FIRST MARINE INTERNATIONAL

First Marine International findings for the global shipbuilding industrial base benchmarking study

Part 1: Major shipyards

TURNING IDEAS INTO REALITY

FIRST MARINE INTERNATIONAL

FINDINGS FOR THE GLOBAL SHIPBUILDING
INDUSTRIAL BASE BENCHMARKING STUDY

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Findings of the Global Shipbuilding Industrial Base Benchmarking Study

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CONTENTS

1 INTRODUCTION

1.1 Background

This report has been written to present the findings of the benchmarking survey carried out by First Marine International Ltd (FMI) as part of a global shipbuilding industrial base benchmarking study (GSIBBS) undertaken by the U.S. Office of the Deputy Under Secretary of Defense (Industrial Policy) (ODUSD(IP)) in 2004/2005. The objectives of the study were to:

- Compare the practices of U.S. and selected leading international commercial and naval shipbuilders in Europe and Asia.
- Identify specific changes to U.S. shipbuilding industry processes and to U.S. naval design and acquisition practices that will improve the performance of the shipbuilding enterprise.

The FMI shipyard benchmarking system, which is briefly described in Section 1.6 and more fully in Appendix 2, has been used to make the comparisons.

The report presents the combined results of the benchmarking surveys of the group of seven international shipyards (commercial and naval) and the six major U.S. shipyards undertaken in 2004. Although the performance and practices of individual shipyards are not discussed, the characteristics of the two shipyard groups are compared and, as a consequence, suggestions for performance improvement actions in the U.S. Industry and Navy are proposed. Each participating shipyard has also received a confidential report which defines the use of best practice within the yard, how it compares internationally, and presents a prioritized list of action areas with suggestions for improvement actions.

As the system was also used in the National Shipbuilding Research Program Advance Shipbuilding Enterprise NSRP ASE 1999/2000 benchmarking study, the results of the two studies are directly comparable and this has allowed the changes in the level of technology employed in the U.S. industry since that time to be measured.

Where possible, the productivity being achieved by each shipyard has been estimated. However, as most of the U.S. yards did not wish to contribute to this part of the study, the productivity estimates are based on data in the public domain and are therefore considered to be only an indication of the level of performance being achieved. The estimates required the complexity of U.S. naval vessels to be assessed and the effect that naval acquisition procedures and practices have on shipyard productivity to be evaluated. Although only preliminary, the results of this analysis provide an indication of the effect of vessel complexity and areas where the effect of naval acquisition practices and procedures differ significantly from the commercial model.

1.2 First Marine International

First Marine International Limited was formed in 1991 to provide specialist consultancy services to the marine industry. Principal clients include shipbuilders and ship repairers, UK and overseas government departments and agencies, and national and international maritime organizations. Members of the FMI team have worked on projects in over fifty countries and were first involved together in the 1970s in the design and engineering of the some of the largest and most successful shipyards in the world. The company’s expertise includes market research and forecasting; marine industry studies; benchmarking; competitiveness; technology development; upgrading of existing shipyards; design and engineering of greenfield shipyards; and development, implementation and management of shipyard performance improvement programs. Further information is available on the internet at www.firstmarine.co.uk.

1.3 The FMI benchmarking system

Described in detail in Appendix 2, the FMI shipyard benchmarking system allows the processes and practices applied in individual shipyards to be compared to others and to international best practice. The system has a number of uses but is most commonly applied in assisting shipyards to develop performance improvement programs. The system was first used to support the nationalization of the British shipbuilding industry in the mid-1970s. It has since been applied in over 150 shipyards world wide and has been used as the basis for the following industry studies:

1978: U.S. shipyard technology survey
1985: U.S. shipyard technology survey
1992: EC shipbuilding competitiveness study
1993: EC Eastern European shipyard study
1995: National Shipbuilding Research Program study (system derivative)
2000: U.S., Asian and European shipyard benchmarking study
2001: UK shipyard benchmarking study

The full system contains one hundred and twenty-nine elements of shipbuilding, ship repair and ship conversion technology grouped into eighteen functional areas. The seven functional areas of shipbuilding practice covered by this study are as follows (these areas have a total of fifty elements).

- Steelwork production
- Outfit manufacturing and storage
- Pre-erection activities
- Ship construction and outfitting
- Yard layout and environment
- Design, engineering and production engineering
- Organization and operating systems

The benchmarking system describes five levels of use of best practice in each element of each group. In broad terms, the levels of use of best practice correspond to the state of development of leading shipyards at different times over the last thirty years. Those yards that are less advanced remain at the level of technology of an earlier period. On the basis of interviews and inspections carried out during the survey, a “level of technology” mark (or best practice rating) is assigned to each element. Elements that are subcontracted are noted and if sufficient information is available to evaluate subcontractor performance, then the element is scored. The scores are aggregated, first, for the individual groupings, and second, for the whole yard. The results are presented graphically so the strengths and weaknesses are clearly shown.

1.4 General approach

A more detailed explanation of the methods use has been included in the relevant sections of the report and in the appendices. The overall approach to the FMI part of the study was as follows:

1. Survey the 50 manufacturing and business processes and practices of a representative group of leading international commercial and naval shipyards using the benchmarking system.
2. Survey the same processes and practices in the six first tier private U.S. shipyards.
3. Compare the technology applied in the international yards to that applied in U.S. yards to identify technology gaps that represent opportunities for making improvement in each U.S. shipyard.
4. Estimate the productivity of U.S. shipbuilders in order to make comparisons with the international yards and to determine how effectively the U.S. yards use the technology applied.
5. Write a report of the findings in each U.S. yard for the use of the shipyard that includes a prioritized list of action areas and suggest actions.
6. Aggregate the findings to an industry level to identify opportunities for industry wide action to improve performance and suggest appropriate remedies.
7. Review the shipyard findings to quantify the effect of DoD policies and contract incentives on shipyard performance and suggest improvements.
8. Present the general findings in an overall report.

The preliminary findings of the study were recorded in a report that was presented to a NSRP focus group in January 2005. The focus group was responsible for prioritizing and costing the FMI recommendations and producing a time-phased action plan to improve industry performance. The NSRP report is available under separate cover. The finding presented in this report, which have benefited from more detailed analysis, vary slightly from those presented in the initial report to the NSRP.

Commander John Zimmerman and John Bissell from ODUSD(IP) were trained in the use of the benchmarking system and accompanied the FMI survey team on each shipyard survey. The findings in each shipyard visited and the implications for U.S. yards were discussed with the ODUSD(IP) team after each visit. However, the benchmarking scores assigned internationally or in the U.S. were not influenced by the ODUSD(IP) team. To provide continuity, the three or four man FMI team was selected from the same four consultants, each of whom are specialists in the areas surveyed. This is an improvement over the 1999/2000 study in which, due to security considerations, the surveys were split between an FMI team and a second team of U.S. nationals who carried out the benchmarking in some of the U.S. naval builders.

1.5 Participating shipyards

In addition to the six major U.S. shipbuilders, ten international shipyards were visited during this study. The benchmarking system was applied in seven of the international yards. These were a mix of high output commercial builders, builders of complex commercial vessels and naval vessel builders. The

U.S. yards predominantly build surface ships but one builds both surface ships and submarines and another builds submarines only.

2 SUMMARY OF USE OF BEST PRACTICE

2.1 Overall findings

In 1998, the industry prioritized the improvements required in the NSRP ASE Strategic Plan which was subsequently modified following the publication of the 2001 benchmarking report to take account of the major deficiencies identified by the study. This has set the course for industry-wide performance improvement efforts and has also influenced the prioritization in the individual shipyards. Other influences have been:

- the individual shipyard benchmarking reports produced at that time
- individual shipyard benchmarking visits to Europe and Asia
- the shipyards' own perceptions of their deficiencies
- cost/ benefit analysis
- shipyard rules regarding return on investment or payback time which are often linked to the size and length of the order book
- the influence of successful NSRP initiatives such as the lean workshops

The Federal Government, and some State Governments, have been providing assistance to improve industry performance for some time and have also influenced the prioritization of the improvement effort. However, in general, the industry picked the "low hanging fruit" first to get an early payback for their investments and then moved on to address the more difficult and expensive areas.

Over the last five years, there has been an increase in performance improvement activity and some substantial investments in facilities, plant and equipment have been made. This may be motivated by the increased competition brought about in part by the reduction in naval demand and pressure brought to bear by the two corporations that own the yards to improve performance and produce higher returns.

Table 2.1 shows the change in the average best practice rating of the U.S. yards between 1999/2000 and 2004 and the comparison with the average rating for the international sample in 2004.

Section	Group	U.S yards average rating 1999/2000	U.S. yards average rating 2004	International yards ave. rating 2004
A	Steelwork production	2.9	3.3	3.7
B	Outfit manufacturing and storage	3.3	3.6	3.6
C	Pre-erection activities	3.1	3.4	3.8
D	Ship construction and outfitting	3.0	3.5	3.7
E	Yard layout and environment	2.6	3.2	3.4
F	Design, engineering and production engineering	3.4	3.6	3.8
G	Organization and operating systems	3.5	3.9	4.0
A – G	**Overall industry rating**	**3.1**	**3.6**	**3.8**

Table 2.1 – U.S. and international industry best practice rating by group and overall

The overall average for the U.S. yards has increased from 3.1 in 1999/2000 to 3.6 in 2004. Although the degree of improvement varies significantly from yard to yard, the average rate of improvement for the industry as a whole is approximately 0.1 point of best practice rating per annum. This is similar to the rates of improvement demonstrated by leading international builders in the past and indicates there has been a marked increase in the rate of improvement in the U.S. yards over the last five years. This is the result of substantial capital expenditure by several yards and a concerted, industry-wide effort to employ a higher level of technology. Although individual U.S. yards still have some way to go, and there are some large gaps in key elements, at an industry level, the technology gap with the international shipbuilders is closing.

Care needs to be taken when drawing conclusions from these comparisons. To achieve the lowest cost, a shipyard needs to have an appropriate level of technology for its cost base (labor and infrastructure costs), its product mix and throughput. The extent to which the use of best practice influences productivity in a particular area is related to the proportion of man-hours spent in the area. For example, in a surface combatant, there are at least twice as many hours in outfitting as there are in structural steelwork and while the quality and integrity of the structure is of vital importance, priority should be given to achieving a high use of best practice in outfitting. Conversely, it is extremely important for some of the South Korean yards that can produce 50 to 60 less-complex ships, and process excess of one million tons of steel per annum, to have equipment and technologies that facilitates high output of low cost steelwork.

Figure 2.1 shows the range of use of best practice observed in the international and U.S. yards in 2004 by element group. The ends of each bar represent the lowest and highest average score in each element group and the black line across the bar is the average for all the yards included.

