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A REVIEW OF DEVELOPMENTS IN SHIPBUILDING TECHNOLOGY AND THE POTENTIAL FOR APPLICATION TO NAVAL SHIPBUILDING IN AUSTRALIA

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ABSTRACT

In February 1976, the joint U.S. government/industry National Shipbuilding Research Program (NSRP) engaged a leading Japanese shipbuilding company in a technology transfer contract. The publications resulting from this ongoing program identify the logic and principles employed by a competitive shipbuilder for the design and construction of vessels of all types, including naval vessels.

The paper presents a brief history of the development of modern shipbuilding methods in Japan, reviews the logic and principles identified in the NSRP publications and discusses some of the implications of this research and potential application to the Australian naval shipbuilding industry.

"In Japan we have to control material because we cannot control people."

Y. Mikami
Senior Manager
IHI Marine Technology Inc.

INTRODUCTION

The Australian shipbuilding industry has been an unsteady one for some time. In recent years, the Australian Department of Defence has placed orders with Commercial and Government owned shipbuilders for a variety of ship types. This is a good trend, but shipbuilding is a competitive industry on a worldwide basis and, in order to secure the future of the Australian shipbuilding industry, the industry must be able to prove that it is at least cost effective in comparison with the shipbuilding industries of other competing countries. Thus, there is a need for the efficiency of the industry to be compared with that of overseas shipbuilders.

The Japanese shipbuilding industry has emerged over the past two decades as the most successful of all countries including America, Europe and the U.K., although other South-East Asian countries, such as South-Korea, are becoming increasingly competitive. A direct comparison of the Australian shipbuilding industry with the Japanese shipbuilding industry is often considered inappropriate because of significant differences between the type of vessels built, the number of vessels of similar type built, differences in labour and material costs, the level of Government support to the industry and cultural differences between the Japanese and Australian industrial society, particularly in relation to the proliferation of Trade Unions in the Australian industry.

Previous analyses of the Australian shipbuilding industry, such as that by the Australian Government Industries Assistance Commission (1), have looked at pricing, industrial relations, import restrictions, subsidies, duty and taxation exemptions, investment and research finance, credit facilities and other assistance to shipbuilders and ship owners. These studies have also briefly addressed the production methods used by overseas shipbuilders. For instance, from (1):

> "Many...overseas yards have achieved a high degree of mechanisation in fabrication shops, including computerised numerically controlled cutting machines, remote control conveyors and automatic panel assembly lines, and extensive use of automatic welding. Many yards use assembly of maximum size units, early outfitting under cover and large capacity berth cranes." This reference goes on to add that "...the introduction of multiple orders for large vessels has led to the maximum use of mechanisation and increased construction efficiency in the leading overseas shipbuilding nations."

Another previous report on Shipbuilding in Australia by the Industrial Mobilisation Course, 1974 (2) said that it has been suggested that Japan's strength has been in its "solid strata of 'middle-class' technicians and engineers from a high standard of education and the support from powerful back-up industries."

The question that perhaps was not asked, however, was whether this view of the production methods used by the leading overseas shipbuilding nations represented the complete story. How did shipbuilding nations, such as Japan, establish their superiority over the established shipbuilding nations such as the U.K. and America?

DEVELOPMENTS IN SHIPBUILDING TECHNOLOGY

In order to understand the problems facing the Australian shipbuilding industry, it is necessary to understand the evolution of shipbuilding technology and the changes which have influenced the international shipbuilding scene.

The Australian shipbuilding industry clearly has its origins in the British shipbuilding industry. The innovations of engineers such as Brunel, and Scott-Russell pioneered the transition from wooden to iron ships during the industrial revolution. Thornycroft and Yarrow pioneered the development of the motor torpedo boat and the torpedo boat destroyer which have since evolved into the modern destroyer/frigate as we know it today.

These vessels were designed as an assembly of functional systems. As succesive classes of ships evolved, those functional systems became more and more complex. For early steel ships, the hull structure represented the major proportion of the cost of the vessel. Today, the hull structure of a warship accounts for only some 10% to 20% of the labour cost of a vessel, whilst outfitting work, painting and testing activities account for the remainder.

The methods used for the construction of early iron ships also evolved on a functional system basis: the keel was laid as a system, then the transverse and longitudinal framing followed by the shell plating and decks, etc. Upon the completion of the watertight hull structure, the vessel was launched and outfitting was completed "on-board".

The organisation of labour involved in accomplishing the work also evolved on a system-by-system basis with each trade specialising in a particular aspect of the total work. Thus, for the traditional ship design and construction process, there was compatibility between the organisation of the design information, the construction method and the organisation of the labour involved. This fundamental organisation was essentially oriented towards functional systems.

The introduction of welding meant that pieces of different individual systems could easily be joined together. For example, pieces of frames could be joined to parts of shell plating to form panels and blocks. The panel could incorporate parts of decks, bulkheads and a keel. Thus, much assembly work was shifted from the building ways to platen areas in or near workshops where work is performed with greater safety, efficiency and accuracy.

The American shipbuilding industry also owes its origins to that of the British shipbuilding industry. The most remarkable improvements in U.S. shipbuilding were pioneered by Henry Kaiser during World War II. Kaiser was an industrialist who was well known for tackling major civil engineering projects. As a newcomer to the shipbuilding industry, Kaiser applied industrial engineering principles to the construction of ships and outproduced established shipbuilders (3).

Chirillo (3) states that:

> "The record shattering performance was due to Kaiser's introduction of the rudiments of Group Technology, i.e. organising work by the problems inherent in manufacture. In this manner, Kaiser's yards were achieving benefits normally associated only with production lines even while producing many different subassemblies in varying quantities as required for building ships. The Kaiser principle was to organise work to fit the worker instead of vice-versa."

After World War II, there was a glut of shipping capacity and much of the expertise gained in the U.S.A. was dispersed. Elmer Hann was a former General Superintendent of Kaiser's Swan Island Shipyard in Oregon where he had been responsible for all production work. After WW II, he found employment with National Bulk Carriers (NBC) of New York. At that time, NBC were seeking a shipyard with the capacity to build large carriers for the iron-ore trade between Venezuela and the United States. A world-wide search was conducted and finally, a lease was arranged for the Japanese Naval Shipyard at Kure which had not been damaged during the war.

Elmer Hann introduced to Kure the shipbuilding technology that had been gained during the construction of ships during WW II in America. Chirillo (3) states that Hann advised the following in a personal communication:

> "Our all-welded construction was introduced into Japan for the first time, to the fullest extent allowed by the classification society. We used the American Bureau of Shipping...as most of our machinery ...came from the U.S.A. for the first several years."

> "Job and material controls were organised into one department. Sequence and scheduling of work was carefully planned and closely monitored along with quality control and inspection which were kept separate from production departments."

With reference to Dr Shinto's own account of this task (9):

> "While I was analysing in detail the complete sets of basic design drawings and engineering data for contemplated airplanes, which were supplied by the Navy, I noticed that engineering information and data issued by the engineering department were in full coincidence with the detail items for the production system. In other words, I was strongly impressed by the fact that all necessary information and data required for each stage of the production system, such as material flow, fabrication, sub-assembly, assembly and final erection, were clearly described in detail sheets by breaking down the detail design drawings, which essentially deal with the finished product (that is the functional design of the airplane)."

With encouragement from Elmer Hann, Dr Shinto led a small team of engineers and applied the production engineering methods which he had observed for the manufacture of aircraft to the construction of the bulk carriers for NBC. The methods were first applied to hull steelwork and subsequently to outfitting work. Shinto (9) stated that this method of outfitting was considered to be complete by 1958-1961. At this stage of progress, building costs at the Kure Shipyards Division of NBC showed marked differences from other Japanese shipyards (9).

Chirillo (3) also states that Hann recalled:

> "One salient feature of the lease required an open door policy for Japanese ship-construction engineers along with training if so desired by bonafide companies (on a cost basis). During our tenure, between four- and five-thousand persons visited our plant and studied methods and techniques being employed."

