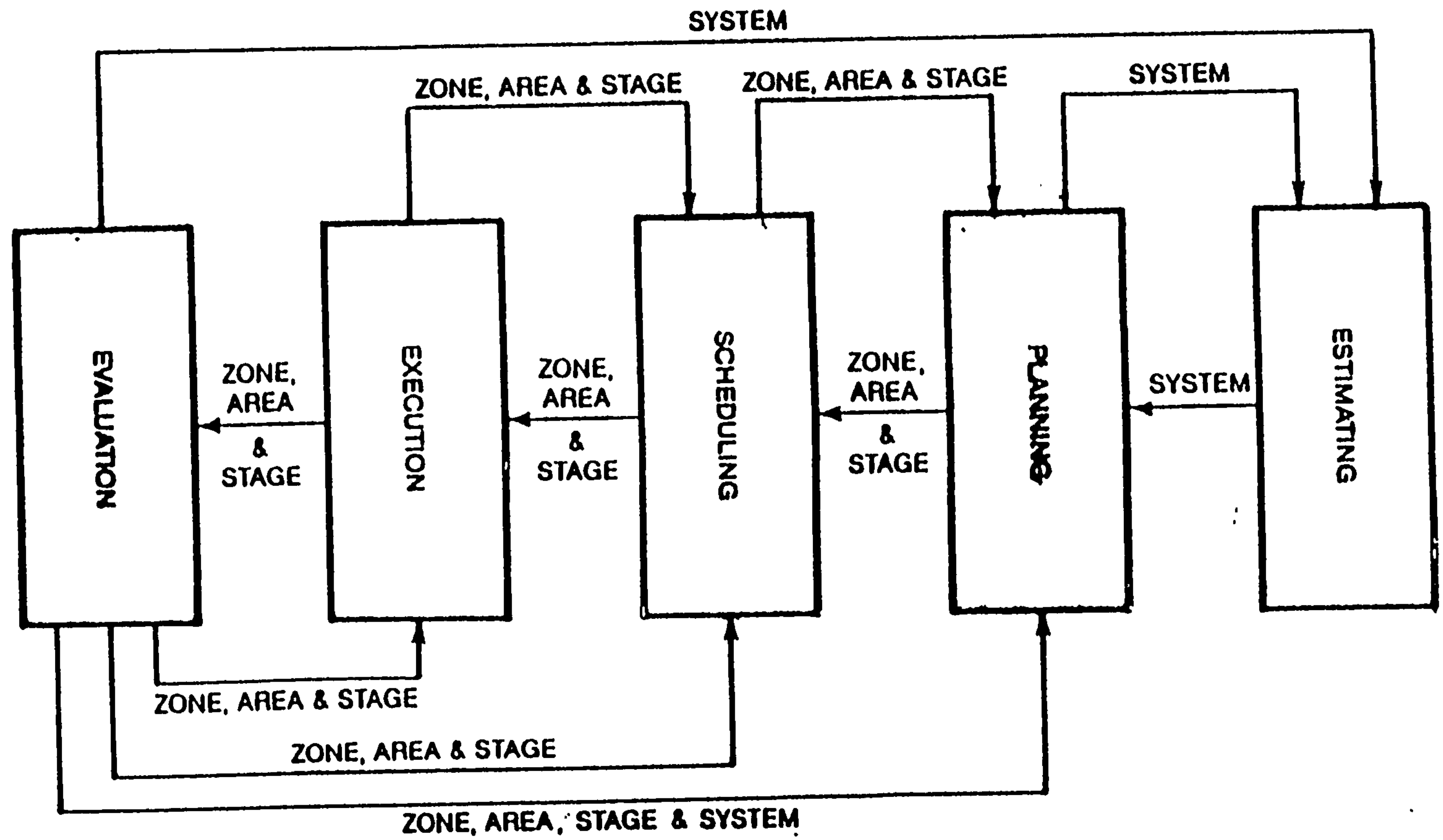


Fig. 7–1. The management cycle.

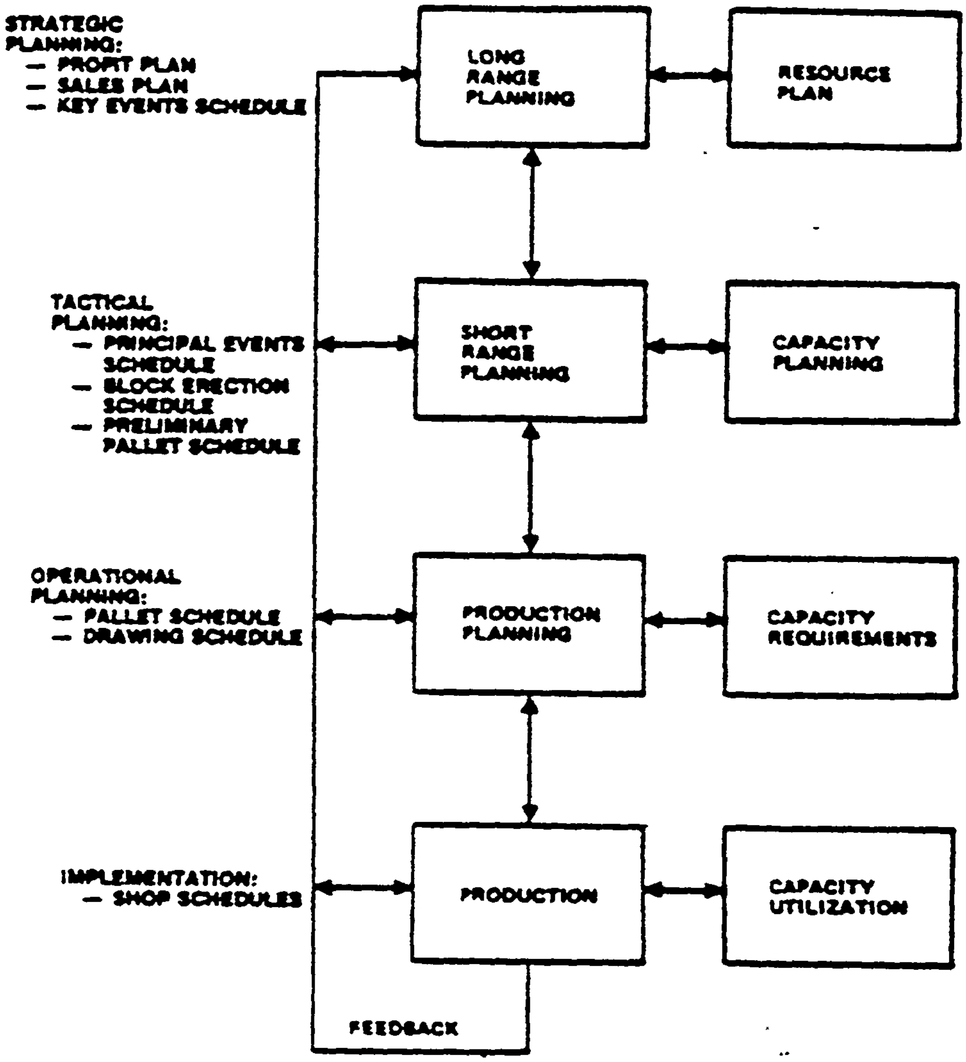


Fig. 7–6. Different levels of detail in planning.

PLANNING AND SCHEDULING

(CONTINUED)

- **SCHEDULING ALSO FOCUSES ON THE FUTURE, BUT ON WHEN THE ACTIVITIES MUST BE PERFORMED**
- **OPERATING SCHEDULES START AT THE TOP OF AN ORGANIZATION IN THE FORM OF THE INTEGRATING "MASTER OR KEY EVENT SCHEDULE" AND CASCADE DOWN THROUGH THE ORGANIZATION TO EACH DEPARTMENT, SECTION, GROUP AND TEAM**
- **OPERATING SCHEDULES RANGE FROM THE SIMPLE TO THE COMPLEX, EACH BEING SUITABLE FOR SPECIFIC APPLICATIONS**
- **POINT TO POINT SCEDULES ARE SUITABLE FOR TASKS TO BE PERFORMED IN SEQUENCE**

PLANNING AND SCHEDULING

(CONTINUED)

- **OVERLAP OR PARALLEL SCHEDULES ARESUITABLE FOR TASKS THAT MUST BE PERFORMED AT THE SAME TIME OR PORTIONS OF THE SAME TIME**
- **FINALLY, NETWORK SCHEDULES ARE SUITABLE FOR COMPLEX TASKS WHERE BOTH SEQUENCE AND PARALLEL APPROACHES ARE NEEDED**
- **PERT/CPM IS THE BEST KNOWN NETWORK SCHEDULING APPROACH (SEE ATTACHED ARTICLES ON PERT/CPM)**
- **A "GANT" CHART IS A GRAPHIC SCEDULING TECHNIQUE. IT CAN BE USED FOR THE SIMPLE SEQUENCE OR PARALLEL TASKS OR THE OUTCOME OF THE PERT/CPM APPROACH ONCE THE NETWORK HAS BEEN DEVELOPED**

PLANNING AND SCHEDULING

(CONTINUED)

- AN IMPORTANT PART OF THE PLANNING PROCESS IS TO MOVE WORK FROM ON BOARD THE SHIP TO THE PRODUCTION SHOPS TO BENEFIT FROM ADVANCED OUTFITTING

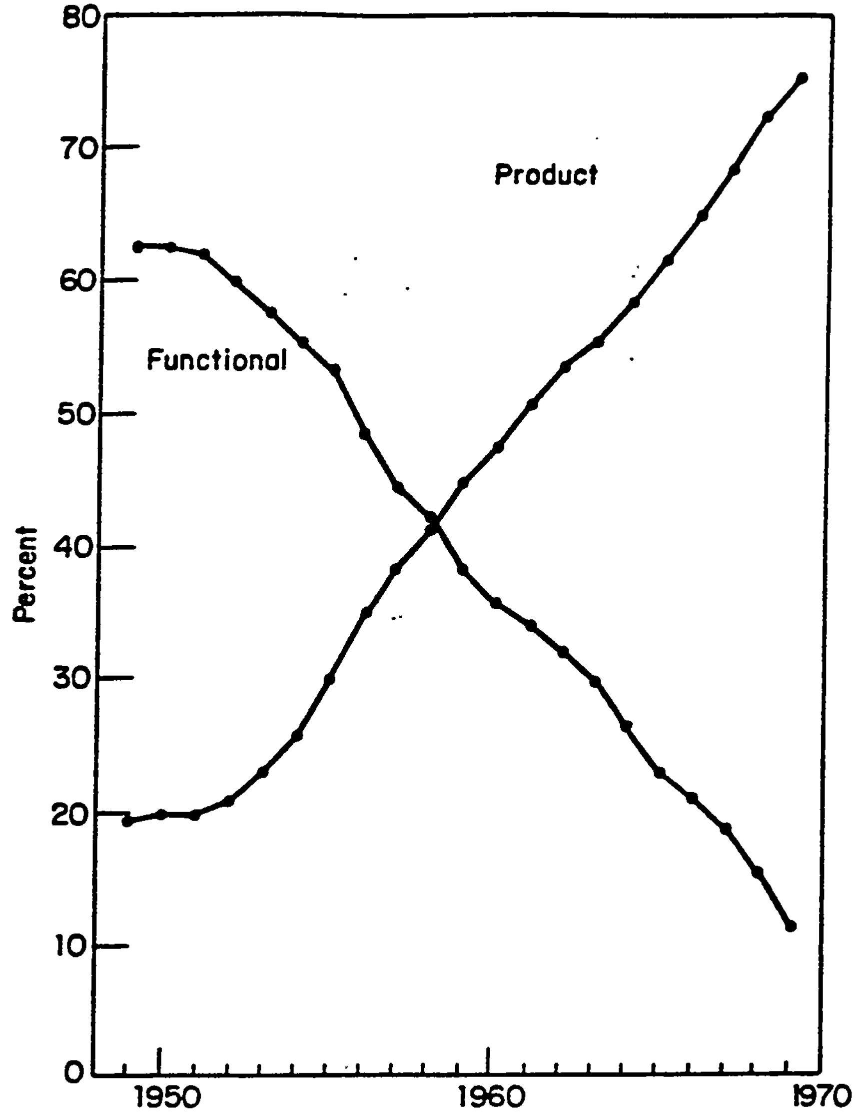
- IN ORDER TO HAVE AN ORDERLY AND LOGICAL BREAKDOWN OF THE WORK A ZONE TECHNOLOGY-ORIENTED WORK BREAKDOWN STRUCTURE SHOULD BE USED TO DEFINE THE INTERIM PRODUCTS AND THE PROCESSES THAT THEY USE [redacted]

- THE INDIVIDUAL WORK ELEMENTS AND THEIR WORK SEQUENCES, ALONG WITH RESOURCE AND MATERIAL REQUIREMENTS AND AVAILABILITY, ARE THEN ENTERED INTO A PROJECT MANAGEMENT SYSTEM AND AN INTEGRATED PRODUCTION PLAN AND COST DEVELOPED

PLANNING AND SCHEDULING

(CONTINUED)

- THIS IS AN AREA WHERE SIMULATION AND COMPUTER AIDED PROCESS PLANNING CAN BE OF GREAT BENEFIT (SEE ATTACHED NSRP REPORT)
- THE SUCCESSFUL BUSINESS PLAN → SHIPBUILDING POLICY → BUILD STRATEGY APPROACH CAN BE APPLIED TO SHIP REPAIR AND OVERHAUL [redacted]
- SENSITIVITY OR "WHAT.IF" ANALYSIS CAN NOW BE PERFORMED TO DETERMINE ALTERNATIVES THAT MAY OFFER IMPROVEMENT IN PRODUCTIVITY OR SCHEDULE. IT MAY BE NECESSARY TO DO SO BECAUSE OF LATE MATERIAL OR UNEXPECTED REPAIRS.



80
70
60
50
40
30
20
10
0
Percent
Product
Functional
1950
1960
1970

10

Project Management: PERT/CPM

In many situations managers assume the responsibility for planning, scheduling, and controlling projects that consist of numerous separate jobs or tasks performed by a variety of departments, individuals, etc. Often these projects are so large and/or complex that the manager cannot possibly keep all the information pertaining to the plan, schedule, and progress of the project in his/her head. In these situations the techniques of PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) have proved to be extremely valuable in assisting managers in carrying out their project management responsibilities.

PERT and CPM have been used to plan, schedule, and control a wide variety of projects, such as

1. Research and development of new products and processes
2. Construction of plants, buildings, highways
3. Maintenance of large and complex equipment
4. Design and installation of new systems

In projects such as these, project managers must schedule and coordinate the various jobs or activities so that the entire project is completed on time. A complicating factor in carrying out this task is the interdependence of the activities; for example, some activities depend upon the completion of other activities before they can be started. When we realize that projects can have as many as several thousand specific activities, we see why project managers look for procedures that will help them answer questions such as the following:

1. What is the total time to complete the project?
2. What are the scheduled start and finish dates for each specific activity?
3. Which activities are "critical" and must be completed *exactly* as scheduled in order to keep the project on schedule?
4. How long can "noncritical" activities be delayed before they cause a delay in the total project?

As you will see, PERT and CPM can be used to help answer the above questions.

While PERT and CPM have the same general purpose and utilize much of the same terminology, the techniques were actually developed independently. PERT was introduced in the late 1950s specifically for planning, scheduling, and controlling the Polaris missile project. Since many jobs or activities associated with the Polaris missile project had never been attempted previously, it was different to predict the time to complete the various jobs or activities. Consequently, PERT was developed with an objective of being able to handle uncertainties in activity completion times.

On the other hand, CPM was developed primarily for scheduling and controlling industrial projects where job or activity times were considered known. CPM offered the option of reducing activity times by adding more workers and/or resources, usually at an increased cost. Thus a distinguishing feature of CPM was that it enabled time and cost tide-offs for the various activities in the project.

In today's usage the distinction between PERT and CPM as two separate techniques has largely disappeared. Computerized versions of the PERT/CPM approach often contain options for considering uncertainty in activity times as well as activity time-cost trade-offs. In this regard modem project planning, scheduling, and controlling procedures have essentially combined the features of PERT and CPM such that a distinction between the two techniques is no longer necessary.

10.1 PERT/CPM NETWORKS

The first step in the PERT/CPM project scheduling process is to determine the specific jobs, or activities, that makeup the project. As a simple illustration involving the process of buying a small business, consider the list of four activities shown in Table 10.1. The development of an accurate list of activities such as this is a key step in any project. Since we will be planning the entire project and estimating the project completion date based on the list of activities, poor planning and omission of activities will be disastrous and lead to inaccurate schedules. We will assume that careful planning has been completed for the example problem and that Table 10.1 lists all activities for the small business project.

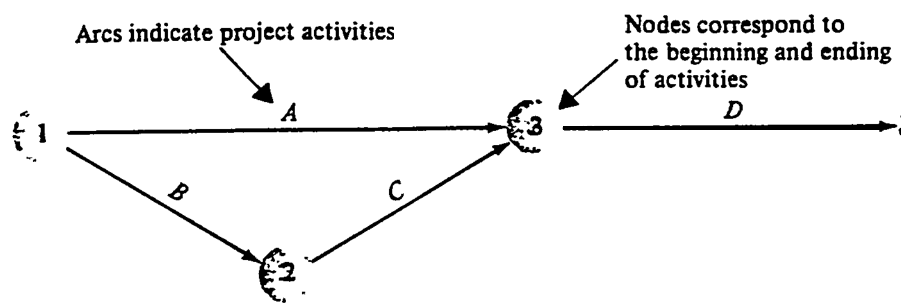
TABLE 10.1
Activity List for the Example Project of Buying a Small Business

Activity	Description	Immediate Predecessors
A	Develop a list of sources for financing	
B	Analyze the financial records of the business	
C	Develop a business plan (e.g., sales projections, cash flow projections, etc.)	*B*
D	Submit a proposal to a lending institution	*A, C*

Note that Table 10.1 contains additional information in the column labeled immediate predecessors. The ***immediate predecessors*** for a particular activity are the activities that, when completed, enable the start of the activity in question. For example, the information in Table 10.1 tells us we can start work on activities A and B anytime, since neither of these activities depends upon the completion of prior activities. However, activity C cannot be started until activity B has been Completed, and aCtiVity D cannot be started until both activities *A* and C have been completed. As YOU will see, immediate predecessor information must be known for each activity in order to describe the interdependencies among the activities in the project.

In Figure 10.1 we have drawn a network that not only depicts the activities listed in Table 10.1 but also portrays the predecessor relationships among the activities. This graphical representation is referred to as the PERT/CPM network for the project. The activities are shown on the branches, or arcs, of the network. The circles, or nodes, of the network correspond to the beginning and ending Of the activities" The completion Of all the activities that lead into a node is referred to as an event. For example, node 2 corresponds to the event that activity *B* has been completed, and node 3 corresponds to the event that both activities A and c have been completed.

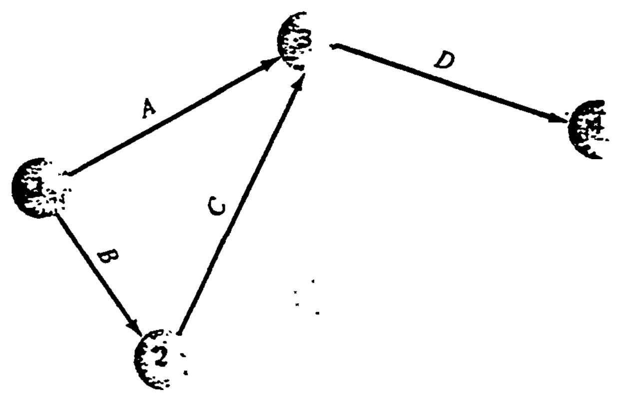
FIGURE 10.1
PERT/CPM Network for the Example Project of Buying a Small Business



Let us now attempt to develop the network for a project having the following activities and immediate predecessors:

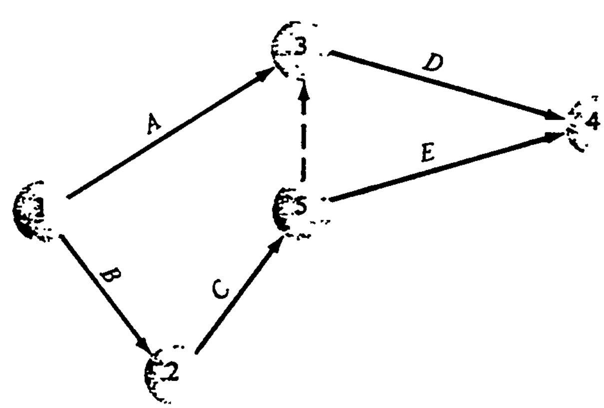
Activity	Immediate Predecessors
A	—
B	—
C	*B*
D	*A*, *C*
E	*C*
F	*C*
G	*D*, *E*, *F*

A portion of the PERT/CPM network that could be used for the first four activities is as follows:



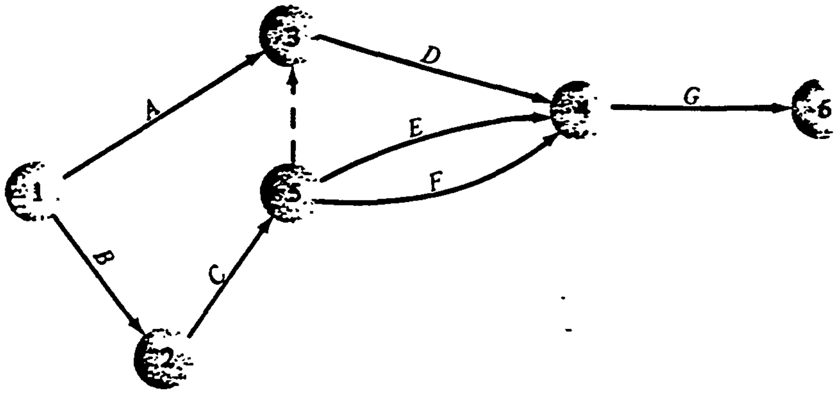
This portion of the network causes no particular problem for activity D, since it shows activities *A* and C as the correct immediate predecessors. However, when we attempt to add activity E to the network, we encounter a problem. At first we might attempt to show activity E beginning at node 3. However, this indicates that both activities *A* and C are the immediate predecessors for activity E, which is incorrect. Referring to the original activity schedule for the project, we see that activity E only has activity C as its immediate predecessor.

We can avoid the above problem by inserting a *dummy activity,* which, as the name implies, is not an actual activity but rather a fictitious activity used to ensure that the proper precedence relationships among the activities are depicted in the network. For example, we can add node 5 and insert a dummy activity, indicated by a dashed line, from node 5 to node 3 forming the network shown below.

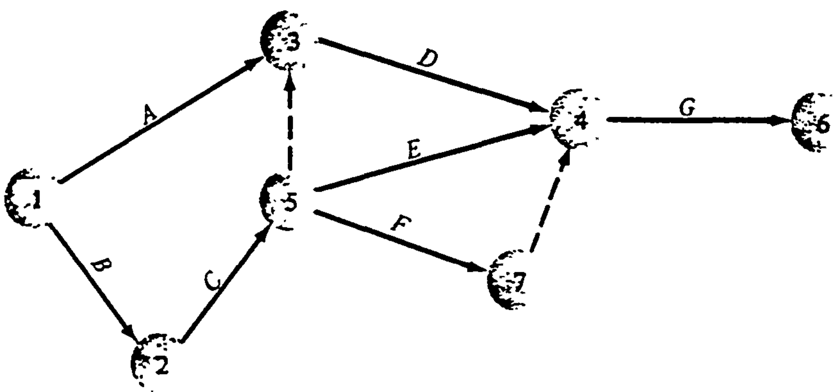


With this change in the network, activity E starting at node 5 has the correct predecessor of only activity C. The dummy activity does not have a time requirement but is merely used to maintain the proper precedence relationships in the network. Note that the insertion of the dummy activity also correctly shows activities *A* and C as the immediate predecessors for activity D.

Completion of the seven-activity network could be shown as follows:



Note how the network correctly identifies activities D, E, and F as the immediate predecessors for activity G. However, note that activities E and F both start at node 5 and end at node 4. This situation causes problems for certain computer programs that use start. ng and ending nodes to identify the activities in a PERT/CPM network. In these progr .ms the computer procedure would recognize activities E and F as the same activity since they have the same starting and ending nodes. When this condition occurs, dummy activities can be added to a network to make sure that two or more activities do not have the same starting and ending nodes. The use of node 7 and a dummy activity as shown below eliminates this problem for activities *E* and F.



Dummy activities can be used to identify precedence relationships correctly as well as to eliminate the possible confusion of two or more activities having the same starting and ending nodes. Although dummy activities may not be required for all PERT/CPM net works, larger and/or more complex projects may require many dummy activities in order to depict the project network properly.

10.2 PROJECT SCHEDULING WITH PERT/CPM

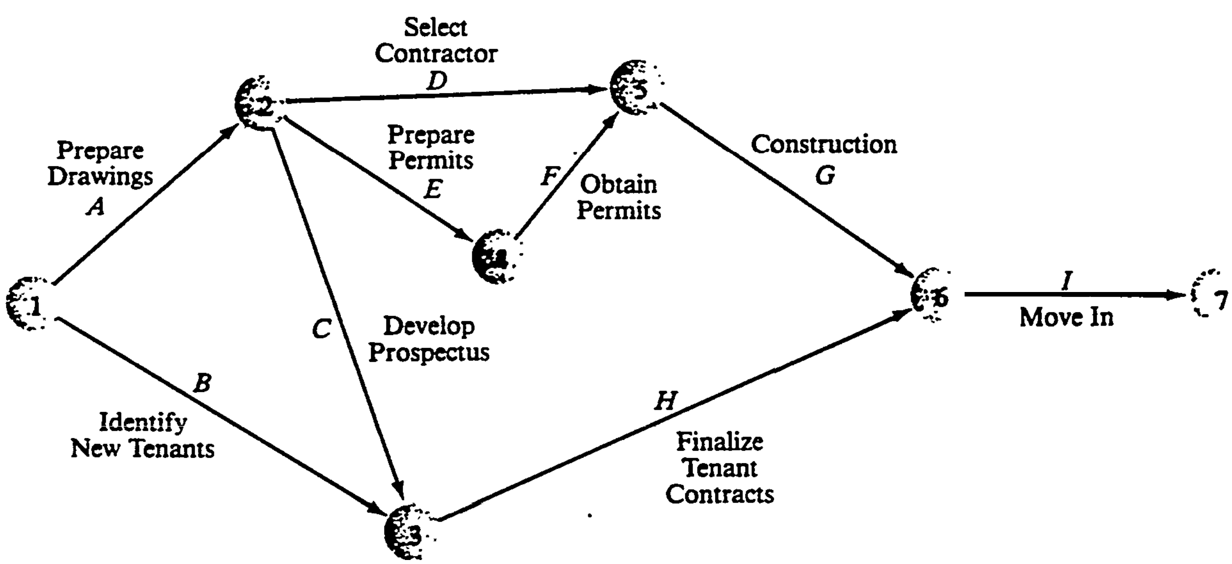
The owner of the Western Hills Shopping Center is considering modernizing and expanding the current 32-business shopping complex. Financing for the expansion has been arranged through a private investor. If the expansion project is undertaken, the owner hopes to add eight to 10 new businesses or tenants to the shopping complex.

The specific activities that make up the expansion project are listed in Table 10.2. Note that the list includes the immediate predecessor for each activity as well as the number of weeks required to complete the activity. The PERT/CPM network for the project is shown in Figure 10.2. Check for yourself to see that the network does in fact maintain the immediate predecessor relationships shown in Table 10.2.

TABLE 10.2
Activity List for the Western Hilis Shopping Center Expansion Project

Activity	Activity Description	Immediate Predecessor	Completion Time (Weeks)
A	Prepare architectural drawings of planned expansion	—	5
B	Identify potential new tenants	—	6
C	Develop prospectus for tenants	*A*	4
D	Select contract r	*A*	3
E	Prepare building permits	*A*	1
F	Obtain approval for building permits	*E*	4
G	Construction	*D, F*	14
H	Finalize contracts with tenants	*B, C*	12
I	Tenants move in	*G, H*	2
		Total	51

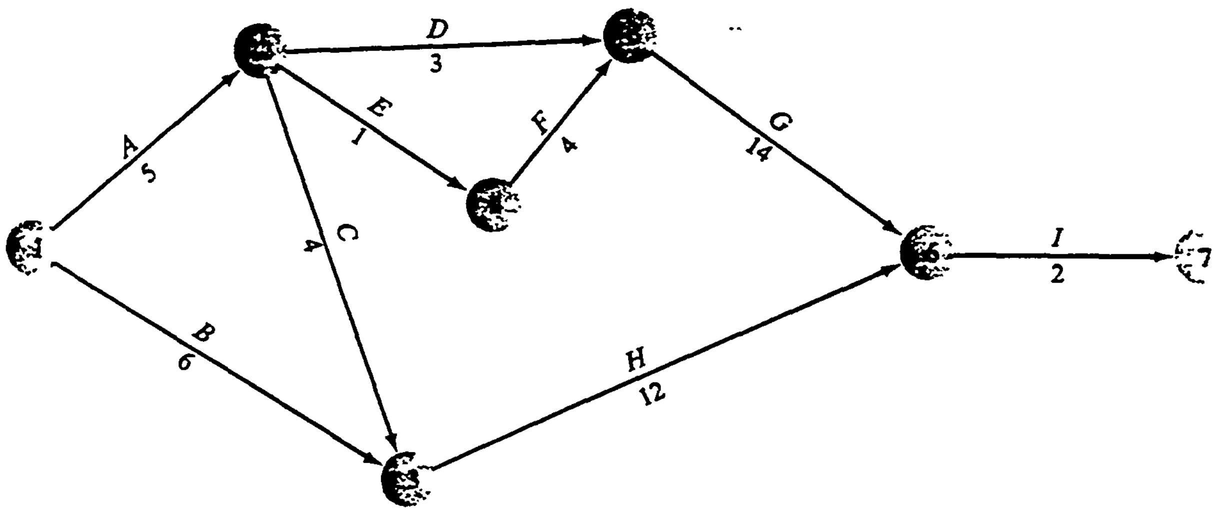
FIGURE 10.2
PERT/CPM Network for the Western Hills Shopping Center Expansion Project



Information in Table 10.2 indicates that the total time required to complete all activities in the shopping center expansion project is 51 weeks. However, we can see from the network (Figure 10.2) that several of the activities can be conducted simultaneously (*A* and *B,* for example). Being able to work on two or more activities at the same time will shorten the total project completion time to less than 51 weeks. However, the required project completion time is not directly available from the data in Table 10.2.

In order to facilitate the PERT/CPM computations that we will be making, the project network has been redrawn as shown in Figure 10.3. Note that each activity letter is written above and each activity time is written below the corresponding arc.

FIGURE 10.3
Western Hills Shopping Center Project Network with Activity Times



The Critical Path

Once we have the project network and the activity times, we are ready to proceed with the calculations necessary to determine the total time required to complete the project. In addition, we will use the results of the *calculations to* develop a detailed start and finish schedule for each activity.

In order to determine the project completion time we will have to analyze the network and identify what is called its *critical path.* A *path is* a sequence of connected activities that leads from the starting node (1) to the completion node (7). The connected activities defined by nodes 1-2-3-6-7 form a path consisting of activities *A, C, H,* and I. Nodes 1-2-5-6-7 define the path associated with activities *A, D, G,* and I. Since *all* paths must be traversed in order to complete the project, we need to analyze the amount of time the various paths require. In particular, we will be interested in the longest path through the network. Since all other paths are shorter in duration, the longest path determines the total time or duration of the project. If activities on the longest path are delayed, the entire project will be delayed. Thus the longest path activities are the *crirical activities* of the project and the longest path is called the *critical path* of the network. If managers wish to reduce the total project time, they will have to reduce the length of the critical path by shortening the duration of the critical activities. The following discussion presents a step-by-step procedure or algorithm for finding the critical path of a project network.

