1.1 Principles

Generally, fabrication of components for ships is planned by addressing ship-systems separately and then considering each component in a system to be unique. Thus, an interim product such as a pipe piece is separately planned and scheduled. As just the engine room of a 20,000 deadweight-ton ship contains approximately 3,500 pipe-pieces, custom manufacturing all of them involves large volumes of data and inherently poor productivity.

Group Technology (GT), a management philosophy, features organizing work so that common solutions are applied to common problems. It is the recognized means for acquiring the benefits of mass production for high variety, mixed quantity products. By identifying similarities in manufacturing problems, different products are grouped for similar processing. A variety of products so grouped to match a set of solutions is called a *family*. Hence, GT when applied to fabrication work is called *Family Manufacturing*.

Ideally, the various machines needed to fabricate products of a particular family should themselves be grouped as a *production line*. Thus, instead of operation-by-operation planning as needed for custom manufacturing, all operations that could be performed by a group of machines are regarded as a preplanned single entity. This is called *process categorization*. Applied in a pipe shop it is called *Pipe-piece Family Manufacturing (PPFM)*.

Normally, the total numbers of pipe pieces for each process categorization do not justify redundant equipment installations that would permit every production line to be independently operated. Thus, preplanning for two or more families anticipates that for some operations the production lines merge so that the use of a single machine, e.g., a pipe bender, is fully exploited.

With facilities so organized and operations so preplanned, the average duration for fabrication of a pipe piece of a particular family can be readily determined. Analysis of work required at each stage and summation of the times needed per stage and between stages is the basis for determining the number of pipe pieces that can be fabricated in a flow lane in a given period. This knowledge permits control by lot for a given period, usually a week, which is very effective.

PPFM is a highly advanced production logic. Competitive shipbuilders recognize it as the prerequisite for pipe shop facilities planning. As work flows can be virtual, even where facilities were left unchanged, PPFM simplified planning, enhanced material and production controls and significantly improved productivity.

Determination of families necessarily considers both design and manufacturing attributes. Among the former are size, material type and shape whereas the latter includes:

- the management control system,
- capacities of both the pipe shop and regularly engaged subcontractors, and
- fabrication equipment and its layout.

In shipbuilding, a pipe shop's work load is dictated by requirements to support outfitting with high variety, mixed quantity pipe pieces in a timely manner. However, traditional shop managers subordinate this objective by batch manufacturing identical or nearly identical components as a means for apparently improving productivity. This limited point-of-view causes a significant number of components to be produced well in advance of outfit assembly requirements. Other real costs are ignored, such as:

- the cost of money for earlier than necessary investments,
- direct and indirect costs associated with additional warehousing and material control problems, and
- disruption costs due to forcing design, material definition and material procurement sequences that do not match an ideal outfit assembly sequence.

This limited viewpoint often causes shop resources to be preoccupied with such batches thus increasing the potential for further disrupting assembly operations.

GT also features batch manufacturing but employs different principles. It features grouping products by problem areas to create pseudo-batches which are very effective for bringing the benefits of mass production to internal pipe-shop operations. At the same time, GT permits the production of various types of pipe pieces as required for zone outfitting. The results are gains in both pipe-piece fabrication and outfit assembly productivity.