Both Chirillo (3) and Shinto (9) acknowledge the contribution of another American, Dr Edwards Deming, to the development of the Japanese shipbuilding industry. Dr Deming, a professor of mathematics, was invited to visit Japan in 1950 by the Japanese Union of Scientists and Engineers (JUSE) to give lectures on the application of statistical methods to the control of industrial processes. During this visit, Dr Deming gave 35 lectures to Japanese top managers and engineers. In 1960, Dr Deming was honored by an award from the Emperor of Japan in recognition of his valuable contribution to Japanese industry. By 1981, Dr Deming had made 19 visits to Japan. Chirillo (6) advises Deming's theorem based on analyses of many manufacturing and service industries:

> "Only 15% of losses resulting from variations are due to special causes, i.e. by workers or machines. The remainder are causes common to management's system."

In 1960, Dr Shinto joined Ishikawajima-Harima Heavy Industries (IHI) as the General Manager of the Shipbuilding Division following the merger of Harima with Ishikawajima Heavy Industries. NBC's lease of the Kure Shipyard facilities expired in 1961 and the staff were transferred to the Kure Shipbuilding and Engineering Co. Ltd. which merged with IHI in 1968. Thus, the expertise which had been transferred from America to Kure by NBC, was passed on to IHI after further development and refinement, principally under the guidance of Dr Shinto.

In 1963, the Australian representative of IHI, Dr Hashimoto, invited Mr Desmond Wittwer to visit Japan. Mr Wittwer was, at that time, the General Manager of Australia's Whyalla Shipbuilding and Engineering Works, a subsidiary of Broken Hill Pty. Ltd. (BHP). As a consequence of this visit, a technical co-operation agreement was signed between IHI and BHP which made provision for Whyalla shipyard staff to visit IHI's shipyards to gain practical experience of their ship production engineering design and shipbuilding methods and for IHI personnel to visit the Whyalla shipyard to provide assistance.

From this time onwards, engineers and draftsmen from the Whyalla shipyard made regular visits to IHI's shipyards at Kure, Aioi and Tokyo. A particular interest was held in IHI's Aioi shipyard due to the fact that this shipyard built vessels of similar size to those which were planned to be built at Whyalla. As the technical cooperation agreement made provision for a two-way exchange of personnel, IHI officers also spent considerable time in the Whyalla yard instructing and advising on the special application of the "hull-block construction" and "zone outfitting" methods.

In addition to assisting BHP with technical aspects of basic ship design, such as hydrodynamic tank testing, IHI provided assistance to BHP in the preparation of the functional diagrammatics required for classification society approval, followed by the preparation of zone-oriented composite drawings and material lists for the construction and outfitting of hull blocks. This was in contrast to the conventional detailed system-oriented production drawings that Whyalla had prepared for previous ships that they had built. The zone-oriented structured material lists, which were prepared in conjunction with the composite drawings, provided the material definition required for marshalling materials into pallets for efficient outfitting.

Thus the basis of the advanced methods which were used by IHI and which had been developed through their association with NBC, were introduced to Australian commercial shipbuilding in the 1960's by the Whyalla Shipbuilding and Engineering Works. These methods were used successfully for the construction of a number of vessels at Whyalla with a substantial improvement in productivity.

As a part of the study in 1976 of the Australian Shipbuilding Industry (1), the Australian Industries Assistance Commision sought information on trends in labour productivity, both for inter-yard comparisons and intra-yard comparisons over time. The index of tonnes fabricated per employee, which was quoted in the 1971 Australian Tariff Board report, was criticised as it may vary widely for different types of vessels for reasons other than worker productivity. A more satisfactory measure of labour productivity was said to be an index recommended by the British Ship Research Association (BSRA). This index calculates the "equivalent" steel weight of the vessel by taking account of a number of factors such as ship type and weight, whether it is the first of a multi-series of vessels and whether any special features are required. The resulting steel weight is divided into the total steel manhours. As such, the index only relates to the hull-construction trades and does not include the outfitting and painting trades or management overheads.

The BSRA labour index provided by BHP for the Whyalla shipyard showed a labour productivity improvement of about one third between 1969 and 1976, compared with that measured by another Australian shipbuilding yard, the Newcastle State Dockyard, which showed only a marginal improvement in man-hours per tonne. It would have been very interesting had outfitting labour productivity been measured also. The IAC report (1) made no attempt to identify the reason for the improvement in the performance by the Whyalla shipyard and thus did not seem to attach any significance to the improvement.

In 1978, following an extensive Government inquiry (1) into the level of assistance that should be provided to the Australian shipbuilding industry, BHP decided to close the Whyalla Shipbuilding and Engineering Works. The decision was perhaps inevitable in view of the limited Australian market for ships of the type that Whyalla was accustomed to building. Despite improvements in productivity, Whyalla Shipyard's ability to compete in the export market was affected by the changes to the level and type of financial assistance provided by the Australian Government to Australian shipbuilders and shipowners when compared with the total level of financial assistance given to competing overseas shipbuilders and shipowners by their respective Governments. Another major factor which contributed to the decision was that the predicted market was for ships that were considerably bigger than the capacity of the existing slipway facilities at Whyalla. The major constraint in this respect was the limited width of the slipway. Changes to increase the capacity of the facilities would have required substantial capital investment which could not be justified under the prevailing circumstances.

In hindsight, the decision to close the Whyalla Shipbuilding and Engineering Works was a major blow to the further introduction of zone-oriented shipbuilding methods to the Australian shipbuilding industry. Following the closure of the yard, former employees were scattered throughout Australian industry. Although some of these trained people found employment with the Australian Department of Defence, they had insufficient authority to influence the methods used by the Department of Defence for the production engineering design and construction of ships for the Royal Australian Navy (RAN).

ZONE-ORIENTED SHIPBUILDING METHODS

The National Shipbuilding Research Program (NSRP) was established in the U.S.A. in 1970 as a co-operative effort by the Maritime Administration's Office of Advanced Ship Development and the U.S. shipbuilding industry. Guidance is provided by the Ship Production Committee of the Society of Naval Architects and Marine Engineers (SNAME). The program features pragmatic research projects on a cost sharing basis by major shipbuilders on behalf of the entire U.S. shipbuilding industry.

During 1976, following visits to Europe and Japan, the managers of the NSRP concluded (3) that:

> "The IHI shipbuilding system was the most developed in the world and was even regarded as such by other shipbuilders in Japan".

Furthermore, they discovered that:

> "the shipbuilding system was thriving and constantly being improved in IHI's three pre-WW II shipyards, i.e. Kure, Aioi and Tokyo, particularly for one-of-a-kind ships and for end products other than ships."

As a consequence of this visit, in 1976 the SNAME Ship Production Panel SP-2 initiated a program involving a transfer of Japanese shipbuilding technology from IHI to the U.S. shipbuilding industry.

In his paper entitled "Shipbuilding is a Science", Chirillo (5) states that the best overall framework for the effective shipbuilding methods developed by IHI is documented in the NSRP publication "Product Work Breakdown Structure" (PWBS) which was published in November 1980 and revised in December 1982. The organisation of work described in PWBS illustrates how zone-oriented methods and Group Technology can be applied to shipbuilding. Group Technology is a rationale for achieving the benefits of mass production for the manufacture of a variety of products in widely varying quantities. PWBS illustrates how these principles are applied to the many parts and subassemblies, known collectively as "interim products", which characterise shipbuilding.

The Product Work Breakdown Structure categorises inherently different shipbuilding work in accordance with three zone-oriented methods. These methods are:

- Hull-Block Construction Method (HBCM)
- Zone Outfitting Method (ZOFM)
- Zone Painting Method (ZPTM)

Further classification by zone, problem area and stage is utilised to enable the effective use of both real and virtual production lines for the many different interim products required to build a ship. In this context, the zone classification represents a geographic subdivision of the ship and describes what is to be manufactured; the problem area classification, when matched to an industrial process, represents how a product is to be manufactured; and the stage classification, as a subdivision in time, represents when a product is to be manufactured. A real production line is one in which the product moves from workstation to workstation whereas in a virtual production line, the product remains stationary whilst the workers move.

A fourth supporting method, known as the Pipe Piece Family Manufacturing Method (PPFM) is problem area/stage oriented and facilitates the application of Group Technology for the manufacture of parts such as pipe pieces.

The relationship between these methods for hull construction, zone outfitting, zone painting and pipe piece family manufacturing is illustrated in figure 1.