Starting at the network's origin (node 1) and using a starting time of O, compute an ***earliest start*** and ***earliest finish time*** for each activity in the network. Let

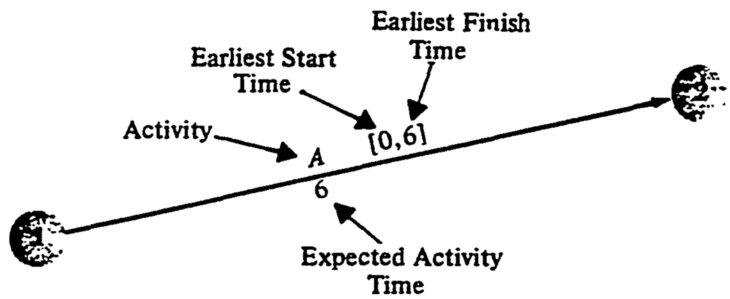
ES = earliest start time for a particular activity
EF = earliest finish time for a particular activity
t = expected activity time for the activity

The following expression can be used to find the earliest finish time for a given activity:

$$EF. = ES + t \tag{10.1}$$

For example, for activity A, $ES = 0$ & $t = 5$; thus the earliest finish time for activity A is $EF = 0 + 5 = 5$.

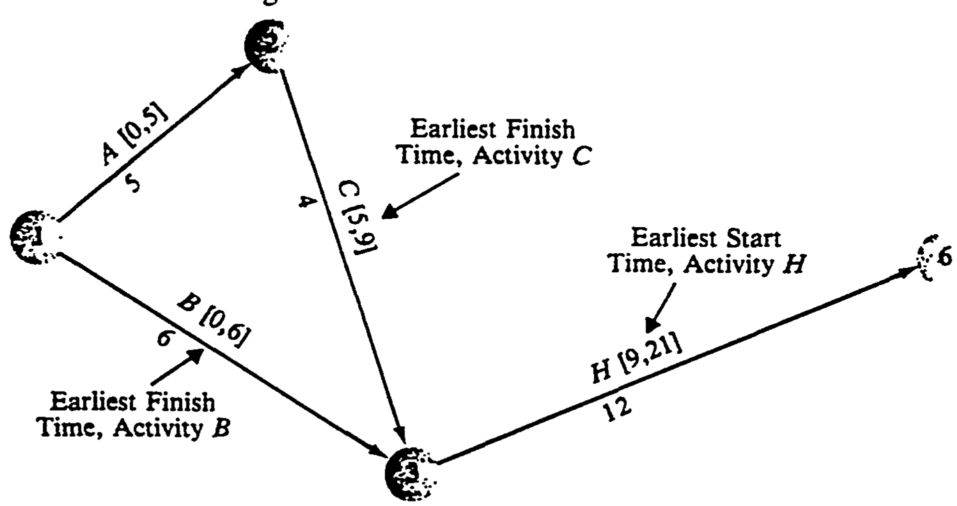
We will write the earliest start and earliest finish times directly on the network in brackets next to the letter of the activity. Using activity A as an example, we have



Since activities leaving a node cannot be started until ***all*** immediately preceding activities have been completed, the following rule can be used to determine the earliest start times for activities:

> ***Earliest Start Time Rule:***
> **The earliest start time for an activity leaving a particular node is equal to the *largest* of the earliest finish times for all activities entering the node.**

In applying this rule to a portion of the network involving activities A, B, C, and H, we obtain the following:

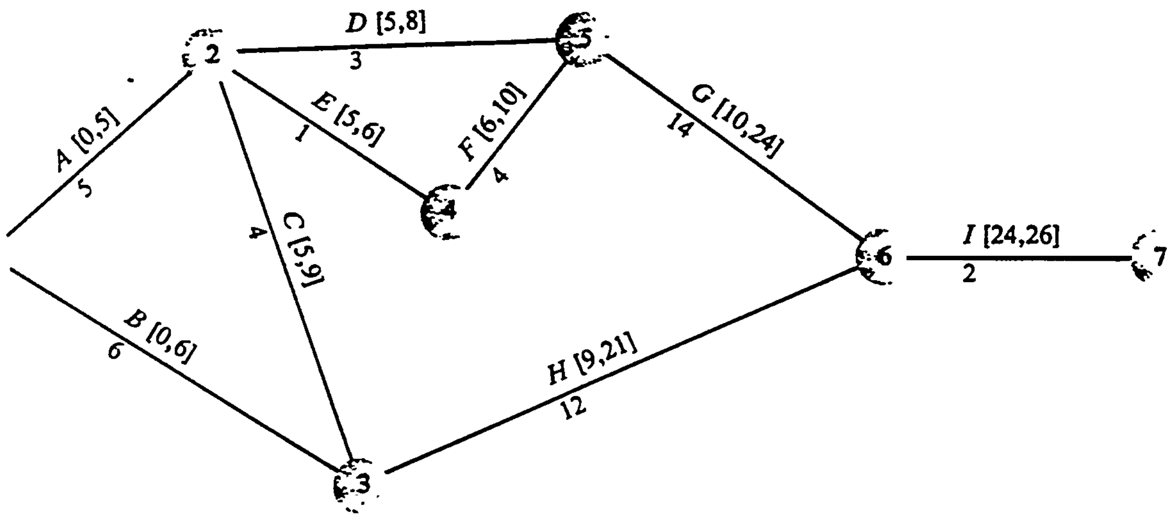


Note that in applying the earliest start time rule for activity C, which leaves node 2, we first recognized that activity *A is the* only activity entering node 2. Since the earliest finish time for activity *A is* 5, the earliest **start time** for activity C is 5. Thus the earliest finish time for activity C must be EF=ES +t =5+4=9.

The above diagram also shows that the earliest finish time for activity B is 6. Applying the earliest start time rule for activity H, we see that the earliest start time for this activity must be equal to the largest of the earliest finish times for the two activities that enter node 3, activities *B* and C. Thus the earliestst time for activity H is 9, and the earliest finish time is EF=ES+t =9+12= 21.

Proceeding in a ***forward pass*** through the network, we can establish the earliest start time and then the earliest finish time for each activity. The Western Hills Shopping Center PERT/CPM network, with the ES and EF values for each activity, is shown in Figure 10.4. Note that the earliest finish time for activity I, the last activity, is 26 weeks. Thus the completion time for the entire project is 26 weeks.

FIGURE 10.4
Western Hills Shopping Center Project with Earliest Start Times and Earliest Finish Times Shown Above the Activity Arcs



We now continue the algorithm for finding the critical path by making a ***backward pass*** calculation. Starting at the completion point (node 7) and using a latest finish time of 26 for activity I, we trace back through the network computing a latest start and latest finish time for each activity. Let

LS = latest start time for a particular activity
L F = latest finish time for a particular activity

The following expression can be used to find the latest start time for a given activity:

$$LS = LF - f \qquad (10.2)$$

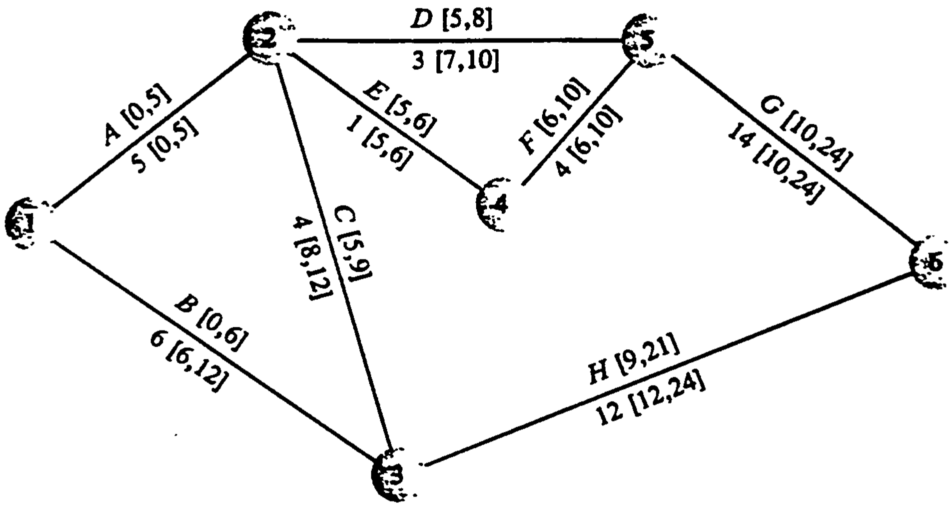
Given LF = 26 and t = 2 for activity I, the latest start time for this activity can be computed as LS = 26 – 2 = 24.

The following rule is necessary in order to determine the latest finish time for any activity in the network:

Latest Finish Time Rule:
The latest finish time for an activity entering a particular node is equal to the smallest of the latest start times for all activities leaving the node.

Logically the above rule states that the latest time an activity can be finished is equal to the earliest (smallest) value for the latest start time of following activities. The complete network with the LS and LF backward pass calculations is shown in Figure 10.5. The latest start and latest finish times for the activities are written in brackets directly under the earliest start and earliest finish times.

FIGURE 10.5
Western Hills Shopping Center Project with best Start Times and Latest Finish Times Shown Below the Activity Arcs



Note the application of the latest finish time rule for activity ***A***, which enters node 2. The latest finish time for activity ***A*** (LF = 5) is the smallest of the latest start times for the activities that leave node 2; that is, the smallest LS value for activities C (LS = 8), E (LS = 5), andD (LS = 7) is 5.

After obtaining the start and finish activity times as summarized in Figure 10.5, we can find the amount of slack or free time associated with each of the activities. ***Slack*** is defined as the length of time an activity can be delayed without affecting the completion date for the entire project. The amount of slack for each activity is computed as follows:

$$\text{Slack} = LS - ES = LF - EF \tag{10.3}$$

For example, we see that the slack associated with activity C is LS - ES = 8-5 = 3 weeks. This means that activity C can be delayed Up to 3 weeks (start anywhere between weeks 5 and 8) and the entire project can still be completed in 26 weeks. Thus activity C is not a critical activity and is not part of the critical path. Using (10.3), we see that the slack associated with activity ***E*** is LS – ES = 5 – 5 = O. Thus activity ***E*** has no slack time and must be held to the 5-week start time schedule. Since activity ***E*** cannot be delayed without affecting the entire project, it is a critical activity and is on the critical path: In general, the critical path activities are the activities with zero slack.

The start and finish times shown on the network in Figure 10.5 provide a detailed schedule for all activities. That is, from Figure 10.5 we know the earliest and latest start and finish times for the activities. Putting this information in tabular form provides the activity schedule shown in Table 10.3. Note that by computing the slack associated with each activity, we see that activities ***A, E, F,*** G, and I each have zero slack; hence these activities form the critical path in the shopping center expansion network. Note that Table ; 3.3 also shows the slack or delay that can be tolerated for the noncritical activities before these activities will cause a project delay.

TABLE 103
Activity Schedule *for the Western* ***Hills Shopping Center Expansion Project***

Activity	Earliest Start (ES)	Latest Start (LS)	Earliest Finish (EF)	Latest Finish (LF)	Slack (LS-ES)	Critical Path?
A	0	0	5	5	0	Yes
B	0	6	6	12	6	
C	5	8	9	12	3	
D	5	7	8	10	2	
E	5	5	6	6	0	Yes
F	6	6	10	10	0	Yes
G	10	10	24	24	0	Yes
H	9	12	21	24	3	
I	24	24	26	26	0	Yes

Contributions of PERT/CPM

Previously we stated that project managers look for procedures that will help answer many important questions regarding the planning, scheduling, and controlling of projects. Let us reconsider these questions in light of the information the PERT/CPM network and critical path calculations have provided about the Western Hills Shopping Center expansion project.

1. What is the total time to complete the project?
   Answer: PERT/CPM has shown that the project can be completed in 26 weeks if the individual activities are completed on schedule.

2. What are the scheduled start and completion times for each activity?
   Answer: PERT/CPM has provided the detailed activity schedule that shows the earliest start, latest start, earliest finish, and latest finish times for each activity (Table 10.3).

3. Which activities are "critical" and must be completed *exactly as* scheduled in order to keep the project on schedule?
Answer: PERT/CPM has identified the five activities-A, *E, F, G,* and I—as the critical activities for the project.

4. How long can "noncritical" activities be delayed before they cause a delay in the completion time for the project?
Answer: PERT/CPM has identified the slack time available for all activities as shown . in Table 10.3.

In the management of any project the above information is important and valuable. While larger projects may substantially increase. the time required to draw the PERT/CPM network and to make the necessary calculations, the procedure and contributions of PERT/CPM to larger projects are identical to those observed in the shopping center expansion project. Furthermore, computer packages exist that carry out the steps of the PERT/CPM procedure. Figure 10.6 shows the activity schedule for the shopping center expansion project developed by *The Management Scientis.* computer software package. Input to the program included the activities, their immediate predecessors, and the expected activity times. Only a few minutes were required to input the information and generate this critical path and activity schedule information.

FIGURE 10.6
Activity Schedule for the Western Hills Shopping Center Expansion Project Developed using the Management Scientist®

Activity	Earliest Start (ES)	Latest Start (LS)	Earliest Finish (EF)	Latest Finish (LF)	Slack (LS-ES)	Critical Path?
A	0	0	5	5	0	Yes
B	0	6	6	12	6	
C	5	8	9	12	3	
D	5	7	8	10	2	
E	5	5	6	6	0	Yes
F	6	6	10	10	0	Yes
G	10	10	24	24	0	Yes
H	9	12	21	24	3	
I	24	24	26	26	0	Yes

The critical path is *A–E–F–G–I*.
The project completion time is 26.

Summary of the PERT/CPM Critical Path Procedure

Before leaving this section, let us summarize the PERT/CPM critical path procedure that can be used to plan, schedule, and control projects.

Step 1 Develop a list of activities that makeup the project.
Step 2 Determine the immediate predecessor activities for each activity in the project.
Step 3 Estimate the completion time for each activity.
Step 4 Draw a network depicting the activities and immediate predecessors listed in steps 1 and 2.
Step 5 Using the network and the activity time estimates, determine the earliest start time and the earliest finish time for each activity by making a forward pass through the network. The earliest finish time for the last activity in the project identifies the completion time for the entire project.
Step 6 Using the project completion time identified in step 5 as the latest finish time for the last activity, make a backward pass through the network to identify the latest start time and latest finish time for each activity.
Step 7 Use the difference between the latest start time and the earliest start time for each activity to identify the slack time available for the activity.
Step 8 The critical path activities are the activities with zero slack.
Step 9 Use the information from steps 5 and 6 to develop a detailed activity schedule for the project.

10.3 PROJECT SCHEDULING WITH UNCERTAIN ACTIVITY TIMES

In this section we consider the details of project scheduling for a problem involving the research and development of a new product. Because many of the activities in this project have never been previously attempted, the project manager wants to identify and account for the uncertainties in the activity times. Let us show how project scheduling can be conducted with uncertain activity times.

The Daugherty Porta-Vac Project

The H. S. Daugherty Company as manufactured industrial vacuum cleaning systems for a number of years. Recently a member of the company's new-product research team submitted a report suggesting the company consider manufacturing a cordless vacuum cleaner that could be powered by a rechgeable battery. The vacuum cleaner, referred to as a Porta-Vac, could contribute to Daugherty's expansion into the household market. Management hopes that the new product can be manufactured at a reasonable cost and that its portability and no-cord convenience will make it extremely attractive.

Daugherty's management would like to initiate a project to study the feasibility of proceeding with the Porta-Vac idea. The end result of the feasibility study will be a report recommending the action to be taken for the new product. In order to complete the feasibility study, information must be obtained from the firm's research and development (R&D), product testing, manufacturing, cost estimating, and market research groups. How long do you think this feasibility study project will take? When should we tell the product testing group to schedule its work? Obviously, we do not have enough information to answer these questions at this time. In the following discussion' we will learn how to answer these questions and provide the complete schedule and control information for the project.

processes (such as the mass production of a product or the periodic reorders of inventory for which management has past experience, standards, and costs), historical data are not available for nonrepetitive projects. However, each task in a one-of-a-kind program must be performed on time and be of the necessary quality, just as with routine work. In other words, management must still plan and control nonroutine operations. PERT is extremely helpful in such situations because it enables a manager to think through a project in its entirety. As such, it usually results in a more optimum utilization of resources.

Specific Applications of PERT

PERT (and variations of it) is probably one of the most widely used production planning models. It was developed through the cooperation of the U.S. Navy and the management consulting firm of Booz Allen & Hamilton Inc. Introduced by the Special Projects office of the U.S. Navy in 1958 on the Polaris missile project, PERT was widely credited with helping to reduce by two years the time originally estimated for the completion of the engineering and development programs for the missile. By identifying the longest paths through all of the tasks necessary to complete the project, it enabled the program managers to concentrate efforts on those tasks at vitally affected the total project time. PERT' has spread rapidly tkoughout the defense and space industries. Today, almost every major government agency involved in the space program utilizes PERT. In fact, many government agencies require contractors to use PERT and other network models in planning and controlling their work on government contracts.

While the areospace business faces peculiar problems, one-of-a-kind development work *is also* an important element in many other kinds of organizations and industries. In addition to developing space vehicles and putting a man on the moon, PERT has also been utilized successfully in

1. Constructing new plants, buildings, and hospitals.
2. Designing new automobiles.
3. Coordinating the numerous activities (production, marketing, and so forth) involved in managing a new product or project. 18
4. Planning and scheduling space probes.[19]
5. Managing accounts receivable.[20]
6. Coordinating the installation of large-scale computer systems.
7. Coordinating ship construction and aircraft repairs.

In addition to engineering-oriented applications, PERT has been used to coordinate the numerous activities associated with mergers and acquisitions and with economic planning in underdeveloped counties. The technique has also contributed to planning large conventions and meetings. The Management Focus describes PERT's application to a special type of a convention: the Olympics.

Examples of Production Planning with PERT

Using PERT and other network models involves two fundamental steps (1) constructing the network and (2) estimating activity time requirements

MANAGEMENT FOCUS

PERT Goes to the International Olympics

History does not record much about the first Olympiad. However, if Hercules had at-, tempted to coordinate over 30,000 activities food, security, transportation, assistants, and medical backup for thousands of competitors-relating to the 1988 Winter Games in Calgary, Canada he might be cried uncle. A company --named project Software and Development, however, rose to the Olympian task. Employing PERT-based software developed for the space shuttle, PSD broke down the games into 15-minute segments. PSD also developed an integrated computer network to monitor the Olympic activities. Although a few glitches occurred, the games were completed in a manner that would have pleased Hercules.

Adapted from Nell Margolis, "Software Firm Tackles Olympian Project Management Task," ***Computerworld,*** **February 22, 1988, pp. 85ff.**

Constructing the Network

PERT networks are developed around two key concepts: activities and events. An activity is the work necessary to complete a particular event. An event is an accomplishment at a particular point in time and consumes no time. In PERT diagrams, an event is designated with a circle and an activity as an arrow connecting two circles. These two concepts are shown in Figure 18-3.

Before a PERT network can be constructed, the activities and events that will be represented on the diagram must be identified. Table 18-2 describes the activities and events required to manufacture a prototype aircraft engine.

The information from Table 18-2 is represented by the network model shown in Figure 18-4. Examination indicates that event 1 is the network beginning event since there are no activities leading to it and event 8 is the network ending event since there are no activities leading away from it. Note also that event 2 is the beginning event for two activities and event 6 is the ending event for two activities as well as the beginning event for one activity.

PERT emphasizes identifying events and activities with enough precision so that it is possible to monitor accomplishment as the project proceeds. There are four basic phases in constructing a PERT network:

1. Define each necessary activity.
2. Estimate how long each activity will take.
3. Construct the network.
4. Find the critical path-that is, the longest path, in time, from the beginning event to the ending event.

All events and activities must be sequenced in the network under a strict set of logical rules (e. g., no event can be considered complete until all predecessor

FIGURE 18–3

Two Events and One Activity

The basic building blocks of PERT are events (circles 1 and 2) and activities (arrow).

TABLE 18–2

Description of PERT Activities and Events for Manufacturing of Prototype Aircraft Engine

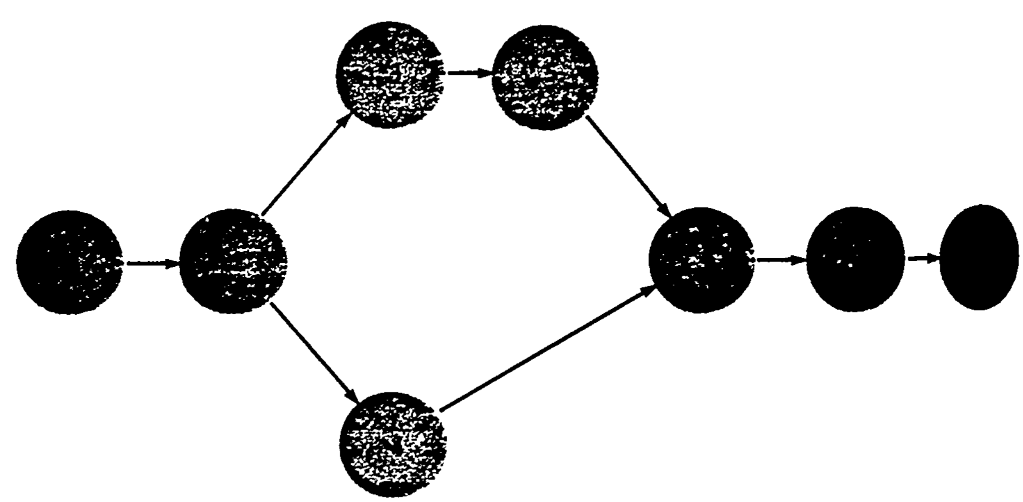
The effectiveness of PERT depends on accurate determination of all events and activities.

Activity		Event		
Arrow	*Description*	*Prerequisite*	*Circle*	*Description*
1–2	Develop engineering specifications.		2	Specifications completed.
2–3	Obtain test models.	1–2	3	Test models obtained.
2–4	Locate suppliers of component parts.	1–2	4	Suppliers located.
3–5	Develop production plans.	2–3	5	Plans completed.
5–6	Begin subassembly 1.	3–5	6	Subassembly 1 completed.
4–6	Place orders for component parts and await receipt.	2–4	6	Component parts received.
6–7	Begin subassembly 2.	5–6 and 4–6	7	Subassembly 2 completed.
7–8	Begin final assembly.	6–7	8	Engine completed.

FIGURE 18–4

PERT Network for Information in Table 18–2

A PERT network chart enables managers to perceive complex problems in relatively simple graphic form.



ting time requirements
ıdamental part of doing
s. A hot, tasty pizza
ɪend on it.

events have been completed) that allows for the determination of the critical path.[21]

The paramount variable in a PERT network is time.[22] Estimating how long each activity will take is extremely difficult, since the manager may have no experience on which to rely.

Estimating Activity Time Requirements

Since PERT projects are usually unique, they are subject to a great deal of uncertainty. PERT is designed to deal specifically with the problem of determining time estimates.

For example, assume you are trying to estimate how long it will take to complete a term project for your management class. You know that one activity will be to collect certain information. If all goes well, you believe that you could complete this one activity in eight weeks. However, if you encounter numerous obstacles (dates, parties, illness, material not available in the library), this one activity will take much longer to complete. Estimating the time needed to complete your term project becomes a complex process when you try to account for the delays that might occur.

For PERT projects, *three time estimates are required for each activity.* The individual or group chosen to make each time estimate should be that individual or group most closely connected with and responsible for the particular activity under consideration. The three time estimates needed are:

Optimistic time (a): The time in which the activity can be completed if everything goes exceptionally well and no obstacles or problems are encountered.

Most likely time (m): The most realistic estimate of how long an activity might take. This is the time we would expect to occur most often if repeated numerous times.

Pessimistic time (b): The time that would be required if everything goes wrong and numerous obstacles and problems are encountered.

It is extremely difficult to deal simultaneously with the optimistic time, the most likely time, and the pessimistic time. Fortunately a way has been developed to arrive at one time estimate. An expected time (t_e) can be estimated satisfactorily for each activity by using the following formula:

$$t_e = \frac{a + 4m + b}{6}$$

Note that in the formula for computing the expected time (t_e), the weight that is given to the most likely time (m) is much greater than the weight given to the optimistic and pessimistic times, since each of them has only a small chance of occurring. Also note that optimistic and pessimistic time each receive the same weight.

To illustrate the use of this formula, recall the prototype-engine project described in Table 18–2. Suppose you estimate that three weeks is the most likely completion time (m) for the activity of developing engineering specifications. However, you feel that there is a small chance that the activity might be completed in one week. Therefore, the optimistic time (a) is 1. You also feel there is a slight chance things could go wrong and it would take eight weeks to develop specifications. Therefore, the pessimistic time (b) is 8.

To compute the expected time from the three time estimates, we must determine at what time there is a 50–50 chance of completing the activity. The expected time formula provides that figure. The time estimates are as follows:

Optimistic time (a) = 1 week
Most likely time (m) = 3 weeks
Pessimistic time (b) = 8 weeks

Substituting these time estimates into the formula yields:

$$\text{Expected time} = t_e = \frac{1 + 4(3) + 8}{6} = 3.5$$

Thus, there is a 50-50 chance that the engineering specifications can be developed in 3.5 weeks.

The expected time may be either longer or shorter than the most likely time, depending on the three time estimates. To illustrate an expected time shorter than the most likely time, assume the following three time estimate for developing engineering specifications:

Optimistic time (a) = 3 weeks
Most likely time (m) = 4 weeks
Pessimistic time (b) = 10 weeks

PLANNING SCHEDULING AND PRODUCTION CONTROL

I. OVERVIEW

A. Required to prevent chaos. There are different levels of planning, depending on whether it is strategic, tactical, or detail. (See Figure I, this section).

B. Productivity of the project is dependent on coordination of resource expenditure

1. Material
2. Manpower
3. Facilities
4. Capital
5. Information

c. Definitions

1. Planning--identifying all task, determining order of accomplishment and resource needs, including when, and where, and how much.
2. Scheduling--lays out the time order, and location.
3. Production Control--monitoring performance and responding to requirements.

D. Must be integrated with other shipbuilding functions to take advantage of advanced productivity concepts.

E. Build Strategy: Reflects the total integration, and the various levels of planning. (See Figure II, this section).

F. The planning and scheduling functions

1. Hull production planning
2. Outfit planning

II. HULL PRODUCTION PLANNING (SEE FIGURE III, THIS SECTION)

A. The purpose of hull production planning is to develop and maintain a planned schedule for ship's steel construction that will:

1. Maintain the desired design accuracy
2. Maintain expected performance
3. Meet expected productivity
4. Meet planned schedule.

B. Key Events Schedule (See Figures IV and V, this section)

1. Determines
   a. Keel
   b. Launch
   Delivery, Actual
2. Based on
   a. Contract Go Ahead
   b. Contract Delivery Date.
   c. Steel Tonnage
      M/H available
      Material Delivery
   d. Basin Capacity/Available
3. Tori Level Schedule..All subsegment schedules are derived from this schedule.

C. Production Scheduling

1. Hull Blocks (See Figure VI, this section)
   a. Erection Sequence (See Figure VII, this section)
   b. Determine Precedence Relationships
      notice where it starts
      notice time/between block as a function of location
   c. Relate to dimension control.
2. Assembly schedule. (See Figures VIII,IX, and X, this section)
   a. Driven by Block Erection Schedule
   b. Dates Based on Historical data base of time requirements for sized, flow lane category,
   c. Process.
      list in order of need
      allocate to process lane category
      develop scheduling network for sub assembly and fabrication
      develop detailed assembly specification plans for each block

IV. OUTFIT PLANNING

A. Previous discussion has stressed the interrelationship between hull and outfit planning. It's obvious as we move toward advanced outfitting that integration must be close. For that reason it's IMPERATIVE that outfit personnel be involved in all of the design and production planning phases.

B. The evolution of outfitting has progressed through three phases:

1. conventional outfitting-the planning and implementation by functional systems.

2. Pre-outfitting-applies resources by outfitting large structural sections prior to erection. Still allocates activities by ship's system.

3. Zone outfitting-addresses everything within a limited 3-dimensional space. Frees outfitting as much as possible from dependence on hull construction progress.

C. There are five reasons for zone outfitting:

1. to reduce the outfitting period
2. to simplify outfit planning
3. to achieve greater efficiency of erection cranes
4. to avoid interferences between trades
5. to minimize outfitting on-board.

D. The keys to the system are:

1. the pallet--contains the material properly fabricated and the support information (drawings, assembly instructions, material lists, etc.) that will consitute the work package.

2. accuracy control concepts. Zone outfitting requires an exponential increase in dimensional control. Very difficult to achieve and requires very rigorous control mechanisms. Control must be effective in three dimensions.

E. Figure XI (this section), shows the material development and allocation relationships.

F. The zones are designed for outfit convenience (see Figure XII, this section)

1. Major transverse breaks
2. Type of outfit (i.e., machinery, deck, accommodation, electrical)

G. Figure XIII (this section) shows the relationship of materials lists to design and material function.

1. MLS--Material Lists of Systems
2. MLP--Material Lists of Pipe
3. MLC--Materials Lists of Components (other than pipe)
4. MLF--Materials Lists of Fittings (for a pallet)
5. $\Sigma(MLS) = \Sigma(MLC) + \Sigma(MLP) = \Sigma(MLF)$

H. Outfit Planning is closely akin to planning in repair and overhaul. Linkup is in 3-d spaces where repair/overhaul is mainly foundations, piping, and components repair and replacement.