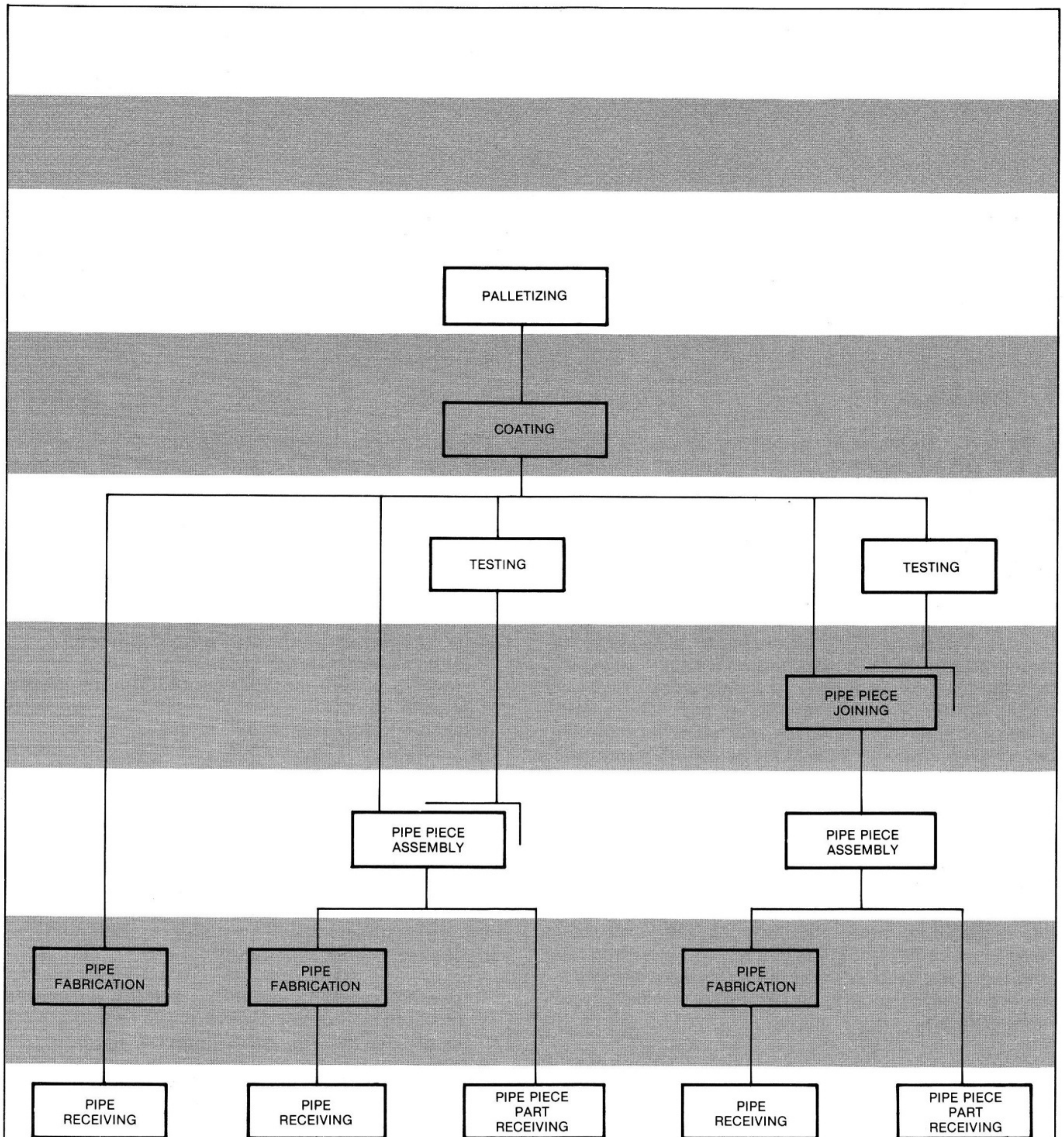

Figure 1-1: Typical Manufacturing Levels for Pipe Piece Family Manufacturing (PPFM). Note that Coating and Palletizing are each a manufacturing level, i.e., each pipe piece is not complete until it is coated and grouped with other required pipe pieces in order to support zone outfitting.

PLAN'G LEVEL	M'F'G LEVEL	PRODUCT ASPECTS: ZONE		PRODUCT ASPECTS: AREA			PRODUCT ASPECTS: STAGE		CODES: ZONE	CODES: AREA	CODES: STAGE
1	7	PALLET		DECK INCLUDING ELECTRICAL	ACCOMMODATION INCLUDING ELECTRICAL	MACHINERY INCLUDING ELECTRICAL	PALLETIZING		PALLET CODE	SHOP NO.	SHOP NO.
2	6			COATING PROCESS			COATING PICKLING	NIL NIL	PIPE PIECE NO.	COATING CODE	COATING CODE
3	5			TEST PROCESS			TESTING	NIL			
4	4	PIPE PIECE	NIL	PIPE MATERIAL/ X-RAY OR NIL/ BORE/STRAIGHT OR BENT/ LENGTH			FINISHING WELDING JOINING MARKING & CUTTING	 NIL	PIPE PIECE NO./ MAIN OR BRANCH SIGN	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
5	3			PIPE MATERIAL/ X-RAY OR NIL/ MAIN OR BRANCH/ BORE/STRAIGHT OR BENT/LENGTH			BENDING ON PIPE PIECE FINISHING WELDING ASSEMBLY CUT PIPE JOINING	NIL NIL NIL NIL			
6	2	CUT PIPE	NIL	PIPE MATERIAL/PIPE MAIN OR BRANCH/ BORE			MACHINING BENDING ON CUT PIPE MARKING & CUTTING	NIL NIL 			
7	1	MATERIAL		PIPE	PIPE PIECE PART		RECEIVING		MATERIAL CODE	MATERIAL CODE	NIL

Figure 1-2: Typical Classifications of Product Aspects for Pipe Piece Family Manufacturing (PPFM). *System* is absent and *zone* has virtually no significance until palletizing. Pipe shop organization is based only on problem *area* and *stage* except for palletizing. Typical problem area subdivisions are presented in Appendix A.