For the Hull Block Construction Method, the zone classification breaks the ship down into blocks, sub-blocks and piece parts. The problem area classification, for example, separates the manufacture of flat panels from the manufacture of curved panels, whilst the stage classification identifies different stages in the assembly process, such as the bending of parts, plate joining, framing and erection.

The primary objective in the HBCM is the identification of ideal hull blocks, or zones, recognising that the definition of these blocks impacts the subsequent efficiency of zone-outfitting and painting operations. Thus, the definition of hull blocks, compared to the definition of other interim products, has the greatest influence on shipbuilding productivity.

The application of statistical methods to the control of industrial processes required for shipbuilding is a feature of the methods used by IHI to improve the efficiency, quality and accuracy of production operations. However, Chirillo (5) states that;

> "Statistical control theory can only be applied successfully when manufactured interim products are classified by the problem areas that their manufacture imposes, i.e. in accordance with the principles of Group Technology."

This classification of problem area is one of the classifications inherent in the PWBS. When interim products are classified in this way so that they match pre-planned production lines, the same work situation is sufficiently repeated for statistical analysis and control to be performed.

When applied to ship hull production, such statistical process analysis is called "Accuracy Control". Accuracy control helps managers and workers to quantitatively identify those manufacturing variations which are normal from those which are abnormal, thus focusing management attention on problem areas which affect productivity, quality and safety. The analytical identification of problems leads to spontaneous quality circles in which everyone is involved in solving the problem so as to constantly improve productivity.

To assist with the introduction of Accuracy Control to the U.S. shipbuilding industry, the NSRP have published the book "Process Analysis via Accuracy Control" (12). This publication documents the methods used by competitive shipbuilders to monitor and control the variation in the geometry of interim products in order to achieve overall improvements in productivity and quality.

An important method used by Japanese shipbuilders to control the accuracy of structural pieces, sub-assemblies and assemblies is the technique of "line heating". To many conventional shipbuilders, the practice of line heating is more of an art than an industrial process to be used to advantage. In order to change this attitude, the NSRP have published the book "Line Heating" (13) to explain the method in detail.

The zone outfitting method divides outfitting operations into three zone classifications:

- on-unit
- on-block
- on-board

For "on-unit" outfitting, outfit components are grouped into packages which can be assembled and tested on a foundation independent from the ship's hull structure. Thus, zone outfitting separates outfitting as much as possible from dependence on hull construction progress and from arbitrary control as part of a ship's systems. The zone outfitting method is described in the NSRP publication "Outfit Planning" (14).

By comparison, conventional pre-outfitting breaks the outfitting process into only the two basic zone classifications of "on-block" and "on-board". Pre-outfitting applies resources earlier than traditional "on-board" outfitting by outfitting large structural sections prior to erection of a hull. This necessitates construction of steel assemblies in a sequence which is probably not optimum for maximising steel throughput with minimum expenditure of resources. Pre-outfitting also requires the allocation of appreciable time and facilities and is usually planned by allocating resources to activities associated with ship's systems.

The zone-outfitting method identifies the following product-oriented problem area classifications for outfitting work:

- Deck Outfitting
- Accommodations Outfitting
- Machinery Outfitting
- Electrical Outfitting

For warships, a weapons specialty is added as well. Deck outfitting includes everything that is not in accommodations, machinery or weapons spaces. Electrical outfitting addresses all spaces respectively.

A feature of the zone-oriented methods documented by the NSRP is that painting requirements are rightfully accorded the same priority as hull construction and outfitting. The NSRP publications "Zone Painting Method" (17) and the associated descriptive overview (18) document the application of zone-oriented methods to the surface preparation and painting of ships.

Another NSRP publication "Pipe Piece Family Manufacturing" (19), addresses the design, material definition and manufacture of individual piece parts and their subsequent sorting into pallets as required for efficient zone outfitting. Although this publication uses the manufacture of pipe pieces as an example, the methods are also applicable to the manufacture of other interim products such as ventilation trunking and the cutting and sorting of electrical cable.

The integration of these methods into a shipbuilding system, as developed by Japanese shipbuilders, has been documented by the NSRP in the publication "Integrated Hull Construction, Outfitting and Painting" (11). This publication emphasises the need to involve production people in design matters, starting with the development of contract design, to ensure that the design effort is consistent with a pre-defined build strategy.

The development of shipbuilding methods from system-oriented hull construction and outfitting through to integrated zone-oriented methods is illustrated in figure 2.

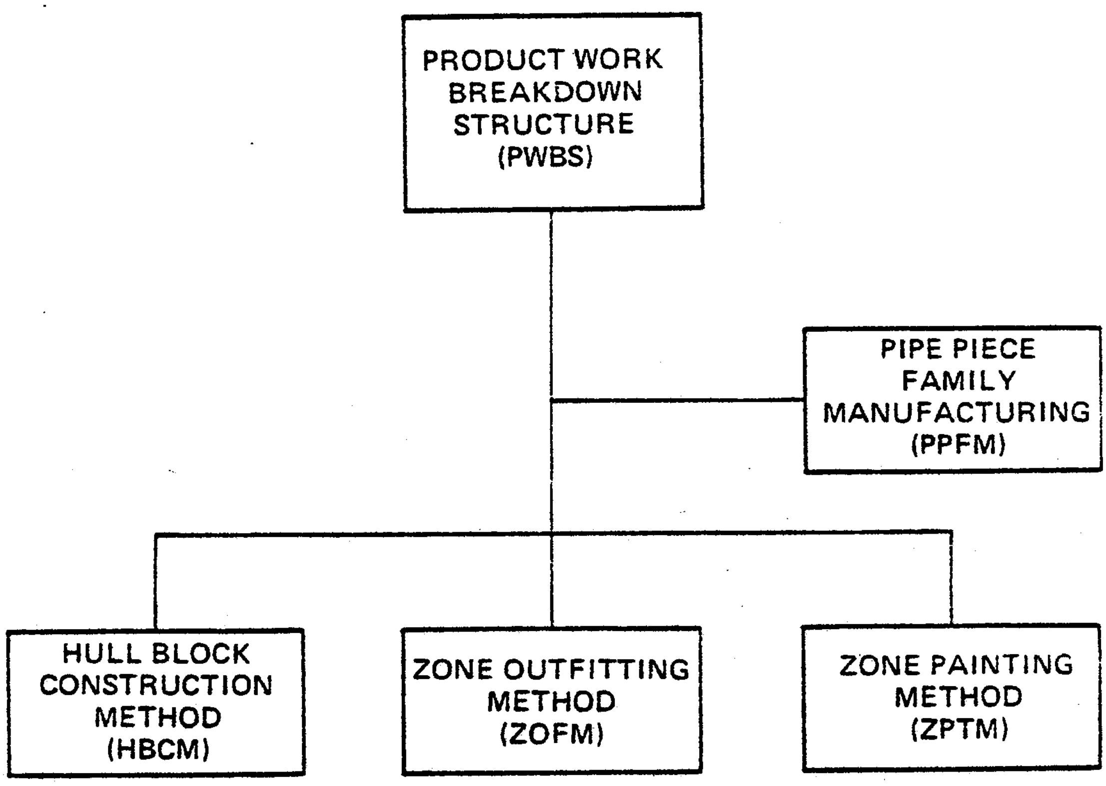


Figure 1 PRODUCT WORK BREAKDOWN STRUCTURE (PWBS). In shipbuilding PWBS features three basic methods. Each addresses a distinct type of work. As all are zone/problem-area/stage oriented, they can be readily integrated. Also, they facilitate real and virtual flow processes in accordance with the principles of Group Technology. A fourth supporting method which is problem-area/stage oriented facilitates the application of Group Technology for fabricating parts such as pipe pieces.

Reproduced from ref. (18).