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FIGURE PL-I

DIFFERENT LEVELS OF DETAIL PLANNING

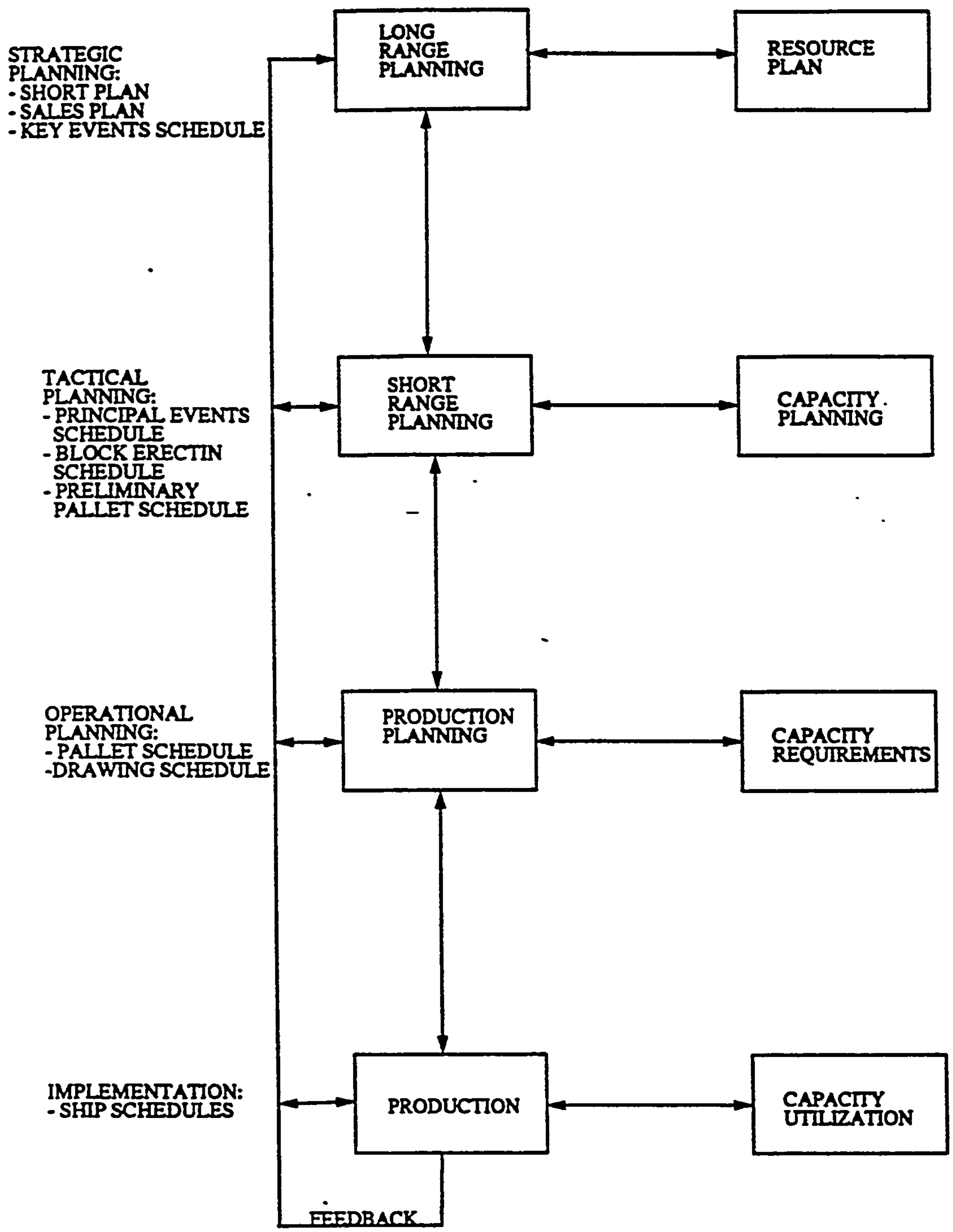

FIGURE PL-II
OUTPUTS FROM A BUILDING STRATEGY

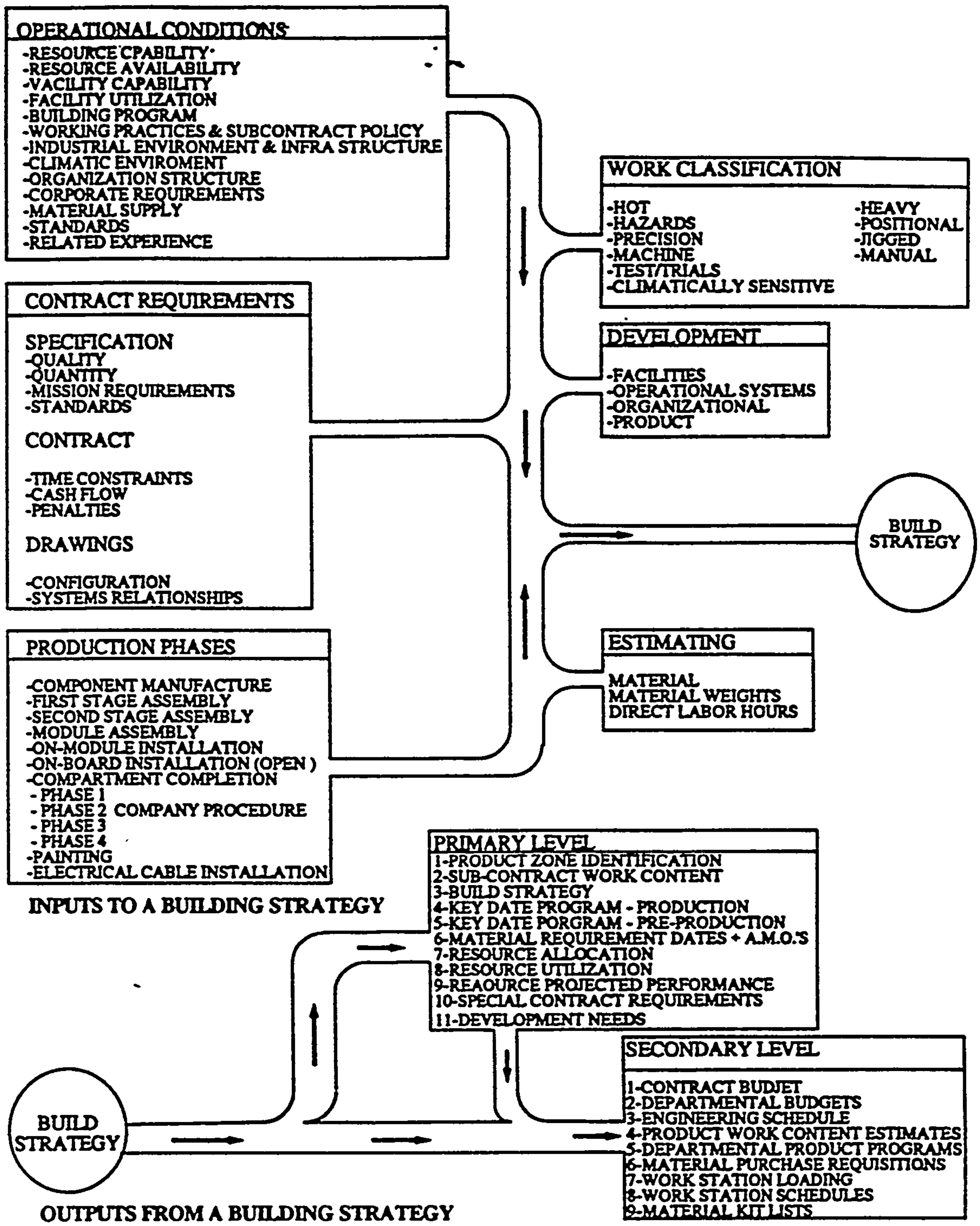

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FIGURE PL-III
TYPICAL HULL PLANNING STEPS

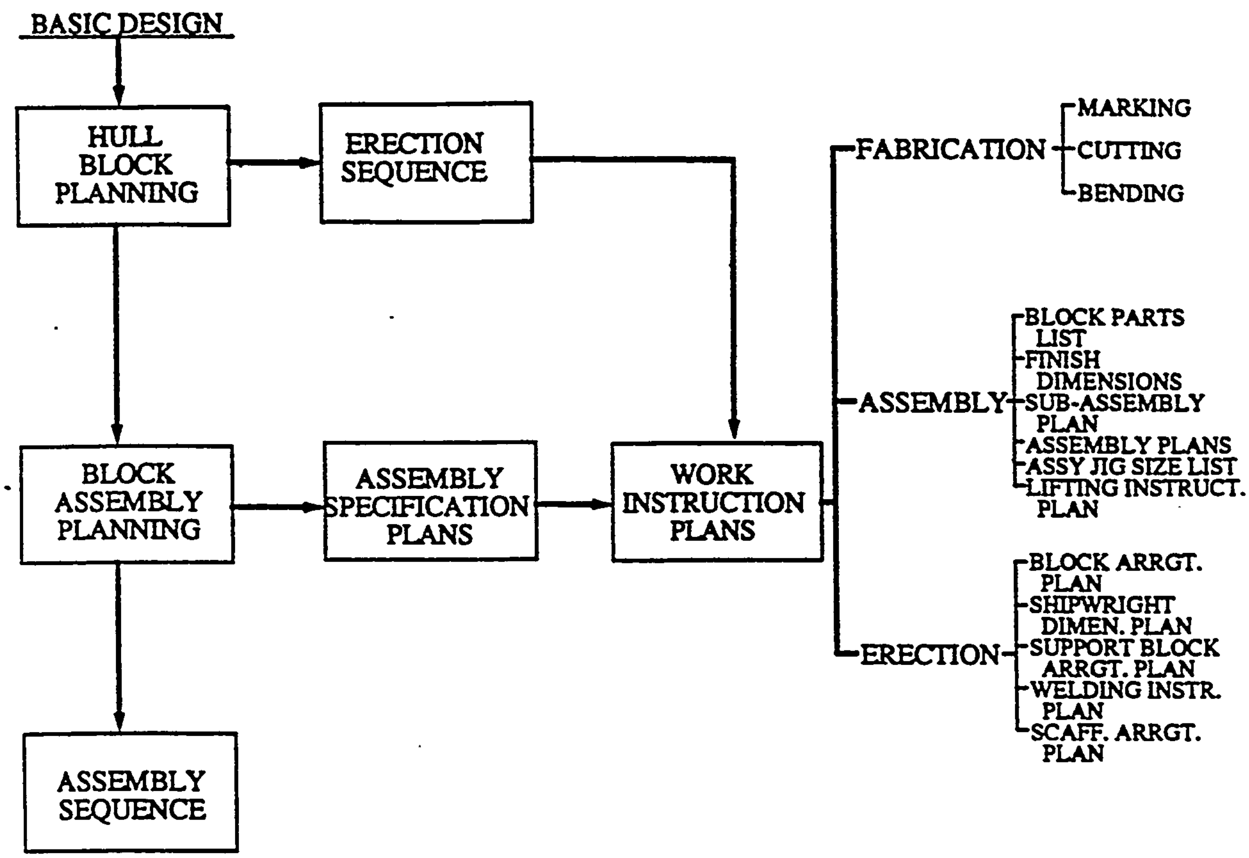


FIGURE PL-IV
MILESTONE SCHEDULE

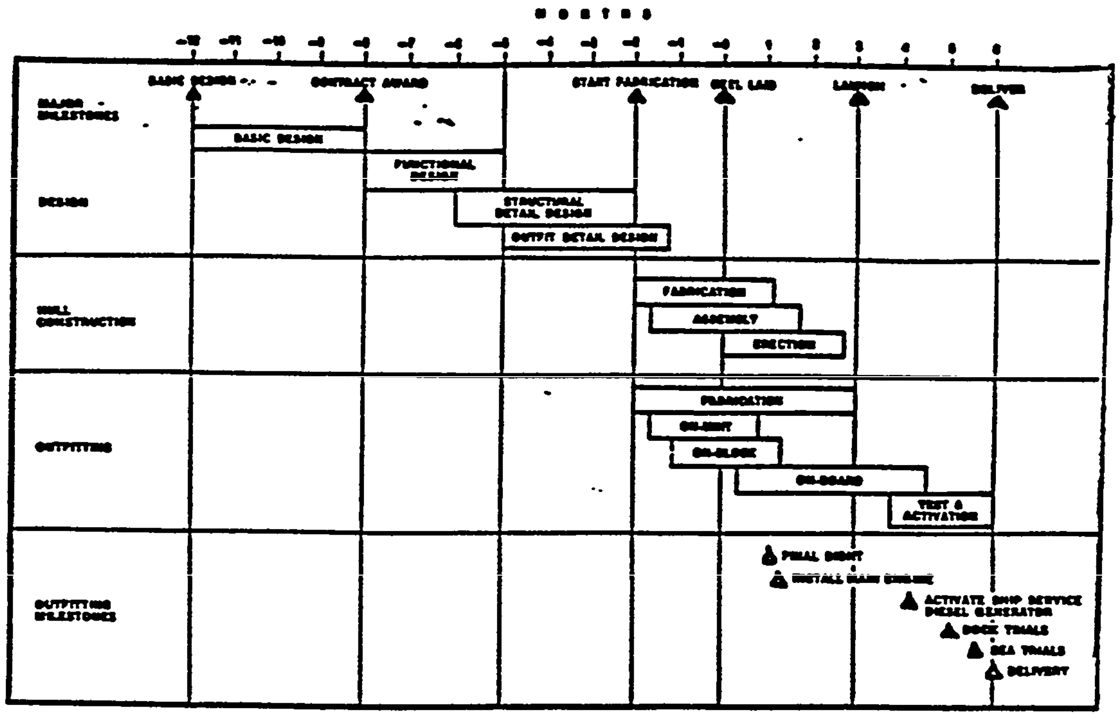
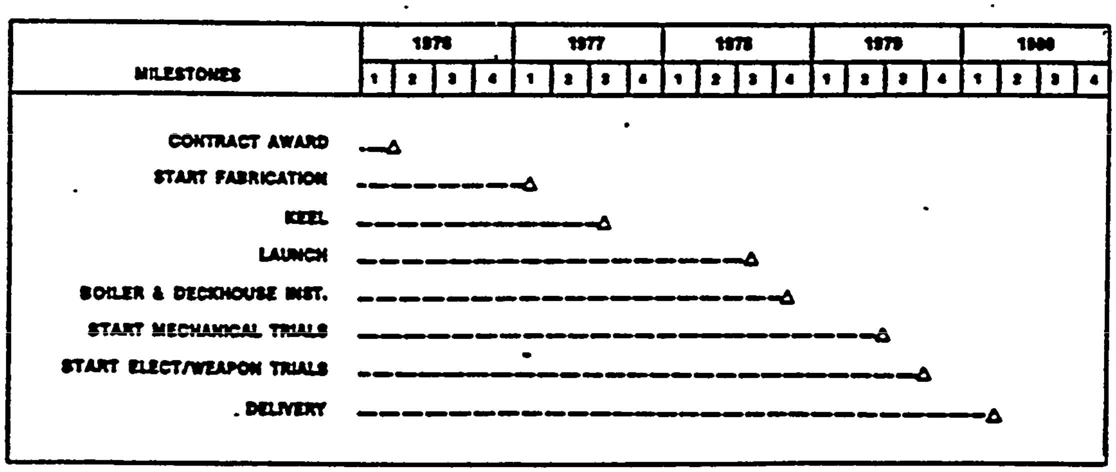


FIGURE PL-V
SCHEDULE FOR AN IHI 5200-TON DESTROYER



Schedule for a IHI 5200 ton destroyer (DDH). It is typical for the first of a class having similar machinery to a previous class. Limited on-unit and extensive on-block outfitting were used on the first hull.

FIGURE PL-VI
HULL BLOCK BREAKS FOR COMMERCIAL SHIP

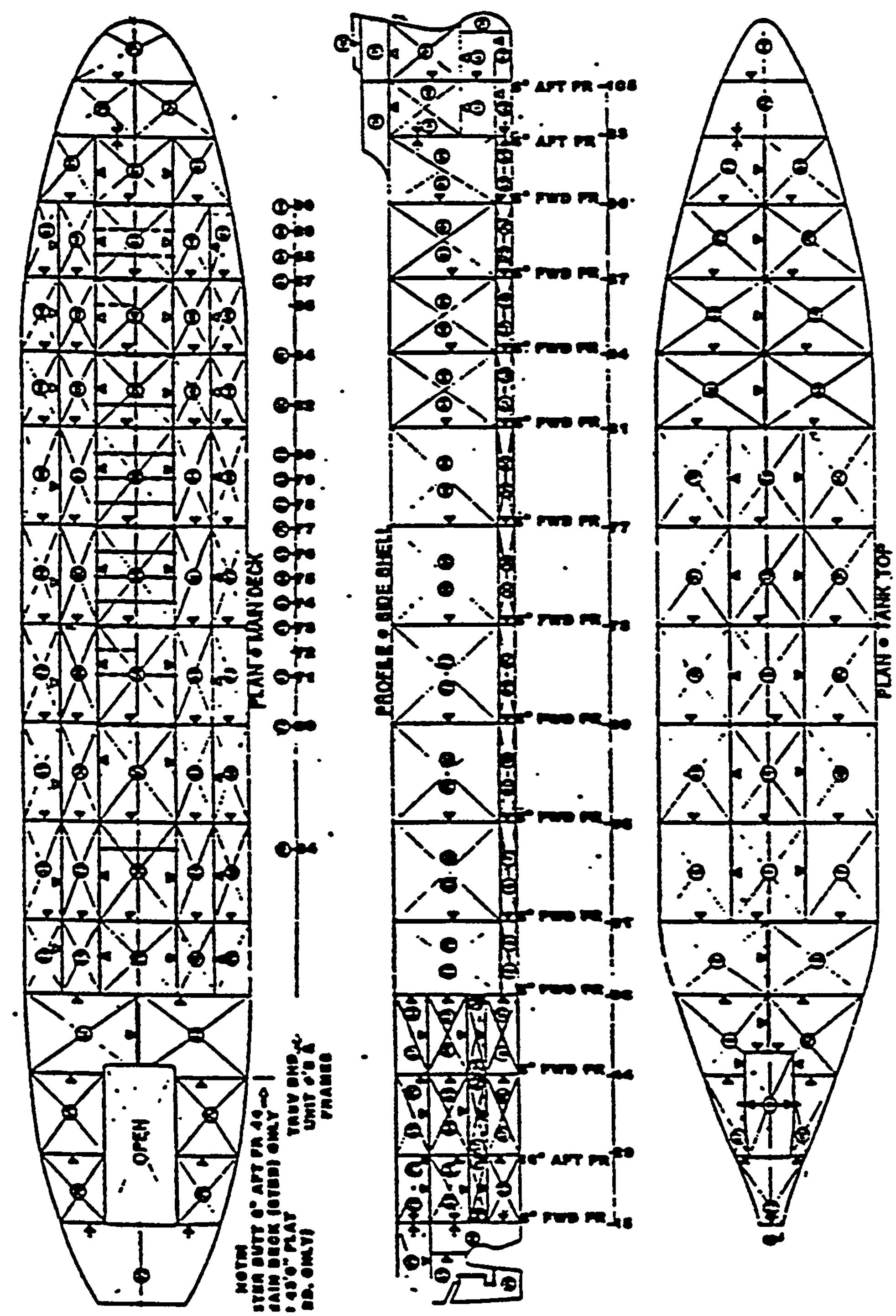


FIGURE PL-VII
TYPICAL HULL ERECTION CLAW CHART

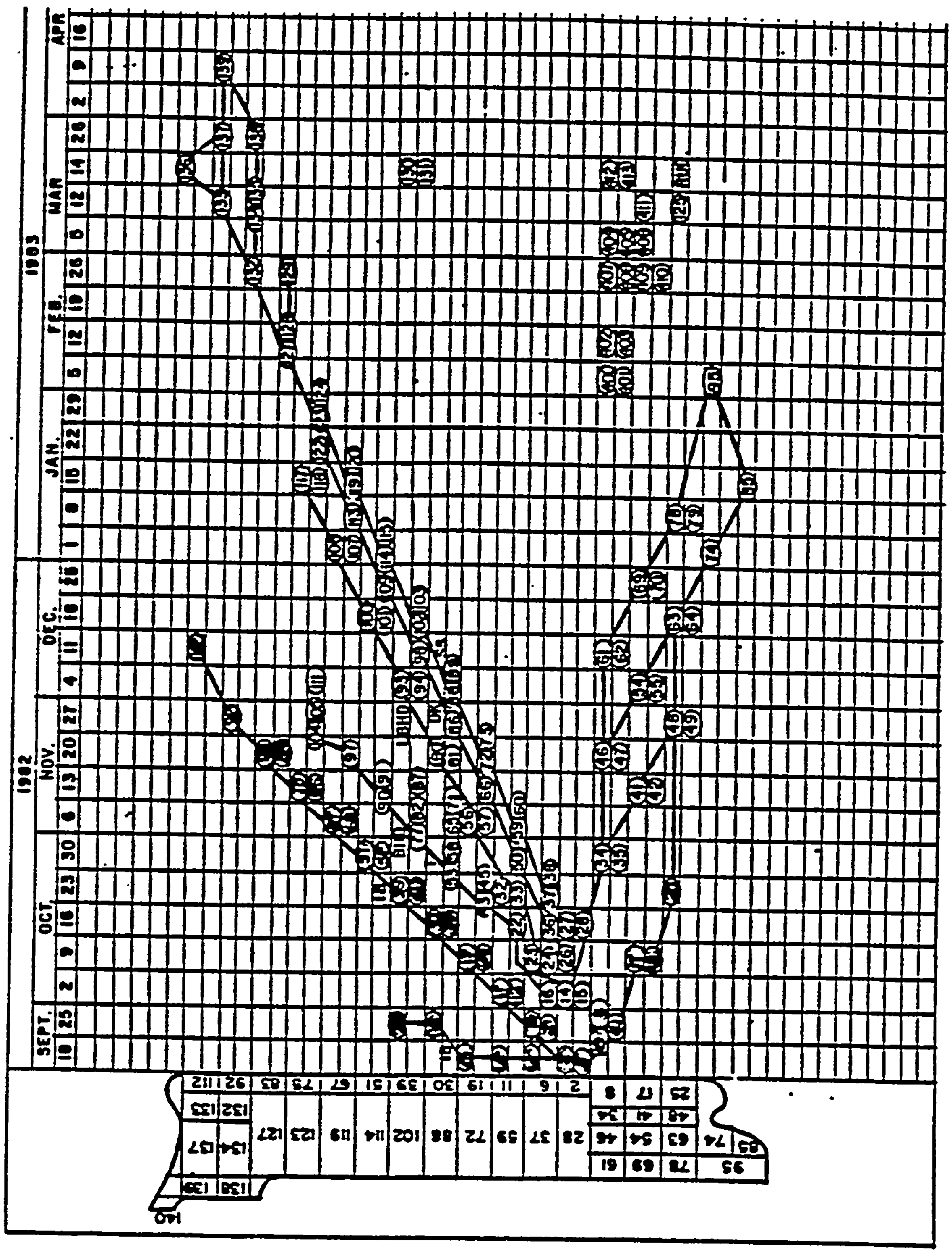


FIGURE PL-VIII
BLOCK SCHEDULE SCHEDULE .