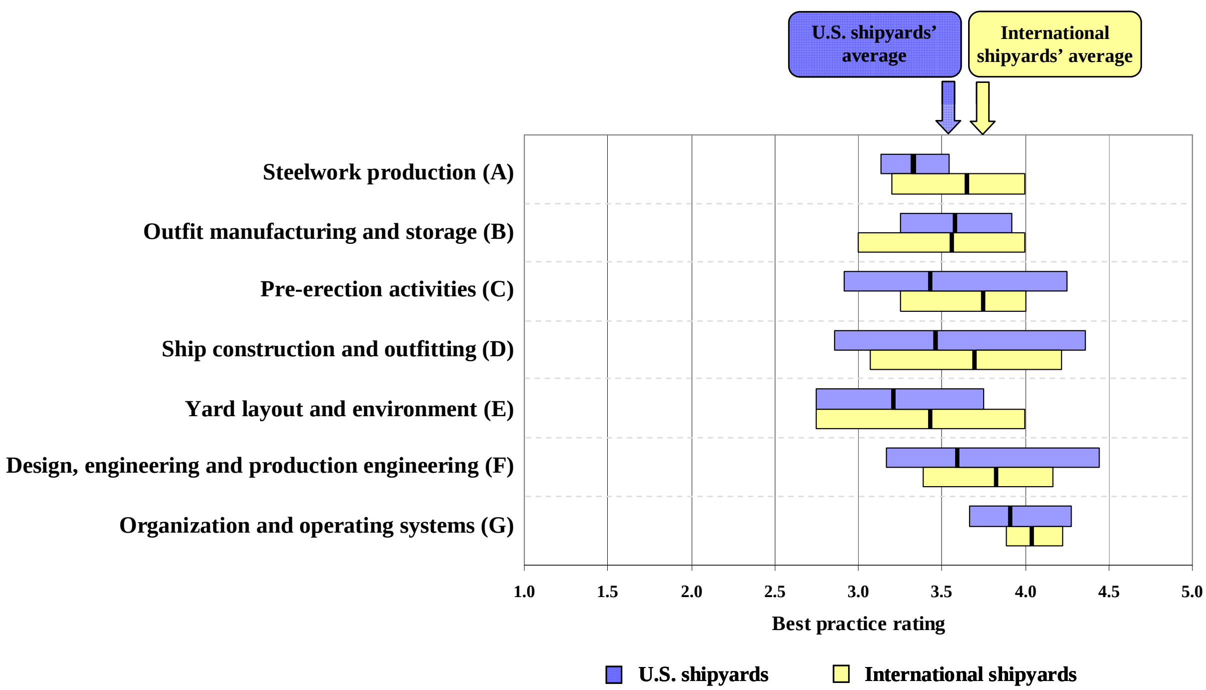

Figure 2.1 – Overall use of best practice 2004

Some of the U.S. yards have clear strengths and the benchmarking team were impressed by the improvements that have resulted from the recent efforts. However, with the exception of outfit manufacturing and storage, in terms of average best practice rating, the U.S. yards lag behind the international yards in all element groups. The largest technology gaps occur in steelwork production and the pre-erection activities which includes pre-erection outfitting and outfit module building. For the reasons explained above, the gap in steelwork is less important than the gap in the pre-erection activities and the smaller gaps in design, engineering and production engineering and the organization and operating systems groups. These latter two groups include production engineering, design for production and planning. To build the complex vessels produced by the U.S. yards most effectively, the averages in these groups should lead the international yards which tend to build less complicated vessels.

The following paragraphs summarize the current situation in U.S. yards, the changes that have occurred since 1999/2000 and make comparisons to the practices of the yards in the international sample. A more detailed review at the element level is included in Appendix 2. The appendix includes suggestions for industry-wide corrective actions. The suggestions are prioritized high (H), medium (M) and low (L) within the element to which they apply. However, overall emphasis should be placed on the rankings from the overall prioritization presented in Section 4. In other words, an item identified as a low priority within an element that has been ranked highly in Table 4.1, may have a higher overall priority than an item which has been scored as being a high priority within a lower ranking element.

2.2 Steelwork production

There has been significant investment and advances in the application of higher technology in steelwork production over the last five years with an increase in the best practice rating from 2.9 to 3.3. However, it remains one of the lowest scoring groups and there is a significant technology gap when compared with the international yards surveyed, whose average rating was 3.7.

There has been negligible improvement in the storage and treatment of steel over the last five years. Little has changed in the stockyards; stock levels have reduced but are still very high compared to the international yards and in some cases materials handling methods are outdated. Of all the production elements, these areas are the furthest behind the international yards with an average rating difference of 0.8.

Plate cutting is now universally high technology. Profile cutting lags behind and even though there has been an increase in robotic cutting, there is still a high proportion of manual marking and cutting. Plate and profile forming has moved forward with the wider introduction of numerically controlled machines and the technology is not significantly different from that found overseas.

The most significant improvements have been in the areas of minor assembly, sub-assembly and flat unit assembly where the improvement has averaged 0.8 over the five-year period. The industry averages for these areas is equal to that of the international sample. Many yards have invested in new equipment and introduced more mechanized assembly lines. Cell-based manufacturing is now widely adopted. In these and the other assembly areas, U.S. yards have made good progress in closing the gap with their international counterparts although there is considerable room for further improvements. In all the assembly stages, a particular weakness compared to overseas yards is the lack of focus on variety reduction and product standardization.

U.S yards scored well in outfit steel, leading the international yards by 0.3. However, little has changed since 1999/2000 and the favorable international comparison is mainly because outfit steel is almost always subcontracted in overseas yards. Where U.S. yards manufacture outfit steel in-house, it is usually well-organized.

2.3 Outfit manufacturing and storage

Although some individual elements lead the international yards, outfit manufacturing and storage is the only group where the U.S average leads the international average, albeit by a small margin. The main reason for this is that international yards outsource the majority of outfit manufacturing and retain only a basic capability, which attracts a low score. Although some further investment is required, outfit manufacturing in U.S. yards is relatively well organized, having benefited from various lean initiatives in recent years. The group improvement of 0.3 since the 1999/2000 survey is all the more notable because the two elements relating to storage and warehousing have actually deteriorated.

The improvement in the four outfit manufacturing elements of the group is 0.5. The lowest scoring element is pipe manufacturing. In general this is because some equipment is quite basic, there is a relatively low level of automation and many shops are not focused on manufacturing pipe families. One serious performance inhibitor in outfit manufacturing is the product variety the U.S. shops have to deal with, and the lack of focus on interim product families.

The two elements in this group concerned with general storage and warehousing and the storage of large and heavy items were rated lower in 2004, at 3.5, than in 1999/2000 when they were rated at 3.7. There have been some developments in this area so the main reason for this is probably the increase in inventory levels in some yards. Leading international yards have adopted systems that significantly reduce costs through carrying less inventory and minimizing the handling of bought-in material and equipment. Although some U.S. yards have made serious efforts in this direction, others maintain a high level of inventory and have not developed their handling processes. The level of inventory may be compounded by poor schedule adherence and a recent Navy cost-saving initiative to purchase a large number of ship sets of equipment at one time. In general, the physical aspects of the storage and warehousing operations and the associated control systems were not dissimilar to the foreign shipyards surveyed. What differs is the operating philosophy, which is more “lean” in the foreign yards.

2.4 Pre-erection activities

There have been some advances in pre-erection activities although old/legacy designs which have not been designed to maximize the use of outfit assemblies and pre-erection outfitting have in many cases restricted the shipyards’ opportunity to improve their processes. Overall, the U.S. group average of 3.4 has improved by 0.3 since 1999/2000 and is now 0.4 behind the international yards which scored 3.8. The most significant areas of deficiency are in outfit module building and outfit parts marshalling where scores have remained level or deteriorated since 1999/2000.

The building of modules (pre-assembled units of outfit) varies widely and there are almost no dedicated assembly facilities. While outfit parts marshalling is generally effective, the lead-time, inertia and inventory levels in some yards are excessive when compared internationally. A respectable level of pre-erection outfitting has now been achieved in many yards but due to weaknesses in design and production engineering, some would have difficulty in achieving high levels on a new first-of-class.

Block assembly and unit and block storage have both shown a significant improvement of 0.7 since 1999/2000. Vessels are generally broken down into natural (large and self-supporting) blocks although there size and configuration is sub-optimal in some case due to erection cranage limitations. In general, the assembly of blocks in purpose-designed facilities compares well with the international yards. Unit and block storage is generally well organized and is compatible with overseas standards. However, some U.S. shipyards still have excessive in-process storage.

Materials handling in U.S. yards lags the international yards by a significant margin with limited use of conveyor systems, specialist and automated transport systems and purpose-designed pallets.

2.5 Ship construction and outfitting

Ship construction in the U.S. takes place on a mixture of land-level facilities, inclined ways and building docks. Construction cycle times are long. Cranage in many yards is sub-optimal and must be upgraded if large pre-outfitted blocks are to be erected with a consequent reduction of cycle time and onboard man-hours (which are the least productive). In most overseas shipyards, construction takes place in building docks served by high capacity cranes. Although the U.S. average is only marginally behind that of the international yards, there are some major deficiencies in individual yards.

In the block erection and fairing group, the best practice rating in the U.S. yards lags that in the international yards by 0.5. This is largely because although most U.S. yards have an effective accuracy control program, there is still wide use of added material on blocks to compensate for assembly inaccuracies at erection fit-up. Accuracy control at all stages of steel assembly is being focused on but the full effects are yet to be realized and erection rates remain slow.

That said, U.S. yards have improved in six out of the seven elements in this group, raising the group average by 0.5 in the last five years. Good progress has been made in the application of more efficient and productive welding processes. More attention to the application of robotics and further mechanization will help to close the gap. Staging and access, together with outfit installation, showed less improvement over the period. The U.S. yards scored quite well in onboard services and staging and access but more needs to be done to reduce these non-added value activities to the levels achieved in the best international yards.

Apart from a few notable but small changes, painting technology has remained unchanged over the last five years. Painting practices vary across the industry and in general lag behind the international yards which tend to integrate their assembly, painting and outfitting strategies more effectively. One reason behind the lack of progress could be that levels of pre-erection outfitting have increased significantly and the damage to paintwork after block painting has increased, causing large amounts of painting rework.

2.6 Yard layout and environment

Most U.S. yards are composed of facilities which have evolved over a long period. With one exception, their shape is less than ideal (for example, long and narrow) and is constrained by roads or other adjacent facilities. However, material flows are generally unidirectional although they may be poor in local areas. Materials handling distances between production centers are sometimes very long. Many foreign yards visited were purpose-designed in the last thirty to forty years and are therefore more logically and efficiently laid out.

There has, however, been significant improvement in the last five years. Some of this is the result of the facility development projects undertaken by many of the U.S. shipyards. The general environment has also improved and this is a reflection of the recent rigorous lean manufacturing programs initiated in many yards together with a focus on work-cell organization and much improved housekeeping. Conditions vary from area to area but the newer workshops and facilities provide factory-like conditions. The worst housekeeping was found in the ship construction areas and onboard and this is where the greatest gap exists between the U.S. and leading foreign shipyards.

2.7 Design, engineering and production engineering

The use of best practice in this group has improved a little (0.2 in best practice rating) since the last survey but the overall average remains below that of the international yards.

The design and engineering systems and the format of the outputs in some U.S. yards are on a par with or ahead of the international yards. The design methodology compares well although the wide use of legacy designs has hindered the introduction of more up to date design methods. However, design cycles are quite long and although it might be appropriate to attribute a high proportion of the expenditure to research and development, typically, huge numbers of man-hours are consumed when compared to the international yards. The Navy also has a significant influence on this.

There have been some improvements in the last five years but the yards and the Navy seem to have had little success in introducing production engineering principles into the design and engineering process and the production engineering function remains a secondary effort. With a few exceptions, the use of best practice in production engineering and its application in terms of design for production lags significantly behind the international yards.