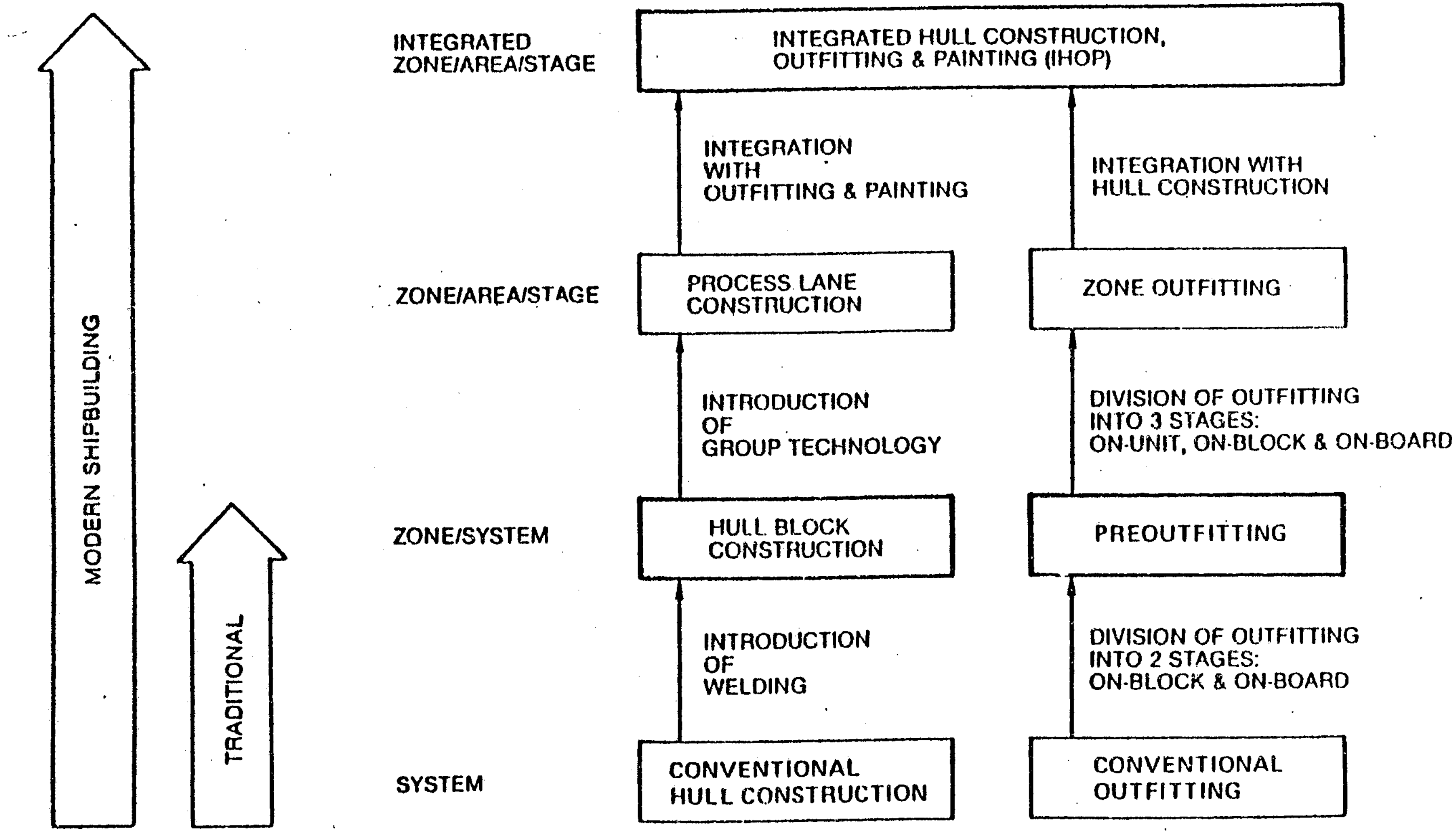


FIGURE **2** : History of Basic Improvements in Shipbuilding Methods.

Reproduced from ref. (11).

The responsibility for the successful introduction of zone-oriented shipbuilding methods does not rest entirely with the production department. There are extremely important implications for the entire design process and for the design organisation. The build strategy must be established at a much earlier stage than has been the case for the conventional ship design process and this build strategy must be reflected in the preparation of composite arrangement drawings and the associated structured material lists necessary for marshalling material.

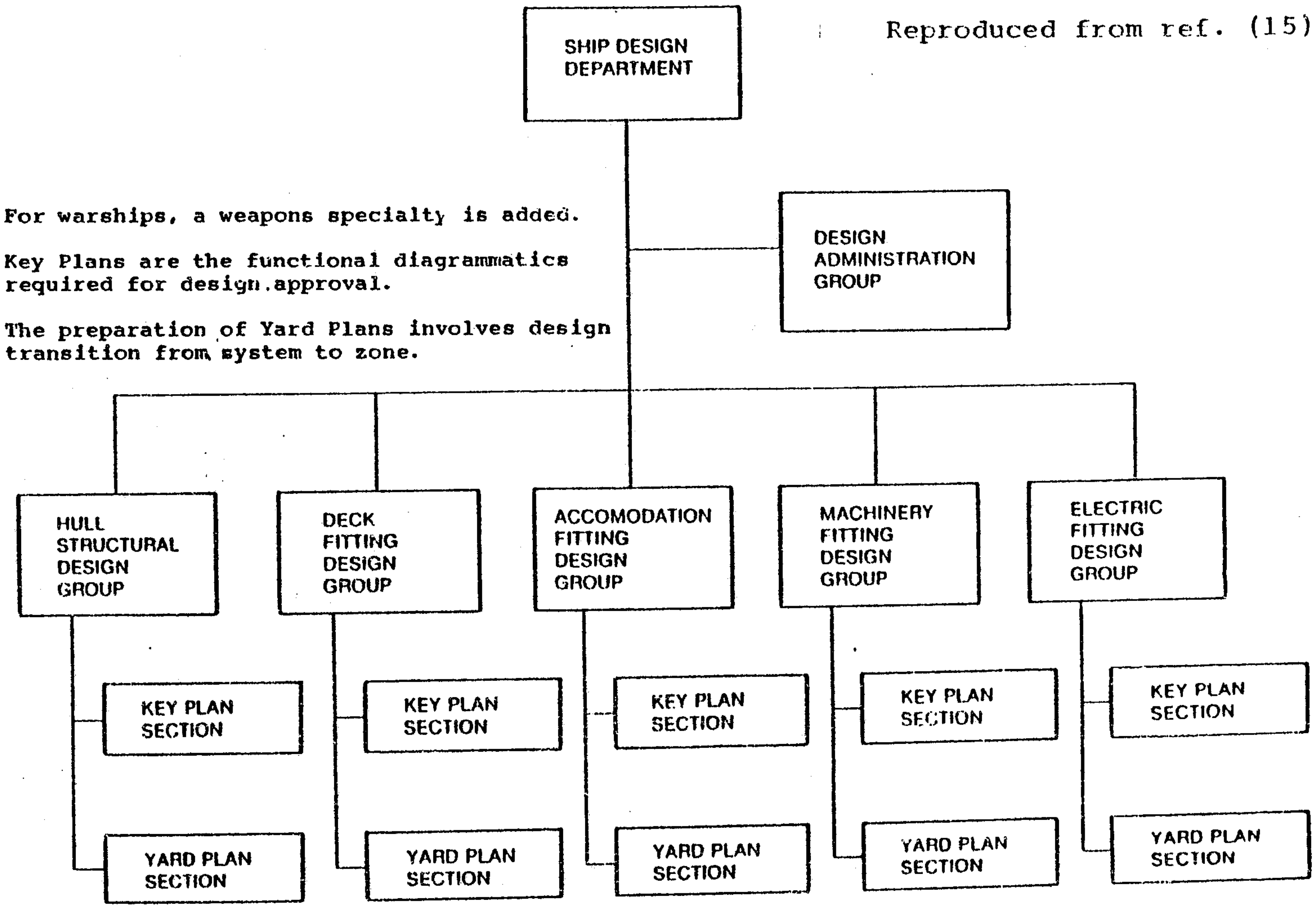
Chirillo (4) advises that:

> "Design, the creation and grouping of information becomes a true aspect of planning by faithfully incorporating a building strategy for a ship in all design phases including contract (basic) design. Thus, while having to manage change in the way their work is accomplished, designers simultaneously have to undertake more work. An inherent issue is the vital need for shipbuilder's control of contract-design."