The goal for selecting families and planning their routes is to utilize production-line principles. A production line frees workers from having to plan a work sequence for each pipe piece. Instead, they concentrate on executing normal work processes. Because of this expertise, workers are better able to participate in constant evaluation and improvement of work methods. However, a production line cannot free workers from unnecessary, repetitive planning chores unless:

- fabrication problems are anticipated by people who perform design and material definition, and
- shop planning and scheduling is consistent with production-line principles.

The production-line principles are:

- standardization of processes,
- simplification and specialization of operations,
- establishment of fixed work stations,
- moving work pieces along a fixed route, and
- designating positions for workers or teams of workers.

Figure 1-1 illustrates typical manufacturing levels and basic logic used by a competitive shipbuilder to organize production lines and work flows for both manual and automated operations. *Coating* and *palletizing* are each included as a distinct manufacturing level necessary for supporting zone outfitting.

Figure 1-2 shows associated classifications consistent with a product-oriented work breakdown.[1] The product aspects described are noteworthy. *System* is absent and *zone* has virtually no significance until palletizing. As long as each pipe piece is produced by its scheduled pallet date, the organization of production lines and work flows are based only on problem *area* and *stage*. In other words, pipe-shop operations are idealized without being encumbered by having to separate pipe pieces per ship or per system.

Figures 1-1 and 1-2 are examples of the logic necessary for any mix of pipe-piece requirements to establish:

- pipe-piece families,
- production lines, and
- work flows which optimize use of facilities.

1.2 Design

As shown in Figure 1-3, modern shipbuilding technology requires that design be truly an aspect of planning. As a design effort progresses, planning requirements change formats in order to:

- describe a ship as a system,
- address individual systems,
- provide an interrelationship between systems and zones,
- produce design details organized by relatively small increments for assembly work classified by zone, problem area and stage, and finally,
- subdivide the latter into work instructions for prerequisite fabrication work.

1.2.1 Functional design is the first stage for planning fabrication activities. For pipe-piece fabrication several key elements are determined:

- diameter,
- material,
- service pressure,
- testing requirements by system, and
- surface treatment.

Using standards as much as possible, functional designers define *all* material requirements for each system diagrammatic. The material so identified is also organized by relatively large zones sequenced in the order that a ship will be erected. The format for such integrated information is called: MLS - Material List by (ship's functional) System (by purchasing zone).

MLS indicate what materials are required and approximately where and when they are required. Although portions are necessarily estimates, MLS are practical enough for fast start-up of material ordering before detail design commences. Early resolution of difficult material procurements is essential for productive PPFM.

1.2.2 Transition design addresses the shift from system to zone orientation. As shown in Figure 1-4, system diagrammatics are quickly routed, often freehand, on machinery arrangement drawings. These serve as analytical tools for examination of such aspects as:

- access for safe and efficient equipment operation,
- relative positions of piping and hull structure,
- maximum utilization of straight pipe,
- pipes grouped in parallel to facilitate assembly,
- access for outfitting on-unit, on-block and on-board, and
- inclusion of all systems.

[1] "Product Work Breakdown Structure - November 1980" by Y. Okayama and L.D. Chirillo for the National Shipbuilding Research Program.