In coding systems and parts listing procedures there has been a significant improvement (0.9 in best practice rating) indicating a major focus on material and production control over the last five years. The use of best practice in accuracy control and quality control has also significantly increased and although considerably behind that of the international competition, the yards are now in a position to catch up.

2.8 Organization and operating systems

This group of elements has shown an improvement of 0.4 in use of best practice since 1999/2000 and only lags the international yards by 0.1. However, the relative strengths of the U.S. yards in elements such as production management information systems, quality assurance, stores control and production control are offset by weaknesses in other important areas. These include manpower and organization of work, and planning and scheduling.

Significant improvements have been made in manpower and organization of work in the last five years with an increase in rating of 0.6. However, there remains much to do to raise the low average score which is principally due to low levels of flexible working, limited use of multi-disciplinary teams and limited implementation of area management and workstation organization in some yards.

The U.S. yards lag behind in planning and scheduling because systems tend to be more complicated, less integrated and less responsive and appear to require proportionately more manpower to run them. In addition, the international yards place far more emphasis on schedule adherence.

The majority of U.S. yards are focused on meeting budgets for a particular ship and plan improvements from ship to ship. The best international yards set targets and measure progress by area with the goal of continuously improving performance regardless of the project.

3 U.S. INDUSTRY PRODUCTIVITY

3.1 Measurement of productivity

Compensated Gross Tonnage (CGT) is the measure of work content that forms the basis of the productivity estimate. CGT is the international gross tonnage (a measure of internal volume) of the vessel multiplied by a compensation coefficient which represents the complexity of the vessel design. It allows the productivity of different shipyards to be compared even though they may be building different types and sizes of ship. This is because the work content is based on the characteristics of the subject vessel and is not expressed in terms of man-hours. The man-hours required by a particular shipyard to execute the work content are determined by multiplying the CGT for the vessel by the productivity of the yard in terms of man-hours per CGT.

There are internationally agreed CGT coefficients for commercial vessels but none for naval vessels. A recent study carried out by FMI on behalf of the UK Ministry of Defence (UK MoD) has provided the basis for the coefficients used in this project. The shipyards were unable to provide the data necessary to calculate the CGT coefficients for all the vessels built in the U.S. and so coefficients have been estimated from public domain data and from visual inspection of some of the vessels concerned. The coefficients are therefore preliminary and the estimates of shipyard productivity on which they are based must be treated accordingly. The difference in the work content of typical U.S. and European designs was estimated from analysis of the data presented by Ferraro and Stonehouse[1] in 1994 and Craggs et al[2] in 2004. The analysis indicates that a typical U.S. surface combatant has more work content per gross ton than an equivalent international vessel. Therefore, relatively high CGT coefficients have been assumed.

In the U.S. and other developed nations, naval design and construction projects require the shipbuilder to commit proportionately more management, technical and administrative resources than would be the norm on a commercial vessel. This is because the customer requires the shipbuilder to adopt practices that are not normally necessary in commercial shipbuilding and there is simply more work involved in dealing with, and responding to, the customer. To be able to make a fair comparison between the work content of commercial and naval vessels, the additional effort needs to be taken into account in the CGT coefficient. This correction has been called the customer factor. It is expressed as a percentage and applied to the vessel's base CGT coefficient to account for the additional work content. The method used to calculate the factor for the U.S. is explained in Section 3.2 following.

The measure of shipyard productivity is man-hours per CGT. The man-hours used in the calculation are the hours of the workforce, both direct and indirect, involved in shipbuilding plus the sub-contracted man-hours. It is therefore a measure of the efficiency of the whole organization. Three aspects of shipyard productivity have been considered: core productivity, rate of improvement in core productivity and first-of-class performance drop-off. Core productivity is the best productivity a shipyard can achieve with its current production technology and a mature design. Shipyards do not always work at this level of productivity because first-of-class effects, interference between contacts, facilities development and other disruptions tend to cause the actual productivity to reduce. First-of-

[1] Ferreiro L.D. and Stonehouse M.H. "A Comparative Study of US and UK Frigate Design" RINA Transactions 1994 Part A

[2] Craggs J., Bloor D., Tanner B. and Bullen H. 2004 "Naval Compensated Gross Tonnage Coefficients and Shipyard Learning." *Journal of Ship Production*, Vol 20, No. 2.

class performance drop-off is the degree to which actual productivity drops off on a new first-of-class. Less effective preproduction processes and complex vessels tend to result in higher first-of-class performance drop-offs.

As the majority of the U.S. shipyards benchmarked were unable to supply the information required to calculate shipyard performance, productivity has been estimated from information available in the public domain. The method used, the assumptions applied, and the sources of data are included in Appendix 2. The resulting estimates are considered to be indicative only and would need to be validated by calculations supported by the shipyards before any robust conclusions could be drawn. Even so, the estimate of overall industry productivity is in-line with the expectations resulting from the technology survey carried out in the shipyards.

3.2 Customer factor

The customer factor was estimated by analyzing shipyard data and by interviewing shipyard managers. The industry provided a limited amount of data necessary to carry out a numerical analysis for naval auxiliaries. The man-hours spent in each area of the shipyard were expressed as a proportion of the blue collar man-hours for a range of commercial vessels and a range of naval vessels built by the same shipyard. The average proportions for the commercial and the naval vessels were then compared to determine if there were any consistent differences between the two sets of data. Significant differences in the effort required were found in the following areas:

- Engineering not associated with first-of-class design
- Administration
- Master planning
- Industrial engineering
- Program management
- Material procurement and warehousing
- Production and support services
- Quality assurance

The interviews explained some of the reasons for the differences. They were also used to verify the order of magnitude of the differences indicated by the calculation. In addition to the requirements placed on the shipyard relating directly to the design and construction of the vessel, a disproportionate amount of effort is required to deal with the number of people involved in the acquisition process, the number of reviews and reports required, and the effects of such things as ILS, FAR, Prime Contracts Flow Down, material procurement, ITAR and the Truth in Negotiating Act.

The analysis concluded that there was an increase of about 10% in man-hours for naval auxiliaries. A customer factor of 1.1 has therefore been assumed for these vessels. The factor appears to increase with vessel complexity and function. The higher the level of classification, the higher the factor tends to be. The shipyards provided no data that could be used to calculated customer factor for surface combatants, submarines or aircraft carriers. However, based on experience in the UK and comments made by shipyards and NAVSEA, it has been assumed that the factor for surfaces combatants is 15%. However, this may be a relatively conservative estimate. The factor is likely to be even higher for submarines and aircraft carriers.

3.3 Vessel complexity and specification

Technological advances, the need to gain enhanced capability from a reduced number of vessels and compromises between Congress and the Navy have resulted in a trend of increased vessel complexity. This is reflected in higher CGT coefficients. The principal driver of complexity and hence work content, is the vessel's specification. For example, the specification of DDG appears to have resulted in a design that has about 50% more work content per unit of volume than a modern international destroyer. Part of the difference is related to capability but a substantial proportion is due to the outfit density and the general complexity of the vessel. Furthermore, an incremental increase in the complexity of an already complex vessel results in a disproportionate increase in work content. Therefore, enhancements to the specification of many legacy designs that increase the complexity of vessels which are already densely packed are likely to result in disproportionately higher construction costs.

Cost, risk, first-of-class performance drop-off, and the probability of cost and schedule overrun, all increase with vessel complexity. Therefore, if exposure to all of the above is to be minimized, overly complex vessels should be avoided. The current trend for complex vessels may not be giving the best balance between capability and value for money.

3.4 Shipyard productivity

The increase in best practice rating in some U.S. yards since 1999/2000 has been impressive and there is likely to have been a corresponding improvement in productivity. Using the method described in Appendix 1, an order of magnitude estimate of productivity was made for the majority of yards by comparing historic annual shipyard output, expressed in terms of CGT, to the effort required to produce it and reviewing the trends over a ten-year period. In some cases, the lack of data or uncertainty associated with it meant that it was not possible to apply this method and consequently a likely range of productivity was estimated from the results of the technology survey.

The analysis shows that shipyard core productivity in the major shipyards probably falls within the range of 30 to 60 man-hours per CGT. However, due to first-of-class performance drop-off, performance and other factors could be up to 50% less than this. This means that the actual productivity being achieved by individual builders during 2004 could fall in the range 30 to 90 man-hours per CGT. Core productivity in the best U.S. yards appears to be comparable to some leading international naval builders but U.S. first-of-class performance drop-off appears to be much higher, indicating relative weakness in the pre-production areas.

The rate of improvement in core productivity over the last ten years appears to have ranged from 0% to +5%. However, given the improvement in best practice rating in all yards, it is hard to believe that productivity has not improved in all of them. A more rigorous analysis supported by the shipyards may confirm that core productivity has improved throughout the industry. Based on previous benchmarking results, a good rate of improvement in core productivity in shipyards of this type is considered to be 3 to 5% per annum.

3.5 International comparison

Past competitiveness studies have established a correlation between use of best practice, performance and profitability. One of the most thorough of these was the 1992 EC Study of the Competitiveness of European Shipyards carried out by KPMG (UK) and FMI. This study proposed that each yard must maximize its use of resources by ensuring that it is using best practice appropriate to its size, type and individual business objectives. The research program and analysis demonstrated the link between the use of best practice and output performance. The results are shown in Figure 3.1, together with the results from subsequent studies. The overall position of the U.S yards have also been plotted to provide a tentative comparison with international shipyards.

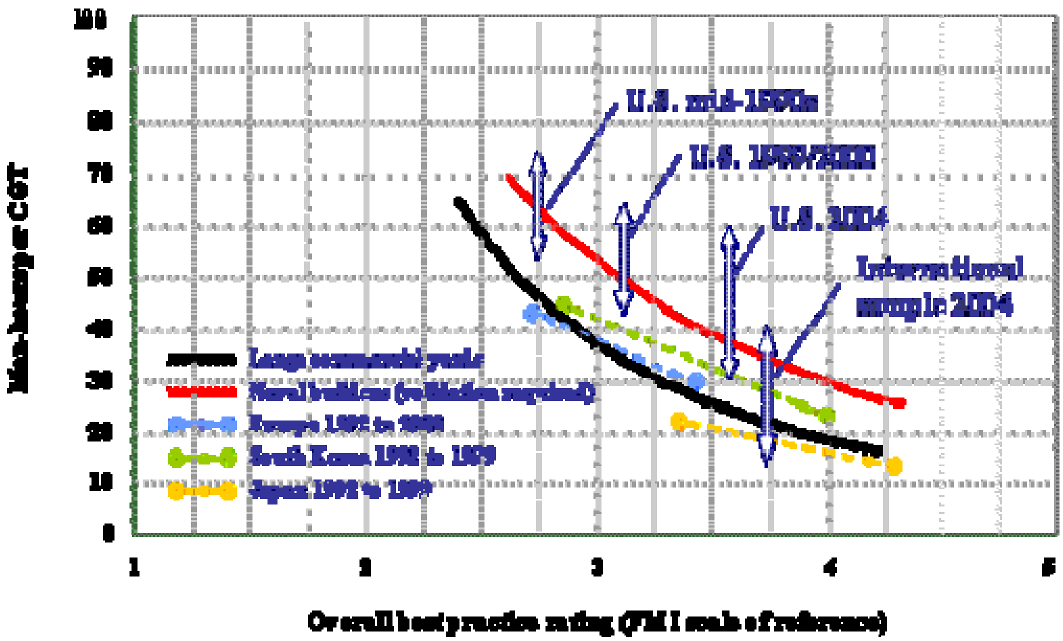

Figure 3.1 – Best practice and core productivity

The arrows indicating the position of the U.S. yards show the average use of best practice and range estimate of core productivity at each point in time. The productivity of the U.S. yards in the mid 1990s and 1999/2000 has been adjusted from that previously published to reflect the current estimate of core productivity rather than the actual productivity that appeared to be being achieved at the time. The actual productivity includes performance drop-off as explained in Section 3.1 above and Appendix 1. It should be noted that most leading U.S. shipyards declined to take part in the productivity determination aspects of the 1999/2000 study so there is also a low level of confidence associated with previous estimates of productivity.