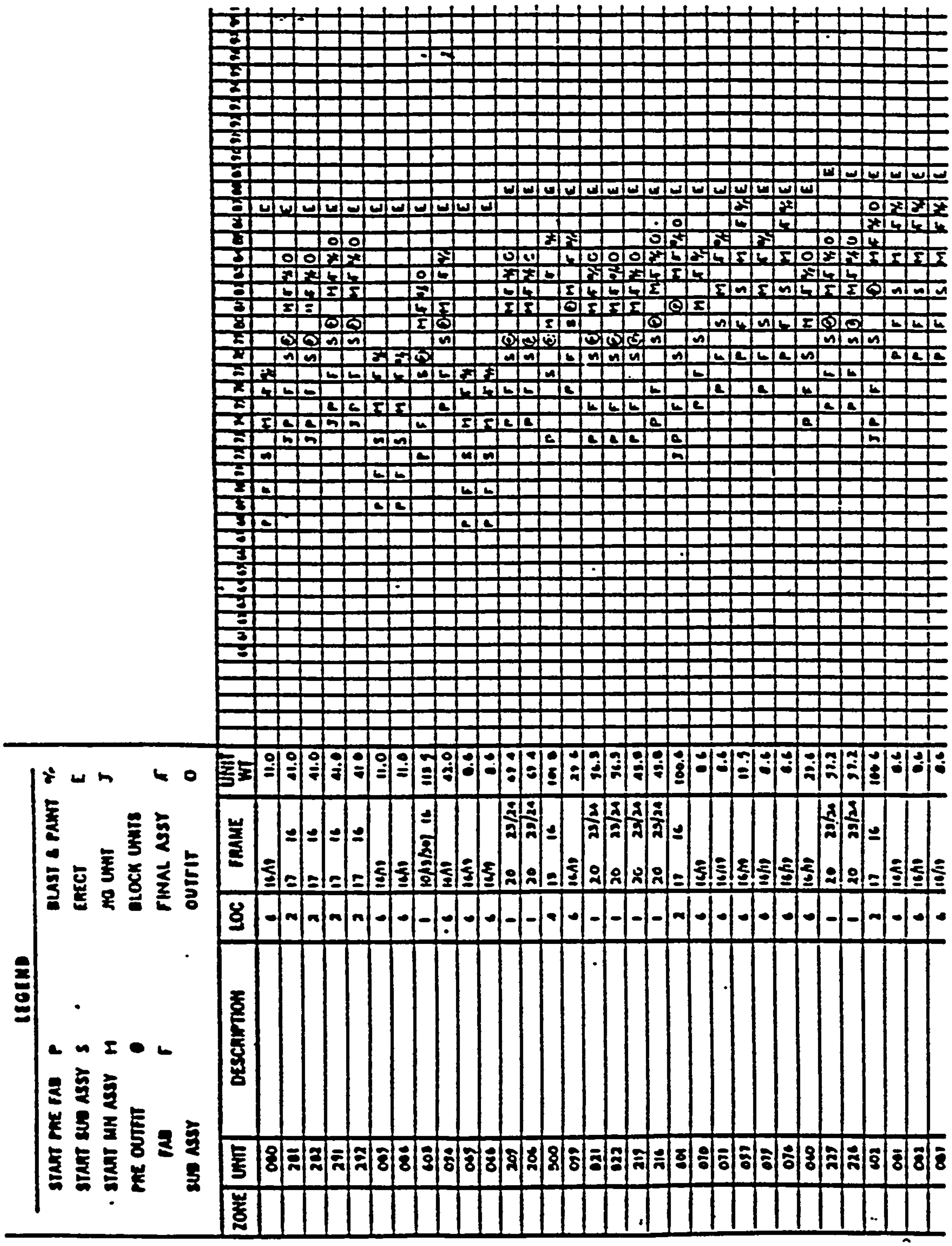


FIGURE PL-IX
SCHEDULING MECHANISM AND NETWORK

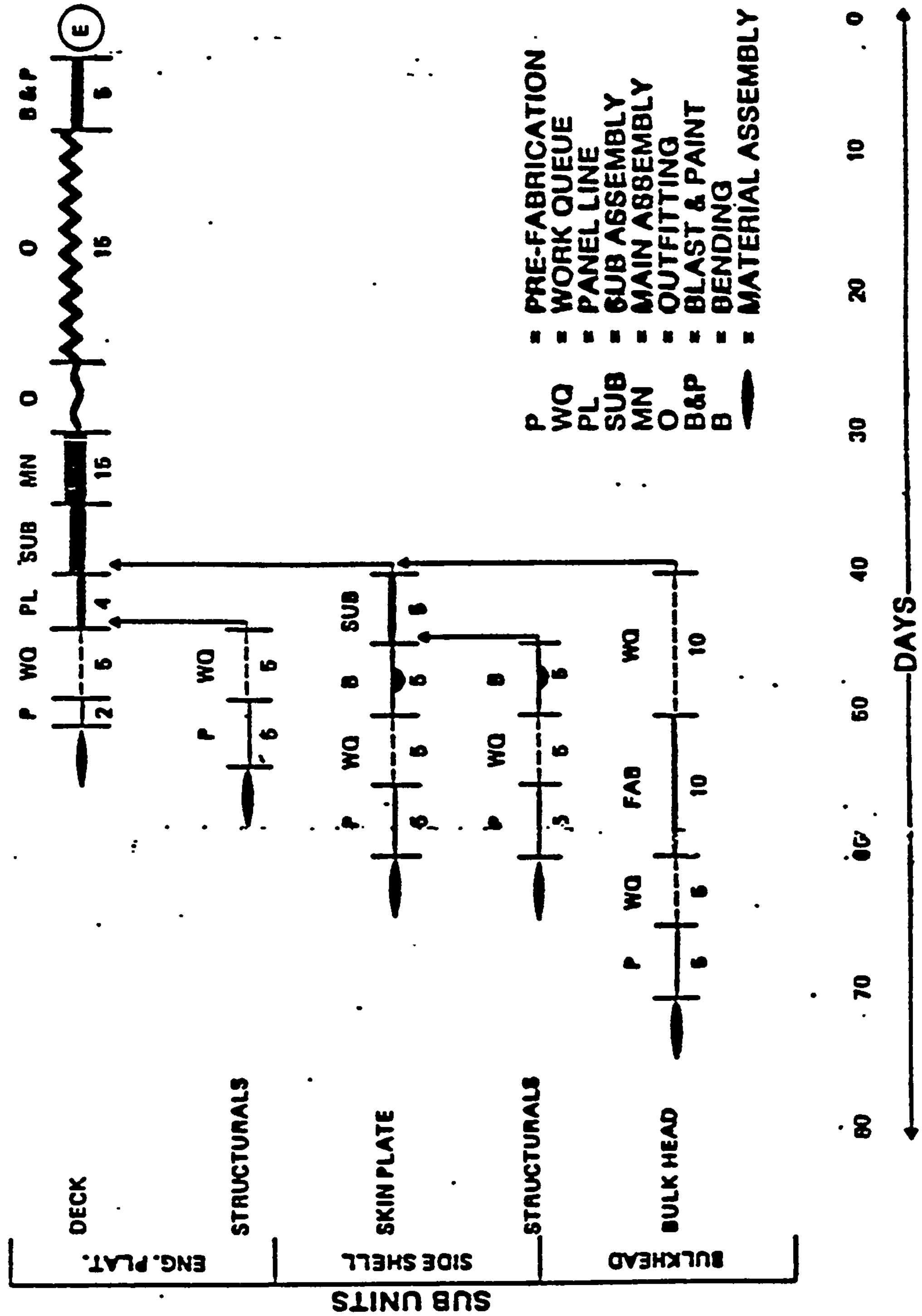


FIGURE PL-X
ASSEMBLY SPECIFICATION PLANS

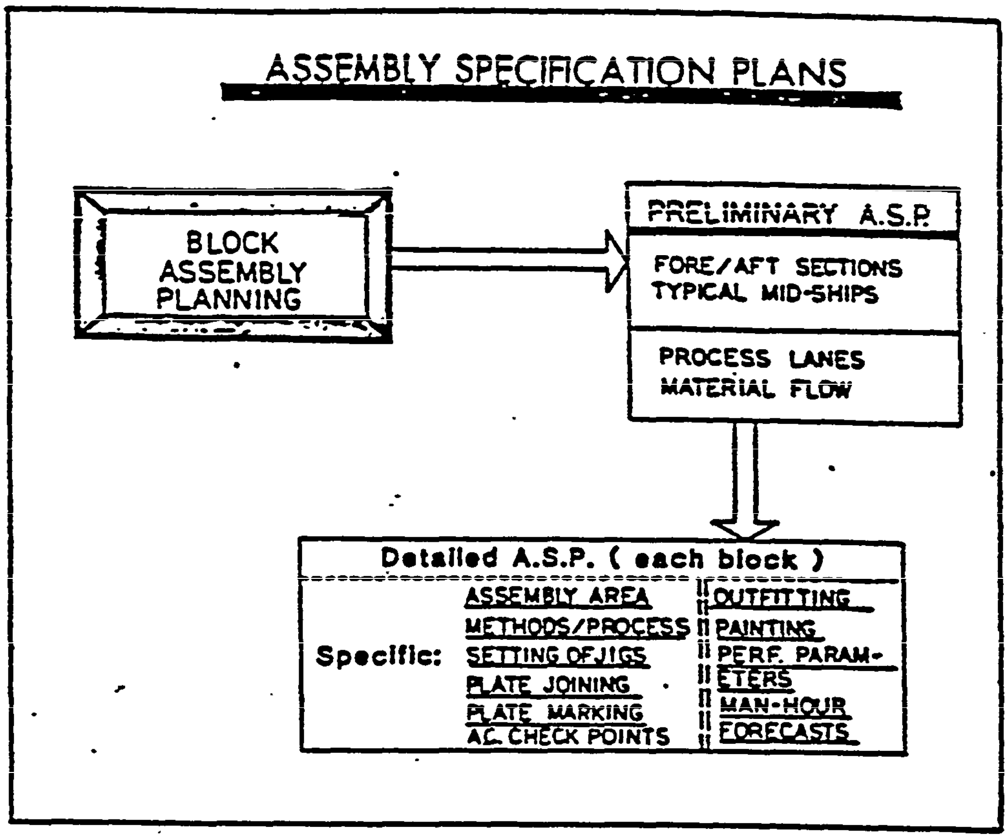


FIGURE PL-XI
SCHEMATIC SHOWING SYSTEMS/PRODUCTION RELATIONSHIPS

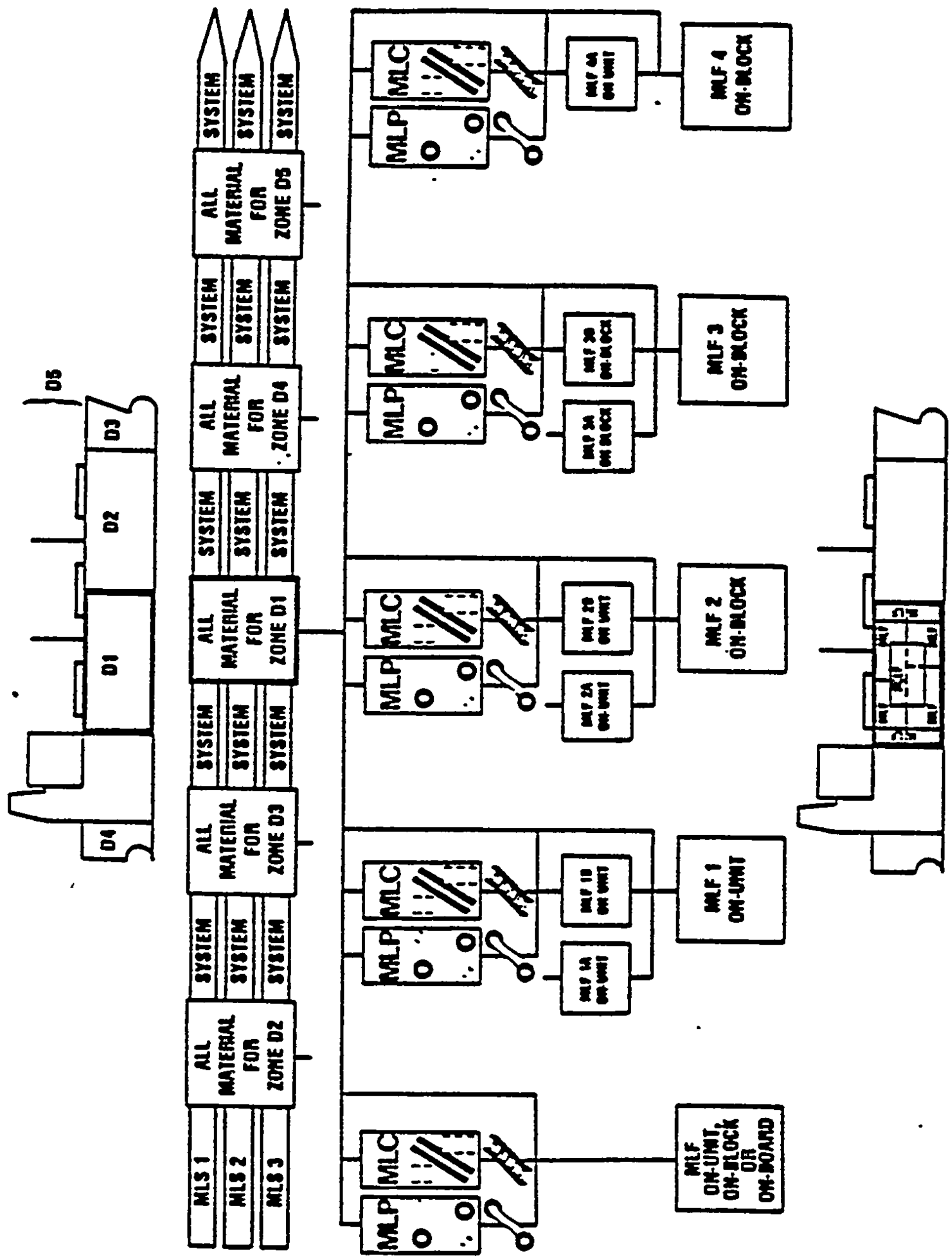


FIGURE PL-XII
SHIP DIVISIONS TO SUPPORT OUTFIT ANNING

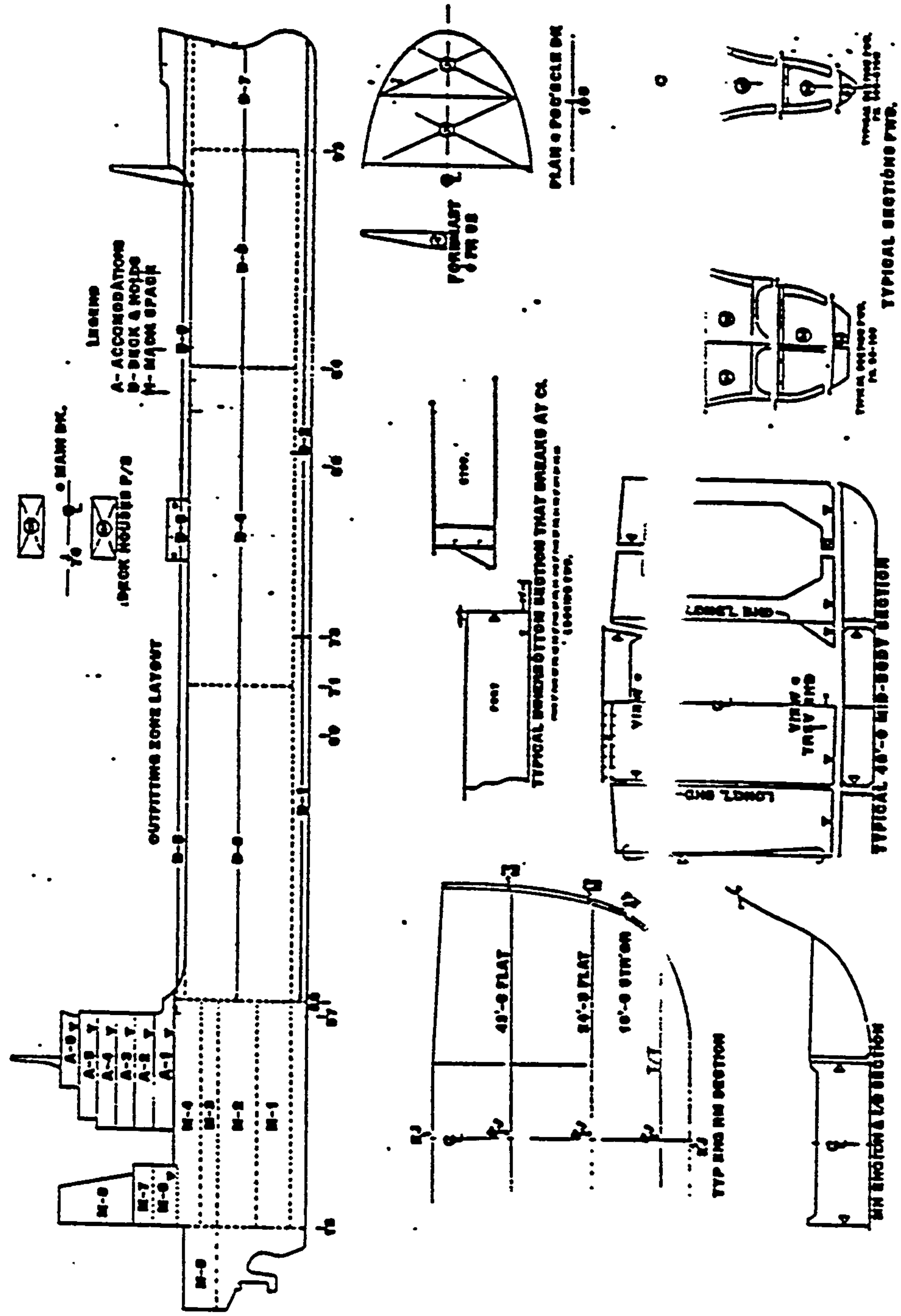
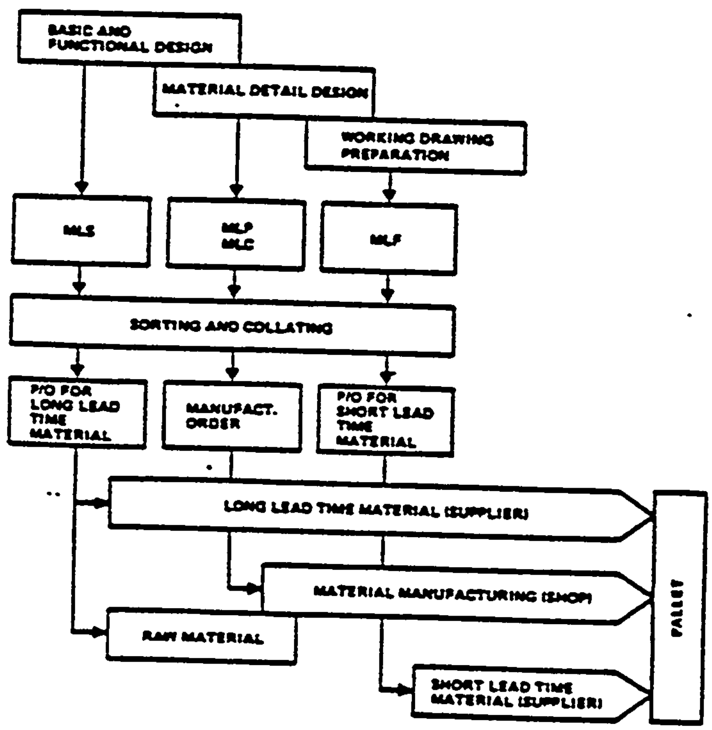


FIGURE PL-XIII
MATERIAL FLOWS IN SHIP PRODUCTION



NATIONAL SHIPBUILDING RESEARCH PROGRAM

PRODUCTION AND MATERIAL CONTROL

PRODUCTION AND MATERIAL CONTROL

(CONTINUED)

- PRODUCTION CONTROL BEGINS WITH TECHNIQUES FOR ORGANIZING AND CONCEPTUALIZING INFORMATION ABOUT THE PLAN AND THE CURRENT STATUS OF EVENTS PURSUING THE PLAN
- IN MANY REPAIR COMPANIES, PRODUCTION CONTROL IS RESPONSIBLE FOR THE ISSUANCE OF THE WORK PACKAGES AND MATERIAL RELEASE DOCUMENTS
- TOOLS USED BY PRODUCTION CONTROL INCLUDE INVENTORY MODELING, QUEUING THEORY, MATERIAL & RESOURCE PLANNING AND PERT/CPM
- PRODUCTION CONTROL AND MATERIAL CONTROL ARE SO CLOSELY INTERTWINED THAT MANY ORGANIZATIONS COMBINE THEM

PRODUCTION AND MATERIAL CONTROL

- PRODUCTION CONTROL CONSISTS OF CONTINUOUS ADJUSTMENTS WHICH ARE REQUIRED TO ACCOMPLISH THE PLAN AND INFERS THE EXISTANCE OF:
  1. AN INFORMATION SYSTEM BY WHICH THE ACTUAL STATE OF THE ACTIVITIES IS COMPARED TO THE PLANNED STATE
  2. A FEED BACK SYSTEM BY WHICH ADJUSTMENTS CAN BE MADE TO THE PRODUCTION PLANNING STAGE

  (SEE ATTACHED PAPER ON SHIP CONVERSION PROJECT MONITORING)

- PRODUCTION CONTROL DEPENDS UPON PROCESSING ADEQUATE AMOUNTS OFACCURATE AND TIMELY INFORMATION REGARDING CURRENT STATUS OF THE PRODUCTION PLAN, THE WORK IN PROCESS; INVENTORIES; HUMAN, FACILITY AND MATERIAL RESOURCES; AND REQUIREMENTS PROJECTIONS

PRODUCTION AND MATERIAL CONTROL

(CONTINUED)

- MATERIAL CONTROL (MC) IS OFTEN CALLED MATERIAL MANAGEMENT
- MC STARTS WITH A BILL OF MATERIAL FOR A GIVEN PRODUCT, USUALLY DEVELOPED BY ENGINEERING AND MANIPULATED BY PRODUCTION PLANNING TO SORT INTO REQUIRED SEQUENCING AND DELIVERY DATES
- MC THEN INVOLVES PROCURING, RECEIVING, WHAREHOUSING, HANDLING, DELIVERING WITHIN THE REPAIR YARD, PLUS ALL THE INFORMATION MANAGEMENT REQUIRES FOR THE SUCCESSFUL OPERATION OF THE ABOVE ACTIVITIES
- MC TOOLS INCLUDE INVENTORY CONTROL AND MATERIAL REQUIREMENTS PLANNING, SOMETIMES REFERRED TO AS MRPI

PRODUCTION AND MATERIAL CONTROL

(CONTINUED)

- AGAIN, MATERIAL CONTROL AND PRODUCTION CONTROL ARE SO CLOSELY INTERTWINED THAT MANY COMPANIES COMBINE THEM, ESPECIALLY IF THEY USE MRPII WHICH CAN HANDLE BOTH IN AN INTEGRATED DATABASE
- TO SUPPORT ZONE TECHNOLOGY THE COST COLLECTION SYSTEM FOR THE LABOR AND MATERIAL MUST BE BASED ON A ZONE TECHNOLOGY-ORIENTED WORK BREAKDOWN STRUCTURE
- USING THE ABOVE TOOLS THE PROJECT PERFORMANCE MUST BE MONITORED CONTINUOUSLY AND CHANGES MADE TO MAINTAIN THE BUDGETS AND SCHEDULES
- MANAGEMENT MUST BE PROVIDED ACCURATE AND TIMELY REPORTS ON PROJECT PERFORMANCE
- P&MC MUST BE THE COMPANY'S FOCUS FOR CONTINUOUS PROCESS IMPROVEMENT

What we need:

0 A smart number" system that starts -in Engineering and gives us a part number through all review processes, through all manufacturing processes and through all accountability processes.

0 A system that can be accessed through work stations in any user location.

0 A system that uses a common data base with our Financial, Work Control, CAD, and Work Scheduling systems.

0 A system that lends itself to labor saving through standardization where standardization is possible.

... To be concise--

A material Control System that is an element of a larger Management Information System.

The elements of material control are:

(a) A procedure.

(b) A means of tracking and monitoring.

(c) A material identification function.

(d) A material requisitioning function.

(e) A material requisitioning review function.

(f) A material ordering scheduling function.

(g) A material ordering function.

(h) An expediting function.

(i) A budget control function.

(j) A receipt function.

(k) A warehousing function.

(1) A material staging function.

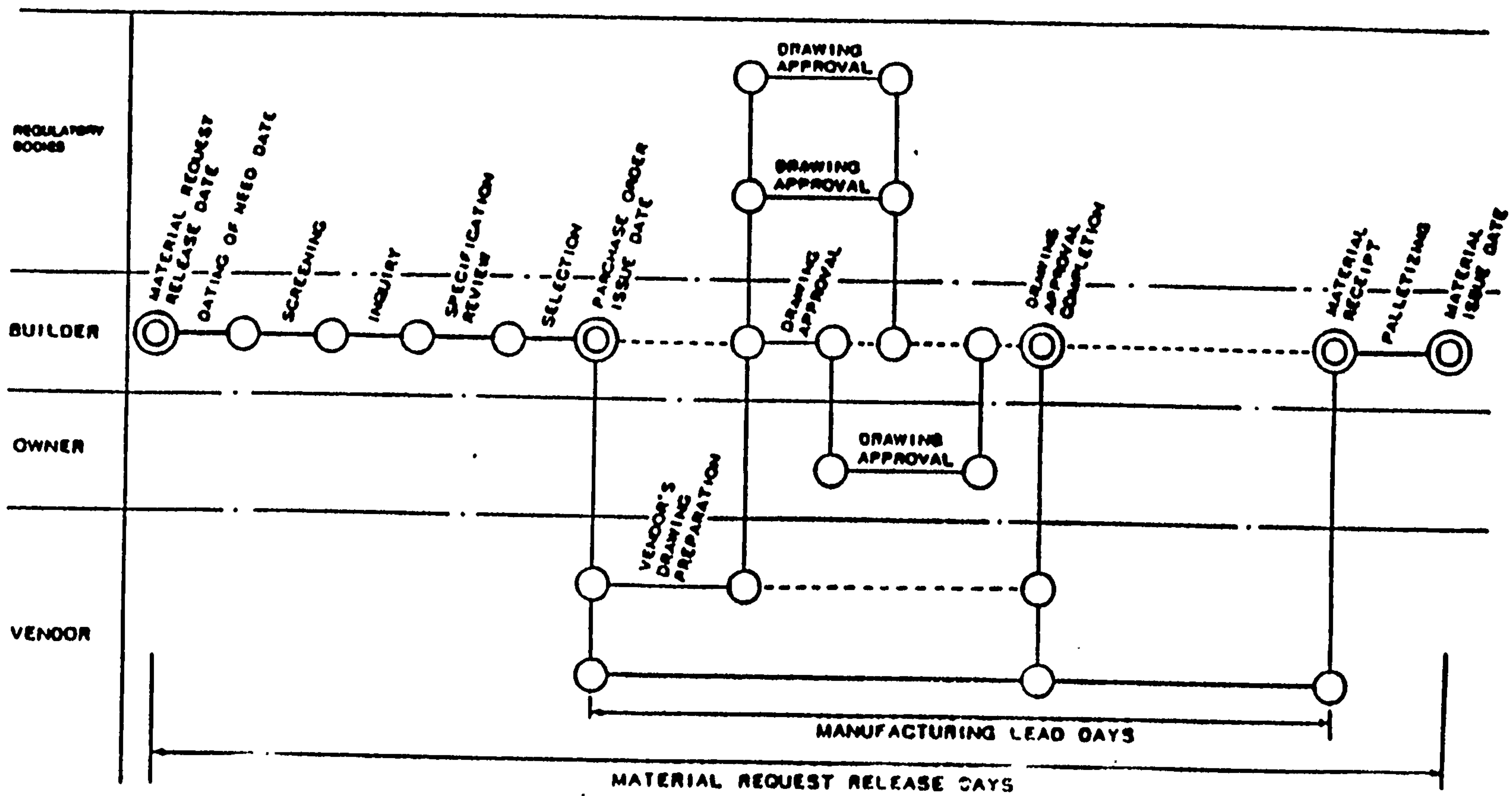


Fig. 7–46. Critical path model of material lead times.

MATERIAL CONTROL

I. CONCEPT OF GROUPING FOR MATERIAL CONTROL SYSTEM

A. In order to maintain high production efficiency and low production cost, classification of various materials should be standardized in the fields of cost estimation, design, material control, warehouse, purchase, and production to suit each function of material procurement. By applying standard classifications, high performance can be maintained in procuring materials.

B. By starting material procurement with sufficient lead time, the production period could be shortened and the ship could be delivered earlier. The shortening of the production period reduces the total cost due to time savings in material storage and material outfitting. With sufficient lead time, not only can procurement begin earlier, but total procurement time can be reduced,.

C. FIGURE MC-1, this section, is a chart showing the concept of IHI's material control system. The non-shaded portion shows material identification and scheduling issuance of material specifications by the design department, taking necessary lead time for delivery to the work site for palletizing. The shaded portion shows the activity of the material procurement department.

D. Planning is done on a :

1. Material-by-material basis
2. Ship-by-ship basis

II. PLANNING MATERIAL-BY-MATERIAL

To attain high performance in material procurement, the following procedures should be rationalized and standardized:

1. What materials are to be identified and to which requisition class will they be assigned? (MateriaI identification, FIGURE MC-2)
2. At which design stage are the materials to be specified? (Material listing, FIGURE MC-3)
3. How are materials controlled for procurement? (Material control classification, FIGURE MC-4)
4. The logic and principles of these procedures are illustrated in the judgement block chart (FIGURE MC-1, mentioned earlier).

A. Material Listing--Codes are developed.

1. Typical codes:
    a. **Material code,** which identifies what the material is, with detailed descriptions of what kind, type, size, grade, etc.
    b. **Piece number,** which identifies, serially in each system, at what part of the system the material is to be assembled..
    c. **Pallet code,** which identifies at which level, on which zone, in what area, and at which stage the material is to be assembled for each particular ship.
    d. **Material cost classification** number, which classifies in which system of each ship the material will belong.

2. Material Listing Identifies
    1. The design stage
    2. Which material list materials are specified
        a. Time dependent
        b. Defined as "not Final"Or "Final"

C. Material Control Classification (see FIGURE MC-4)

1. How to control material for procurement, based on CHARACTERISTIC of material
    a. With or without ANTICIPATION
    b. Surplus or not
    c. New design or past data.

2. Developed by classification.
   a. Allocated Material--Requisitioned by quantity specified by design.
   b. Allocated Stock Material--Quantity specified by design plus a surplus.
   c. Stock Material--Common consumption requisitioned in economic quantities.
   d. Remains--Leftovers from" "allocated material" or from "allocated stock material.

D. Material Purchasing Classification--How to purchase material by standardization of purchasing procedure. See FIGURE MC-5.

1. Spot Order--only when purchase requisition is released.
2. Long term agreement--Agreement over a certain period. Contracts are issued.
   a. Price
   b. Delivery Schedule
   c. Certification of processes being in statistical control.

III. SHIP-BY-SHIP PLANNING (SEE FIGURE MC-6)

Constantly required to adjust material system and to reflect construction progress.

FIGURE MC-1
RELATIONSHIPS AMONG DESIGN, MATERIAL PROCUREMENT, AND PRODUCTION ACTIVITIES

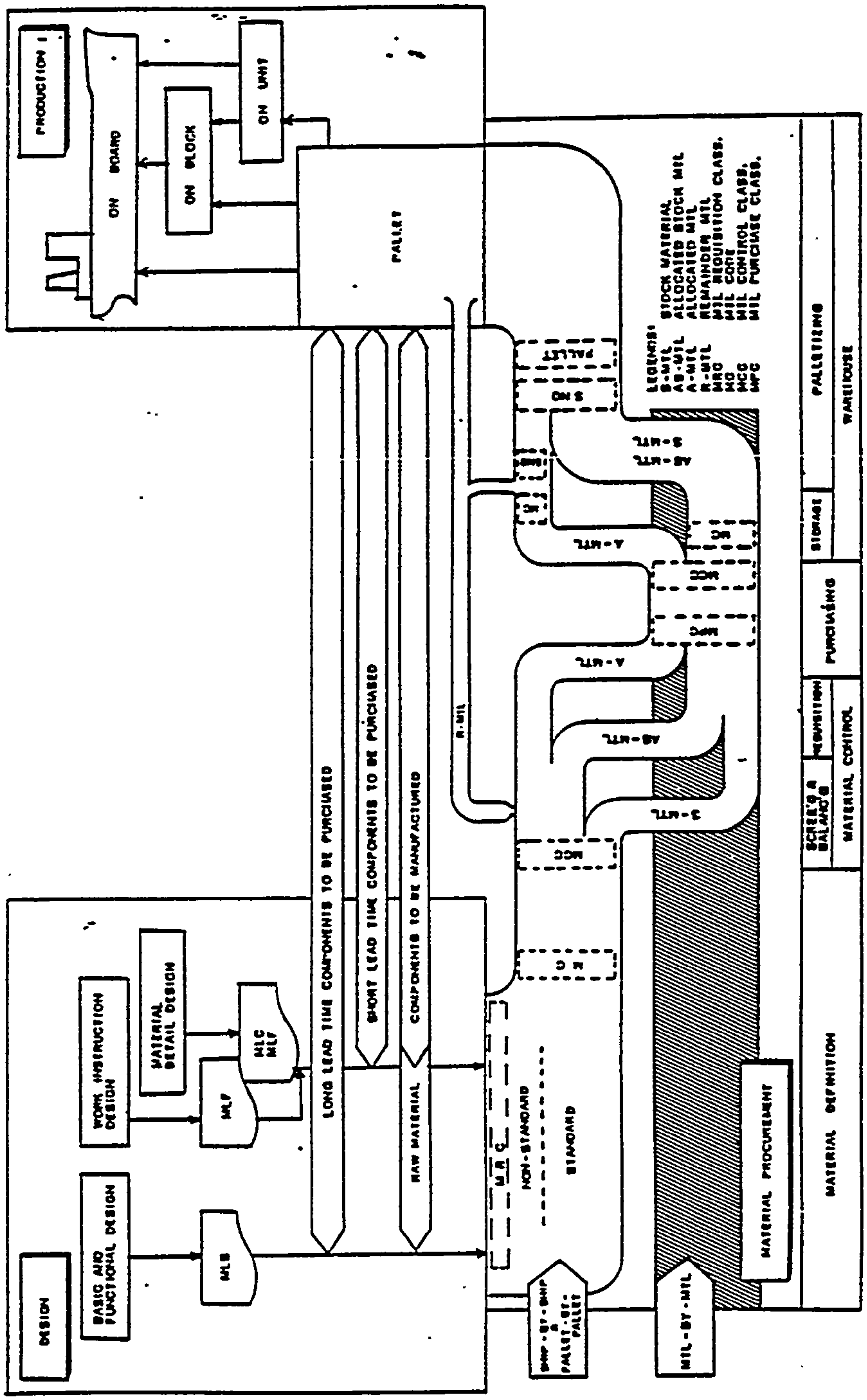


FIGURE MC-2
IDENTIFICATION CODES FOR MATERIALS

MATERIAL	W/S	MATERIAL IDENTIFICATION				IDENTIFICATION ON SHIP
		COMMONNESS	REQUISITION CLASSIFICATION	STANDARDIZATION	MATERIAL CODE	PIECE NUMBER
MATERIAL	HULL CONSTRUC-TION	STEEL MATERIAL SHIPBUILDING GRADE	AS	SKETCH SIZE	MATERIAL/GRADE/SIZE	SHIP/BLOCK/SUB-BLOCK/ SERIAL NUMBER
				STANDARD WITHIN A SHIP		
				STANDARD		
		OTHER MATERIAL	SAME AS FITTING			
	FITTING	COMMON	AS & S	INDIVIDUAL	BLANK/FULL DESCRIPTION	SHIP/SYSTEM/SERIAL NO.
				FAMILY	NIL	
			A	INDIVIDUAL	BLANK/FULL DESCRIPTION	
				FAMILY	BLANK/FAMILY DESCRIP.	
		NON-COMMON	AS & S	INDIVIDUAL	SYSTEM/FULL DESCRIP.	
				FAMILY	NIL	
			A	INDIVIDUAL	SYSTEM/FULL DESCRIP.	
				FAMILY	SYSTEM/FAMILY DESCRIP.	