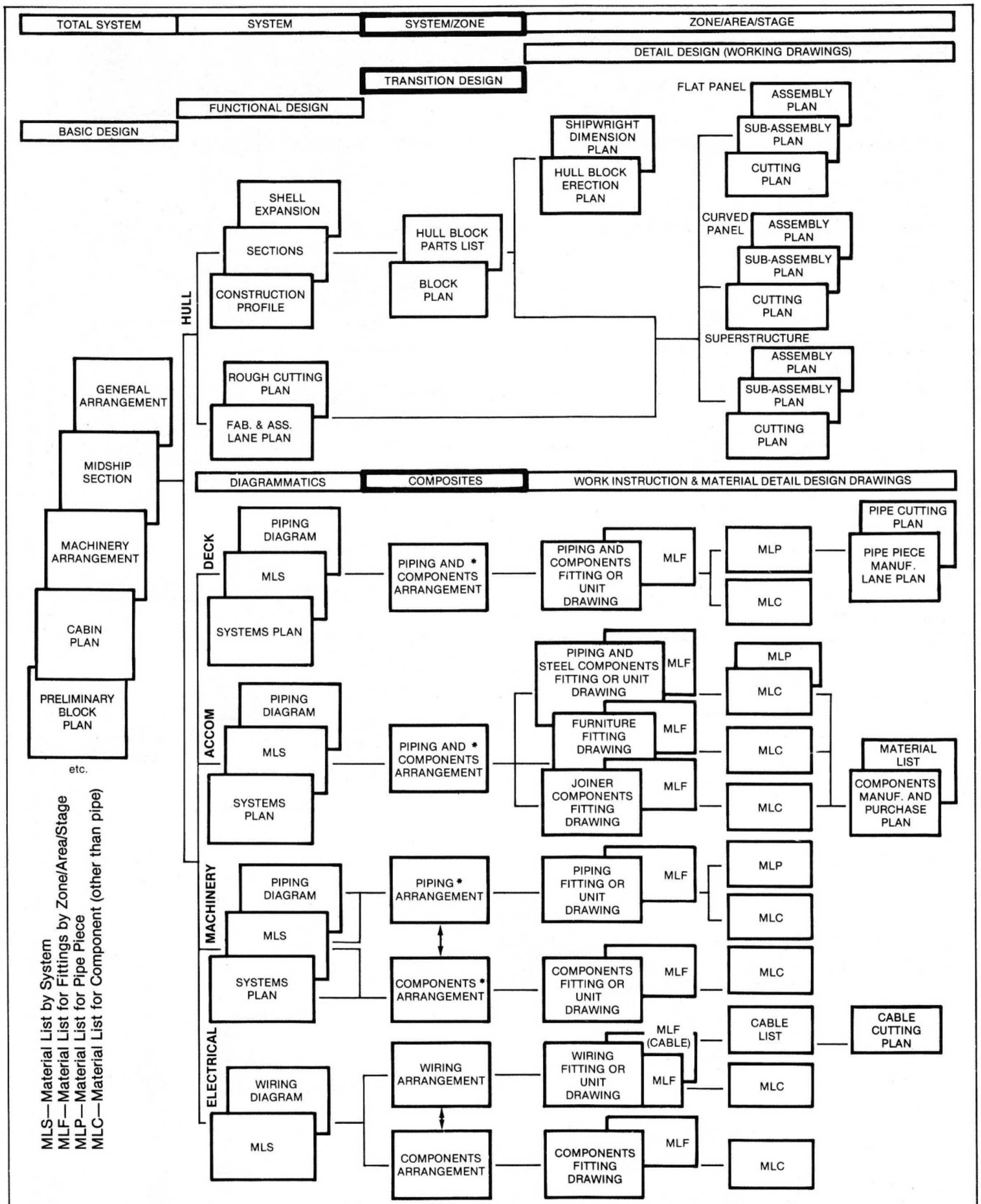

Figure 1-3: Product-oriented Design Process. Transition Design introduces zones and interrelations with systems. The items marked "*" are for quickly conveying arrangements and system/zone relationships to detail designers. The latter refine arrangements and incorporate stage designations as they prepare work instruction and material detail-design drawings.