The trend lines for the large commercial yards and naval builders have been derived from previous benchmarking studies. High performing shipyards that make the most effective use of their applied technology tend to be close to or below the trend line for their sector. Conversely, yards that perform less well tend to be above the line, indicating there is waste in the shipbuilding system. In some cases this could be partly due to over manning. In general, there appears to be a high number of people in some U.S yards for the output they produce. Although there may be some good reasons why this should be the case: including research and development, first-of-class design, logistics support and technical support for the existing fleet, the lack of data means that this has not been analyzed.

The general positioning of the U.S. yards above the trend lines could indicate that there is scope in some yards to improve performance by working more effectively without necessarily having to make fundamental changes to infrastructure or the basic technologies employed. Generally though, to improve significantly, shipyards need to reduce waste (become more lean), increase their use of best practice and reduce the inherent work content designed into the vessels they build. Improving the use of best practice and the effectiveness of the pre-production areas will also result in reducing first-of-class performance drop-off.

While significant advances appear to have been made in closing the core productivity gap with comparable international yards, the first-of-class performance drop-off is still much higher in U.S. yards. This also points to opportunities to make improvements in key pre-production areas which are reflected in benchmarking scores. As a number of new classes of U.S. naval vessels are now planned, the minimization of first-of-class performance drop-off must be a priority.

The productivity of naval builders is often compared to commercial builders and some observers comment that it should be broadly the same. The positioning of the naval builders' trend line in Figure 3.1 still requires validation and further analysis may show that there is insufficient justification for the large gap between this and the commercial shipbuilders' trend line. However, the naval builders are required by the market they operate in to behave in a different manner and this requires a different overhead structure and operating philosophy. The relationship between use of best practice and productivity should therefore be different[3]. In addition, long cycle times and lower levels of throughput in naval yards also means that they have fewer opportunities in a given time frame to make improvements.

Some observers have commented that as the commercial vessels built by naval shipbuilders tend to be expensive, they must inherently be constructing equally expensive naval vessels. Other studies (Craggs et al 2004) have shown that a naval builder can provide good value for money in the construction of naval vessels but be unable to compete in high-volume commercial markets, even though attempts have been made to make appropriate changes to the yard overhead structure and operating philosophy. This said, both governments and naval builders can undoubtedly continue to make improvements by studying the most successful commercial models.

Government and naval acquisition rules and practices increase shipyard work content significantly above the norm for commercial shipbuilding and appear sometimes to encourage poor shipyard practices. There are currently opportunities in the U.S. to rectify this on new contacts. Continuous performance improvement in many international yards is not only due to improvements in processes and practices but also to a progressive reduction in vessel work content. This is one of the key areas that the U.S. industry and government could address in partnership. The new programs offer opportunities to make changes that will avoid needless costs being carried for years to come. For example, there are reports that DDX incorporates significant steps forward in design for production but, based on the results of the technology survey, it is very likely that more could be done.

[3] The customer factor only corrects the CGT coefficient for the direct man-hours. It is in the indirect departments such as administration, security, marketing and basic design where the differences lie.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The industry is now generally well equipped to achieve internationally comparable levels of productivity in naval construction. However, there are major opportunities for improvement in the 'soft' areas including design, production engineering, planning, estimating, logistics, accuracy control, and manpower and organization. Deficiencies in these areas results in high levels of inherent work content, high first-of-class performance drop-off, and poor cost and schedule adherence.

The high inherent work content[4] in U.S. naval vessels also contributes to the perception of poor overall productivity. While it appears that there is potential to significantly improve core productivity in most yards, the previous sections have shown that in general, and relative to international builders of comparable vessels, core productivity is probably not as bad as many perceive it to be. It is in actual productivity that includes the performance drop-off in early vessels in a series where the performance gap is the greatest.

The Navy and government can also have an adverse effect on shipyard performance through:

- Instability in the acquisition program
- The FAR and similar rules
- The design process and oversight
- The management of change orders
- Contract terms and conditions
- Unstable funding of performance improvement programs such as the NSRP

Suppliers of materials and equipment account for a higher proportion of vessel cost than the shipyard added value and have significant influence on cost and schedule adherence. Therefore, improvements in that part of the industrial base should be considered in any future study.

Although the principal focus of the study has been naval construction, a clear benefit of improving performance is that the industry will become more competitive in naval export markets and in domestic and international commercial markets.

4.2 Priority areas for improvement

It is possible to set best practice rating targets on the basis of the need to achieve a specific, market driven, level of productivity. However, for this project, targets have been proposed for each element in each shipyard based on a review of the international benchmarking data, the shipyards product mix and the particular circumstances within the yard. Along with the additional criteria listed below, the targets have been used to produce a list which prioritizes the elements for action. The additional criteria are:

1. The size of the gap between the current and target level of use of best practice (high priority given to large gaps).

[4] High inherent work content and hence high vessel CGT coefficient also increases technical, financial and schedule risks.

2. The impact that the activity has on ship cost (high priority given to high impact).
3. Contracts (current or future) on which the benefits would be realized (high priority given to current contacts).
4. The typical dollar cost of raising the level of technology in the area concerned (high priority given to low cost items).

The individual shipyard priority lists have been combined and the number of shipyards that need to take action in each area has been added as a fifth prioritization criteria. This has resulted in a prioritized list for the industry as a whole which is shown in the Table 4.1. The highest ranking items in the table are those which were ranked the highest in all, or the majority, of the U.S. shipyards.

Element description	Rank	Element description	Rank
Design for production (F7)	1	Steelwork production information (F2)	26
Production engineering (F6)	2	Onboard services (D4)	27
Steelwork scheduling (G3)	3	Profile stockyard and treatment (A2)	28
Outfit scheduling (G4)	3	Module building (C1)	28
Pre-erection outfitting (C3)	5	Block assembly (C4)	28
Master planning (G2)	5	Curved and 3D unit assembly (A9)	31
Dimensional accuracy and QC (F8)	7	Profile cutting (A4)	32
Ship design (F1)	8	Staging and access (D5)	32
Outfit parts marshalling (C2)	9	Layout and material flow (E1)	34
Steelwork coding system (F4)	10	Plate stockyard and treatment (A1)	35
Materials handling (C6)	11	Storage of large heavy items (B6)	35
Pipe shop (B1)	12	Flat unit assembly (A8)	37
Manpower and organization of work (G1)	13	Welding (D3)	38
Outfit production information (F3)	14	Sub-assembly (A7)	39
Erection and fairing (D2)	15	Superstructure unit assembly (A10)	40
General storage and warehousing (B5)	16	Outfit steel (A11)	41
Painting (D7)	16	Minor assembly (A6)	42
Outfit installation (D6)	18	Quality assurance (G8)	43
Production control (G5)	19	Electrical (B4)	44
Parts listing procedure (F5)	20	Sheet metal working (B3)	45
Performance and efficiency calcs (G7)	20	Unit and block storage (C5)	45
Plate and profile forming (A5)	22	Machine shop (B2)	47
General environment (E2)	22	Plate cutting (A3)	OK
Ship construction (D1)	24	Stores control (G6)	OK
Lofting Methods (F9)	25	Production management info systems (G9)	OK

Table 4.1 – Industry summary of elements requiring action, in order of priority

The following sections contain suggestions for industry wide, shipyard-specific, government and collaborative initiatives to make the necessary improvements in high priority areas. These are based on the findings and recommendations made in Appendix 2. Some initiatives will effect more than one high priority element so the actions have been grouped into the top ten priority areas as follows:

1. Ship design and design for production
2. Production engineering
3. Master planning and steel and outfit scheduling
4. Outfit module building, pre-erection outfitting and onboard outfitting
5. Dimensional and accuracy control
6. Outfit parts marshalling and general storage and warehousing
7. Pipe shop and other outfit manufacturing activities
8. Manpower and organization of work
9. Steelwork and outfit production information
10. Steelwork coding system

The responsibility to effect the majority of the improvements suggested principally lies with the industry; however, Congress, the Navy and other government departments could take action to assist. The principal suggestions for the Navy and government, which are discussed in more detail in the following sections, are:

- Gain a more in-depth understanding of the relationship between ship specification, complexity and work content and work with the design authorities to reduce the inherent work content of naval vessels while not compromising functionality (i.e., reduce the CGT coefficient).
- Work with industry to develop the pre-production processes to reduce first-of-class performance drop-off.
- Review the acquisition rules, regulations and practices to determine if each adds value and work with the shipyards to find ways to reduce the effect these have on shipyard work content. (i.e., reduce customer factor).
- Stabilize the ship acquisition program.
- Improve shipyard incentives.
- Continue to support performance improvement initiatives such as NSRP.

The scope of the suggested initiatives is limited to the elements of the benchmarking system included in the study. There may be other areas that require attention such as those relating to human resources, purchasing, accounting and contract management that are not discussed here. The industry already has several improvement programs in place. The NSRP lean initiative is such an example which appears to be very successful. It is recommended that the scope of the current initiatives and programs are reviewed in the context of the findings of this study.

4.3 Ship design and design for production

Compared to the international yards, the general approach adopted by U.S. shipyards to basic functional design is sound. However, man-hour expenditure and design lead-times are excessive. Much of this can be attributed to an inconsistent and ill-defined design process in a high portion of the yards and intervention from the Navy. International shipyards have a standard approach to ship design with well-defined design stages and clearly specified outputs for each stage.

There are two major actions required to improve ship design performance at an industry level:

1. Develop a standard and consistent design approach to be applied to all vessel types.
2. Establish a progressive design approval program with design freeze points at prescribed intervals in the design process.

Design for production in U.S. yards is given a very low priority when compared to international norms. Design and engineering staff are relatively ignorant of production processes and methodology compared to their international counterparts. Although there has been some progress, in general the practice of incorporating producibility in a design through the formation of design/build teams leads to inconsistency and increased design man-hours and missed opportunities for making savings in production. Industry actions suggested above will help enable design for production but in addition there should be:

1. Regular reviews of legacy designs to define the cost benefits of a re-design exercise to reduce production costs.
2. Multi-yard teams for the development of vessel designs to a predetermined level that enables the individual building yards to continue the detail design for optimum producibility.

At shipyard level, each yard should have a formalized and consistent shipbuilding strategy from which design rules and guidelines are developed for each stage of the design process in order to optimize production performance.

4.4 Production engineering

In all the foreign yards surveyed, the production engineering function leads the development of both technical and production methodology and processes. This is not the case in the U.S. and the lack of a strong production engineering function is one of the major contributors to poor performance. The issue needs to be addressed by the Navy, at an industry level and within the individual shipyards.