A – ALLOCATED MATERIAL
AS – ALLOCATED STOCK MATERIAL
S – STOCK MATERIAL

FIGURE MC-3
MATERIAL LISTING

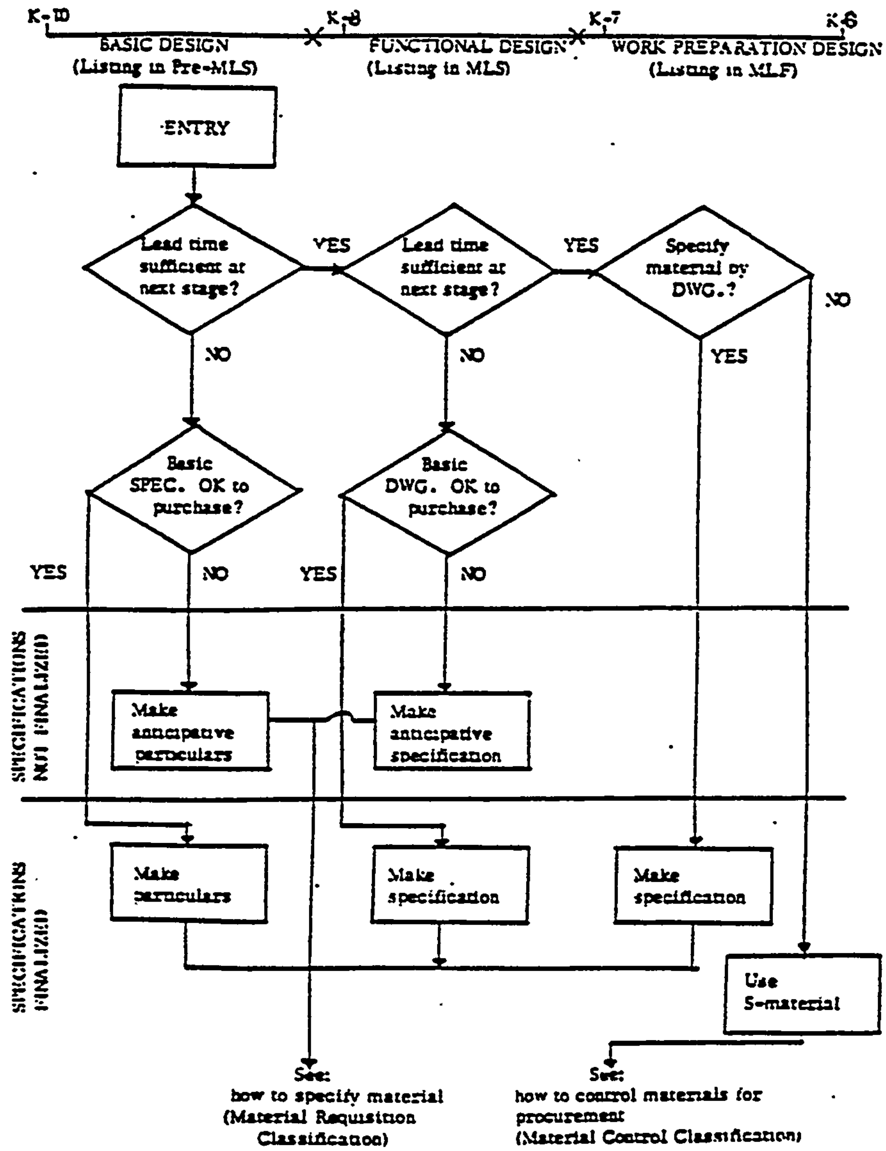


FIGURE MC-4
MATERIAL CONTROL CLASSIFICATION

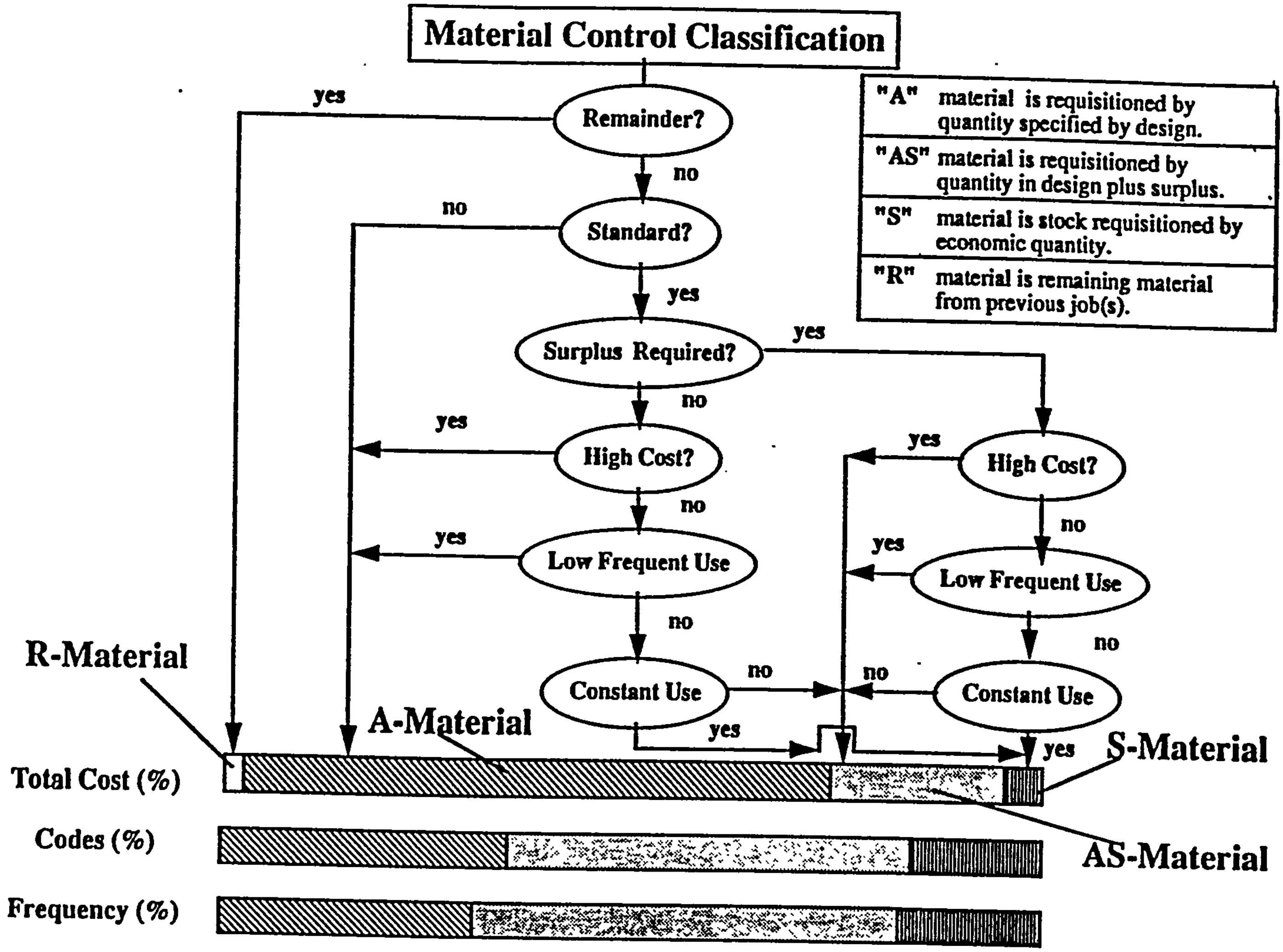


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FIGURE MC-5
MATERIAL PURCHASING CLASSIFICATION

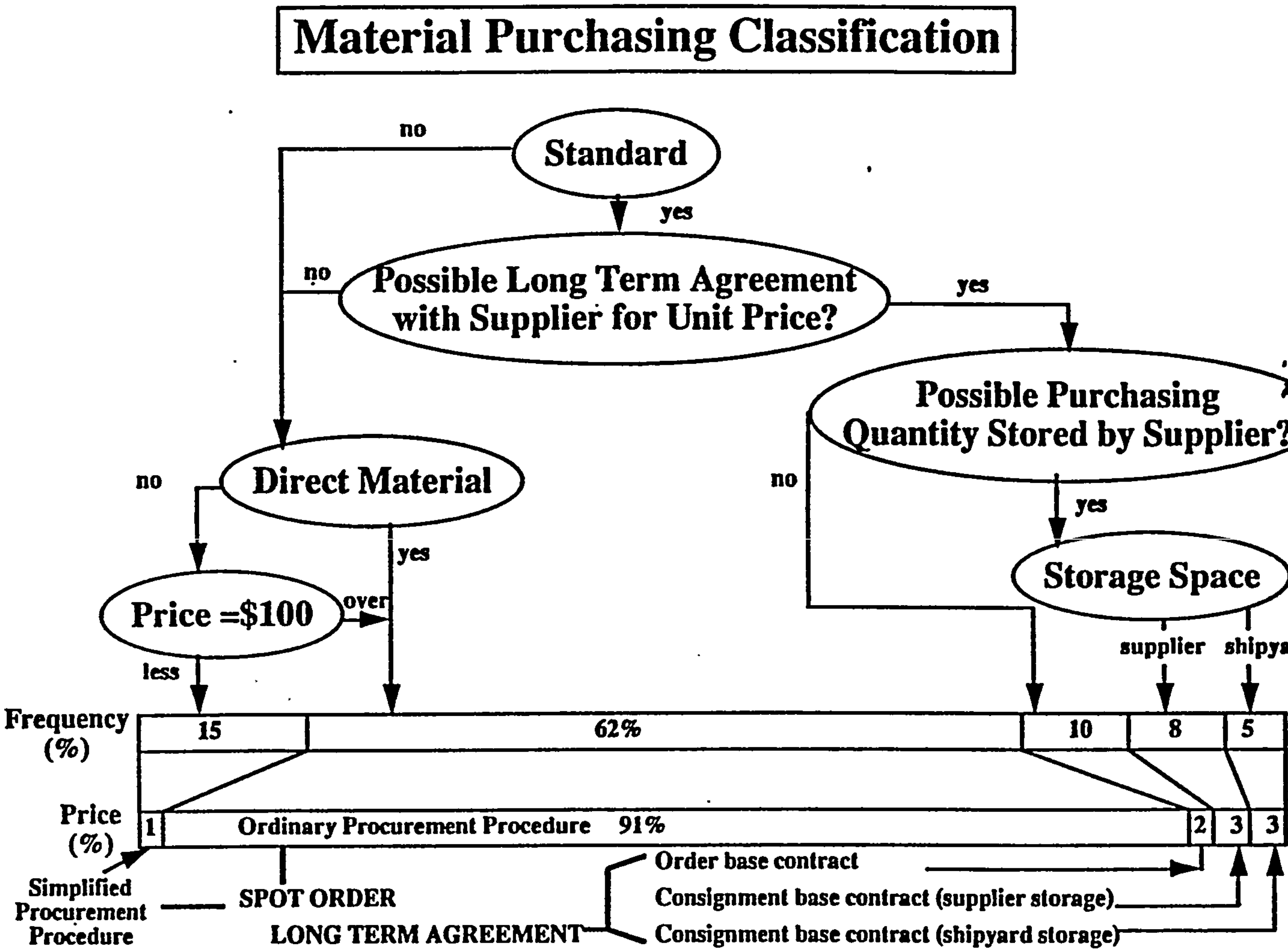
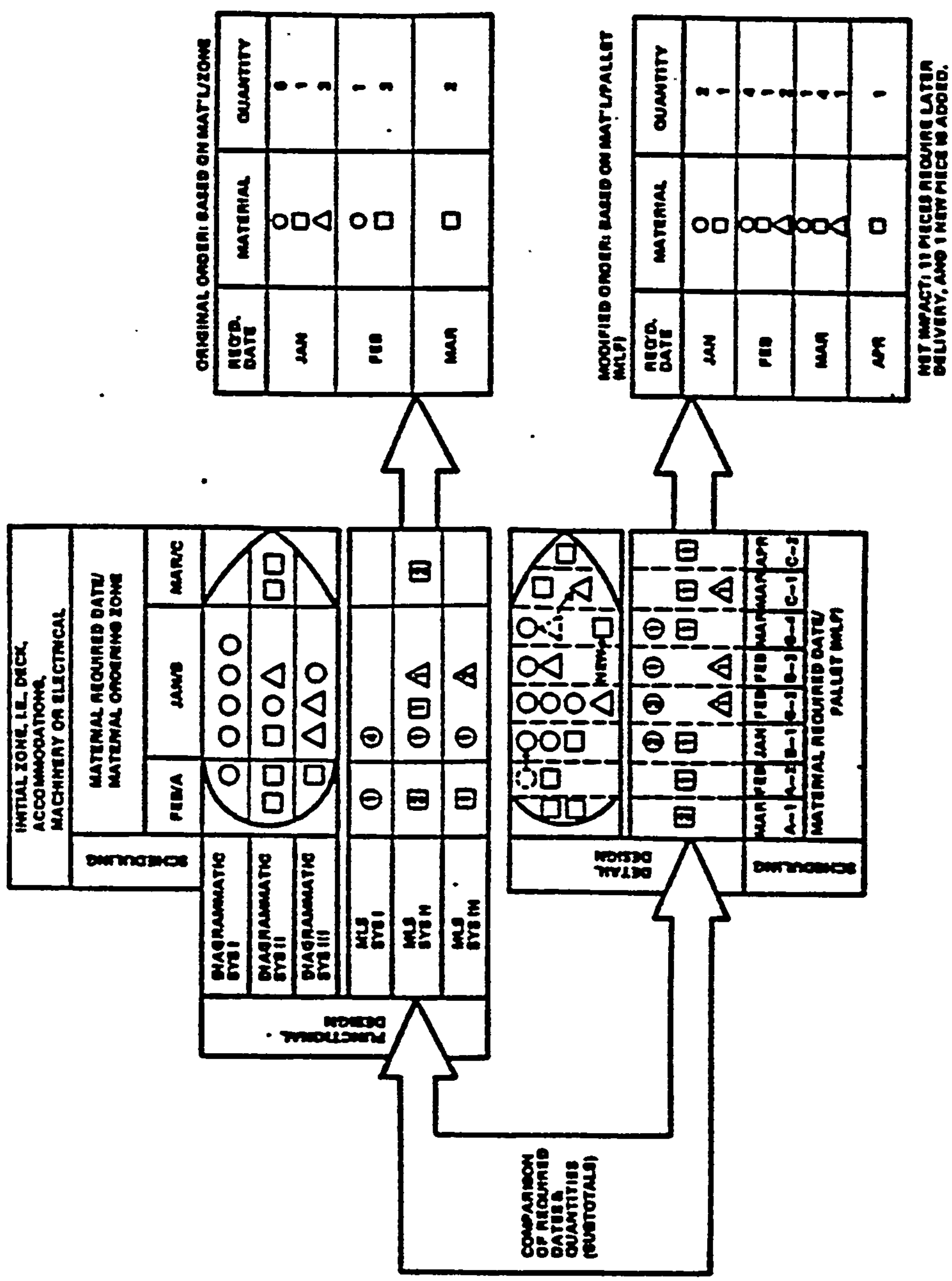


FIGURE MC-6

REFINEMENT OF PROCUREMENT DATA FOR "AS" MATERAL AS DESIGN DEVELOPS--SHIP-TO-SHIP PROCUREMENT



D. Modules provide basic system models, units, machinery

II. APPLICATIONS OF STANDARDS AND DESIGNS IN VARIOUS STAGES FROM DESIGN TO PRODUCTION

A. Basic Design--mainly in functional design. Engineering standards play major role.

1. Frame spacing Modules-- Instead of optimizing to weight, optimizing to construction efficiency leads to modules (See Figure SD-3).

2.. Base Ship Module-- Extension of frame space module to selection of hull dimension. (See Figures SD-4 and SD-5).

   It is utilized as a basic hull form for a series of ship designs, selecting several sizes to cover the major part of market.

   Each ship optimized to hull form and dimensional ratios.

B. Machinery Design

a. Propulsion Engine Modules (See Figure SD-6).

b. Machinery Layout Modules-- grouping of machinery by systems. (Figure SD-7)

C. Piping Layout Modules-- layout as partial systems or a complete units. (See Fig SD-8 and SD-9).

STANDARDS

I. INTRODUCTION

A. History

1. Mentioned in SNAME as earlyas 1900

2.WWII--tremendous production of standard ships by all combatants. U.S. built over 4000 ships in 4-year period. Largest output was the "standard" merchant ship

--2700 Victory ships
--700 Liberty ships
--500 T-2 tankers

3. Shipbuilders have long desired to infuse standardization into system. There are significant long-term benefits, as seen in Figure SD-1. Reasons for not doing it are:

--expensive initial investment
--long-term payoff orientation
--perception that not many standard units needed
--perception that each client has a unique taste and need

B. Definitions

1. **Standard:** basic element, component on unit. a basic rule or condition. Should not be changed.

2. Module: is an integrated pre determined group of components that can be retrieved by a simple code

C. Standards Include (see Figure SD-2)

1. Material
   - Raw Material
   - a. Basic
   - Standard fittings
2. Engineering Standards
   - a. Design
   - b. Production engineering
   - c. Inspection

C. Detail Design Area

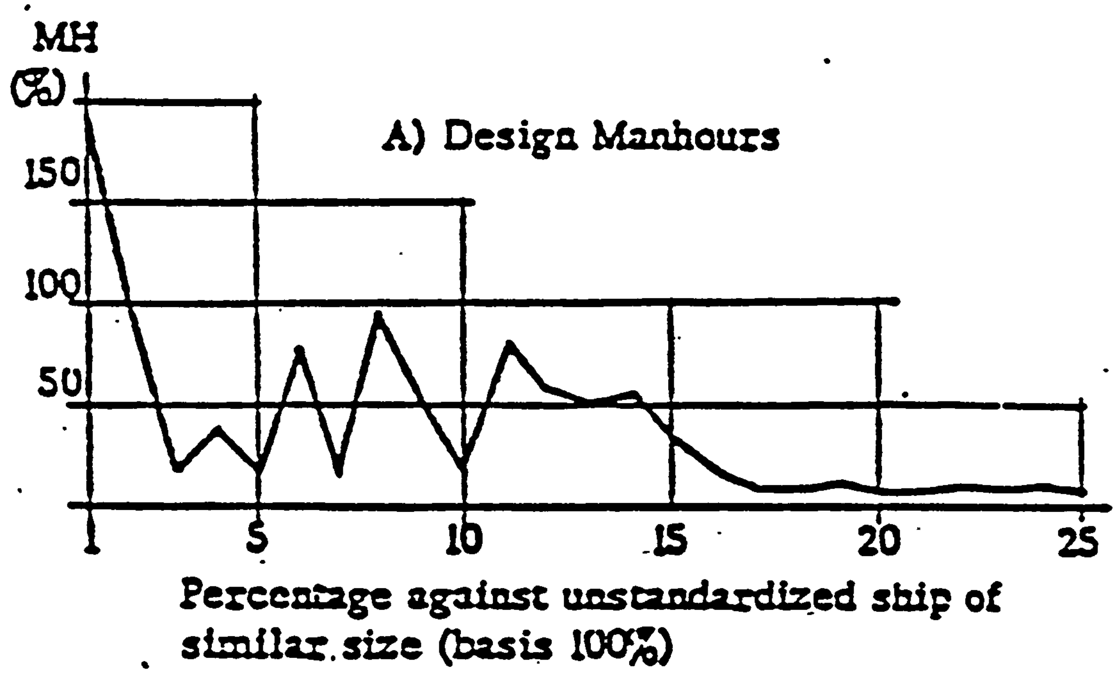
1. Pattern is a partial piping diagram of a system that can he applied to different sizes and types of ships. Is divided into panels (See Figure SD-10).

2. Panel includes an arrangement plan, a list of materials, etc. They are individual elementary modules of specific configurations.

3 Application (See Figure SD-11)

FIGURE SD-1

EFFECT OF STANDARDIZATION UPON LABOR HOUR EXPENDITURES



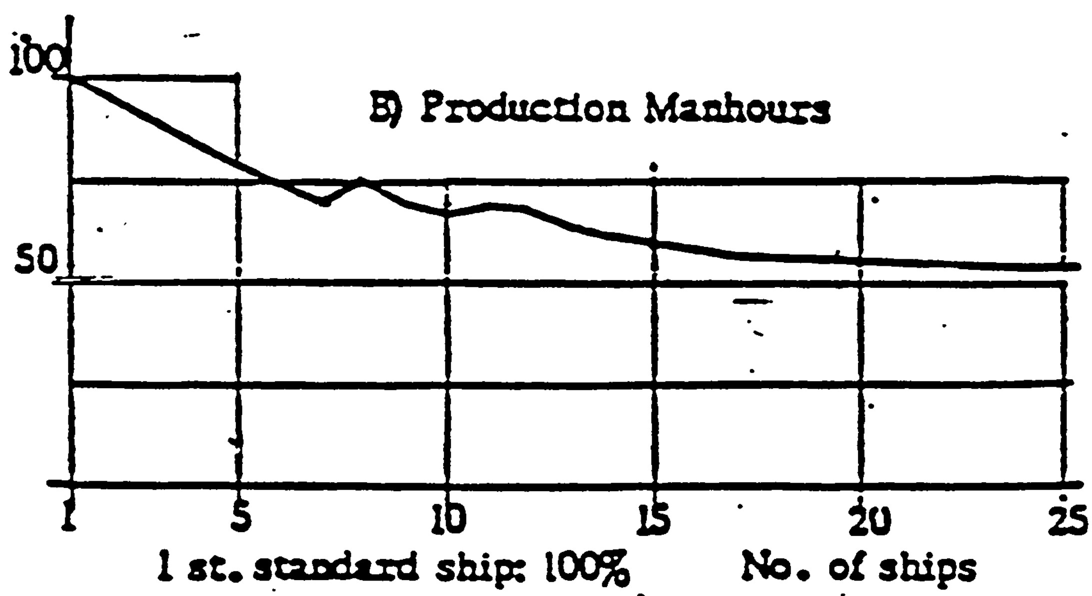
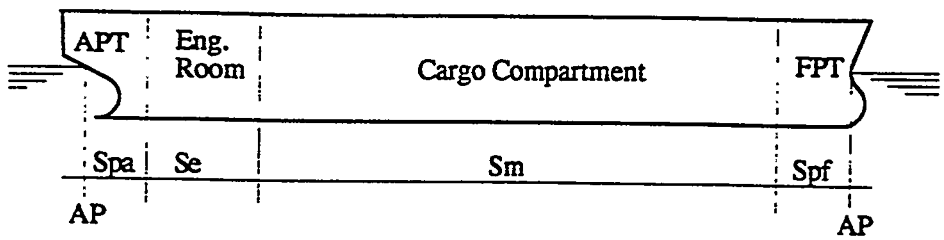


FIGURE SD-2

CLASSIFICATION OF STANDARDS IN SHIP DESIGN AND SHIP PRODUCTION

Classification of Standards				Nos.
IS	SO	Material Standards	Common components	600
			Hull fittings	600
			Machinery fittings	200
			Electric fittings	200
		sub-total		1,600
	SOT	Design process standard		1,100
		Prod. eng'r'g. process standards		100
		Inspection process standard		200
		Sub-total		1,400
SD		Machinery drawings		1,200
		Component and fitting, standard drawings		350
		Other guidance drawings		350
		Sub-total		1,900
Grand total				4,900

FIGURE SD-3
EXAMPLE OF STANDARD FRAME SPACE MODULES



Transverse Frame Space L=Lbp

Space (mm) / L(m)	Spa	Se	Sm: Tanker & Ore C.	Sm: Bulk C. Cargo	Spf
90 ≤ L ≤ 100	600	700	3,800	not stand-ardized	2,000-2,400
100 ≤ L ≤ 120	700	750			
120 ≤ L ≤ 150		800			
150 ≤ L ≤ 200	800		4,600	800	
200 ≤ L ≤ 250		900	4,800		2,440 3,000
250 ≤ L ≤ 290	900		5,000		
290 ≤ L ≤ 320			5,300		3,000 3,300
320 ≤ L			5,100 (Hor.Main)		

Longitudinal Space B=Breadth mid.

Space (mm) / B(m)	Longl. Space: Deck & Bottom	Longl. Space: Side
B < 16	not standardized	
16 ≤ B < 23	750	750
23 ≤ B <32.2	800	800
32.2 ≤ B <54.5	850	850
54.5 ≤B	940	850

FIGURE SD-4
EXAMPLE OF BASE SHIP MODIFICATION

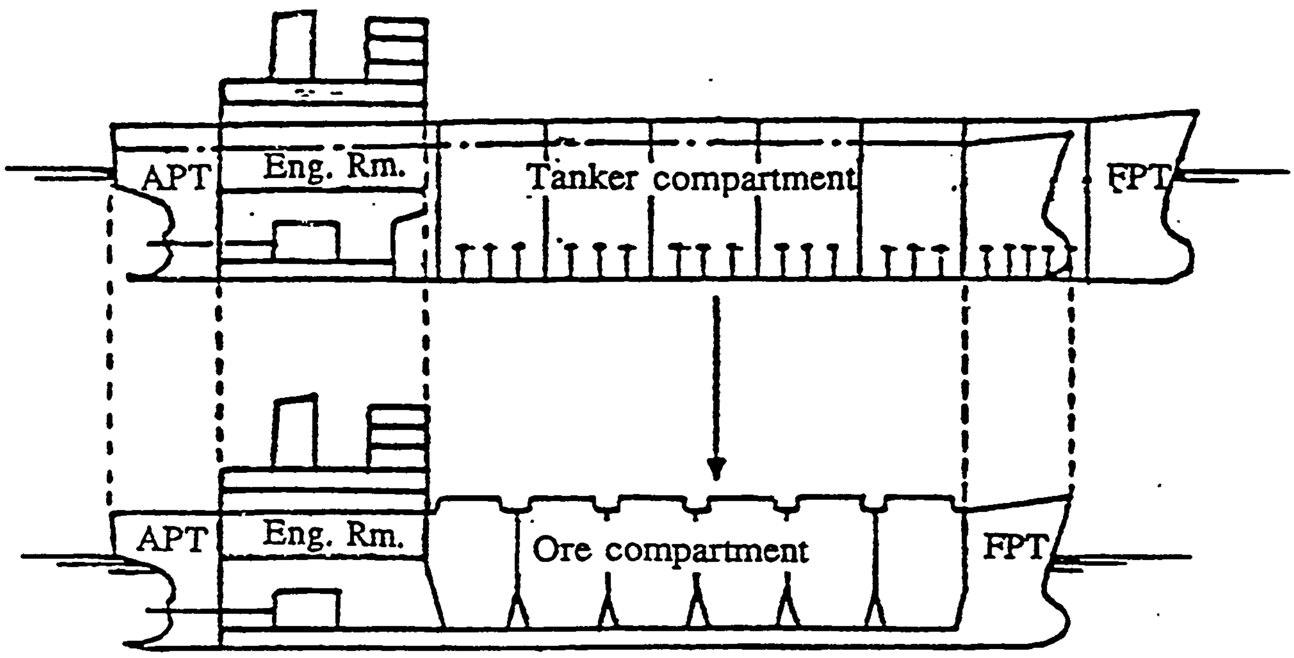


FIGURE SD-5
EXAMPLE OF BASE SHIP VARIATIONS

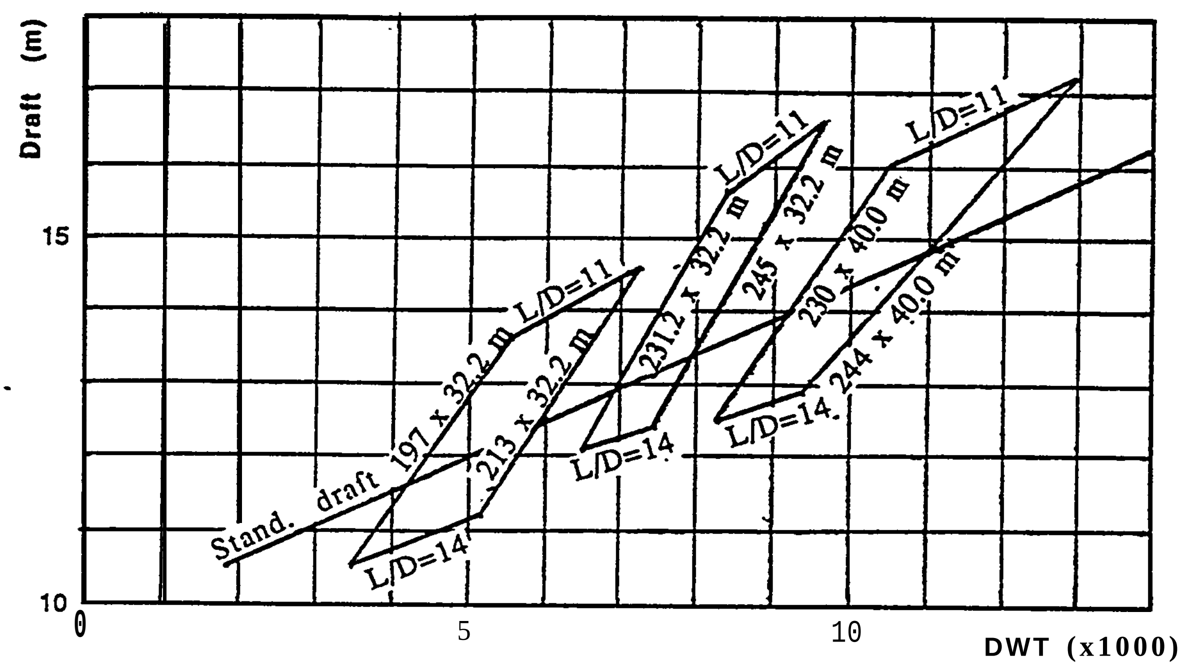


FIGURE SD-6
TYPICAL MACHINRY PARTICULAR MODULES

Main Steam Turbine							Mach. No.	M 0 0 1	
Main Eng. rating			P S	24,000	27,000	30,000	33,000	36,000	40,000
M. Turbine	Type			Impulse, 2-Cyl, cross compound turbine with 2-st. red. gear					
M. Turbine	Model No.	H. P. Turbine		CNH - 21		CNH-22	CNH-31	CNH-32	
M. Turbine	Model No.	L. P. Turbine		C N L - 21		C N L - 41		C N L - 51	
M. Turbine	Weight		t	46.61		49.83	52.03	55.25	
Red. Gear	Type			Tandem	Dual tandem				
Red. Gear	Prop. Shaft RPM			8 0					
Red. Gear	Type			C 4 5 A	D 4 9 A			D 5 1 A	
Red. Gear	Weight		t	1 4 5.0	1 4 8. 0			1 6 6. 0	
Stand. Drwg. No.			S D 1	41112110	4111 21120	4111 21130	4111 21140	4111 21150	

Main Condenser Pump							Mach. No.	M O 21	
							Type	V E C	
Main Eng. Rating			P S	24,000	27,000	30,000	33,000	36,000	40,000
Capacity			m3/h x m	7 0 x 9 5	7 5 x 9 5	8 5 x 1 0 0	9 0 x 100	100 x 100	110 x 105
Maker A	Model No			E V Z 130					EVZ 131-2
Maker A	Stand. Drwg. No		S D 1	440011380A					440011390
Maker A	Motor capacity		KW x rpm	37 x 1800	45 x 1800		55 x 1800		75 x 1800
Maker A	Motor Model No.			225S	225M		250M		280S
Maker A	Capacity range		m3/h x m	70 x 95	71 x 95 90 x 95	66 x 100 85 x 100	86 x 100	100 x 100	103 x 105 130 x 105
Maker A	Weight	Pump	t	0.59					0.64
Maker A	Weight	Motor	t	0. 25	0. 28		0. 3 4 5		0.46
Maker B	Model No.			2 5 0 x 1 2 5 - 2 V C D S - A					
Maker B	Stand. Drwg. No.		S D 1	4 4 0 0 2 1 7 4 0 A					
Maker B	Motor capacity			37 x 1800	4 5 x 1 8 0 0		5 5 x 1 5 0 0		
Maker B	Motor Model No.			2 2 5 S	2 2 5 M		2 5 0 M		
Maker B	Capacity range		m3/h x m	7 0 x 9 5	7 1 x 9 5	85 x 1800	86 x 100	100 x 100	110 x 105
Maker B	Weight	Pump	t	0.61					
Maker B	Weight	Motor	t	0 .25	0.28		0.345		0.46