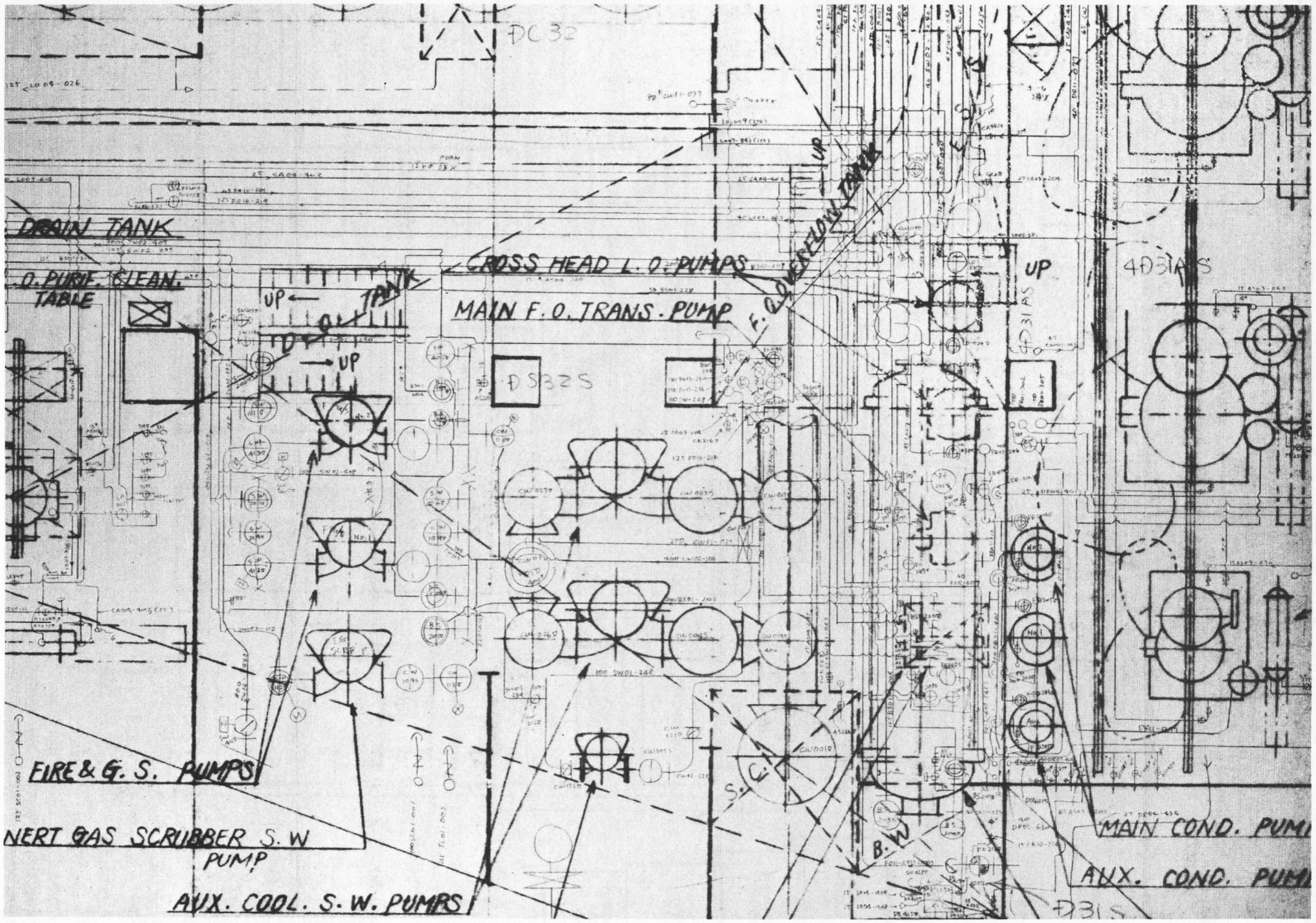

Figure 1-4: Outfit Transition Design. In order to quickly relate systems and zones, machinery-space arrangement specialists arrange diagrammatics together. Relative positions of distributive systems, including fittings such as valves, are frequently adapted from a file of design modules and/or anticipate work packages classified by zone/problem area/stage.