Design organisations have traditionally been organised by functional discipline, i.e. hull, mechanical and electrical. For a naval ship design organisation, separate weapons and communications disciplines are common as well. With the introduction of zone-oriented logic and an emphasis on the application of Group Technology, design organisations must focus their attention on the design of "ideal" interim products which comprise multiple functional systems. In order to assist with the introduction of these methods to traditional design organisations, the NSRP has prepared the publication "Design for Zone Outfitting" (15) in addition to the publication on Integrated Hull Construction, Outfitting and Painting. These publications describe the organisation of design activities which competitive shipbuilders have evolved to integrate the design process with the subsequent activities of material procurement and production. A typical organisation for a zone-oriented ship design department is illustrated in figure 3. Another NSRP publication "Design Modelling" (16) describes the modelling methods which are used as an aid in the design of complex interim products such as machinery spaces.

In order to re-organise design information from "system-oriented" at the functional design stage to "zone-oriented" at the detail or "work instruction" design stage, it is necessary to go through a "transition design" stage. This transition stage in the product-oriented design process is illustrated in figure 4. During this process, the ship is broken down into its major blocks and outfit units and the detail design and material definition then proceeds for each block in the same sequence as that which is to be used for construction. There is a continual need to check that compatabilty is maintained at the boundaries of each block. The interchange of design and material information that is necessary for the introduction of integrated hull construction, outfitting and painting is illustrated in figure 5.

Reproduced from ref. (15).



Notes:

1. For warships, a weapons specialty is added.
2. Key Plans are the functional diagrammatics required for design approval.
3. The preparation of Yard Plans involves design transition from system to zone.

FIGURE **3** : Typical organization for a zone-oriented ship design department. Basic design, not shown, is usually performed elsewhere.

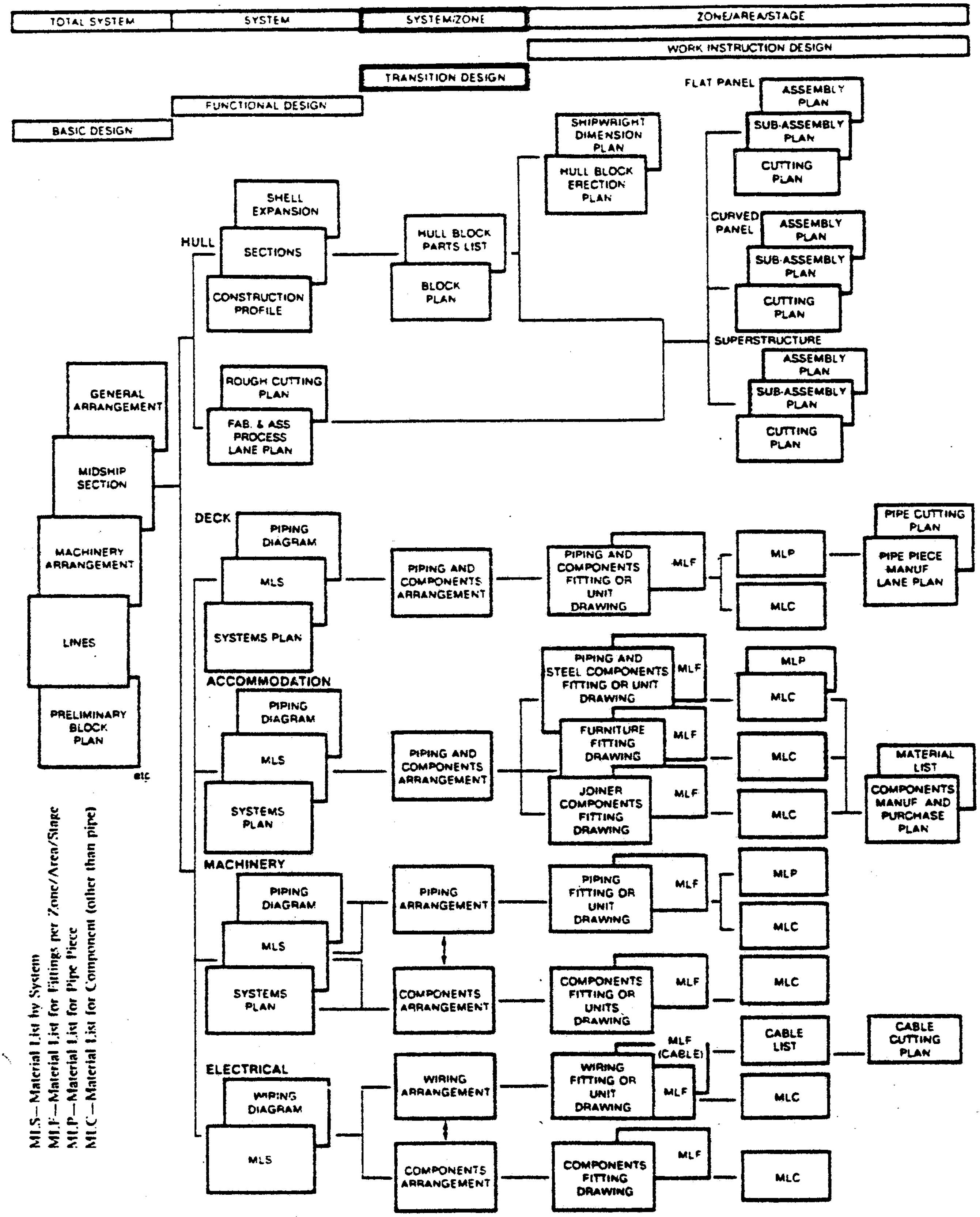


FIGURE **4** Product-oriented Design Process. Transition Design introduces zones and interrelations with systems.

Reproduced from ref. (4).

Reproduced from ref. (15).

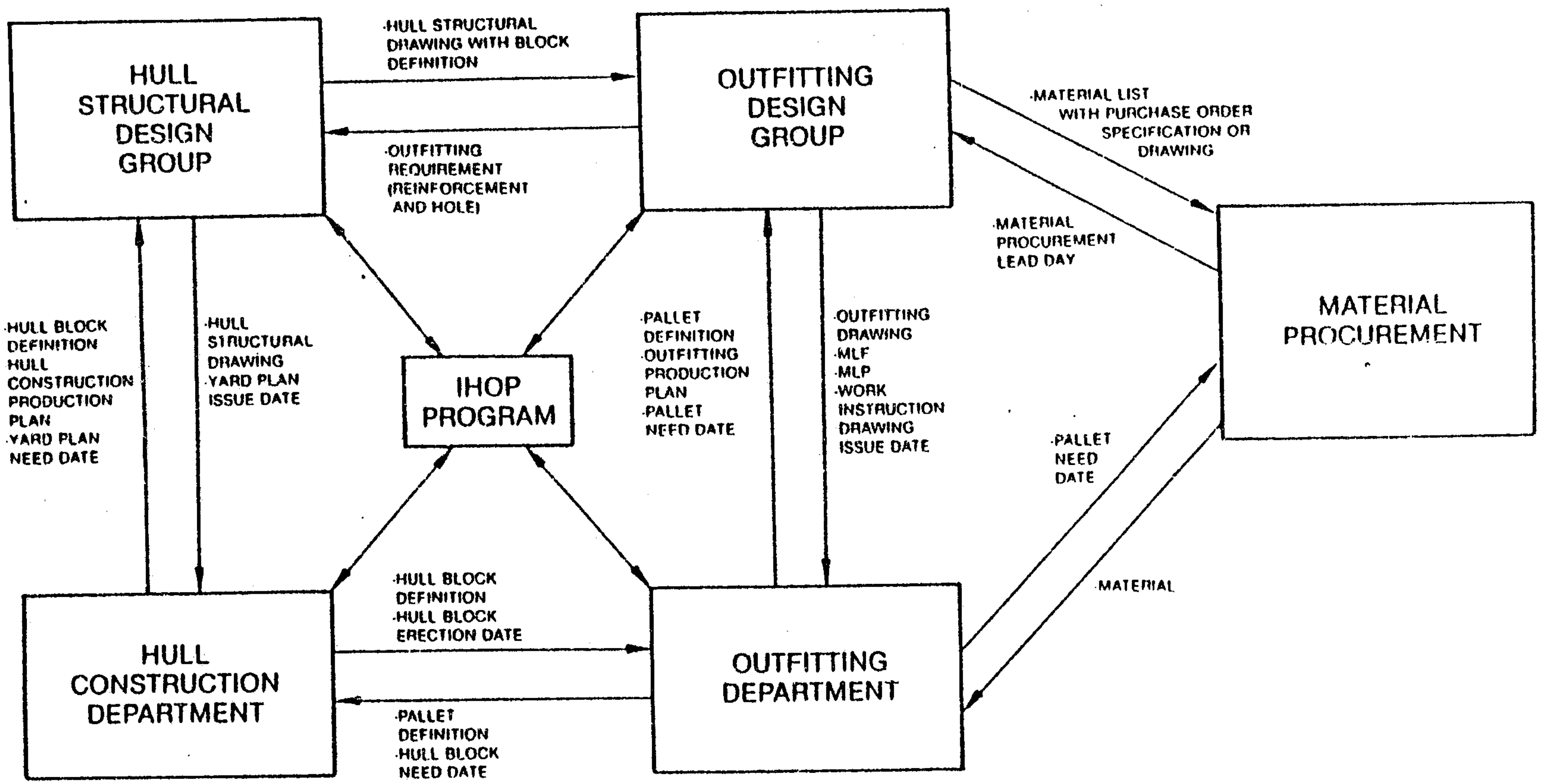


FIGURE **5**: Information interchange for Integrated Hull Construction, Outfitting and Painting (IHOP).