Current vessel acquisitioning practices are not conducive to the development of producible designs. These practices create excessive design lead times with a low priority on producibility and include:

1. Widespread use of legacy designs, sometimes over twenty years old.
2. Design and build contracts not necessarily awarded to the same shipyard.
3. Fundamental changes to the basic design of a vessel at any stage in the design cycle.

The industry needs to understand the importance of a strong production engineering function and it is recommended that this should be encouraged at industry level by:

1. Developing a shipbuilding industry production engineering charter defining the role and functional responsibilities of production engineering in U.S. yards to be in line with those of the world's leading shipyards.
2. Introducing a production engineering requirement for future ship acquisition. This could be introduced as part of the design process to demonstrate the developing production methodology at each stage of design.
3. Regular design upgrades of legacy designs to incorporate up-to-date production engineering principles.

At shipyard level, production engineering needs to assume a leading role in performance improvement, and facilities and methods development.

4.5 Master planning and steel and outfit scheduling

In general, planning systems in international yards are simpler and require a much lower level of effort to operate them than those in U.S. yards. Furthermore, scheduling and budgeting for vessels early in a new series tends to be more accurate. Even though the international yards are far more focused on schedule adherence, their systems tend to be much more flexible and responsive to change.

While all U.S. yards adopt the recognized three-tier approach to planning (strategic, tactical and detailed), the definition of the scope of each tier varies from yard to yard as does the level of detail produced at the lowest level. The full capabilities of design modeling software are not fully exploited with respect to planning and scheduling and consequently there is often rework and duplication of effort. There is also a tendency to develop detailed levels of planning too early and there is often a lack of integration with the other pre-production activities. In general, time fences for design freezes and change orders are not rigidly applied.

These deficiencies manifest themselves in high levels of inventory, high overhead costs, overrun budgets and poor schedule adherence - especially on a first-of-class. They also present barriers to the introduction of a higher technology in other areas such as material control.

Many U.S. yards have an opportunity to improve matters by upgrading their planning systems but there appears to be uncertainty as to the best way forward. It is therefore recommended that a model planning framework is developed to provide the necessary guidance. This should consider the development of the vessel design and approvals and provide guidance for the structuring and simplification of the planning process.

It is also recommended that the Navy addresses the problems created by introducing change orders at a late stage. It is suggest that time fences are agreed with each yard for each type of change and then rigidly applied.

4.6 Module building, pre-erection outfitting and onboard outfitting

In these three interrelated activities, the range of use of best practice in U.S. yards is wide and the industry average score is significantly lower than the international yards' average.

With a few exceptions, the extent of module building (the assembly of functionally-related outfit components onto a steel frame) in U.S. yards is disappointingly low. This is often the result of building legacy designs where the vessel design did not incorporate outfit modules. Although most yards now accept the benefits of outfit module building, they, and in some cases the Navy, appear to be are reluctant to spend man-hours re-designing legacy vessels and few are familiar with the spatial design techniques that make module building highly efficient and effective. In addition, most yards lack dedicated module assembly facilities and, even in those yards that are active in module building, the work is often carried out in dispersed areas within different buildings or even in the open.

Although there are some excellent examples in the U.S., the low level of pre-erection outfitting (the fitting of outfit components and assemblies onto steel blocks prior to erection at the construction point) achieved by some U.S. yards is also disappointing. The wide range of achievement can be attributed to some extent to the use of legacy designs in some yards which means that over a long series build program, the levels of pre-outfitting increase slowly but significantly above that achieved on the first-of-class. Overall, the yards are well aware of their shortcomings in this area although they may not be aware of the design methodology applied in the leading international yards that enables high levels of pre-outfitting on a first-of-class vessel.

With regard to the installation of outfit on board, low levels of module building and pre-erection outfitting have the consequence of pushing outfitting work to the more costly onboard stage. One of the reasons for this is the low priority given to production engineering and design for production in the design process of new classes of vessel. In addition, the lack of a zone by stage outfitting methodology makes the co-ordination of the various outfitting trades more difficult to manage. Excessive onboard outfitting is often characterized by too much staging, poor housekeeping and workers competing for limited working space.

In addition to actions take by individual shipyards, it is recommended that the following industry-wide actions are considered to improve the level technology in outfitting:

1. Carry out training and familiarization to increase the understanding and to quantify the savings from advancing outfit to earlier build stages.
2. Develop the production engineering process; incorporating product analysis, process engineering, methods engineering and industrial (facilities) engineering, to provide the design process with specific design for production guidance.
3. Encourage funding of purpose-designed module building facilities or other facility developments that would facilitate a higher level of advanced outfitting.
4. Investigate the feasibility of regional module assembly facilities.

4.7 Dimensional and accuracy control

Although there has been a higher degree of focus recently on the implementation of accuracy control (AC) and quality control (QC) procedures in the U.S. industry, there still remains a wide gap in the use of best practice between the U.S. (average 3.5) and the international yards (average 4.1).

Most U.S. shipyards have firmly established AC and QC departments; however, a lack of understanding of the benefits of AC and the true cost of poor accuracy, often gives it a low priority and it is not generally recognized as being a key aspect of performance improvement. In addition, a low level of confidence and instability in the assembly processes results in the continuing practice of leaving additional material on units and blocks which has to be removed at a later stage and thus constitutes rework. There is still a general acceptance of rework such as re-burning and distortion removal in the assembly processes, as being an inherent part of the shipbuilding process

By comparison, leading international yards have adopted a total quality approach and many no longer have dedicated AC and QC departments. AC and QC requirements are fully integrated into all pre-production and production activities with cross-functional teams meeting at regular intervals to discuss problem areas.

The following industry-level actions are proposed to assist the shipyards make the necessary improvements:

1. Promote awareness of the true costs of non-added-value work through training, seminars and workshops for all levels of the workforce.
2. Fully implement the AC control techniques that have been developed by the industry over the last 25 years.
3. Promote the use of statistical analysis as an intrinsic part of the performance improvement process.

4.8 Outfit parts marshalling and general storage and warehousing

Outfit parts marshalling, general storage and warehousing, and the storage of large and heavy items are all important because of the significant cost associated with receiving and storing material and equipment and delivering it to the point of use. Lean doctrines have been well applied in the some U.S. yards but, in most, inventory levels are very high and although improvements have been made, there is too much inertia associated with the outfit parts marshalling systems. The solutions required in each yard are slightly different but in general the yards need to:

1. Achieve schedule stability and adherence.
2. Reduce inventory levels in main warehouses.
3. As far as possible order and receive goods just in time.
4. Take large and heavy items directly to the point of use.
5. Minimize the use of buffer stores.
6. Make more effort to keep workers on the job by ensuring that they have all the items required to carry out the work.
7. Place more reliance on the suppliers' QA systems to provide the quality required.
8. Make better use of line-side stores.
9. Use consignment stocks.
10. In the longer term move towards a palletization system where the production pallet is compiled in the warehouse from day one.
11. Ensure that a pallet of materials is only large enough for a few days work.

There may be merit in producing guidance at an industry level as to which are the best systems. To assist with this effort, the Navy could ensure that contract arrangements do not encourage the build up of inventory in shipyards.

4.9 Pipe shop and other outfit manufacturing activities

Outfit manufacturing includes the manufacture of pipes, modules (outfit assemblies), electrical components, outfit steel (ladders, foundations, handrails, masts, etc) and sheet metal items such as furniture and vent ducting. In an international context, the fact that the shipyards still manufacture these items in-house is unusual. U.S. yards appear to be reluctant to outsource this work and in some cases are prevented from doing so by the Navy. However, it is recommended that further regional consolidation of these activities is considered. This will provide the opportunity to achieve higher levels of throughput in higher technology manufacturing environments, thus improving productivity, reducing costs and enhancing employment stability.

Pipe manufacturing is the weakest of these areas and performance levels appears to be much lower than in the international yards. There are two reasons for this; first, pipes manufactured in U.S. yards tend to be far more complicated than their international counterparts, and second, a generally lower level of technology is applied. The implementation of the design for production and production engineering recommendations referred to earlier will reduce complexity and there will be a corresponding improvement in performance. This will also facilitate the implementation of higher levels of mechanization and automation.

Much more attention needs to be paid to reducing the variety of the outfit components manufactured. This will provide the opportunity to reorganize manufacturing facilities to focus more strongly on manufacturing families of products. The common parts catalogue recent developed with the assistance of NSRP will provide an ideal vehicle for this.

4.10 Manpower and the organization of work

Some U.S. yards have score relatively well in this element but generally lag behind the international yards. The reasons for this include:

1. There is often a high level of trade demarcation.
2. There is limited flexible working.
3. Limited use is made of multidisciplinary teams.
4. Only a small number of yards have managed to successfully implement area management through the whole organization.
5. Re-training of mature personnel is not widespread.
6. Employment levels are relatively unstable (but this is improving).

These shortcomings are understood by the U.S. yards which are aware of the benefits of making improvements. However, successful implementation of best practice requires the full cooperation of the workforce and the unions. The government and Navy could assist by working in partnership with the industry to smooth demand in order to provide more stable employment. This in turn will allow the yards to focus more on the wellbeing and long-term development of their employees.

With regard to the future capability and performance of the industry, the boom and bust in the technical areas is of particular concern and this is another issue that could be most effectively tackled at industry level.

4.11 Steelwork and outfit production information

There is a wide variation in both the methodology applied for the development of production information and the format and content of that information. Yards building naval vessels from legacy designs currently tend towards using traditional ship unit based information. Those active in the commercial sector tend towards the workstation style of production information. In almost all yards there is a severe lack of ship production knowledge in the engineering departments that makes the preparation of workstation-specific information extremely difficult. Attempts to compensate for this are generally through the development of design/build teams that are not conducive to a stabilized engineering process.

The engineering man-hours and design cycle time for developing the detailed design model are far in excess of those in international yards and there is a heavy reliance on production feed-back for the completion and development of production information for subsequent vessels in the series. The process of developing production information is ill-defined and unstable, generally varying from ship to ship and within individual yards. Similarly, the format and content of production information constantly varies, sometimes depending upon personal preferences.

The current instability in the design and engineering processes together with the lack of production knowledge in the design and engineering departments is resulting in the relatively poor performance in the engineering activities, particularly in those yards attempting to implement workstation production information. Actions at an industry level suggested in the sections above addressing production engineering, ship design, design for production and planning will help considerably in stabilizing the design process and providing the environment for the efficient development of production information.

Also, at an industry level, a design and engineering methodology template should be developed for use in all yards as a guide to standardization of the approach to development of production information.

At shipyard level, each shipyard needs to develop a ship design and production definition strategy that reflects the yard's shipbuilding strategy in a set of rules and guidelines for each stage of the design and engineering process to the level of individual production workstation information requirements.

4.12 Steelwork coding systems

To be effective, any coding system cannot be confined to steelwork only but must extend to embrace all areas of ship pre-production and production operations. Only in this way can the various databases within a shipyard be effectively and efficiently utilized without extensive manual intervention.

All of the U.S. shipyards surveyed have a coding system of one form or another that include various aspects of material and labor control. Although some are semi-intelligent in that they identify some interim products to areas of production, the majority are little more than numbering systems that are generally individual to specific areas of operation without a common yard-wide structure. For example, the steelwork coding structure is different to the outfit coding structure which is different to the workstation coding structure.