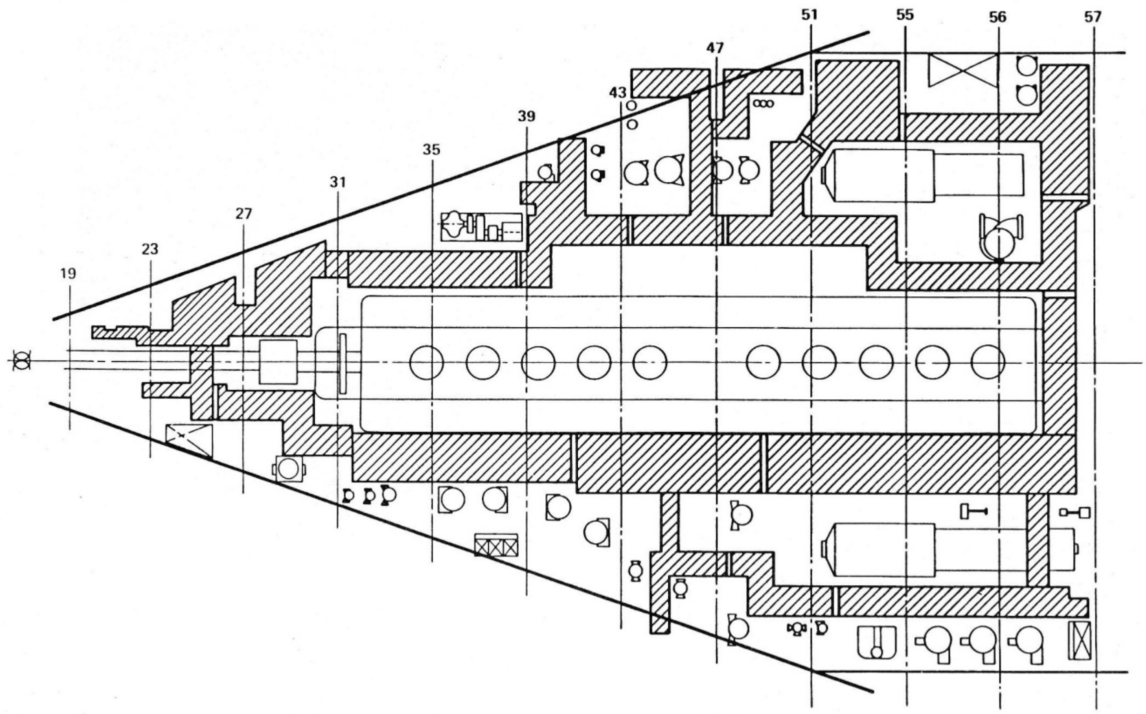

Figure 1-5: Preconceived Arrangement Zones are useful during transition design for grouping straight pipe in parallel and standardizing bends as much as possible. Pipe runs do not follow hull curvature.

Transition analysis requires the most experienced designers because it determines outfitting costs. Further, it impacts on maintenance costs during a ship's lifetime. During transition analysis, designers incorporate straight pipe in parallel as much as possible in pre-conceived *arrangement zones*.[2] Clearly, a designer's systematic incorporation of straight and parallel pipe-runs greatly impacts on the productivity of both pipe-piece fabrication and outfit-unit assembly; see Figure 1-5.

Typical goals for transition designers are:

- equal distribution of pipe-runs to port and starboard,
- equal distribution of pipe-runs on all levels,
- minimum total pipe length in order to minimize pressure drops and material costs,
- valves on operating sides of machinery,
- branches on machinery sides of mains,
- straight pipe-runs beneath passages around the main engine and auxiliary machinery,
- straight pipe-runs incorporating only 45° and 90° bends, and
- preliminary arrangement of all diagrammatics for pipe 15 millimeters diameter and larger.

Usually, the output of transition design features plan views only. Elevations are limited to complicated arrangements. Transition design produces a master which facilitates control when work-instruction (detail) design is apportioned to a number of people.

1.2.3 Work-instruction design at first produces a composite, as illustrated in Figure 1-6, which incorporates details such as exact delineation of pipe pieces and their orientations to each other and to other fittings. Alternative methods for creating and maintaining a detailed composite design are:

- scale models, and
- computer-operated interactive graphics.

A common inefficiency, often imposed by owners and sometimes by shipbuilders themselves, is the use of more than one of the above methods for simultaneously maintaining the same composite design. Some compound this inefficiency by further requiring unneeded system-arrangement drawings. As a result, design manhours are unnecessarily consumed and, more seriously, detail-design progress is impeded. Progress is especially retarded by attempts to coordinate use of two methods for the same composite, e.g., drawings plus a scale model.

[2] Arrangement zones are described in Chapter 3.0, "Outfit Planning - December 1979" by C.S. Jonson and L.D. Chirillo for the National Shipbuilding Research Program.