In general terms, the Japanese approach to shipbuilding as an integrated production system, concentrates on the manufacture of ideal interim products, such as hull blocks which are fully outfitted, painted and tested. As an entity, the ship is almost incidental to the construction process because the assembly of hull blocks to form a ship progresses comparatively quickly once the hull blocks are available. The consolidation of hull blocks to form the ship usually does not commence until approximately 40% to 60% of the hull blocks are available. The major reason for this practice is that ships are generally assembled in a building dock, rather than on a slipway, and the total assembly time must be minimised to ensure optimum utilisation of the facility.

An objective in the management of shipbuilding projects is to size each work package such that the work content of the package is approximately uniform. This assists with the scheduling and flow of real and virtual production lines and assists in the co-ordination of work and material flow. For example, the duration of each outfit work package is approximately two weeks and the labour content is generally limited to between 80 and 100 manhours.

The problem facing the shipbuilder is how to build, outfit, paint and test hull blocks efficiently. In the first instance, the hull blocks must be designed to facilitate construction, outfitting and painting operations. To do so requires that material and information be available for each hull block or zone. Thus the objective of the design process is to identify the information and material requirements, not for each system, but for each zone or interim product. The term "pallet" is used as a conceptual expression to define the material and information requirements for a given work package.

To do this, it is necessary to undergo a transition stage in the design process from the development of functional system diagrammatics, which are required to ensure that the ship will satisfy the performance requirements, to the development of work instructions, composite arrangement drawings and structured material lists required for each production zone or interim product.

Competitive shipbuilders concentrate heavily on minimising their material inventory. They have developed what is commonly called the "just-in-time" approach to material management. Long lead equipment and material requirements are estimated from the functional diagrammatics and basic quantities are ordered in advance, well before the detail design phase is complete. As the work instruction design is progressed for each zone of the ship and the detailed material requirements are finalised, procurement action is taken for those items not already on order and procurement schedules are refined. Thus, there is an integrated approach to the shipbuilding process across the design, procurement and production departments.

Outfitting operations are simplified because each hull block has been designed to facilitate outfitting. For example: overhead crane access is available; each hull block facilitates ground access for workers and small portable cranes from at least two sides; material and information required for the job have been marshalled as outfit pallets; and ceilings are outfitted and painted when upside down. This approach also leads to improvements in the detail design of outfit components. For example: pipe flange locations are sited to correspond with zone boundaries; different pipe systems are supported from common hangers instead of each system having its own hangers and all systems are routed parallel to the XYZ axes of the ship. The total result of all these detailed improvements simplifies the outfitting process significantly.

Painting operations are considerably simplified because careful design of hull blocks ensures a reduction in staging requirements and improved access. Also, since all attachments to, and penetrations through, hull structure are installed prior to painting, the need for costly repair work to damaged paintwork is eliminated.

Quality control and certain testing activities are conducted before an interim product leaves the work area, thus defective work is not passed further down the production line where it will disrupt subsequent manufacturing operations.

The final assembly process, where hull blocks are joined in a building dock to form the ship, is simplified because of the control of the geometrical accuracy of structural and outfit piece parts, sub-assemblies and assemblies. Hull blocks are finish cut in the workshop which eliminates the need for alignment, marking, and the cutting of margins, commonly known as "Green", on the berth.

The need for costly "on-board outfitting" is minimised by the use of "on-block" outfitting and the installation of "outfit units" which comprise pre-packaged outfit assemblies which are manufactured as separate interim products, complete with a structurally independent foundation.

The publications of the U.S. National Shipbuilding Research Program collectively identify the fundamental engineering methods used by one of the worlds leading shipbuilders for the design and construction of large industrial products which include both merchant and naval ships. The methods integrate the previously conflicting requirements of design, material procurement and construction and thus should be of interest to everyone associated with the planning and management of major projects.

Chirillo (5) states that:

> "Identification of the real source of Japanese productivity is a milestone. Clearly the reason is not superhuman workers combined with miraculous subsidies. The truth is far more substantial and logical. In Japan, shipbuilding has developed as a science with clearly defined principles, theorems, procedures, etc. It is analytic in the extreme."

Thus, it is apparent that previous studies of the Australian shipbuilding industry have missed a fundamental difference when endeavouring to compare the Australian shipbuilding industry with that of competitive overseas shipbuilding industries. That difference is the organisation of design and material information and the organisation of work. This difference is not apparent from a study of industry statistics. It is only apparent from a detailed study of the methods used. The Australian shipbuilding industry certainly cannot be competitive, scarcely even cost effective, while it persists with conventional engineering methods. It is not worthwhile to evaluate, in terms of indices, how the Australian industry compares with that of competitive overseas shipbuilding industries when there are such fundamental differences.

THE POTENTIAL FOR APPLICATION TO NAVAL SHIPBUILDING IN AUSTRALIA

But what significance does the identification of the real source of Japanese productivity hold for the Australian naval shipbuilding industry? Why should those who are involved with the Australian shipbuilding industry bother to investigate the introduction of zone-oriented methods when the current system-oriented design and construction methods have been developed and refined over many years?

The success of any system depends upon whether the output from that system achieves the stated objectives. Furthermore, the system must achieve those objectives with an acceptable degree of efficiency. In the case of a total shipbuilding system which has input from both the customer and the shipbuilder, the objectives are to deliver a defined end-product within an agreed cost, to an agreed schedule and to the required quality as defined by the technical specification.

For recent Australian naval shipbuilding programmes, there have been numerous examples of cost overruns, late delivery and deficiencies in product performance when compared with the requirements of the technical specification. A general assessment of the efficiency of the overall shipbuilding system would most likely conclude that the Australian shipbuilding system is significantly less efficient than that of overseas countries, particularly when compared with that of Japan.

In the current situation, the decision whether a naval vessel should be built in Australia rather than overseas is very marginal. If overseas shipbuilders were to improve their performance by a quantum step through the introduction of proven zone-oriented methods whilst the Australian shipbuilding industry persisted with conventional methods, then the balance may swing clearly in favour of procurement overseas. Under these circumstances, the Australian naval shipbuilding industry would either cease to exist or simply become an increased burden on the taxpayer.

The benefits that can be expected to eventually accrue from the introduction of zone-oriented methods include:

- improved overall efficiency and reduced costs;
- improved cost and schedule control;
- improved quality;
- improved safety.

Thus the Australian shipbuilding industry, together with the Australian Department of Defence must investigate the introduction of zone-oriented methods if it is to have any chance of long term survival and potential for future growth. Only in this way can the industry offer, to those it employs, the security and satisfaction that comes through achievement and progress.

The most important and difficult question at this stage is how to introduce these methods to the Australian shipbuilding industry?

As a major customer for ships from Australian shipbuilders, the Australian Department of Defence is in a very strong position to influence the introduction of these methods to the Australian shipbuilding industry.