If it is the intention to continue with the current practice of having a lead shipyard for the design of naval vessels with a number of yards involved in construction, there should be an industry-wide common coding structure applied throughout all levels of the design process that at a minimum identifies vessel types, systems, zones, and products. Ideally the system should encompass workforce and workstation identification in a common structure of code fields. Any industry-wide structure must be hierarchical and capable of top-down application so that a lead design yard can apply the higher levels of the coding system in the various fields that will be further populated by the various yards constructing the vessels.

While the current Ship Work Breakdown Structure (SWBS) system may possibly provide one field of a common coding structure, in its current form it is cumbersome and open to inconsistent interpretation and application and would benefit from a major overhaul.

It is recommended that as a start to developing a common coding structure, there is a national initiative to develop a common coding system for application throughout the design and engineering process that consistently identifies vessel types, shipboard zones, ship systems and interim products.

4.13 Customer factor

There may be good reasons why the customer factor appears to be so high. Some are within the control of the Navy or other government departments, others are not. However, it is recommended that the Navy, with input from industry, carries out a review of practices and procedures to ascertain if the additional work it creates for the shipyards, which is over and above the norm for commercial contracts, adds value. Where this is not the case, practices should be revised to reduce the burden. Reducing customer factor effectively decreases vessel work content and would therefore lead to lower unit procurement cost.

4.14 Specification and vessel complexity

Clearly the vessel specification has the most effect on the inherent work content of a vessel. Therefore, it is important that all stakeholders understand the implications of high levels of complexity from the outset and if possible avoid it. Much work has been done in this study and others to gain an understanding of these factors and it is recommended that the Navy uses recent work, supplemented with additional research as required, to draw up guidelines for those who write vessel specifications that will lead to lower levels of inherent work content. Some members of the industry have commented that the Navy's current weight-based estimating method will by its nature indicate that complex, dense vessels will result in the lowest cost. This has not been reviewed but it is recommended that estimating methods are considered as part of the production of the guidelines.

Following the basic specification, the design approach, and the production engineering and design for production techniques, discussed earlier in this report, should be implemented to minimize the work content.

4.15 Shipyard incentives

One of the keys to encouraging performance improvement in the industry is to build appropriate incentives into contracts. Over the years, the Navy has adopted a range of shipyard incentive schemes. Ideally contractual incentives focused on performance improvement should promote profitability through higher efficiency and should not reward the shipyard for simply spending more man-hours. Current schemes limit profits in some way and share-lines provide a shipyard safety net but may not always provide sufficient incentive to improve. Naval demand is also relatively unstable and this does not create an environment conducive to investment and performance improvement.

Profit limitations imposed on the contractor are considered to be a barrier to formulating effective incentive schemes because, ultimately, the only way for a shipyard to make more profit is to spend more man-hours. International benchmarking of shipyard cost performance using added-value per CGT and other measures would help to provide the visibility required to make the value comparisons. If such work showed that the government was receiving value for money, regardless of the profit being made by the company, it may be possible to formulate more effective incentive schemes that allowed the company to make higher profits by becoming more efficient.

Recent statements by the Navy indicate that it believes that attempts to control costs by developing competition within the supply base have failed and it is now considering single source solutions. In this environment it is essential to ensure that shipyards continue to be motivated to improve, otherwise there will be a decline in productivity and a subsequent increase in cost. Incentives may therefore play an important part in guaranteeing good value for money in the future.

Some observers have suggested that the Navy should agree a technology improvement plan with each shipyard and attach incentives to achieving it. This may have some merit but it is prescriptive. An alternative may be to agree an annual rate of improvement in core productivity and first-of-class performance drop-off, then allow the shipyard management to determine how to exceed expectations and as a result make increased profits. Government could then provide the necessary technology support through such bodies as NSRP and MANTECH. However, it is suggested that as a general principle it is far more effective to improve shipyards by creating an appropriate commercial environment rather than becoming involved in their day to day management.

Finally, the results of this study indicate that an effective way to improve shipyard performance, reduce cost and provide a climate for investment is to stabilize the naval procurement program.

4.16 Support for performance improvement

A number of government-sponsored schemes have been providing industry with information and financial assistance to support performance improvement efforts. At a national level, these include the National Ship Research Program (NSRP), the Office of Naval Research, MANTECH, and the Center for Naval Shipbuilding Technology. There are also several local schemes dealing with specialist areas. NSRP has been the cornerstone for industry performance improvement efforts for a number of years. The program has provided necessary research and a unique forum for discussion. Although it has been criticized in the past for developing technology that has not been implemented, there is no doubt that in recent years the support provided by NSRP has played an important part in facilitating the improvements seen within the industry since 1999. There is undoubtedly an ongoing role for NSRP in the future and it is recommended that this is supported.

Additional funding would greatly assist the industry in correcting the deficiencies identified by the study and in accelerating the rate of improvement. In order to ensure that investments are being made in the most appropriate areas, the industry and government should work together to further develop the prioritized improvement plan presented here. The findings of this study, as they relate to the individual shipyards and as represented in the individual shipyard reports, should be taken into account when considering funding assistance for individual shipyard projects.

4.17 Cost benefit

The principal focus of this study is to determine how to improve U.S. shipyard productivity by comparing the practices and technology employed in U.S. shipyards with leading international shipyards. When considering proposals for improvement, questions relating to their cost benefit will arise. Assessing the cost benefit of proposals such as these is a complex problem that should ideally be the subject of detailed analysis with the involvement of all stakeholders. However, to provide some high level visibility of the potential benefits, an estimate of the potential savings has been made.

Based on the estimated Compensated Gross Tonnage (CGT) coefficients for naval vessels, the recent average total military output of the six U.S. shipyards is about 850,000 CGT per annum. With reference to Section 3.4, assuming an average productivity of 60 man-hours per CGT (upper limit of estimate of industry core productivity), producing this output would require an expenditure of 51 million man-hours per annum (850,000 x 60). Assuming that 70% of these man-hours are direct, at a notional charge out rate of $50 per man-hour, the man-hour cost would be $1,785 million (51 million x 0.7 x 50).

The proposals made in the study are aimed at both improving shipyard productivity and reducing work content by:

- Increasing the use of best shipbuilding practices in U.S. shipyards
- Making more effective use of the technology employed
- Optimizing ship designs to reduce work content in U.S. naval vessels
- Reducing the customer factor
- Reducing first-of-class performance drop-off

The Table 4.2 provides an estimate of the potential savings that could be achieved by implementing these improvements assuming that the recent average level of output from the shipbuilding industry will continue over the next few years. The effect on overhead of any capital expenditure required to make the improvements has been ignored. The notes following the table explain the estimates.

Focus area	Current value	Realistic target	Estimated annual savings
Increase the use of best shipbuilding practices	Benchmarking rating average of 3.5	Benchmarking rating average of 4.0	$410m
Make more effective use of the technology employed	Many U.S. shipyards do not appear to achieve the same level of productivity for given practices as international yards	5% improvement in effectiveness of shipbuilding practices employed.	$90m
Optimize ship designs to reduce work content in U.S. naval vessels	U.S. naval vessels generally have more work content than equivalent international vessels	Reduce work content by 15%	$270m
Reduce customer factor	Approximately 10% on naval auxiliaries and 15% on combatants	5% on naval auxiliaries 10% on combatants	$90m
Reduce first-of-class performance drop-off	Approximately 50%	25%	Not calculated: this relates to specific new series only

Table 4.2 – Summary of potential cost benefits

Increasing the use of best shipbuilding practices in U.S. shipyards: The gradient of the trend lines in Figure 3.1, which show the relationship between productivity and best practice rating established by numerous studies, indicate that an improvement in best practice rating from 3.5 to 4.0 could improve shipyard core productivity by 23%. This assumes that the shipyards were able to make effective use of the improvement in technology and that customer factor related issues would allow a 23% improvement in core productivity in all departments. This would result in 23% less man-hours being spent to achieve the same output and thus, ignoring the effect on overhead, would result in 23% less cost to the government. This saving would be about $410m ($1,785 million x 0.23).

Making more effective use of the technology employed: A comparison of U.S. shipyards' use of best shipbuilding practices against a large database of international shipyards, illustrated in Figure 3.1, indicates that there is an opportunity for U.S. shipyards to make more effective use of the practices and technology they already employ. An improvement of 5% in this area is reasonable. Based on the assumptions above, this would result in a saving of about $90m per annum ($1,785 million x 0.05).

Optimizing ship designs to reduce work content in U.S. naval vessels: On the basis of the work done in this study, a target of 15% reduction (per unit of volume of ship) in U.S. naval vessel work content would appear to be a demanding but appropriate target. A 15% reduction in work content would have an effect similar to improving productivity by 15%. Based on the assumptions above, this would result in a saving of about $270m per annum ($1,785 million x 0.15).

Reducing the customer factor: Based on practices in other nations, a 5% reduction across all areas would be a reasonable target. This would have the same effect as improving productivity by 5%. Therefore, this would result in a saving of about $90m per annum ($1,785 million x 0.05).

The order of magnitude savings shown in the Table 4.2 confirm that there would be considerable benefit in reaching the targets specified. The time required to achieve these targets will depend on the motivation of the industry, Navy and Congress, and the availability of funding. A good rate of improvement in best practice rating, based on performance demonstrated by shipyards in other countries, is about 0.1 per year. Therefore, a realistic time-frame to achieve the above targets would be of the order of five years.

APPENDIX 1 – ESTIMATE OF SHIPYARD CORE PRODUCTIVITY

In order to provide a direct international comparison, and a comparison between the performance of U.S. naval and commercial builders, man-hours per CGT and $US per CGT were used as overall measures for productivity and cost performance respectively. CGT factors for naval vessels were estimated by building on previous work accomplished in this area. This included an estimate of the customer factor, namely the additional management, technical and administrative effort that is required to build naval vessels when compared to commercial equivalents.

The majority of the U.S. shipyards benchmarked chose not to supply information related to estimating CGT coefficients of naval vessels and the subsequent calculation of their shipyard performance. However, based on information available in the public domain, it was possible to make an order of magnitude estimate of shipyard productivity by comparing historic annual shipyard output, expressed in terms of CGT, to the effort required to produce it and reviewing the trends over a ten-year period.

This method has produced very rough estimates, based on very limited information, and extreme caution is advised regarding its use. Shipyard cooperation is required to produce a more definitive estimate.

The following method was used to determine annual output:

1. A list of ships delivered by the yard was produced from data available at www.coltoncompany.com and in Lloyd's Register.
2. The CGT of each vessel was estimated as follows:
   a) The gross tonnage (GT) was estimated from information available in Janes Fighting Ships and Combat Fleets of the World or on the Internet
   b) An estimate of the base indicative CGT coefficient was made from the ship type line[5], analysis of the Ferreiro paper[6] regarding the difference in the complexity of U.S. and UK frigates and a review, by FMI consultants, of some of the vessels concerned
   c) An estimate of the customer factor was made based on data collected from some U.S. yards and estimates based on findings published in the SNAME paper for combatants
   d) The estimated CGT was calculated using: CGT = GT x Base CGT coefficient x Customer factor
3. The estimated CGT of each vessel was distributed evenly over the build period using keel laying to delivery information available from Janes et al.
4. The estimated CGT contribution from each vessel was summed for each year to estimate the annual CGT shipyard output

Shipyard employment levels from www.coltoncompany.com were used as the basis for the estimate of man-hours spent. The productivity achieved in each year was then calculated as shown in Table A1.1 which includes a worked example for a generic shipyard.