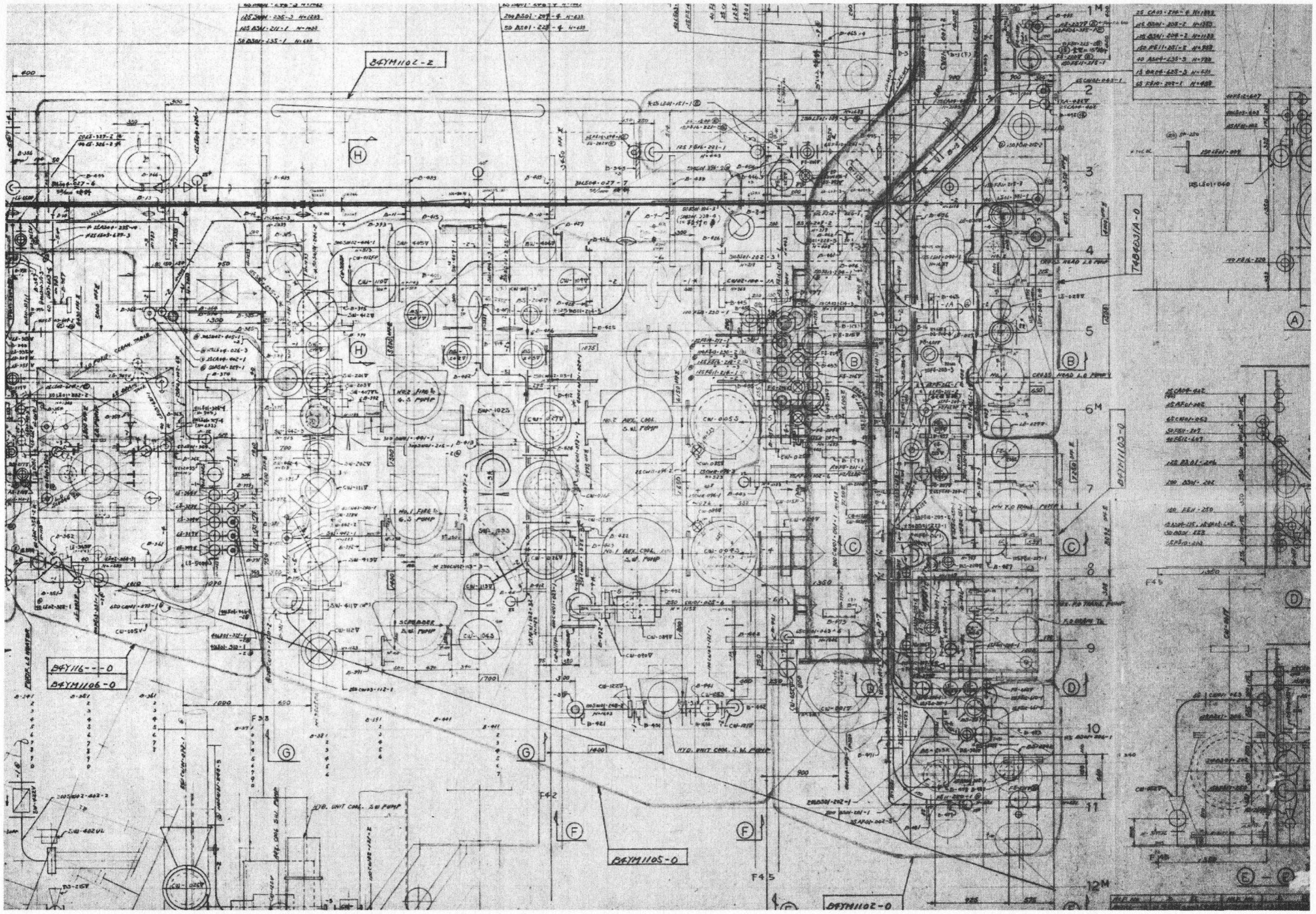

Figure 1-6: Detail Fitting Arrangement. This composite drawing is marked to show zone demarcations. Zone/problem area/stage classifications are coded in work package numbers such as B4YM1105-0. Generally, only plan views with single-line representations of pipe pieces are sufficient. Elevations and double-line representations are limited to complicated regions. Pipe pieces are defined by families and associated with work packages on composites, i.e., before time is taken to produce pipe-fabrication details.

Detailed composites of any kind are required by shipbuilders only for:
- material definition,
- orientation of fittings relative to each other for assembly work instructions, and
- details sufficient for fabrication work instructions.

As practical methods exist for readily digitizing from both composite drawings and scale models, computers can supplement any technique used for *creating* a composite design.[3] Computers are already used to produce pipe-piece fabrication instructions, including their material lists, in various formats, e.g.:
- orthographic (Figure 1-7),
- isometric, and
- symbolic (Figure 1-8).

Symbolic pipe-piece details, now widely accepted, are preferred because they are digitized. They are readily combined and computer processed together with pertinent production control data, e.g., pipe-piece family identifiers, assembly-work package numbers and material lists. Start fabrication and palletizing dates are incorporated so that a single portion of a printout contains all needed planning and scheduling data for each pipe piece. Obviously, necessary revisions are easier to control when all required information appears on one document.

When work instructions are less geometric and more numeric, the necessity for accuracy is reduced to essentials. Even when computers are used, more wherewithal is needed to produce geometrically accurate sketches. On geometrical sketches everything must be accurate, whereas on numerical presentations only major points must be accurate.[4]

Although digital notations are more effective and more naturally processed by computers, some shipbuilders continue to apply computer-aided design tools to produce conventional pipe-piece sketches and their material lists. Some are computer-producing sketches and employing independent material control programs. There is inherent duplication of effort and significantly increased opportunity for human error. Producing pipe-piece *sketches* by computer can be justified if it is an interim measure pending:
- training workers to interpret digitized notations, or
- adoption of numerically-controlled fabrication methods.