But the role of the Department of Defence sometimes goes beyond that of simply "the Customer" because the Department arranges to supply the shipbuilder with a detail design package. In some cases, the design package is in such detail as to constitute a production package. In this situation, the Department of Defence is acting as both the shipbuilder's design and production planning departments because the grouping of design information and material definition are aspects of planning. However, it must be recognised that such arrangements have sometimes been necessitated by a lack of capacity on the part of the shipbuilder to cope with the task of preparing a detail design/production package.

Due to this feature of the role of the Department of Defence and because of the consequent restrictions that it can place on the freedom of the prospective shipbuilder to implement new methods that require design innovation, it is vital that the Department of Defence takes due consideration of the impact of its choice of a design/production or "work instruction" package on the efficiency of the shipbuilder. What is required is for the Department of Defence to act as the corporate planner for the shipbuilder as well as for the customer. Either that, or cease the practice of supplying the shipbuilder with a detail design/production package and leave that task to the shipbuilder as recommended by Fink (8) in 1973 and by Chirillo (6) and (15).

Under the current Australian Department of Defence materiel procurement process, the selection of a suitable ship design and the acquisition or development of a detail design/production package is undertaken in the context of a total ship construction project. As a part of the approval process for Navy ship acquisition projects where "in-country" construction is intended, it is the author's belief that the detail design/production package for the candidate ship design options should be assessed against production engineering criteria that are consistent with the logic and principles identified in the NSRP publications.

Suggested production engineering criteria are as follows:

- The detail design/production package should incorporate a product-oriented work breakdown structure.

- The hull block breakdown should be designed such that hull blocks are the maximum size and weight (when fully outfitted) consistent with the facilities and craneage capacity of the prospective shipbuilder and consistent with the need to provide smooth work flow in workshops.

- Hull blocks should be designed to facilitate outfitting and painting operations. For example, hull blocks should be stable when inverted and should permit access for workers and mobile cranes from at least two sides.

- Material definition for individual piece parts and sub-assemblies should be by zone/problem area/stage, in accordance with the Product Work Breakdown Structure classifications, to facilitate the introduction of process lane manufacturing methods and statistical control of geometrical accuracy.

- The work content of outfit work packages should be balanced such that each work package is of approximately two weeks duration to facilitate the scheduling of work.

- Quality control and test procedures should be product-oriented as well as system-oriented.

- The design/production package should reference rationalised Australian Standards which should be developed in accordance with the strategy recommended in (20).

For the purpose of comparison, it is interesting to assess a current RAN new construction project against these suggested criteria to see to what extent they are met. In view of the author's experience within the Australian Department of Defence of both the Australian Frigate Project and Williamstown Naval Dockyard, it seems appropriate to assess this project against the criteria which have been suggested.

It is acknowledged that such a subjective assessment of production engineering aspects addresses only one of the many factors that must be taken into consideration during the development and approval processes associated with a major defence project. It must be emphasised that the purpose of this assessment is only to identify whether the logic inherent in the production package supplied to the shipbuilder for the Australian Frigate Project is consistent with zone-oriented shipbuilding methods and with the principles of Group Technology. However, it is recognised that the overall management systems which are being introduced for the Australian Frigate Project do represent a significant step forward when compared with previous shipbuilding projects for the Australian Department of Defence.

On 12 October 1983, the Australian Government announced the intention to proceed with the Australian Frigate Project for the construction of two FFG-7 Class frigates at Williamstown Naval Dockyard (WND) in Melbourne. Two important aspects of this project are to re-establish a naval shipbuilding capability based on the introduction of proven methods used by U.S. naval shipbuilders and to introduce formal methods of contract administration between the Department of Defence as "the Customer" and WND as "the Supplier".

For the Australian Frigate Project, the Department of Defence has arranged to supply a "validated" working drawing package to the shipbuilder with the understanding that a ship built to these drawings will meet the requirements of the technical specification. Thus, it is considered that this package represents both a detail design and a production package. Other production information supplied to the shipbuilder, such as workshop sketches of parts, are supplied as "production aids".

The work breakdown structure which has been used by the U.S. Navy for the development of the FFG-7 design and production package is known as the Ship Work Breakdown Structure (SWBS) and is essentially system-oriented. This work breakdown structure also forms the fundamental basis of an important management system called the "Cost/Schedule Control System" which is to be introduced for the Australian Frigate Project. The Cost/Schedule Control System was originally developed by the U.S. Department of Defense in accordance with the requirements of the U.S. DOD Instruction 7000.2. This management system, which is used for all major U.S. Defense Contracts, is currently used by the U.S. Navy for major ship construction projects such as the U.S. FFG Project.

Chirillo (7) advises that:

> "The (U.S.) Department of Defense (DOD) Instruction 7000.2 advises shipbuilders to '...be continuously alert to advances in management control systems...'. It does not require '...the use of any single system...'. Thus, the initiative is open to shipbuilders! Also, the DOD instruction defines a work breakdown structure as: 'A product-oriented family tree division of...work tasks which...define the product to be produced as well as the work to be accomplished...'. The (U.S.) Navy's Ship Work Breakdown Structure (SWBS) does not fulfill this definition because it is system oriented. Neither does it conform with current U.S. shipbuilding methods nor with the world's most productive methods. Thus, the (U.S.) Navy itself is impeding implementation of advances in management control systems! Further, the (U.S.) Navy's SWBS is not consistent with the logic and principles of Group Technology. PWBS adapted for building naval ships, would conform with the DOD definition and, as proven in Japan, is extremely effective for applying Group Technology to shipbuilding operations."

Thus, the production package supplied to WND by the Australian Frigate Project does not satisfy the first of the suggested criteria since the production package does not incorporate a product-oriented work breakdown structure.

The fundamental build strategy for the FFG-7 Class frigates, as developed by the American lead shipbuilder, the Bath Iron Works Corporation (BIW), utilises the Hull Block Construction Method combined with pre-outfitting of those hull blocks. It is well recognised that for efficient hull construction, the blocks constructed should be the maximum size possible consistent with the facilities available within the shipyard, including craneage and covered workshop space, and also with the requirement to ensure smooth work flow in workshops. The craneage available at BIW imposed a constraint of approximately 200 tons on the maximum weight of an oufitted hull block. However, the USN had stated that other shipyards with a lesser craneage capacity of 40-50 tons must also be capable of building the ships.

The BIW build strategy is reflected in the detail design of the ships in that the hull structure is drawn in blocks consistent with the requirements of BIW. Butt joints are located such that the hull blocks can be further subdivided into smaller sub-blocks of around 40-50 tons. At the block breakdown, the detail design is consistent with the zone-oriented Hull Block Construction Method but it is not consistent at the sub-block breakdown.

At Williamstown Naval Dockyard (WND), the craneage capacity and the space available in the workshops limits the maximum size of hull blocks that can be constructed to about 50 tons. Thus the hull block breakdown inherent in the detail design of the FFG hull structure is not consistent with the facilities and craneage available to the shipbuilder, WND, as required by the second suggested criterion.

The constraints imposed upon WND due to limited craneage capacity and workshop space have necessitated a departure from the build strategy adopted by BIW and incorporated in the detail design of the FFG. As a consequence of this change in the build strategy, it is necessary for WND to revise the job orders or work packages, both for hull construction and for outfitting work. This revision to the job orders involves redefining material and information requirements. To do this, it is necessary for a team of production planners to go through individual system drawings and the associated parts lists to identify which items can be installed by which trade at what stage. This information must then be fed to the material procurement section, the stores organisation and to the various manufacturing shops involved in the manufacture of piece parts. Although this is being done in a co-ordinated fashion, it is nevertheless inefficient by comparison with the situation where the build strategy, including outfitting and painting requirements, have been considered at the design stage.

Another aspect which arises from the need to break the 200 ton hull blocks down into 50 ton sub-blocks is that the sub-blocks may not be as ideal for subsequent outfitting and painting operations as the 200 ton blocks. For example, pipe joint locations may not correspond to sub-block boundaries. Thus, there may be scope for improvement in comparison with the third criterion.

For hull block construction, whilst material requirements are classified by zone for the BIW 200 ton hull block breakdown, this is not the case at the 50 ton sub-block breakdown. For outfit systems, the detail design and material definition have been prepared essentially on a system-by-system basis rather than by zone, although the major distributive system arrangements have been drawn in sections between frames which approximately correspond to the BIW hull block breakdown. Furthermore, the material definition associated with the detail design of the FFG hull structure and outfit systems does not classify individual piece parts and sub-assemblies by manufacturing "problem area" or "stage" in accordance with the PWBS. Thus, the production package supplied to WND is not consistent with the shipbuilders build strategy and does not meet the fourth criterion.