FIGURE SD-7
STANDARD MACHINERY MODULES

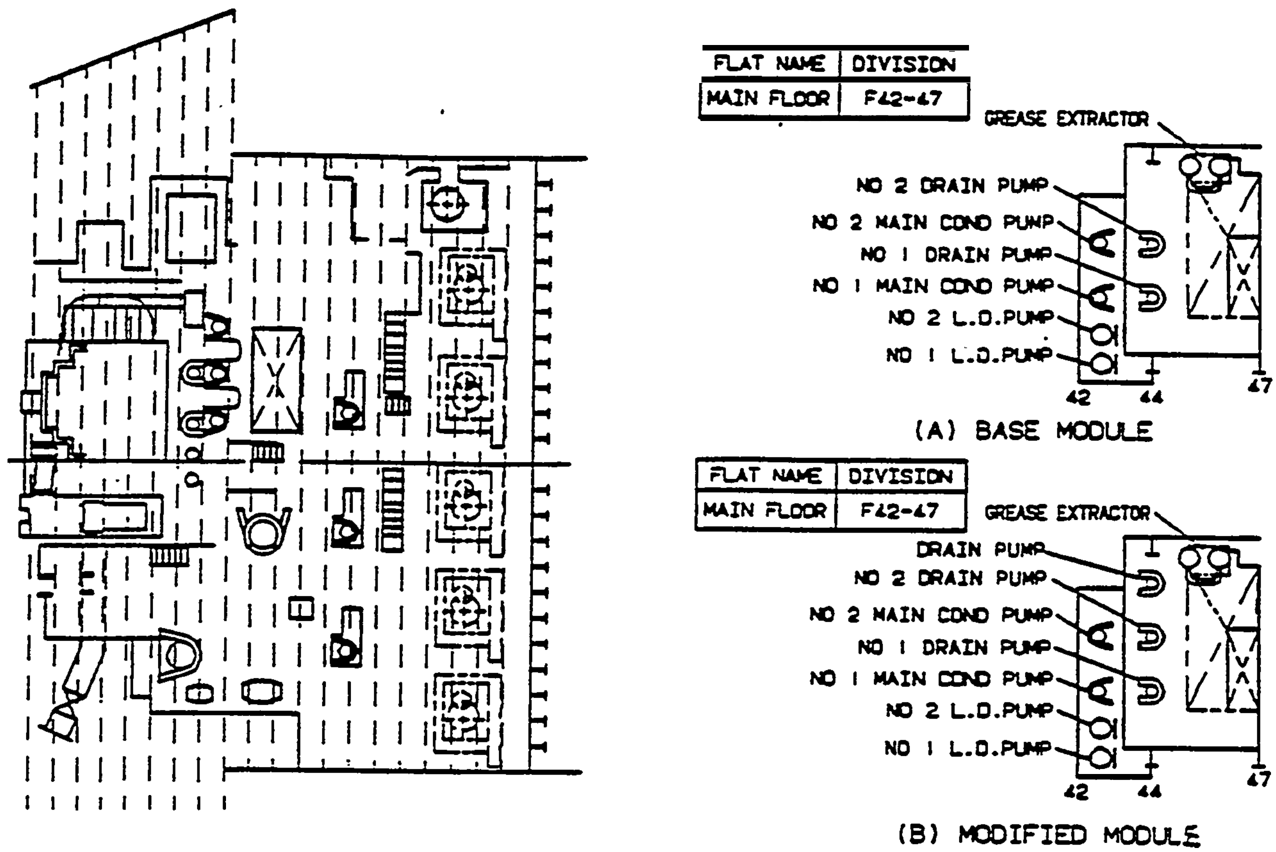


FIGURE SD-8
STANDARD PIPING LAYOUT MODULE

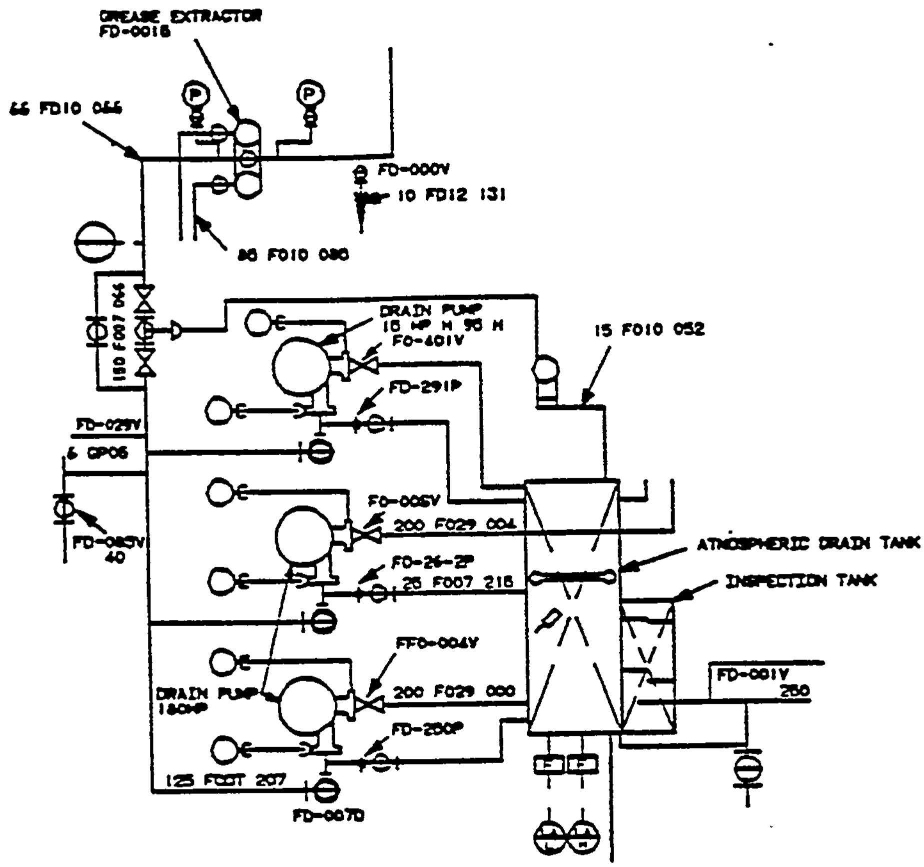


FIGURE SD-9
STANDARD OUTFIT UNIT MODULE

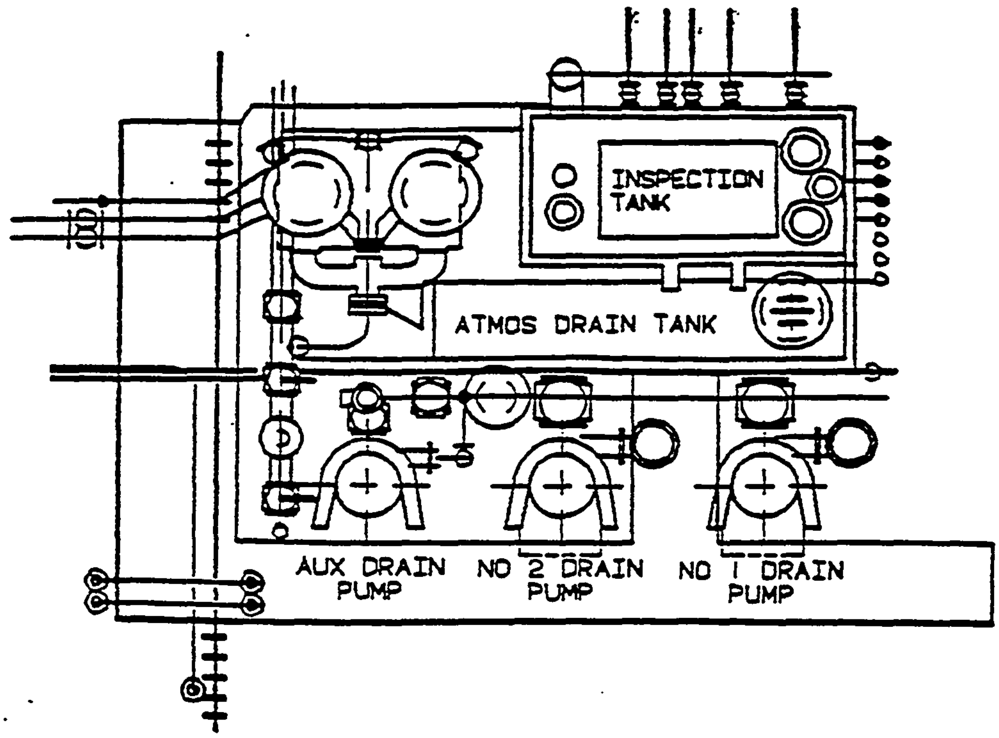


FIGURE SD-10
PATTERNS AND PANELS

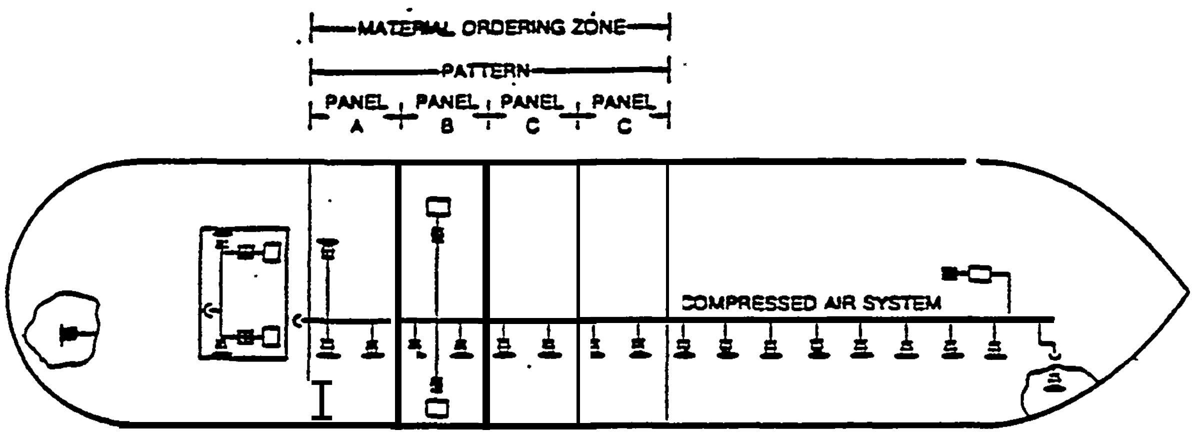
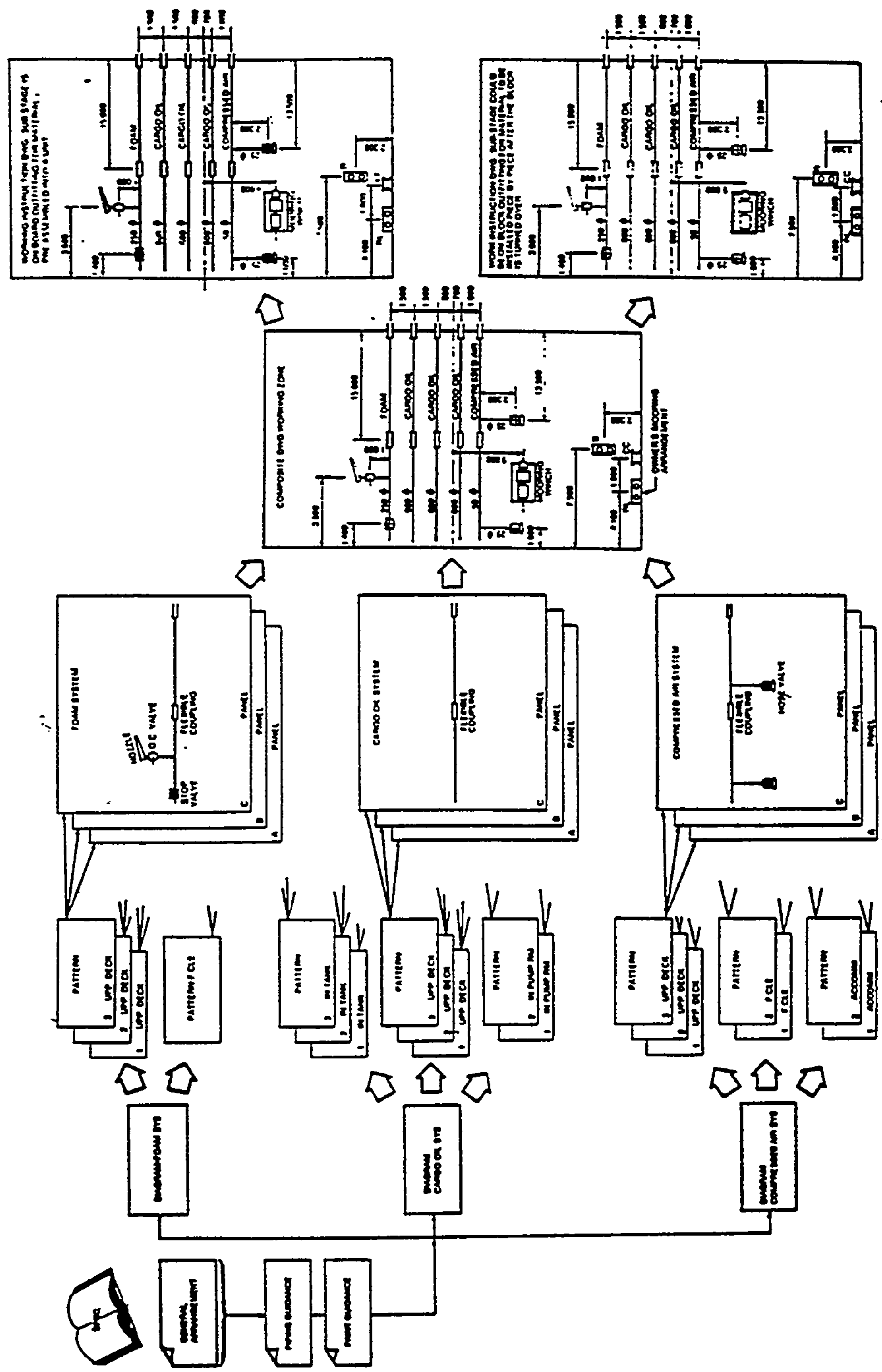


FIGURE SD-11
APPLICATION OF PATTERNS AND PANELS



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Dimensional Control

I. Introduction

A. Define dimensional control:

1. Functions required in the planning and execution of dimensional accuracy (we shall call this "dimensional control")
2. Functions required to continually improve design details and work methods by the regulation of accuracy (we shall call this **"accuracy control").**

B. All shipyards have the first function; some yards have both functions. [Note that when only the first aspect is included we call it dimensional control.]

C. Distinguish between "ship's lines" and "reference lines"

1. Ship's lines are molded offsets defining the external shape of the vessel. Ship's lines are shown on the vessel's lines drawings, and except for the draft marking not marked on the ship.
2. Reference lines form an internal, three-dimensional grid. They are dependent upon the as-built condition of the vessel, and are permanently marked on it.
3. EXAMPLE OF RELATIONSHIP: Hull plating is cut . . . . and bent to offsets derived from the lines drawings. They are physically positioned on the ship, however, by measurements from the reference line grid system.
4. If the world were perfect, ship's lines and reference lines would exactly overlap with each other.

(Ship's Iines)+(Margin)= (Reference Lines)

5. Dimension control is the process to assure that the margin, mentioned above, stays within acceptable limits.
6. Accuracy control is the process to drive the margin to ever smaller limits.

D. Figure DC-1 shows a typical dimension control program. "[If there is no feed back of data, analysis, and improvement of the system it is dimensional control.]

1. Throughout planning effort engineers are developing detail data concerning:
   a. vital dimensions
   b. providing added material
2. Develop base lines for assembly
3. Define tolerance standards.

II. VITAL, POINTS AND DIMENSIONS

A. Holds (or mid-body area), see Figure DC-2

1. Represents majority of units
2. Most critical from standpoint of lines and accuracy
3. Critical points of measurement
   a. skin curvature of the hold bottom units
   b. internal hold structure
4. Vital points
   a. tank top (critical for ship alignment)
   b. top side tank

B. Curved units, see Figure DC-3

1. Vital points
   a. for setting width of curve
   b. for keeping straightness
   c. for setting height and width of lower elevation
2. For maintaining integrity of the curve, itself.

C. Stern sections, see Figure DC-4

1. Critical vital point
2. Difficult to measure and maintain
   a. relationship between center of stern tube and shaft line
   b. relationship between shaft center and rudder center

D. Block assembly

1. Flat units, see Figure DC-5
   a. length
   b. width
   squareness
2. Curved units. see Figure DC-6
   a. alignment

b. girder spacing
c. straightness of each girder
d. positioning of shell of jigs

III. ADDED MATERIAL (SEE FIGURE DC-7)

A. Provides for errors from all factors

B. Specified for each fabricated piece at each production stage.

C. Material is removed as the piece is affixed to the next larger assembly.

D. Primary factors

1. decide which dimensions are "most important" in overall accuracy
2. which dimensions are most difficult
3. which stage is most suitable for removing material
4. how much material is required

E. Process involves (see Figures DC-8 and DC-9)

1. determine erection order
2. decide for each unit which surfaces are most important to preserve dimensions
3. designate critical surfaces as "important dimension" or "difficult dimension".

IV. COMPLICATIONS CAUSED BY HCBM AND ZOPM

A. Units have their own three-dimensional integrity

1. This results in difficulty in match-up, and revision of the reference line. See Figure DC- 10
2. Extra care must be taken to assure that match-up does not compound the error.

B. Advanced dimensional techniques are required to control

1. photogrammetry
2. lasers
3. high-resolution optics Dimensional Control

FIGURE DC-1
VITAL DIMENSIONS AND POINTS OF ACCURACY

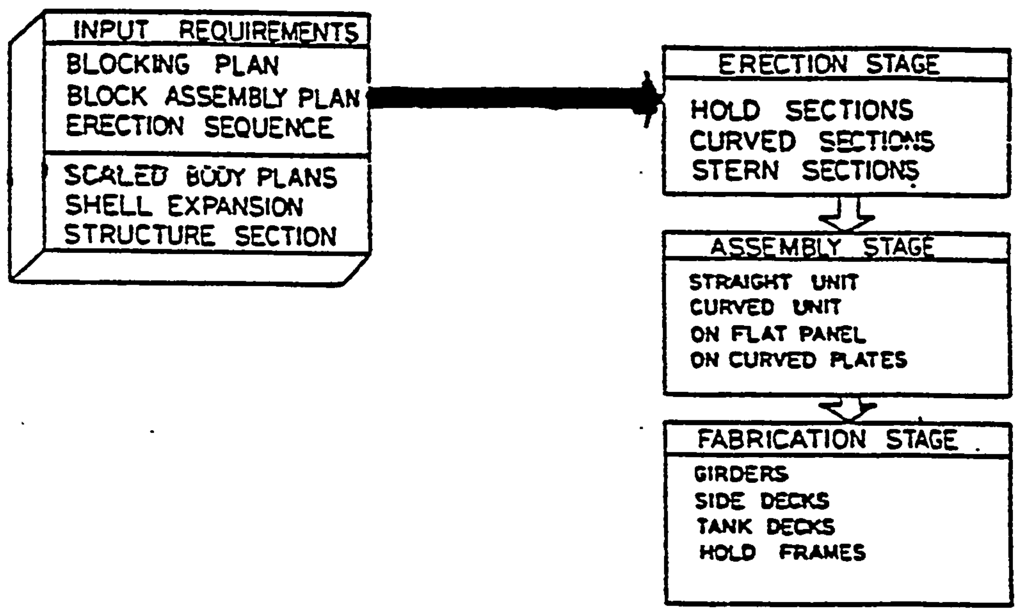


FIGURE DC-2
VITAL DIMENSIONS IN HOLD SECTION

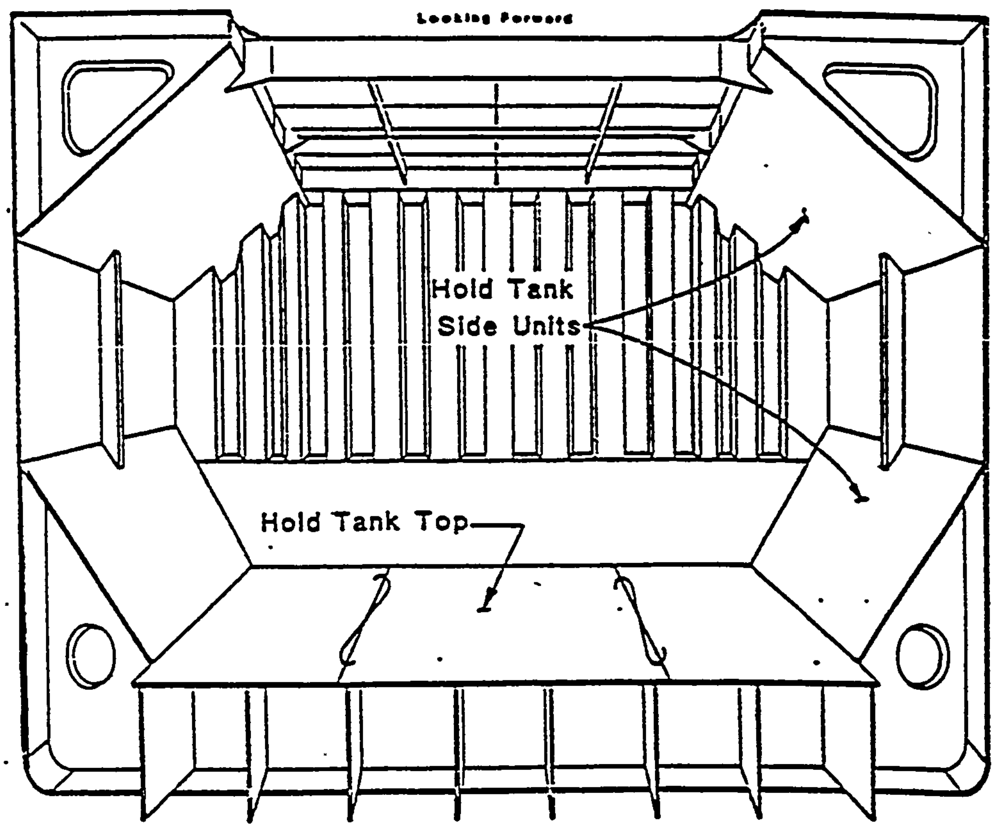
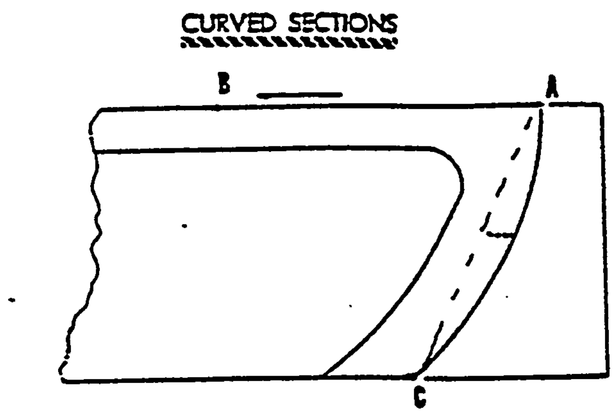


FIGURE DC-3
VITAL DIMENSIONS FOR TYPICAL CURVED UNIT



VITAL POINTS

Point A - For setting width
Point B - For keeping straightness
Point C - For setting height & checking width at lower elevation

FIGURE DC-4
STERN SECTION VITAL POINTS

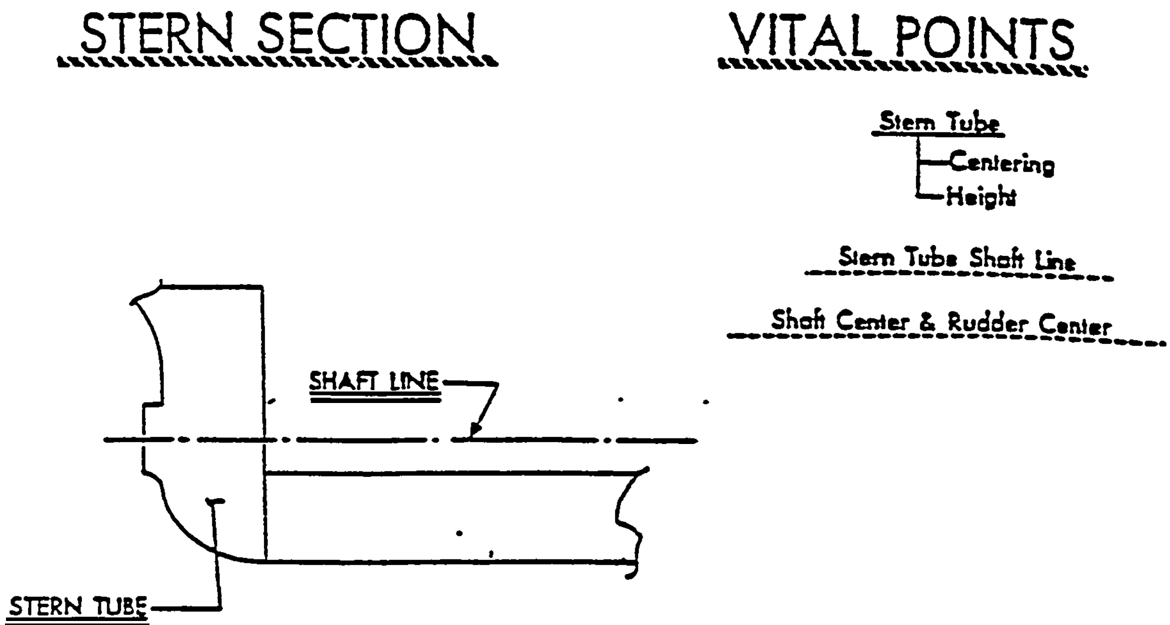
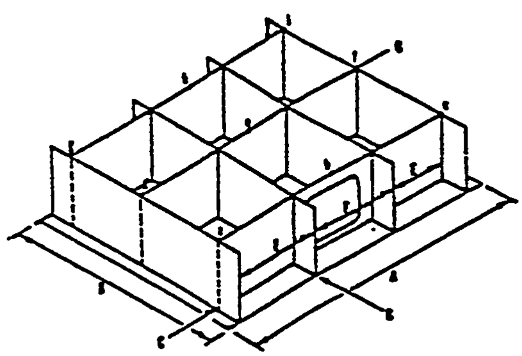