[5] Craggs J., Bloor D., Tanner B. and Bullen H., 2004 "Naval CGT Coefficients and Shipyard Learning" Journal of Ship Production, Vol. 20 No. 2

[6] Ferreiro L.D. and Stonehouse M.H. "A Comparative Study of US and UK Frigate Design" RINA Transactions 1994 Part A

	Information	Value	Notes
A	Total number of shipyard employees	1,000	www.coltoncompany.com
B	Proportion of employees employed in shipbuilding	95%	Educated guess
C	Total number of employees in shipbuilding	950	A x B
D	Average number of hours worked per employee per year	1,800	Based on experience
E	Total number of shipyard man-hours per year	1,710,000	C x D
F	Estimate of annual CGT shipyard output	23,400	Method described above
G	Estimate of actual shipyard performance (man-hours/CGT)	73	E / F

Table A1.1 – Illustrative estimate of actual annual shipyard performance

Figure A1.1 shows this annual information plotted over a period. Core productivity was estimated by drawing a line connecting the points of best shipyard performance on the 'Actual productivity' line. Actual productivity will deviate from core productivity for the following reasons:

- First-of-class performance drop-off
- Performance drop-off on follow-on vessels associated with ship learning
- The interaction between concurrent series
- Drop in shipyard output without a corresponding drop in employment
- Workforce build-up and variations in manning
- General disruption including facilities development

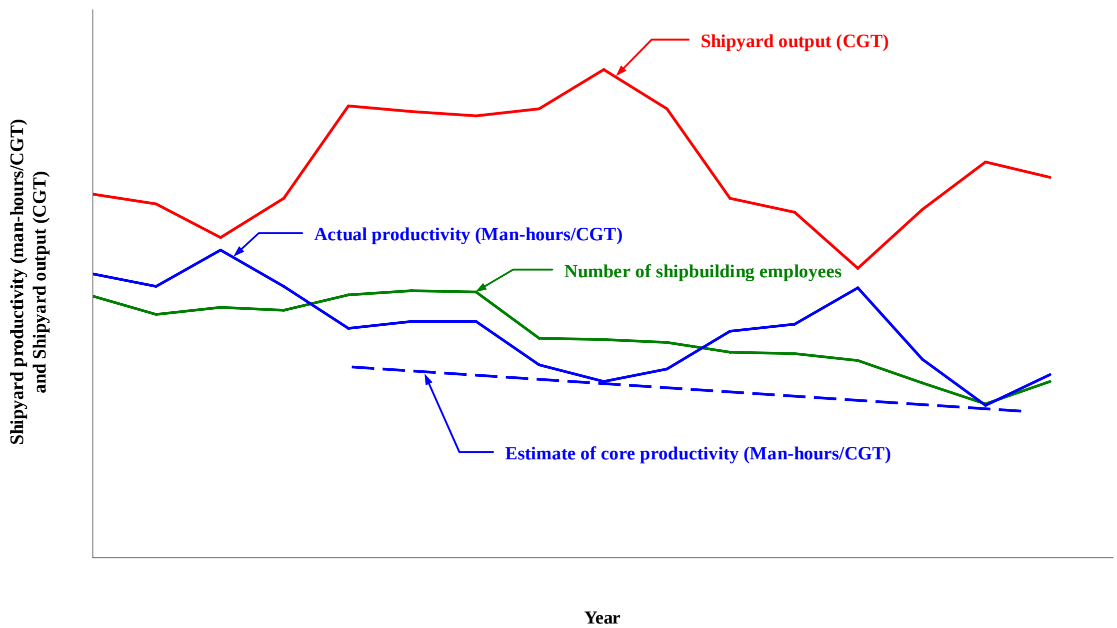

Figure A1.1 – Shipyard performance estimate

APPENDIX 2 – USE OF BEST PRACTICE IN U.S. SHIPYARDS

A STEELWORK PRODUCTION

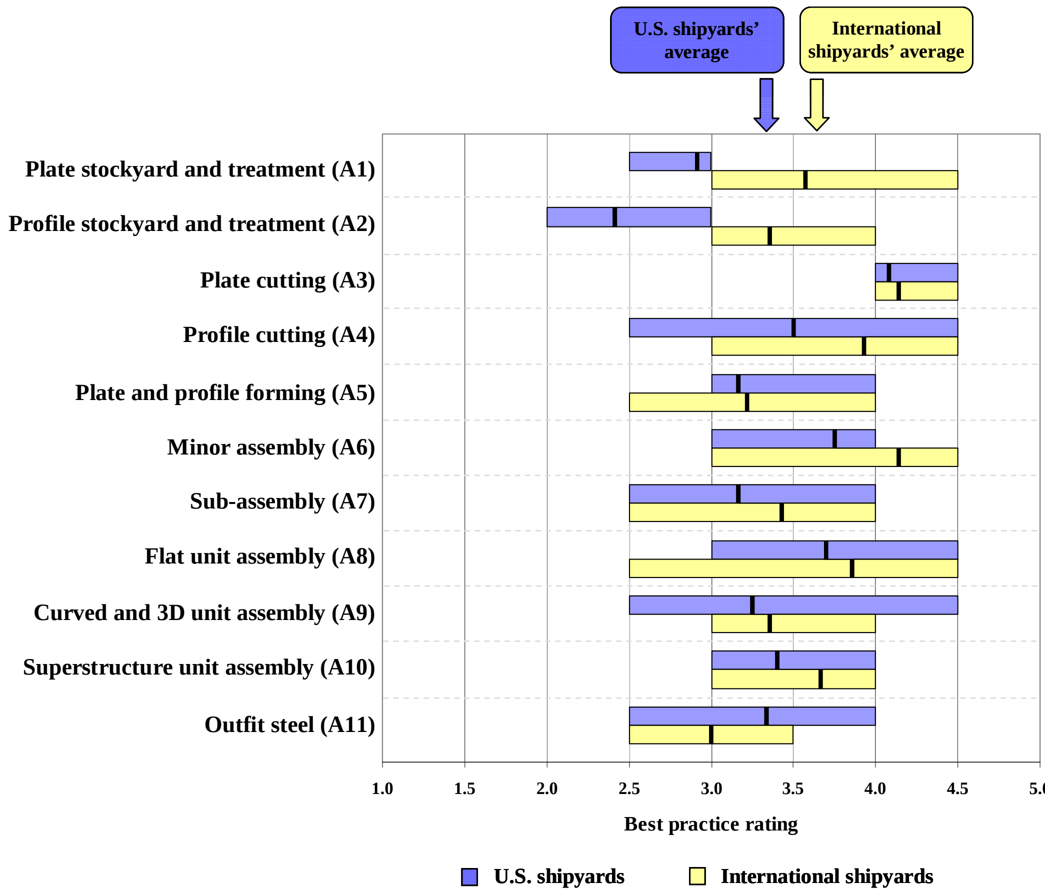

Figure A2.1 – Steelwork production

A1 Plate stockyard and treatment

Most plate stockyards in U.S. shipyards originated twenty to thirty years ago although the technology used is generally adequate for the required levels of throughput. Much of the equipment is old and has high maintenance costs. Most stockyards are characterized by a high variety of scantling material and high stock levels. There has been success in reducing stock levels in some yards but any significant reduction in the variety of scantling has proved much more difficult. This is a major weakness which needs to be addressed at yard level through rationalization of scantlings on new vessel designs and reduction in delivery batch sizes.

It is also important for the yards to look at opportunities to purchase treated steel, to increase co-ordination of acquisition with other yards and to look at the possibilities of establishing regional supply centers.

Proposed action[7]: Coordinate purchasing across shipyards to increase mill batch sizes and purchasing power (H[8]). Promote investigation of regional steel supply centers (M).

A2 Profile stockyard and treatment

Much of the equipment in stiffener stockyards and treatment lines is old and involves high maintenance costs. Often, the methods of handling are outdated. Unless alternative methods of supply are established, some yards will have to invest in new stockyards, handling equipment and treatment lines.

Again, most stockyards are characterized by a high variety of scantling material and high stock levels. There has been limited success in reducing stock levels and any reduction in the variety of scantling has proved very difficult. As for plates, this is a major weakness which needs to be addressed at yard level through rationalization of scantlings on new vessel designs and reduction in delivery batch sizes.

It is also important for the yards to look at opportunities to purchase treated steel, to increase coordination of acquisition with other yards and to look at the possibilities of establishing regional supply centers.

Proposed action: Coordinate purchasing across shipyards to increase mill batch sizes and purchasing power (H). Promote investigation of regional steel supply centers (M).

A3 Plate cutting

The level of applied technology in plate cutting is high across the industry. In some yards, machinery is quite old and will have to be replaced in due course. Otherwise, the issues are principally yard-specific process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

A4 Profile cutting

There is a very wide variety of technology in use from labor intensive manual marking and cutting to state-of-the-art robotics. In some yards with robotic lines, the proportion of material which the lines could not handle was unacceptably high, often due to programming problems. Most issues can best be dealt with at yard level and typically these are process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

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[7] These proposed actions refer to initiatives where there would be benefit for individual shipyards working together on specific projects. There may be other appropriate industry-wide actions proposed under this element which need to be taken within each shipyard but no opportunity for collaborative working has been identified.

[8] The suggestions are prioritized high (H), medium (M) and low (L) within the element to which they apply. However, overall emphasis should be placed on the rankings from overall prioritization presented in Section 4. In other words, an item identified as a low priority within the element that has been ranked highly in Table 4.1 may have a higher overall priority than an item which has been scored as being a high priority within a lower ranking element.

A5 Plate and profile forming

With a few exceptions, plate and stiffener forming equipment is old and forming methods are traditional, i.e., cold forming with computer-generated production information. There was some line heating in evidence but many special steels preclude the use of this method of forming. There were some examples of NC machines and some yards are investing in new higher technology equipment. The issues are principally yard-specific process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

A6 Minor assembly

Some yards have invested in mechanized lines; others have well organized work centers and clearly defined process flows. A recurring feature was the wide variety of product families within the products of the shipyard. Other than this, the issues are principally yard-specific process development and facilities investment issues.

Proposed action: See F6 - Production engineering.

A7 Sub-assembly

There was more varied use of technology in sub-assembly than was found in minor assembly. In this case, workstations were not so well defined and there was a lower-level of mechanization and automation of processes. The issues are principally yard-specific process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

A8 Flat unit assembly

Panel and flat unit assembly lines varied from dated and unreliable through to state-of-the-art. In the lower technology yards, there has to be a re-examination of process engineering and production process analysis to identify areas for improvement and investment. Some of the high technology yards should be focusing on the reduction and elimination of allowances made for product inaccuracies. The issues are principally yard-specific process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

A9 Curved and 3D unit assembly

The common characteristic of curved and 3-D unit assembly is the use of fixed position workstations with pin jigs or pre-formed jig moulds. The application of mechanized assembly lines is hard to justify with the relatively low level of output from most shipyards. Some yards are sensibly focusing on low-cost improvements such as the product accuracy and in reducing the use of non-welded fairing aids in assembly. These two factors are, of course, interrelated. The issues are principally yard-specific process development and facilities investment issues.