For the Australian Frigate Project, the size of each individual outfit work package, or job order, varies from a few hundred manhours up to perhaps 7,000 to 8,000 manhours and the duration of such activities may be up to several months. Thus, there is scope for improvement in the balancing of the work content of work packages and for reducing the work content such that the duration is of the order of two weeks as suggested in the fifth criterion.

The Total Ship Test Management Plan for the Australian Frigate Project is based on seven stages of testing commencing with equipment testing, followed by intra-system testing, system testing, inter-system testing and finally the testing of the ship as a functional entity. Whilst this system-oriented approach is required for final testing, it is not generally supported by a product-oriented test program as suggested in the sixth criterion. This is necessary to ensure that defective work is not passed further along the production process where it can cause significant disruption to the smooth flow of work. An exception to this is the "grooming" of the Combat Data System which involves the preliminary testing of electronic equipment prior to shipment to the shipbuilder.

The FFG production package mostly references American standards including the U.S. Military Standards and Specifications. Thus, there is scope for improvement in relation to the seventh criterion.

It would therefore seem that the production package selected for the Australian Frigate Project is not consistent with the suggested criteria and does not introduce zone-oriented logic and the principles of Group Technology and statistical control of manufacturing as identified in the NSRP publications. The methods being introduced by this project are essentially conventional shipbuilding methods based on system-oriented logic.

In order to improve the future efficiency of the the Australian shipbuilding industry, it is the author's opinion that the detail design/production package acquired or developed for future vessels which are to be built in Australia should be consistent with the suggested production engineering criteria. It is recognised that a balance must be established between the required operational, technical and logistic support requirements as well. To support this principle, it is essential to seek the early involvement of prospective shipbuilders. Shipbuilders should be encouraged to formally document their proposed build strategy in advance and to identify any constraints imposed by their craneage, facilities or other pertinent factors, so that this information can be fed back into the design process.

If an existing design or production package were to be available for future ship construction projects which satisfied all of these requirements and suited the political interests of the Australian Government, then the Department of Defence project approval process should result in the selection of a design which is suitable from a production engineering point of view. But what compromise should be made in the situation where there is no existing "off-the-shelf" design that satisfies the majority of the requirements? Should the production engineering requirements be given a lower priority in relation to the other requirements?

Chirillo (7) states:

> "A productive shipbuilding industry is an indispensable element of seapower".

Whilst the objective of the Australian Department of Defence is not strictly to establish "seapower", a productive shipbuilding industry is nevertheless vital to the defence interests of the country.

In the light of the previous statement, it is considered that production engineering principles should not be compromised and that an alternative approach to the design acquisition process should be pursued, possibly in parallel with the evaluation of existing designs, for future ships which are to be built in Australia for the RAN.

One approach may be to leave the detail design to the prospective shipbuilder as has already been suggested. However, this may not be practical since the acquisition of design information can sometimes only be arranged on a Government to Government basis. Also, Australian shipbuilders may not have the necessary capacity to complete such a task.

A possible alternative approach may be to further develop an existing functional ship design to meet specific production engineering objectives as well as defined operational, technical, and logistic support requirements. This approach is an evolutionary approach rather than the revolutionary approach of selecting an all new design and reduces the likelihood of confronting new production engineering, technical, operational and management problems.

It is believed that the implementation of significant changes, such as are being suggested, should be considered in the context of a major project. It seems appropriate to look towards the ships which may follow after the construction of the Australian Frigates FFGs 05 and 06.

The following reasons are presented in support of this argument:

- The Follow-on Destroyer Programme was originally conceived as a six ship build programme. Whilst it was decided that the first two ships would be FFGs, there was no firm decision concerning the design of following ships, thus retaining the option to select a different design. This decision to build two FFGs initially provides a breathing space and the opportunity for the Australian Department of Defence to consider the introduction of different methods.

- Since Williamstown Naval Dockyard is a Government owned establishment, the Government has the responsibility for the corporate planning required to improve the efficiency of that establishment.

- Finally, if long term benefits are to be gained from constructing FFGs at WND, then a continuing programme should aim to build on the skills and technology introduced at considerable cost through the Australian Frigate Project. The situation that should be avoided is yet another change in direction, from a production engineering point of view, with a completely new production package imposed upon the shipbuilder by the Department of Defence.

The situation would be somewhat simpler if the USN were proceeding along a similar path with the development of the design for a ship of similar size and capability to the FFG-7 Class frigates to incorporate zone-oriented production engineering methods. However, it would seem that for the DDG-51 Project, the USN are contemplating the development of a class of ships of considerably greater capability than the FFG-7 Class. The cost associated with ships of this capability is probably well beyond the budget for the RAN. Thus, it would seem that if the RAN decided to further develop the functional design of an existing ship, such as the FFG, and to prepare a production package, then it would have to do so on its own.

In order to tackle the development of the functional design of an existing ship and the subsequent preparation of a production package tailored to the requirements of the prospective Australian shipbuilder, assistance would be required from an organisation which has experience with the application of modern zone-oriented production engineering methods to the design of naval vessels.

In the U.S.A., six shipyards are currently being assisted with the introduction of modern shipbuilding methods by Japanese consultants. Avondale shipyards were the first, contracting with IHI in 1979. In October 1983, they delivered the products tanker "Exxon Charleston", the first ship to be designed and built in the U.S in accordance with the Japanese methods. Bath Iron Works, in conjunction with Gibbs and Cox, have had representatives visit IHI shipyards in Japan to gain experience with their methods. Consultants from IHI are also currently working with BIW in incorporating zone-oriented logic in the proposal to be submitted to the USN for design and construction of the lead ship for the DDG 51 Project. Similarly, the Los Angeles Division of Todd Pacific Shipyards Corporation is working with consultants from Mitsubishi Heavy Industries (MHI) to incorporate the same logic in a competitive proposal.

Further, the U.S. Navy's Puget Sound Naval Shipyard (PSNS) has successfully completed installation of a Close-In Weapons System in USS RANGER (CV 61) using zone logic. Other such work underway as of October 1984 includes alteration and repair of the electric shop in RANGER, preparations for installation of a TOMAHAWK missile system in a cruiser and planning for overhaul of ballast tanks in a submarine. The latter, which will feature zone-by-stage control, alleviates the problem of people from various shops competing for access in a very confined space at the same time.

Early in 1984, Saint John Shipbuilding and Dry Dock of New Brunswick, Canada, retained BIW as a consultant for applying modern zone logic to the Canadian Patrol Frigate construction programme. At about the same time, Burrard-Yarrows of Vancouver, British Columbia in Canada, engaged IHI consultants in order to apply the same logic to the design and construction of an outfit intensive ice breaker. In the U.K. several firms are familiar with the production engineering methods documented by the NSRP. In Japan, the Japanese Maritime Self-Defence Force have recently placed an order with IHI for the construction of a destroyer of 3400 tonnes displacement which, as for the DDH previously constructed by IHI, will certainly be designed and built in accordance with IHI's own methods.

In July 1984, L.D. Chirillo Associates started to teach "Product Work Breakdown Structure" and "Process Analysis Via Accuracy Control", as descibed in NSRP publications, at the U.S. Navy's Engineering Duty Officer School in Mare Island, California.

Consequently, there are organisations overseas with the necessary expertise who could assist with the introduction of these methods to the Australian shipbuilding industry.

In conclusion, the efforts to improve efficiency by Australian shipbuilders involved in building ships for the RAN are currently constrained because the structure of the design/production package which is supplied to them by the Australian Department of Defence does not incorporate a build strategy which is tailored to the shipbuilder's requirements. The Australian Department of Defence has the opportunity, and indeed a responsibility, to ensure that the design/production package for future RAN ships which are to be built in Australia is developed in accordance with modern zone-oriented production engineering principles. It is considered that an investment now in the introduction of these methods will eventually yield improvements in the control of major ship construction projects, reduced overall costs to the Australian Department of Defence, improvements in the efficiency of the Australian shipbuilding industry and better ships for the Royal Australian Navy.

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