FIGURE DC-5
VITAL DIMENSIONS AND POINTS OF ACCURACY FOR FLAT UNIT ASSEMBLY

Assembly Stage

FLAT UNIT ASSEMBLY

Before being combined with bottom plate



VITAL POINTS

Edge Alignment - Every girder both sides

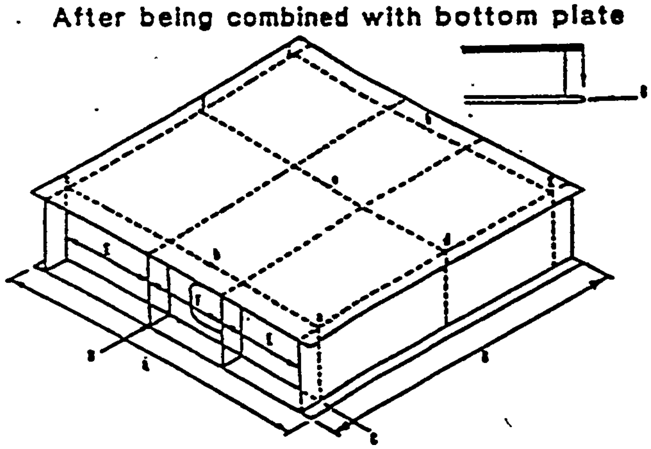
Girder Spocing - Every home

S!raightness - Each girder

Level - 9 points

FLAT UNIT ASSEMBLY

After being combined with bottom plate



VITAL POINTS

Edge alignment - every girder both sides

Girder spacing - every frame

Relativity - 2 points each edge

Level - 9 points

FIGURE DC-6
VITAL DIMENSIONS AND POINTS OF ACCURACY FOR CURVED UNIT ASSEMBLES

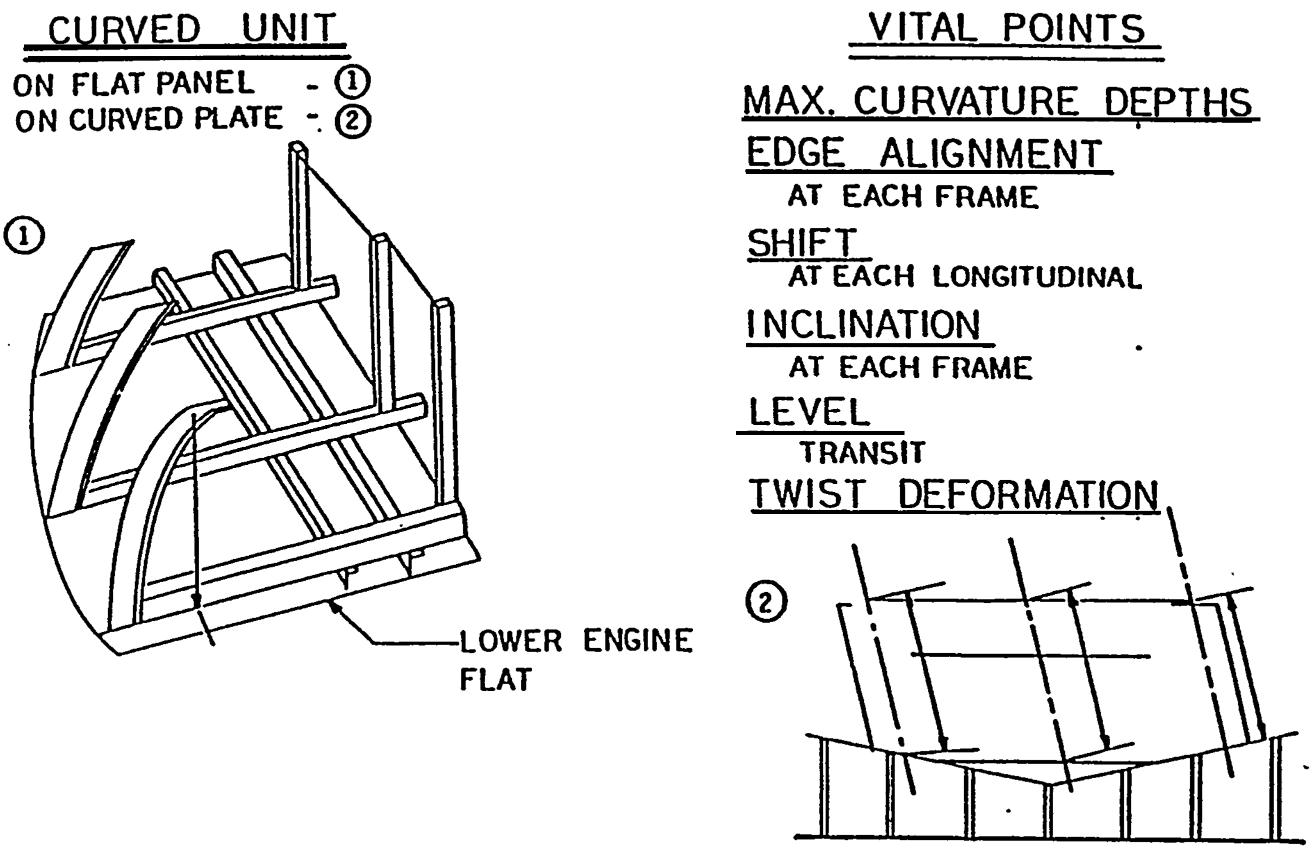


FIGURE DC-7
SCHEME FOR ADDED MATERIAL

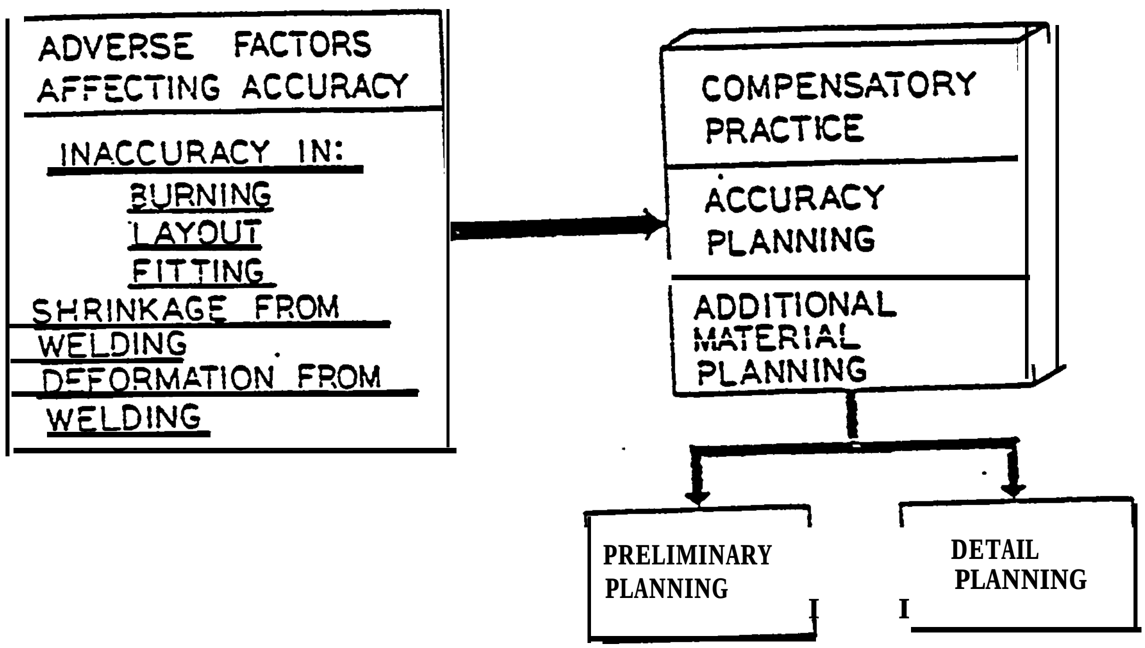


FIGURE DC-8
ADDED MATERIAL PRELIMINARY PLANNING

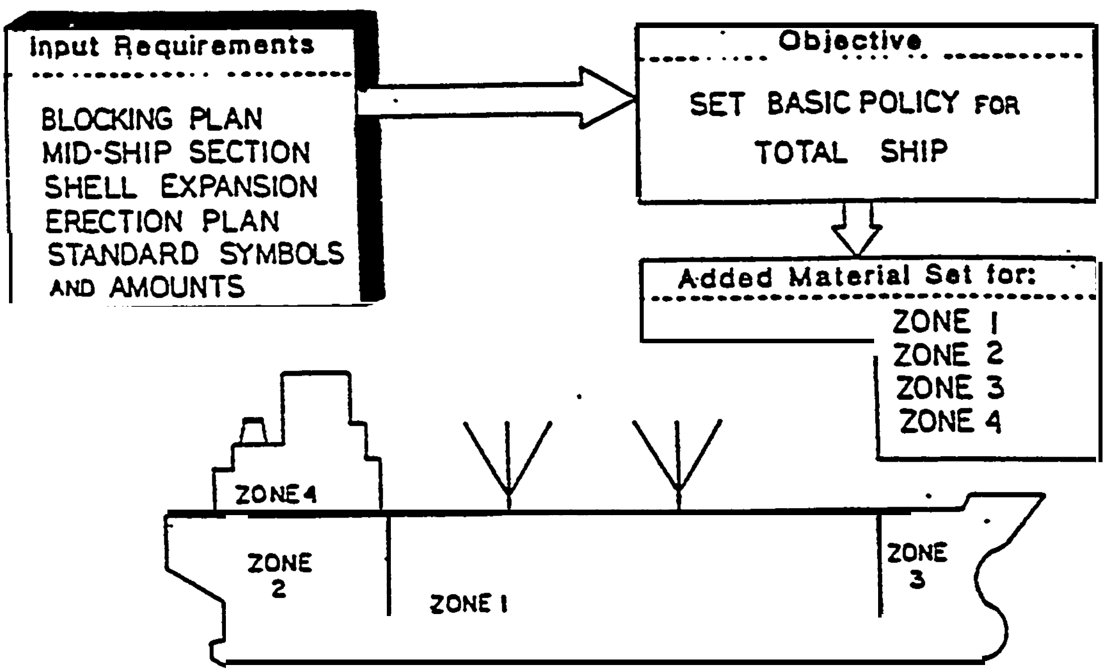


FIGURE DC-9
SCHEME OF ADDED MATERIAL FOR SHELL EXPANSION

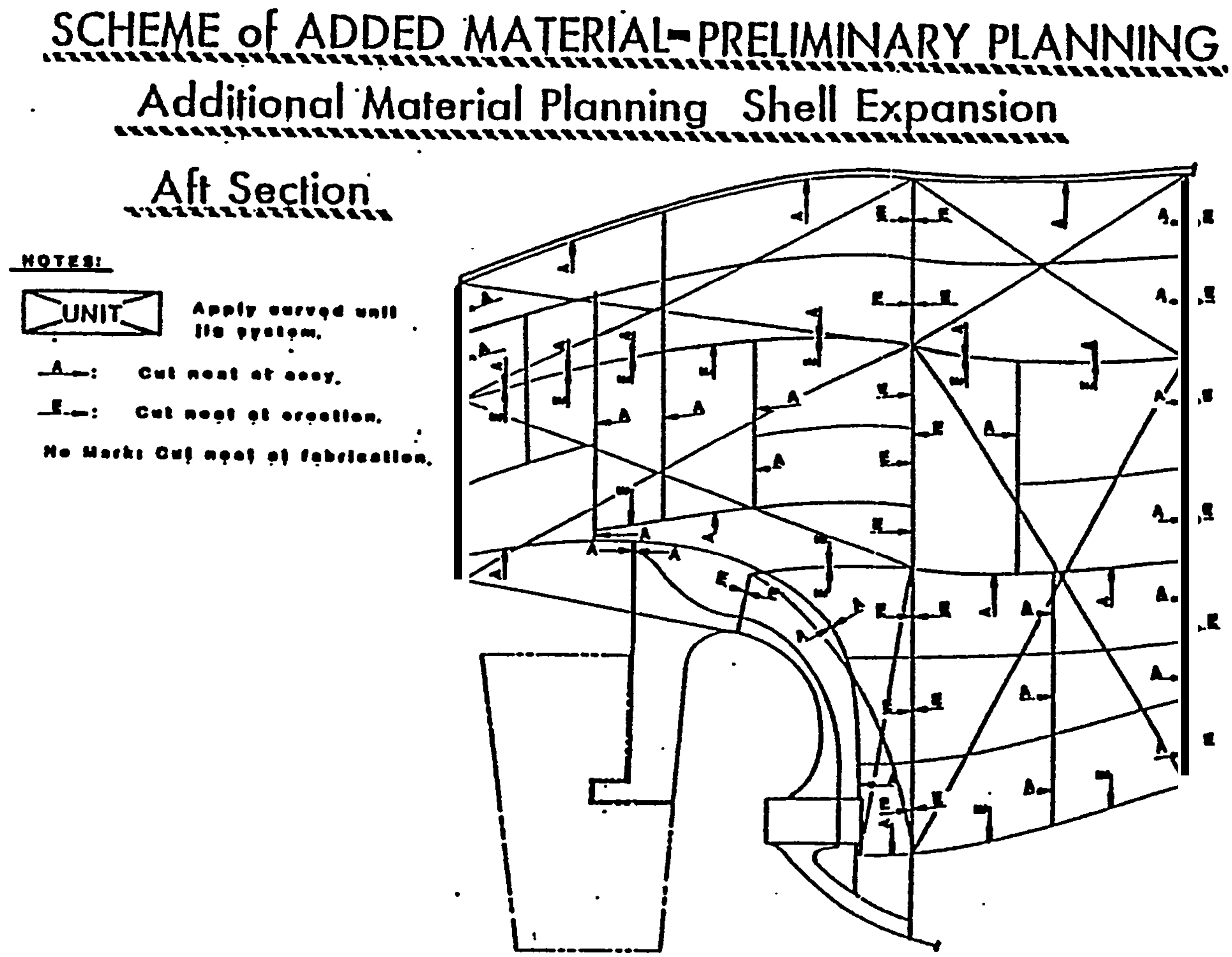
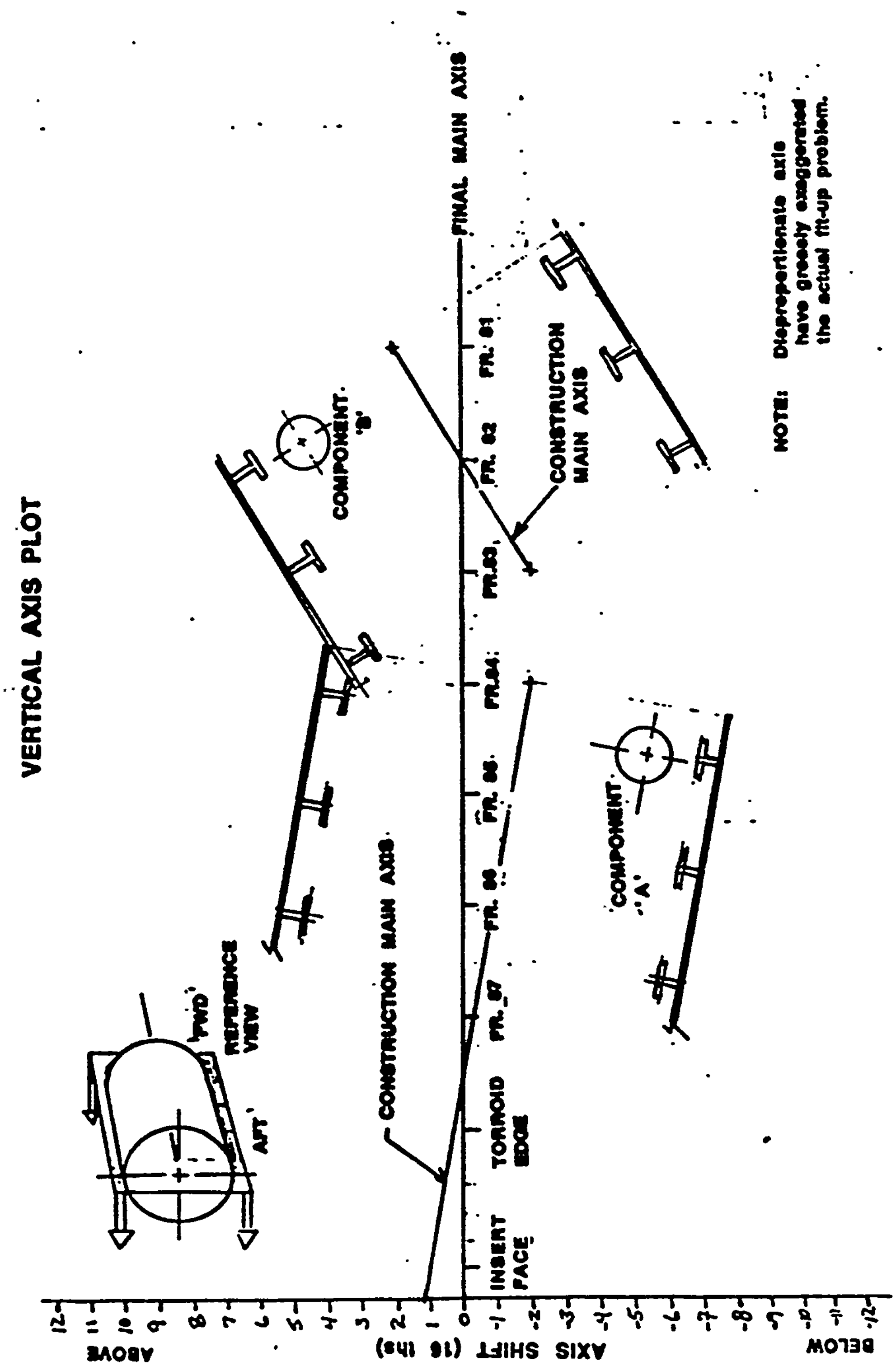


FIGURE DC-10
TYPICAL REFERENCE LINE RELATIONSHIPS FOR SHIP AND FOR CONSTRUCTION BLOCKS



ACCURACY CONTROL

I. ACCURACY CONTROL BACKGROUND .

A. **Thesis statement: the state of the dimension/accuracy control system is one of the strongest indicators of technological advancement within a shipyard.**

B. Every shipyard has dimension control, i. e., there is a system to regulate dimension and to conform to the required dimensional specifications.

1. Most basic is a "cut-to-fit" concern.
   a. Example is Chinese junk method.
   b. Another example is the full-size template made at the erection site.
2. Most advanced is a "cut-neat-at-the-assembly-platen" concept
   a. Requires a constant up-grading of production methods
   b. Require elimination (or reduction) of re-work

C. There is a relationship between the "cut-neat" concept and quality. As Deming and others have shown the result is increased productivity.

1. "We work smarter, not harder,
2. We eliminate or significantly reduce re-work.

D. Definition of an accuracy control program: "The regulation of accuracy as a means for continually improving design details and work methods so as to maximize productivity"

1 The new aspects are "continually improving design" and "maximize productivy". See FIGURE AC-1.
2. The goal is to have a driving force for increasing accuracy and control. productivity is the result.
3. The concept is required for movement into advanced modular construction:

E. That definition is not "Pie-in-sky" concept. Both commercial and naval ships are being built every day in Japan, Korea, Taiwan (and other countries) utilizing that concept of accuracy rigor.

F. Cost of implementation is high. Question: "Is it worth it?"

1. Evidence indicates it is worth it. First we find the shipyards who are dominating the commercial ship world market build their ships with the advanced modular construction technique, and with the Specified dimensional accuracy required for such a construction system.
   a. Japan: 30-40 percent market share;
   b. Korea: 30-40 percent market share;
   c. Taiwan 5-10 percent market share.
2. Second, experience in other industrial applications show that any process that improves production accuracy and quality inevitable has a positive benefit/cost ratio... The cost of implementing advanced concept is-less than the benefit.

G. The benefits are:

1. Productivity improvement
2. Quality improvement
3. Material cost reduction

H. Costs are:

1. Greater personnel cost at initiation.
2. Disruption associated with implementation of new concepts

II. ACCURACY CONTROL APPROACH

A. Statistics is a basic tool in a successful AC program

1. There is a need to collect, analyze, interpret, and present masses of data. And shipbuilding engineers who manage A/C programs must understand college-level elementary statistics.
3. The systematic recording of thousand of measurements. Because of this expense, the manager with short team goals will be deterred.
4. Accuracy control that is applied for the advanced module assembly concept is built around the interim products where work situations are sufficiently repeated within each area for statistical treatment. The system is a repeating cycle of
   - ** Plan
   - **Execute
   - ** Evaluate
   - ** Re-plan

B. Process

1. The vital points and dimension for blocks, sub-blocks, and parts are identified.
2. The points are systematically monitored at designated production stages.
   Measurements are made and carefully documented.
4. Scientifically-valid samples of data are regularly taken.
5. The data are evaluated using statistical methods to verify performance in terms of standard ranges of accuracy
6. As processes become stable. i.e., measurements are consistently within the control limits, attention is then focused on "tightening up" the systern. This results in an upgrading of quality and gradual reduction of; re-work.

C. Details of how the system works.

1. When parts is fabricated, during controlled work circumstances there will be a variance in the measurements.
   a. Samples of the measurements will produce a normal distribution. (See FIGURE AC-2).
   b. The distribution is defined by two variables:
      ** the **mean** value: X-bar
      ** the standard deviation: s

which classes the sizes of the variations from the mean value by their frequencies of occurrence. (See Figure AC-2)

1 s = **68.3%**
2 s = 95.5%
3 s = 99.7%

2. The same normal distribution would apply to fabrication parts (such as flat bars and the spacing of longitudinal). (See FIGURE AC-3).

3. Statistics provide a theorem for addition of two or more normal distributions. Thus a mean value and s can also be expressed for this later assembly process.(Refer to bottom illustration in FIGURE AC-3.)

$$\bar{X}_T = \bar{X}_1 + \bar{X}_2 \ldots + \bar{X}_n$$
$$S_T^2 = S_1^2 + S_2^2 \ldots + S_n^2$$

4. Accuracy goals are expressed in terms of the normal distribution required for the final process. Then by working backwards necessary goals are set for each of the work processes which would insure the desired accuracy for the final process.

$$Z = \hat{A}P_i + \hat{A}S_i + \hat{A}A_i + \hat{A}E_i \text{ where}$$

$\hat{A}P_i$ is the merged variance of the fabrication assemblies
As_i is the merged variance of the sub-block Assemblies
AA_i is the merged variance of the block Assemblies
AE_i is the merged variance of the erection activities

C. Use the standard deviation to give guidance on questions of re-work.

1. A standard range (FIGURE AC-4) will be related to standard deviation to give an estimate of amount of re-work that will occur.
2. Same would hold with lower tolerance and upper tolerance limit.
3. Another statistical element we must deal with is the use of charts to give guidance in whether the process is in statistical control are

control charts (See FIGURE AC-5): "X-BAR" and "R" charts are the most common types.

111. X-BAR AND RANGE CHARTS

A. **"X-BAR" and "RANGE" (also known as "R") charts indicate whether the production process is stabilized. When the data are within established control limits, the process is "in control". If a data set is outside the control limits, there is a need to investigate. In the first case, we are experiencing RANDOM VARIATION. In the latter case we have ASSIGNABLE CAUSE VARIATION.**

B. Random Variation

1. Consists of many individual causes
2. any one variation results in a minute amount of variation.
3. Examples are setting of controls, slight variation in raw material, operator skill.
4. Random variation cannot be eliminated from the process. It is a natural phenomena

When random is present, process is operating at its best. To improve i,e,. narrow the control limits there must be a basic process change.

B. Assignable Cause Variation

1. Consists of one or just a few individual causes
2. Anyone cause can result in a large amount of variation
3. Examples are operator blunder, a faulty production process, defective raw material.
4. Action to eliminate the cause is economically justified,
5. An observation beyond control limits means process should be investigated and corrected.
6. When assignable variation is present, process in out of control.

C. COMPARISON OF CONTROL CHART (See FIGURE AC-5) AND STANDARD RANGE CHART (See Figure AC-4).

1. Control Chart
   a. Group sampling
   b. Correction is to the process
   c. Terms are:
      "process control"
      "range"
2. Standard Range
   a. Individual values
   b. Correction is to the item
   c. Terms are:
      "standards"
      "tolerance"

IV.. OTHER CHARTS FOR PROCESS EVALUATION (SEE FIGURE AC-6)

A Pareto charts

1. Ranks the frequency of occurrence of attributes
2. Separates the "trivial manv" from the "significant few"

B. Flow Diagrams

1. Describes the logic of a process or a system
2. Provides guidance in where and how to monitor process for quality.

C. Histogram

1. Shows frequencv distribution
2. Indicates central tendency of data

D. Cause-Effect Diagram

1. Indicates the interrelationships of causes for a specific result.

2. Helps to sort out the causes of dispersion and to establish their mutual relationships.

E. Run Chart

1. Relates measurements of an event against time
2. Permit long-term tracking of a event

F. Correlation Chart

1. Relates relationships of two variables
2. When plotted on log and semi-log paper shows rates of change, etc., of the two variables.

V. KEY POINTS FOR USE OF SIMPLE TECHNIQUES.

A. Problem is identified (typically from X-BAR/R charts)

B. Focus of areas of greatest significance (from Pareto Analysis)

C. Develop clear understanding of the process (from Flow Diagram)

D. Break problem down into bite-size pieces (from Pareto Analysis)

E. Group causes and their relationships (Cause-Effect Diagram)

VI. SOME EXAMPLES

A. Painting Process Data--Control Chart (FIGURE AC-7)

B. A Process Analysis--The Numerical Control Burning System (Figures AC-8 thru -11)

C. A Simple Assembly peration--an Example of Merged Variance in the Joining two plates. (Figure AC-12)

D. A Block Assembly Situation--A More Complex Example of Merged Variance. (Figure AC-13)

FIGURE AC-1
CONCEPT OF CONTINUOUS IMPROVEMENT

- **Measure the Process (while making the product)**
- **Control the Process**
- **Predict the Outcome**
- **Study Process for Continuous Improvement**

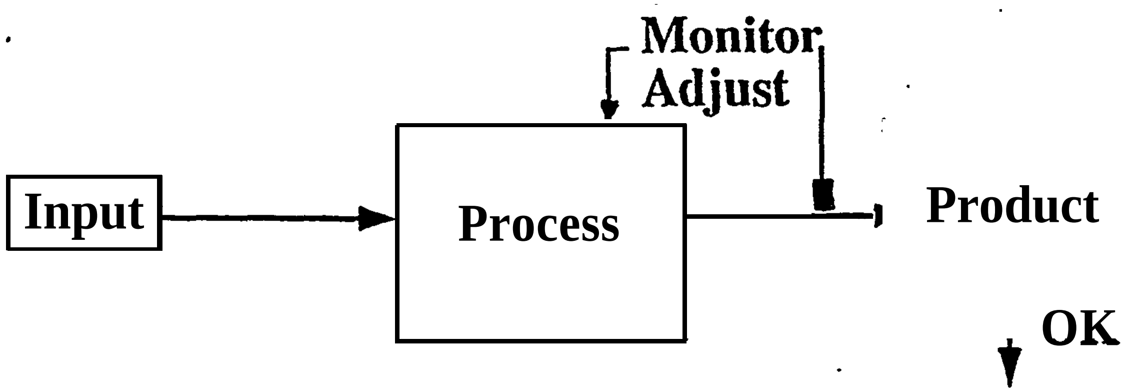


FIGURE AC-2
NORMAL DISTRIBUTION

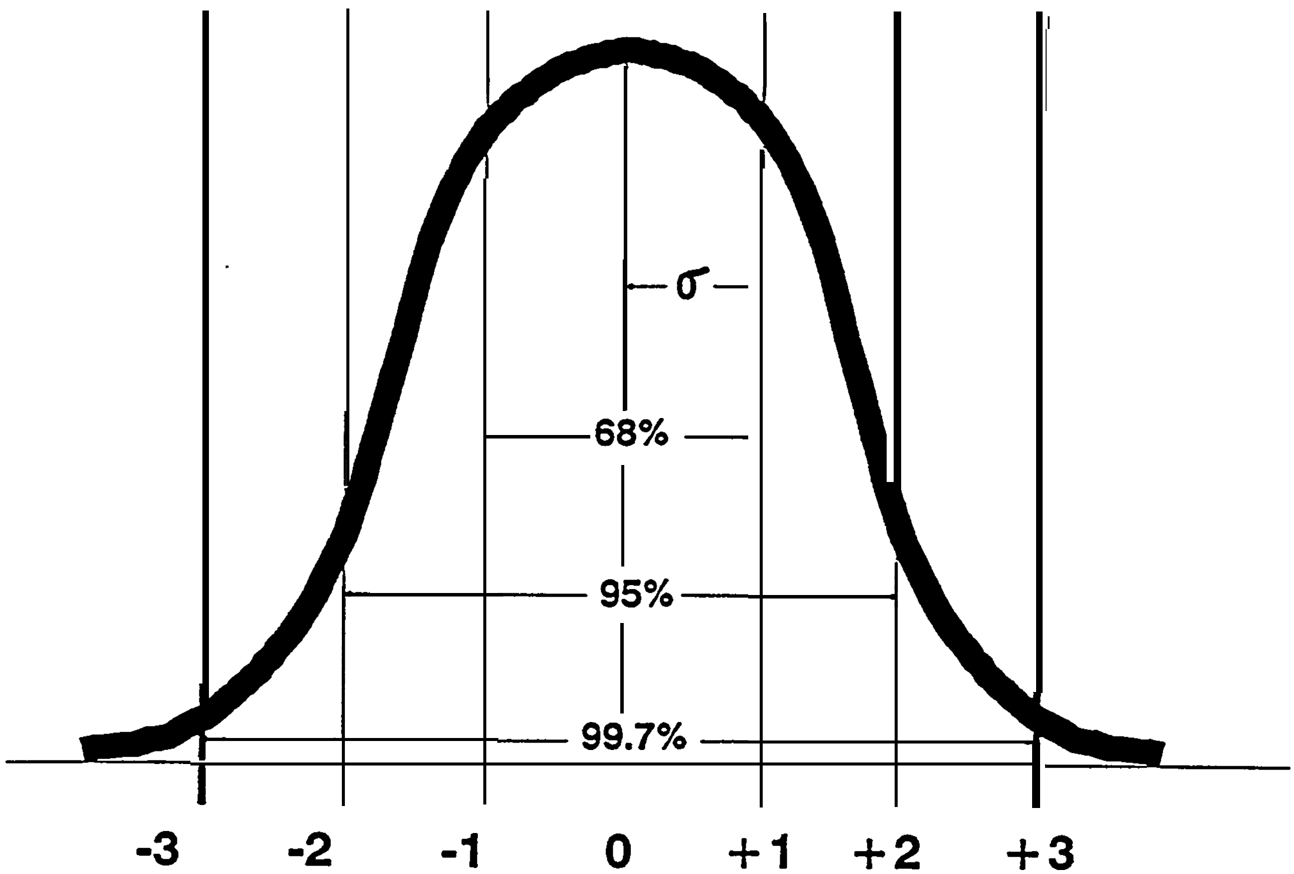
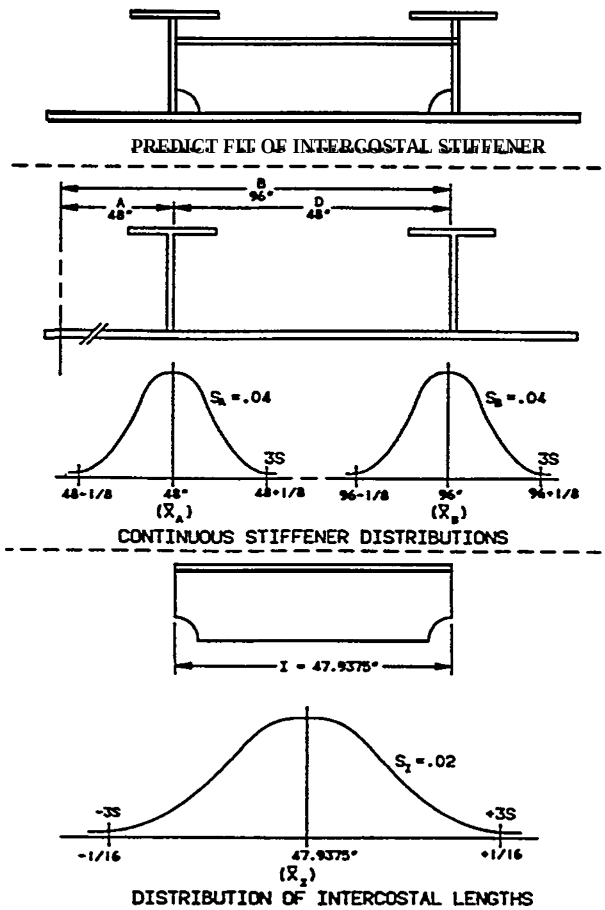
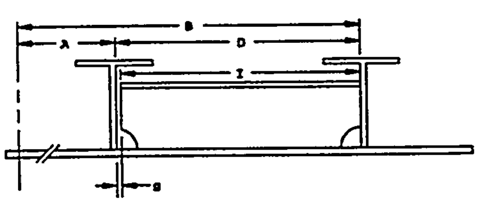


FIGURE AC-3
PROCESS DISTRIBUTION OF CUT PARTS AND THEIR ASSEMBLY





GEOMETRIC EQUATION: $g = D - I = B - A - I$

MEAN OF g: $\bar{X}_g = \bar{X}_B - \bar{X}_A - \bar{X}_I$

$= 96" - 48" - 47.9375" = .0625"$

VARIANCE OF g: $S_g^2 = S_B^2 + S_A^2 + S_I^2$

$= .04^2 + .04^2 + .02^2 = .0036$

STANDARD DEVIATION: $S_g = \sqrt{.0036} = .06$

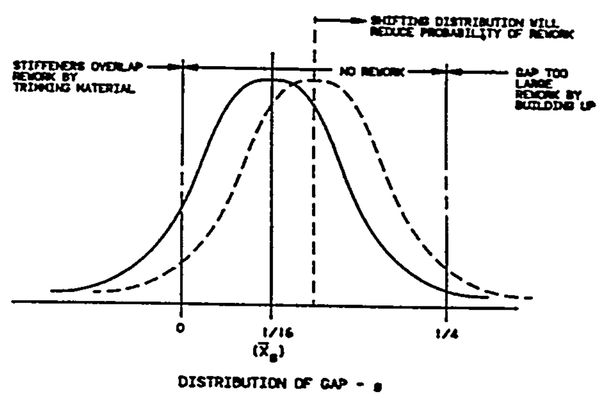
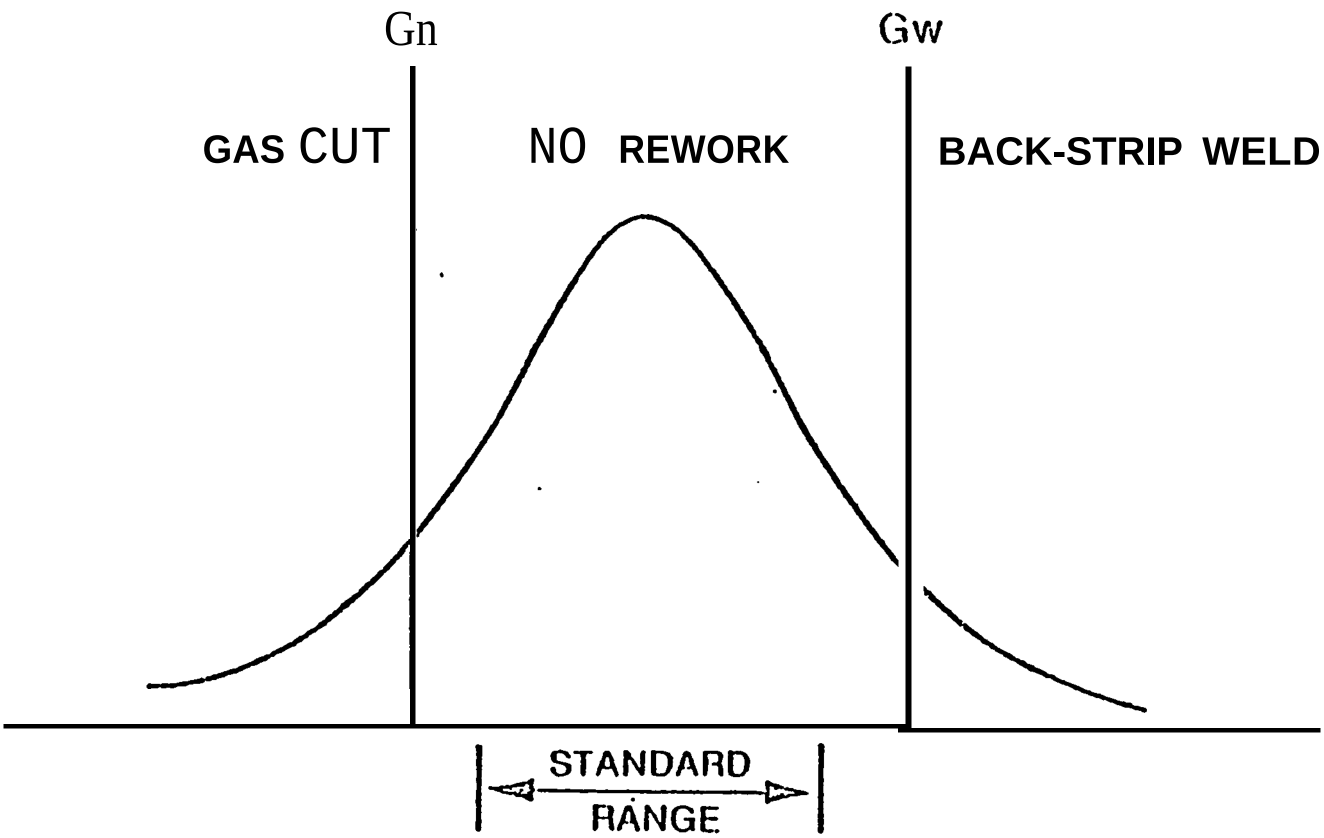


FIGURE AC-4
STANDARD RANGE AND REWORK RELATIONSHIP



Gn - **lower tolerance limit**

Gw - upper tolerance limit

FIGURE AC-5
CONTROL CHART

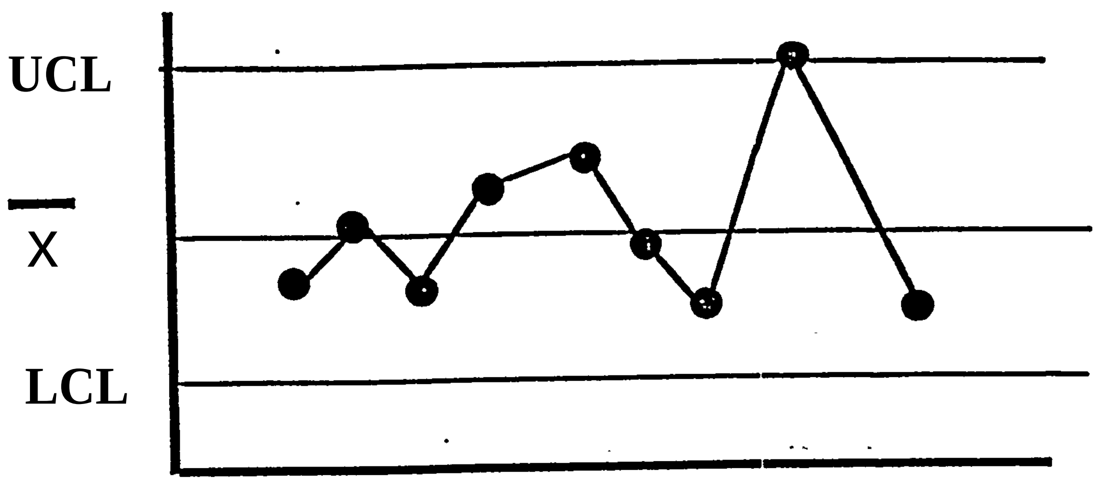


FIGURE AC-6
SEVEN SIMPLE CHARTS

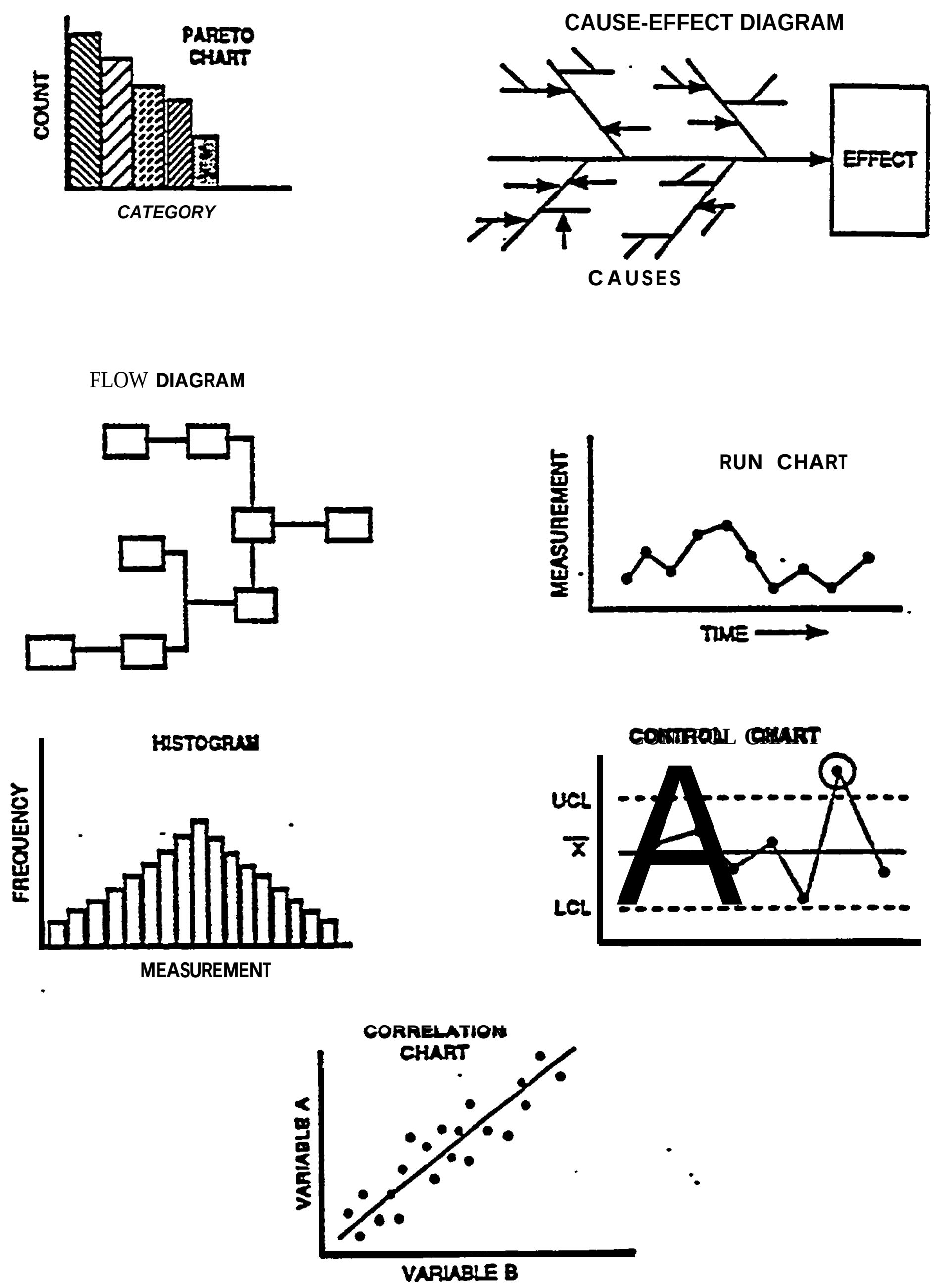
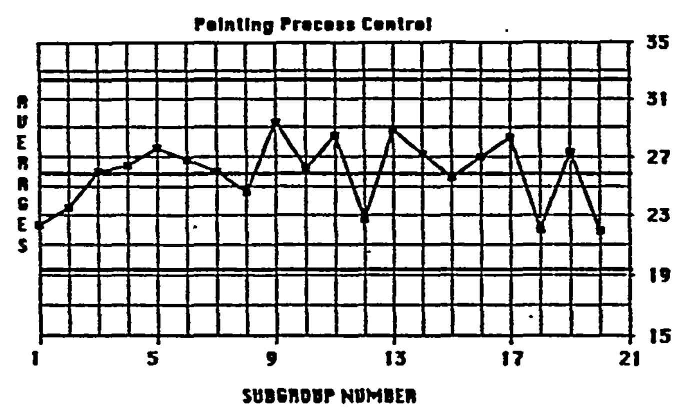