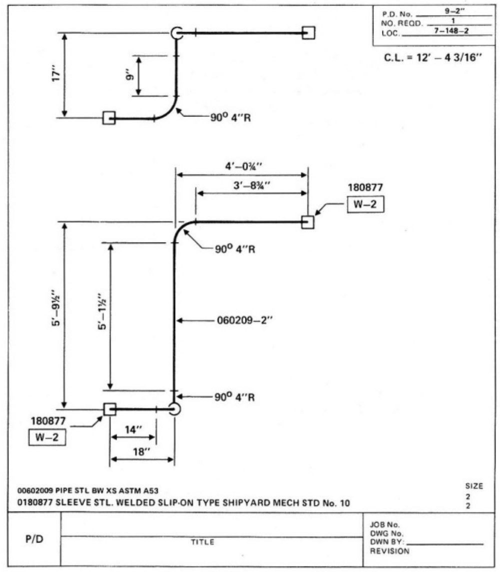

Figure 1-7: Orthographic pipe-piece fabrication-work instruction.

Otherwise, the computer is being used to produce more accurately and more quickly, archaic notions. This is a paradox.

Regardless of the degree of automation, designers must provide the following data as appropriate for each pipe-piece work instruction:
- required length of raw pipe,
- required other materials, e.g., flange, elbow, tee, etc.,
- angle and dimensions for bends,
- margins required for bender grip and flange fitting,
- angle between main and branch,

[3] "Photogrammetric Dimensioning of Ships' Engine-room Models-March 1981" by J.F. Kenefick and L.D. Chirillo for the National Shipbuilding Research Program.

[4] Attributed to K. Ogawa, IHI International Division by C.J. Starkenburg, Avondale Shipyards, Inc. , in the presentation "Implementing IHI Technology at Avondale" to the REAPS Technical Symposium 14-16 October 1980, Philadelphia, Pennsylvania.

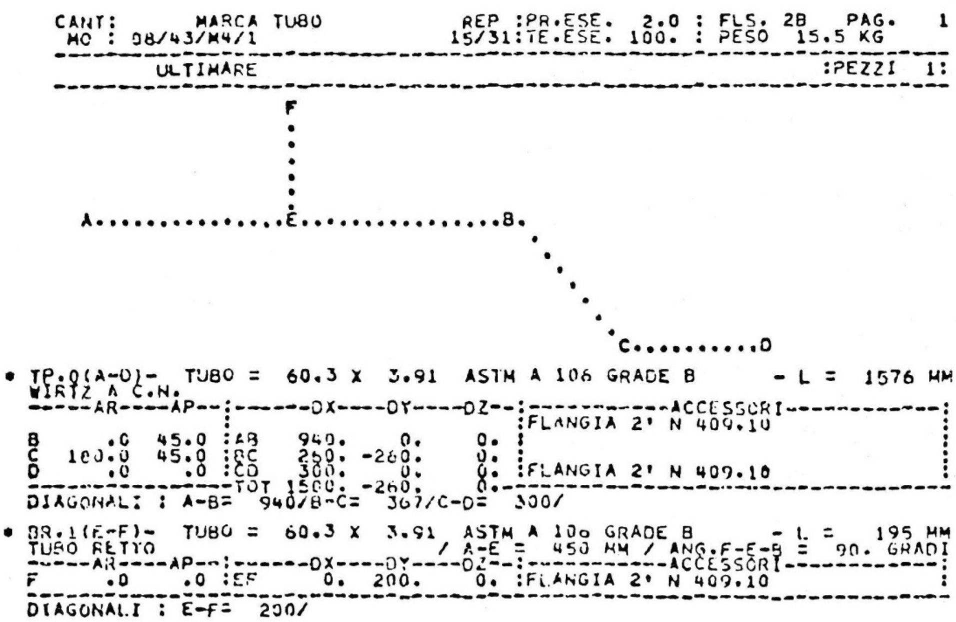

Figure 1-8: Symbolic pipe-piece fabrication-work instructions are natural for cost-effective computer processing.

- flange orientation,
- branch shape,
- branch position,
- material quantities for a complete MLP,
- finishing requirements,
- family identifier,
- end preparation for welding,
- welding specification,
- pallet identification,
- pipe-piece identification,
- special work instructions (e.g., loose fitting a flange),
- flange thickness, and
- distance from flange face to branch centerline, etc.

Figure 1-9 illustrates how such data can be coded and applied to a specific pipe piece.

Many pipe-piece drawings must be developed for each new ship design. The design process follows clearly defined steps some of which require much computation. Others require repetitive reference to basic design data. Thus, computer-aided design tools improve timeliness, accuracy and productivity. Such programs typically provide:

- input-data error checking,
- modification of input data via standards,
- exact material quantities,
- fabrication information, and
- data used for estimating, planning, scheduling, executing and evaluating, e.g., type and length of weld per pipe piece, painting area per pipe piece, man-hours per pipe piece, man-hours per unit weight, weight per pipe piece, etc.