FIGURE AC-7
PAINTING PROCESS CONTROL CHART DATA

Subgroup #	Value of Ounces of Paint to cover 100 sq. ft.					$\bar{X}$	R
1	30.42	22.29	19.68	19.05	20	22.29	11.57
2	27.97	24.64	12.73	23.67	28.42	23.49	15.69
3	25.3	29.28	26.05	20.96	28.19	25.96	8.32
4	32.3	23.61	20.08	32.02	24.12		
5	33.58	23.15	29.54	35.18	16.62		
6	26.69	30.91	24.88	26.7	25.07		
7	28.84	25.21	24.03	29	23.11		
8	32.95	24.41	21.06	19.44	25.35		
9	26.47	35.41	34.01	29.86	20.97		
10	23.82	24.55	31.98	25.97	24.76		
11	24.46	29.95	28.2	31.65	27.54		
12	24.79	15.16	26.01	18.93	28.53		
13	27.4	26.48	28.98	27.44	33.83		
14	18.18	30.15	33.82	26.19	27.71		
15	31.26	24.12	22.42	22.29	27.89		
16	25.79	31.52	21.94	19.45	36.06		
17	27.61	34.53	26.68	21.36	31.21		
18	23.07	21.82	19.62	20.33	25.08		
19	28.93	27.07	23.54	24.8	32.3		
20	15.67	28.74	19.2	25.94	20.17	21.94	13.07
					$\bar{\bar{X}}$	25.90	
					$\bar{R}$		11.19

Source - NSRP#0223, Problem 1.6 pg 53



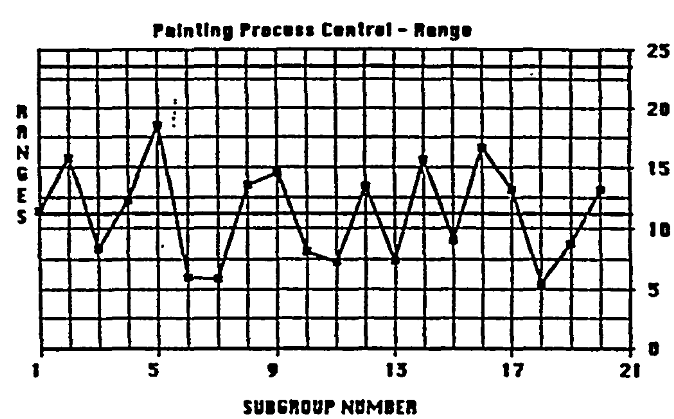


FIGURE AC-8
CONTROL CHART FOR NC BURNING PROCESS

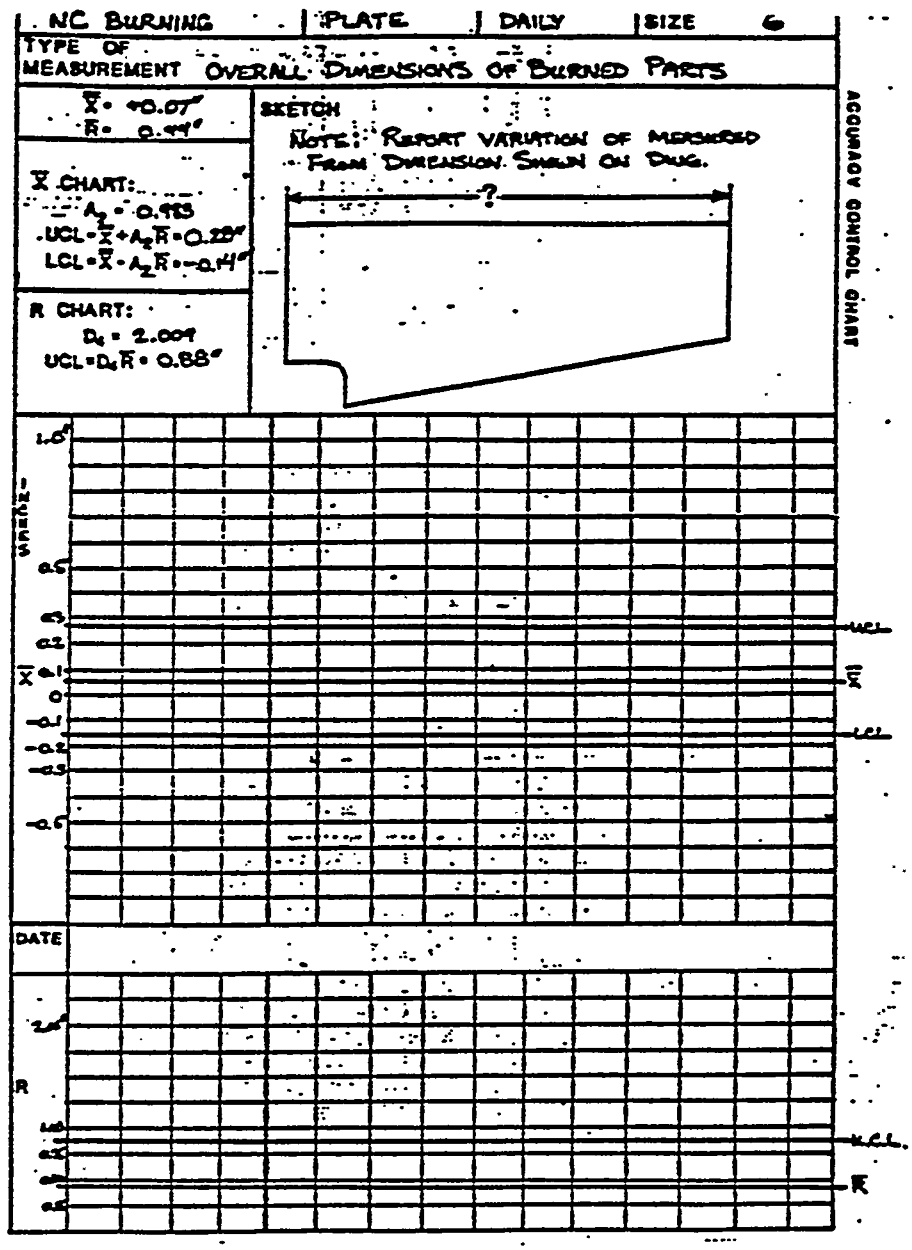


FIGURE AC-9
EXPLODED VIEW OF STRUCTURE PARTS CUT IN NC BURNING PROCESS

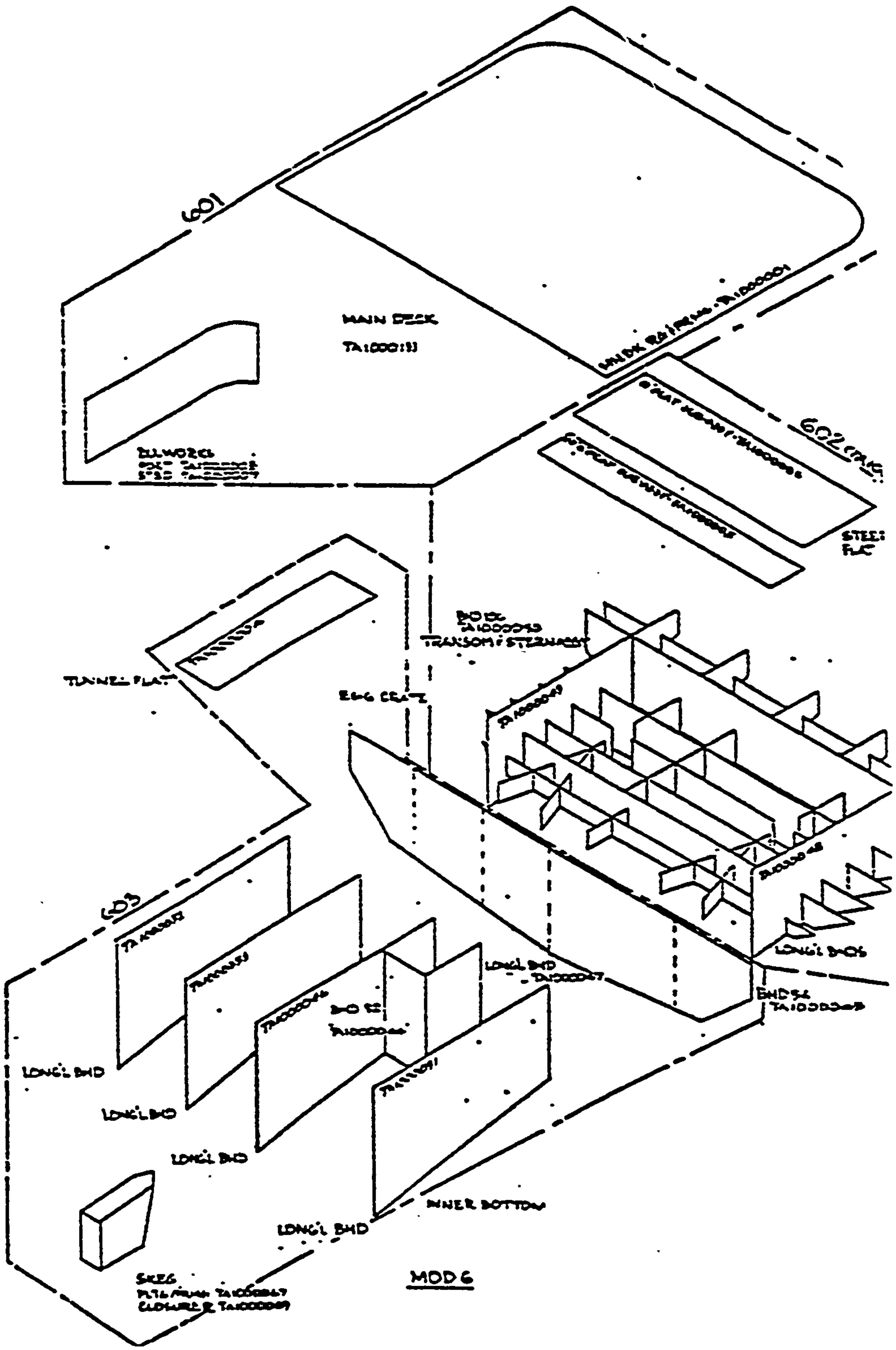


FIGURE AC-10
ACCURACY CONTROL DATA WORK SHEET

DESIGN NAME	HULL NO.	PLATE THK.	NAME	DATE
TAGOS	1,2	5/16"	jrg	1/30/85

PROCESS	STAGE OF CONSTR.	MEASUREMENT DESCRIPTION
NC BURNING	PARTS	OVERALL DIMENSION

	PART NO.	MEASURED FROM	MEASURED TO	DIM. AS MEAS'D. (A)	TARGET DIM. (T)	Variation (X=A-T)	NOTES
1	TA1000004	a	b	192.56"	192.69"	-0.13"	tunnel flat } Hull #1
2	↓	c	d	192.56	192.69	-0.13	↓
3	↓	a	c	59.87	59.84	+0.03	↓
4	↓	b	d	59.87	59.84	+0.03	↓
	TA10000047	a	d	47.63	47.84	-0.21	long'l bhd 48" off ℄
	A10000046	FWD EDGE	AFT EDGE	192.75	192.69	+0.06	long'l bhd on ℄ — Hull #2
12							

X_{min} = -0.21
X_{max} = +0.06

ΣX = -0.35

sample size .... N = 6
ave. variation .... $\bar{X}$ = -0.06"
range .... R = 0.27 in.

FORMULAS:

$$\bar{X} = \frac{\Sigma X}{N}$$

$$R = X_{min} - X_{max}$$

FIGURE AC-11
ACCURACY CONTROL ANALYSIS FOR NC BURNING PROCESS

$\bar{\bar{X}} = 0.07"$

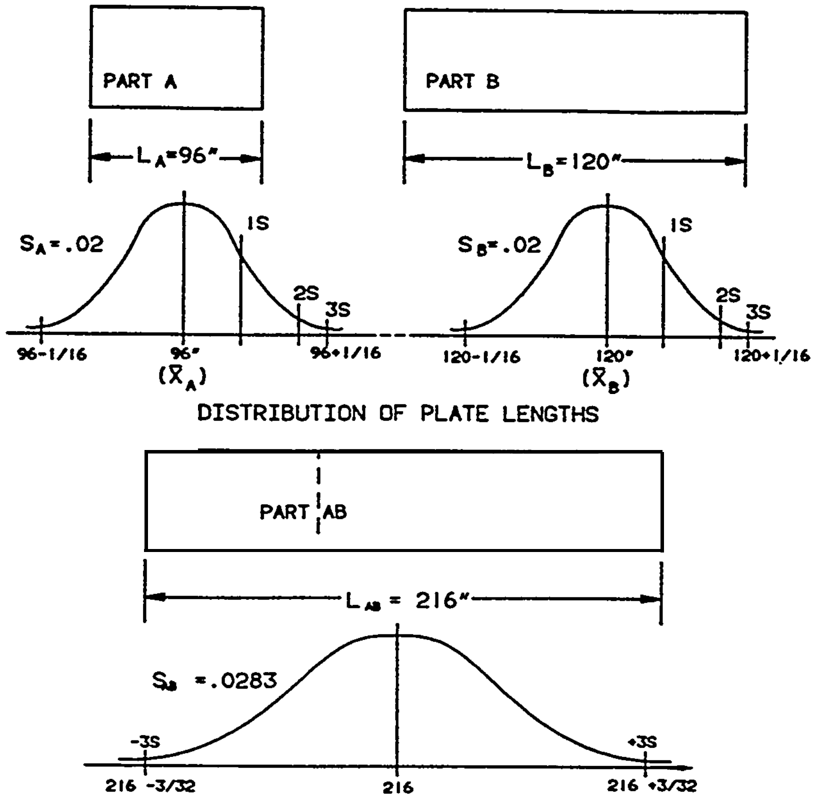
N	X_i	$X_i - \bar{\bar{X}}$	$(X_i - \bar{\bar{X}})$
1	-0.13 in.	-0.20 in.	0.040 in.
2	-0.13	-0.20	0.040
3	+0.03	-0.04	0.016
4	+0.03	-0.04	0.016
5	-0.21	-0.28	0.078
6	+0.06	-0.01	0.000
7	+0.06 in.	-0.01 in	0.000 in.
8	+0.19	+0.12	0.014
9	0.	-0.07	0.005
10	+0.13	+0.06	0.004
11	0.	-0.07	0.005
12	0.	-0.07	0.005
13	+0.25 in.	+0.18 in	0.032 in.
14	0.	-0.07	0.0005
15	+0.03	-0.04	0.002
16	+0.03	-0.04	0.002
17	+0.06	-0.01	0.000
18	+0.85	+0.78	0.608

$\bar{\bar{X}})^2 = 0.872 \text{ in.}^2$

$$\sigma^2 = \frac{\Sigma(X_i - \bar{\bar{X}})^2}{N - 1} = \frac{0.872 \text{ in.}^2}{17} = 0.0513 \text{ in.}^2$$

$$\sigma = \sqrt{\sigma^2} = 0.23 \text{ in.}$$

FIGURE AC-12
CALCULATIONS FOR SIMPLE JOINING PROCESS



GEOMETRIC EQUATION: $L_{AB} = L_A + L_B$

MEAN OF AB: $\bar{X}_{AB} = \bar{X}_A + \bar{X}_B$

$= 96" + 120" = 216"$

VARIANCE OF AB: $S^2_{AB} = S^2_A + S^2_B$

$= .02^2 + .02^2 = .0008$

STANDARD DEVIATION: $S_{AB} = \sqrt{0.0008} = 0.0283$

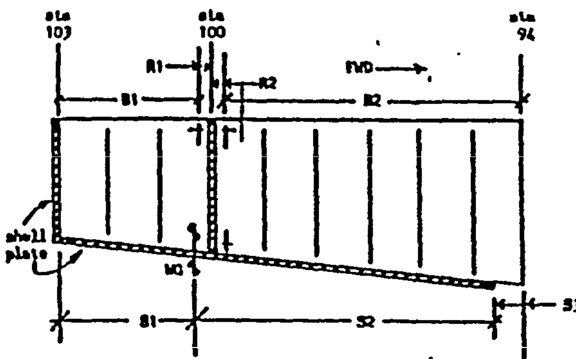
Variation-merging equations and distributions for joining two flat plate parts

FIGURE AC-13
VARIATION MERGING EQUATIONS FOR SUB-BLOCK

ZONE: 602 AREA: Assembly STAGE: Sub-Block

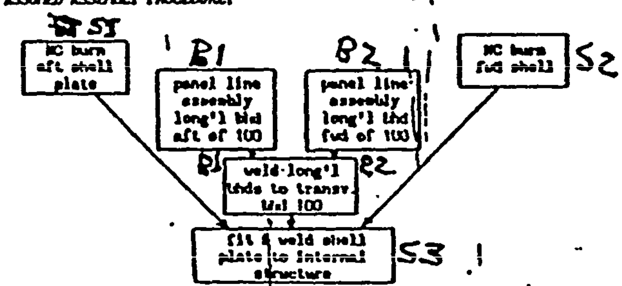
DESCRIPTION: Weld gap in shell plate butt joint aft of transverse bulkhead 100.

SKETCH:



WG = (B1 + R1 − S1) − (R2 + B2 − S3 + S2)

ASSUMED ASSEMBLY PROCEDURE:



RELEVANT DATA:

STAGE	PROCESS MEASUREMENT	VARIATION	PROCESS MEAN	PROCESS STD.DEV.
part fab.	NC burn—part length variation	S1, S2	+0.07*	0.19*
panel line	panel length variation	B1, B2	−0.01	0.17
sub-block	reference line to bhd. fillet weld	R1, R2	−0.04	0.08
sub-block	shell plate offset variation	S3	−0.13	0.16

ANALYSIS:

Assumes—1. aft shell plate aligned at stern (station 103);
2. fwd shell plate aligned at station 94.

$$\bar{X}_{WG} = (\bar{X}_{B1} + \bar{X}_{R1} - \bar{X}_{S1}) - (\bar{X}_{R2} + \bar{X}_{B2} - \bar{X}_{S3} - \bar{X}_{S2})$$

$$= (-0.01-0.04-0.07) - (-0.04-0.01+0.13-0.07) = -0.13 \text{ in.}$$

$$S^2_{WG} = S^2_{B1} + S^2_{R1} + S^2_{S1} + S^2_{R2} + S^2_{B2} + S^2_{S3} + S^2_{S2}$$

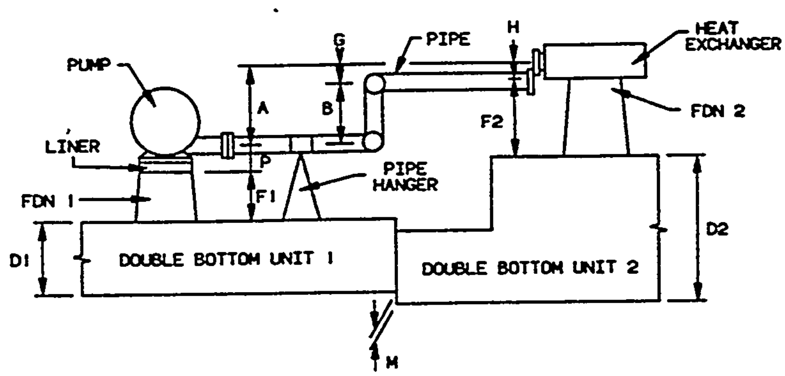
$$= 0.17^2 + 0.08^2 + 0.19^2 + 0.08^2 + 0.17^2 + 0.19^2 + 0.16^2 = (0.41 \text{ in.})^2$$

$\bar{X}_{WG} = -0.13$ in. $S_{WG} = 0.41$ in.

NOTES/REMARKS:

1. The one inch margin (on one shell plate edge in each principal direction) presently used by Tacoma Boatbuilding Co. provides 99.5% probability that rework involving back strip welding will not be required (see bottom of Figure 5);
2. The one inch margin represents a commitment to 99% rework of the shell plate edge (trimming).

FIGURE AC-14
VARIATION MERGINE EQUATIONS FOR PIPE/HEAT EXCHANGER MATCHUP



ELEVATION VIEW

DETERMINE POTENTIAL MISMATCH BETWEEN PIPE AND HEAT EXCHANGER.

ASSEMBLY SEQUENCE

BUILD D.B. UNIT 1
BUILD & INSTALL FDN. 1
INSTALL PUMP

BUILD D.B. UNIT 2
BUILD & INSTALL FDN. 2
INSTALL HEAT EXCHANGER

JOIN DB 1 & DB 2
INSTALL PIPE

GEOMETRIC EQUATIONS: $G = A - B$

$M + D1 + F1 + P + A = D2 + F2 + H$

THEREFORE: $G = D2 + F2 + H - M - D1 - F1 - P - B$

MEAN OF G $\bar{X}_G = \bar{X}_{D2} + \bar{X}_{F2} + \bar{X}_H - \bar{X}_M - \bar{X}_{D1} - \bar{X}_{F1} - \bar{X}_P - \bar{X}_B$

$= 96 + 48 + 12 - 0 - 48 - 36 - 18 - 54 = 0$

VARIANCE OF G: $S_G^2 = S_{D2}^2 + S_{F2}^2 + S_H^2 + S_M^2 + S_{D1}^2 + S_{F1}^2 + S_P^2 + S_B^2$

$= .04^2 + .02^2 + .01^2 + .02^2 + .04^2 + .02^2 + .01^2 + .06^2$

$= .0082$

STANDARD DEVIATION: $S_G = .0906$

Variation-merging equation for pipe/heat exchanger mismatch during joining of double-bottom tank assemblies

Experience Curve and Relation to Shipbuilding

I. BACKGROUND

A. Definition *of* Concept

1. Experience Curve is the name applied to an observed relationship between costs and acculated experience. The relationship shows that cost of value-added declines at some constant rate as a function of acculated experience.
2. Learning Curve is the name applied to an observed relationship between production output and time spent learning a task. The relationship shows that production output in*creases as a* function of total time spent in learning.

B. History

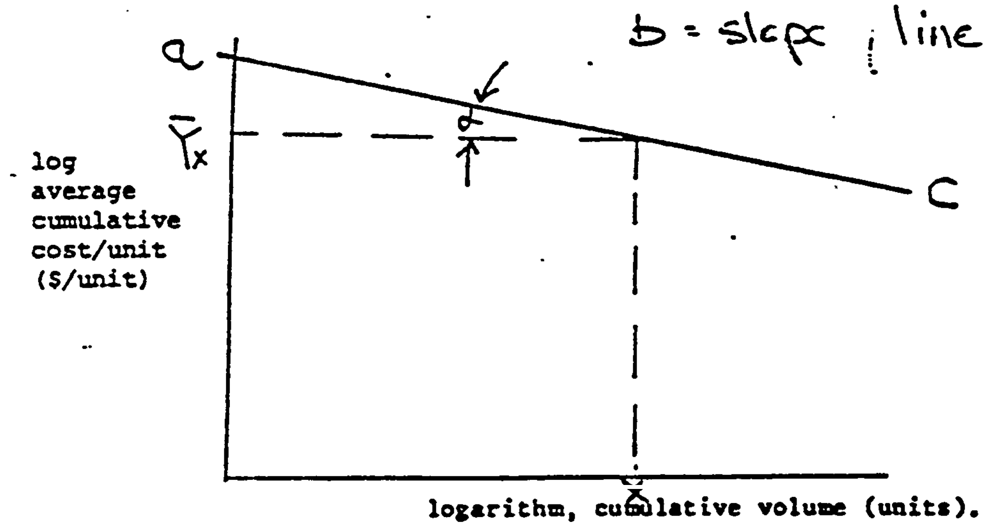
1. Phenomena first observed in Western economic literature in Adam Smith's Wealth of Nations (1776). He discussed the reduction *of* costs that occur in manufacturing pins.
2. Ignored until 20th century as industrial analysts concentrated on new inventions and the design *of* special *purpose* equipment.
3. In 1903 Dr. Frederick Taylor considered l s the "father" *of* industrial *engineering, discussed the phenomena in his* classic text on "shop management."
4. Finally, in 1920 decade, airplane manufacturers began to for-

fully study the phenomena, and to implement methods to encourage it.

5. In shipbuilding experience curve was *recognized* in World War II by all *of* the major maritime combatants. In U.S.A., for example, major planning *effort* existed to reap maximum benefit.

11. FORMULA DEVELOPMENT

A. Average Costs



l - cost of first unit produced

x = total number of units produced

$\bar{Y}_x$ = average cost, x units

b = slope of line $\overline{ac}$

$$b = \frac{\log a - \log \bar{Y}x}{\log x}$$

$$b \log x = \log a - \log \bar{Y}x$$

$$\log \bar{Y}x = \log a - b \log x$$

$$\bar{Y}x = \frac{a}{x^b}$$

B. E<u>xperience *Curve Factor*</u> (X)

1. Experience curve factor is the relationship between average costs each the the total cumulated production is doubled.

$$\frac{\text{Average Cost, "2x" units}}{\text{Average Cost, "x" units}}$$

$$\lambda = \frac{\bar{Y}2}{a} = \frac{\bar{Y}4}{\bar{Y}2} \ldots \frac{\bar{Y}2x}{\bar{Y}x}$$

substituting, $(\bar{Y}2 = \frac{a}{2^b})$

$$\therefore \lambda = \frac{\frac{a}{2b}}{a} = \frac{a}{a.2b}$$

$$\therefore \lambda = \frac{1}{2^b} \qquad (2)$$

2. Research has shown the experience curve factor to be about .90-.95 (for all costs) for merchant ships.

c. Comparison of Costs, and Terms (λ = .935, b = .097)

x	$\bar{Y}x$	Yx	yx
1	100	100	100
2	93.5	187	87
3	89.9	269.7	82.7
4	87.4	349.6	79.9
.	.	.	.
.	.	.	.
.	.	.	.
10	80.0	800	72.8

where:

x = number of units produced

$\bar{Y}$ = average cost of units produced

Y = Total cost of units produced

y = individual cost of last unit produced.

By deduction:

$$Yx = x\bar{Y}x \quad (3)$$

$$yx = Yx - Y(x-1) \quad (4)$$

III. REASONS FOR EXPERIENCE CURVE BENEFITS

A. Learning. As people learn tasks better, they do them faster. Costs are reduced.

B. Specialization. As two people are involved in the same task, it is often possible to break the task into two parts Costs would then decrease faster than otherwise expected.

C. Investment. With incressed sales, capital can be invested to increase productivity (as opposed to capital invested to increase capacity).

D. Scale Effects. . As volume grows materials, supplies, etc. can generally be purchased at lover unit costs. Also fixed costs can be spread over more units.

IV. STRATEGIC PLANNING USES OF EXPERIENCE CURVE

A. Market Share. The return-on-investment increases with market share. The experience curve also favors the producer with largest volume. To achieve this desired position in a developing market, management should strive for early volume advantage.

B. Competition Analysis. By using experience curve phenomena Management can evaluate consequences of different volume price strategies.

C. Procurement Negotiations. Experience curve phenomena can be used to estimate value of a procurement to a supplier.

D. Fixing Break even Volume. Experience curve can be used as simple estimate of number of units that must be sold to recover pre-production costs.

FIGURE EC-I
EXPERIENCE CURVE TO PREDICT COST OF LAST BOAT BUILT

Given.

1. Production run of 10 boats.
2. Experience curve (λ) = 0.9
3. Average cost of 1st/ 2 boats ≐ \$ 2.0 Mil.

Determine :

a. Total cost of 10 boats (Y_{10})
b. Average cost of 10 boats ($\bar{Y}_{10}$)
c. Cost of the 10th boat only (y_{10}).

Solution :

① $\lambda = \frac{1}{2^b} = .9$

$2^b = \frac{1}{.9} = 1.11$

$b = \frac{\log 1.11}{\log 2} \doteq .15056$

② $\bar{Y}_2 = 2.0 = \frac{a}{2^b} = \frac{a}{2^{.15056}}$

$a = 2.0(2^{.15056})$

$\doteq \$\,2.22$ Million

③ $\bar{Y}_{10} = \frac{a}{10^b} = \frac{2.22}{10^{.15056}} = \frac{2.22}{1.414} = \$\,1.57$ Mil.

④ $Y_{10} = 10(1.57\text{ Mil}) = \$\,15.7$ Million.

⑤ $y_{10} = Y_{10} - Y_9$

$= 15.7 - [9(.1595)]$

$= 15.7 - 14.4$

$= \$\,1.3$ Million.

$\bar{Y}_9 = \frac{a}{9^{.15056}} = \$\,1.595$ Mil

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FIGURE EC-II
EXPERIENCE CURVE TO PREDICT BREAKEVEN

Given:

1. Target cost of \$ 7500.00
2. Built and pre-production boats for total cost of \$ 40,000 / 4 bc
3. $\lambda = .90$

Determine:

How many boats must be built to reach target cost for all boats.

Solution:

① $\lambda = \frac{1}{2^b} = 0.9 \qquad 2^b = 1.11$

$$b = \frac{\log 1.11}{\log 2} = .15056$$

② $\bar{Y}_4 = \frac{40,000}{4} = \$\,10,000$

$$\bar{Y}_4 = \frac{a}{4^b} = \frac{a}{4^{.15056}} = \$\,10,000$$

$$a = 10,000 \times 4^{.15056} = \$\,12,321.$$

③ $\$\,7500 = \frac{12,321}{x^{.15056}}$

$$x^{.15056} = \frac{12,321}{7500} = 1.6428$$

$$x = \sqrt[.15056]{1.6428} = 27.032.$$

SAY 28 boats

NATIONAL SHIPBUILDING RESEARCH PROGRAM

DAILY LOG

MODERN SHIPBUILDING METHODS

DAILY LOG

The purpose of this daily log is for you to pick out and record the most personally significant experience of the day and what you learned from it.

This will involve reflecting on:

- what experience during the day was most significant to you personally
- why this was personally significant
- what you learned from it
- any actions you propose to take as a result

Of course, you need not restrict your record to only one experience.

You can also use the daily log to record your thoughts, ideas, insights and feelings. This may include reflections on what worked and what did not work (and why) and ideas for possible improvements. It may include reflections on the relevance of the course experiences to activities and experiences outside of the course.

NSRP SP-9 PANEL SHORT COURSES ON MODERN SHIPBUILDING METHODS

DAILY LOG

DAY 1

WHAT WAS THE MOST PERSONALLY SIGNIFICANT EXPERIENCE?

WHY WAS THIS PERSONALLY SIGNIFICANT?

WHAT DID YOU LEARN?

WHAT ACTIONS WILL YOU TAKE OR PROPOSE AS A **RESULT?**

ALSO RECORD ANY OTHER THOUGHT, IDEAS, INSIGHT AND FEELING

DAILY LOG

DAY 2

WHAT WAS THE MOST PERSONALLY SIGNIFICANT EXPERIENCE?

WHY WAS THIS PERSONALLY **SIGNIFICANT?**

WHAT DID **YOU LEARN?**

WHAT ACTIONS WILL YOU TAKE OR PROPOSE AS A RESULT?

ALSO RECORD ANY OTHER THOUGHT, IDEAS, INSIGHT AND FEELING

MODERN SHIPBUILDING METHODS PERSONAL ACTION PLAN

DESIGN FOR PRODUCTION INTEGRATION

PERSONAL ACTION PLAN

In the light of your thinking and activities during this course, what are now your principal related targets or goals? Write the top three in order of priority:

1.

2.

3.

What actions will be necessary for you to achieve these targets or goals?

Your actions	Other people's action
1.	
2.	
3.	

For each of your three targets or goals, write below something that would be visible evidence that you had achieved them:

1.

2.

3.

Enter the dates that you plan to complete each of your targets or goals:

1.
2.
3.

NAME: **DATE:**

NATIONAL SHIPBUILDING RESEARCH PROGRAM

WORKSHOP EVALUATION

MODERN SHIPBUILDING METHODS

COURSE EVALUATION

We would be very grateful for your feedback on the course. Please complete this evaluation form and return it at the end of the course. Two copies are provided so that you can keep a copy of your evaluation. Thank you!

THE MOST HELPFUL THINGS I LEARNED FROM THE COURSE ARE:

1.

2.

3.

WHAT I LIKED BEST ABOUT THE COURSE WAS:

WHAT I DISLIKED MOST ABOUT THE COURSE WAS:

RECOMMENDATIONS FOR FUTURE COURSES

ANY OTHER COMMENTS?

NAME (OPTIONAL)

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ANY OTHER COMMENTS?

NAME (OPTIONAL)

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