Proposed action: See A10 - Superstructure unit assembly.

A10 Superstructure unit assembly

Most shipyards assemble major superstructure blocks in the open and in some yards consideration needs to be given to providing better protection to the workforce from adverse effects of weather. The main industry-wide issue here is that conventional welded fairing, fitting and aligning aids continue to be widely used. This is a significant area of non-added value effort.

Proposed action: Conduct industry-wide investigation of available stud and non-welded aids, jigs and systems (H). This action is applicable to all steel and outfit assembly, outfit installation and erection processes.

A11 Outfit steel

Almost all the international shipyards surveyed subcontract the fabrication of outfit steel components. This includes such items as minor foundations, small hatches, doors, ladders, walkways, companionways, railings, etc. Many U.S. shipyards still do this work in-house with a relatively wide range of technology applied across industry.

Proposed action: Consider the introduction of high-tech regional centers for the production of a rationalized range of outfit steel items (M).

B OUTFIT MANUFACTURING AND STORAGE

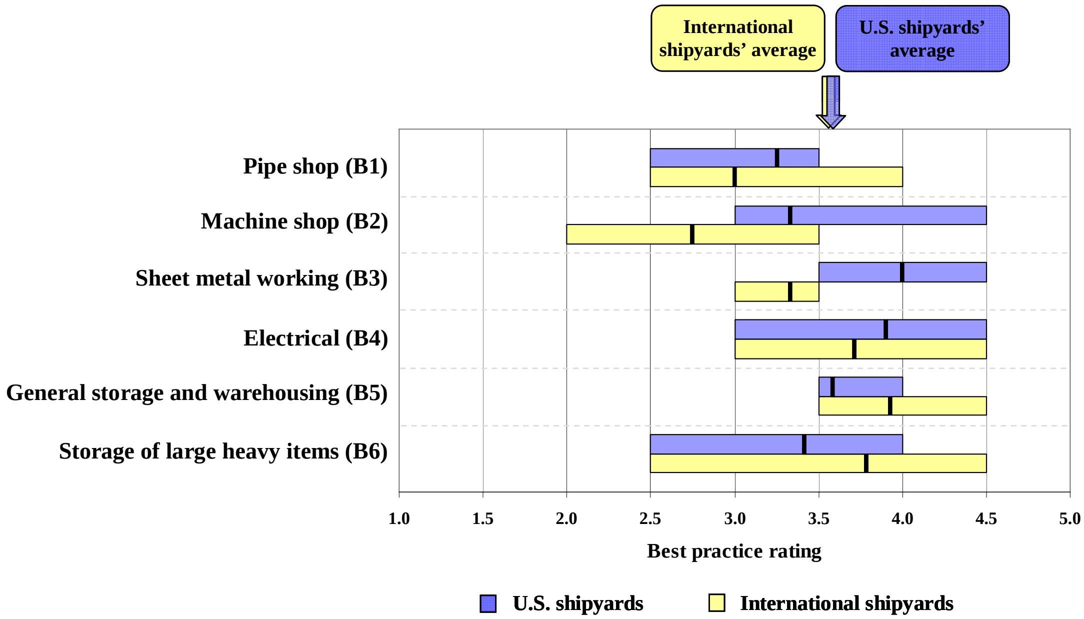

Figure A2.2 – Outfit manufacturing and storage

B1 Pipe shop

There are improvements to be made in pipe shops but a pre-requisite to this is reducing the variety and degree of complication of the pipes that the shops are required to produce. Pipe shops use relatively low levels of automation and not all the yards are using manufacturing cells focused on pipe families. Necessary actions are principally yard-specific product rationalization, variety reduction, process development and facilities investment issues.

Proposed action: Re-visit NSRP reports on pipe piece manufacturing published in the 1980s (H).

B2 Machine shop

To be highly efficient, machine shops require a high throughput of similar types of work. Many shipyards' requirements can be characterized as jobbing shop type work with lower throughputs and higher variety.

Proposed action: Some effort has been made on a regional basis to centralize certain types of machining work in order to increase throughput. Consider extending this initiative (M).

B3 Sheet metal working

Nearly all leading international shipyards subcontract the manufacture of sheet metal products. Subcontract of onboard installation work, including HVAC, is not uncommon. Depending on the volumes and costs in each U.S. yard, a potential weakness is that each yard still retains this capability.

Proposed action: Investigate regional sheet metal manufacturing facilities (M).

B4 Electrical

The degree to which the manufacture of electrical components is subcontracted varies between yards. With the exception of wire ways, almost all electrical manufacturing in leading international yards is subcontracted. Depending on the volumes and costs in each U.S. yard, a potential weakness is that some yards still retain a high capability in this area.

Proposed action: Investigate regional electrical component manufacturing facilities (M).

B5 General storage and warehousing

Most shipyards run proficient but traditional warehouse operations. However, inventory levels tend to be very high and there is limited use of just-in-time deliveries. Material is handled a large number of times between the supplier and the point of use. There is limited use of line-side stores in some yards.

Proposed action: Industry study to determine how to correct the deficiencies (H). Achieve schedule stability (H). Navy should consider writing contracts that do not encourage taking the delivery of equipment earlier than it is required (H). Navy observe realistic time fences for change orders (H). Consider moving towards a palletized stores system (storing items by work package) (M).

B6 Storage of large/heavy items

Although the need for just-in-time delivery to avoid the storage of large and heavy items for long period of time is recognized, many U.S. shipyards appear to store these items for considerable periods prior to the installation. One of the reasons for this is poor schedule stability and adherence. Not all shipyards have purpose-built facilities to store these items and some are protected by makeshift arrangements.

Proposed action: Move towards better schedule stability and co-ordination with suppliers to increase the use of just-in-time deliveries for large and heavy items (H).

C PRE-ERECTION ACTIVITIES

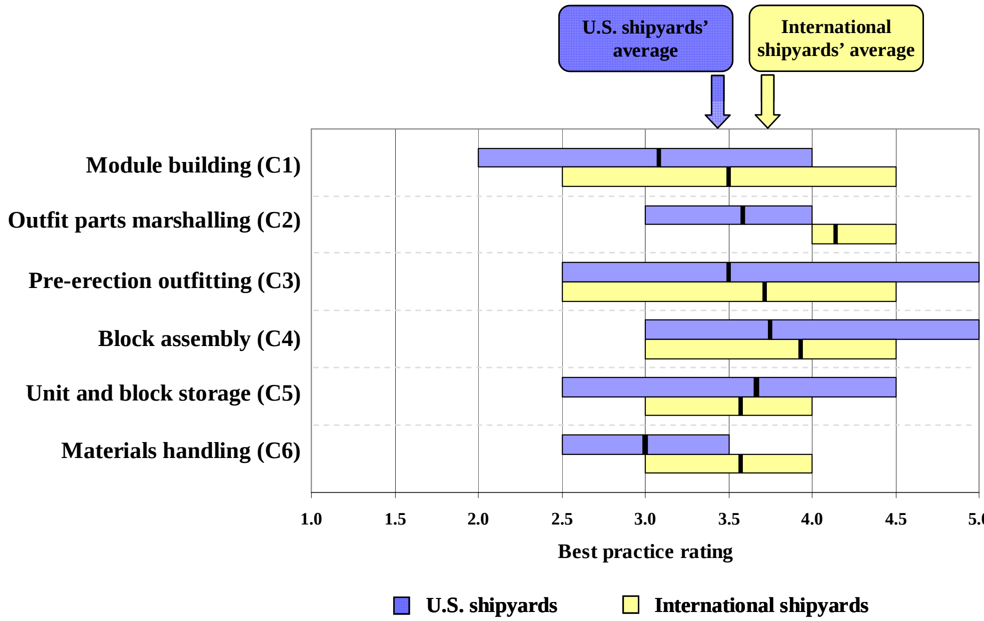

Figure A2.3 – Pre-erection activities

C1 Module building

Although there is a wide spread in the best practice rating across the U.S. yards (2.0 to 4.0), U.S. yards scored on average significantly less than the international yards (3.1 compared to 3.5).

There is a low level of outfit module assembly (pre-assembled units of outfit) in many yards. This is mainly the result of the use of legacy designs that do not incorporate module design practices. In addition, most yards lack dedicated module assembly facilities that can be expensive to construct and equip. In the yards where module building is active, the work is often carried out in dispersed areas within other buildings or in open spaces.

Although most yards are aware of the benefits of module building, it is felt that few are familiar with the spatial design techniques that make module building highly efficient and effective.

Proposed action: Investigate feasibility of regional module assembly facilities (M). Also refer to comments under F6 - production engineering.

C2 Outfit parts marshalling

Almost all U.S. shipyards operate an effective outfit parts marshalling system. In some cases the lead time and inertia in the system appears to be too much when compared to some of the leading international shipyards surveyed. Some yards make excessive use of buffer storage.

Proposed action: Industry study to review alternatives to current systems (M).

C3 Pre-erection outfitting

Many U.S. shipyards achieve a respectable level of pre-erection outfitting and the average rating of 3.5 is not far below that of the international yards at 3.7. Across the yards, the range of use of best practice is wide – from 2.5 to 5.0. This can be attributed to some extent to the use of legacy designs in some yards which means that over a long series-build program the levels of pre-outfitting increase significantly above that achieved on the first-of-class.

Overall, the yards appear to be well aware of their shortcomings in this area although they may not be aware of the design methodology applied in the international yards that enables high levels of pre-outfitting on a first-of-class vessel.

Proposed action: No industry-wide collaborative initiatives proposed.

C4 Block assembly

The majority of the U.S. yards adopt a natural block breakdown although this is sub-optimal in some cases due to erection cranage limitations. Most have purpose-designed block assembly facilities. Consequently, the average rating of 3.8 compares quite favorably with the international score of 3.9. In order to reduce construction time, some yards have introduced the assembly of complete cross-section ship modules.

Proposed action: No industry-wide collaborative initiatives proposed.

C5 Unit and block storage

Most of the U.S. yards have block storage areas and transport arrangements comparable with international yards and the average rating of 3.7 for the U.S. yards compares well with 3.6 for international yards. Most yards have well laid out and serviced block storage areas and there is general use of self-loading transporters for the movement of blocks. In most yards, the level of block storage prior to erection is relatively low although in a few it is excessively high, which needs to be remedied.

Proposed action: No industry-wide collaborative initiatives proposed.

C6 Materials handling

The U.S. shipyards have an average score of 3.0 which is significantly less than the 3.6 average in the international yards. There are few yards either in the U.S. or overseas where transport distances are not long and therefore the majority of movement is in "unit loads" by road. There is little use in U.S. yards of integrated conveyor systems and NC controlled transport systems as is found in some leading international yards.

In all U.S. shipyards, there is a notable lack of purpose-designed pallets and trestles for the transport of parts and assemblies. While storage areas are generally well defined, pallets and trestles are stored at a single level and there is very little use of high density, multi-level pallet stacking.

The extent of inefficient materials handling is significantly higher in U.S. shipyards and results in high levels of non-added value effort.

Proposed action: Support an industry-wide study of materials handling and storage requirements, costs and solutions, including the design of specialized equipment (M).

D SHIP CONSTRUCTION AND OUTFITTING

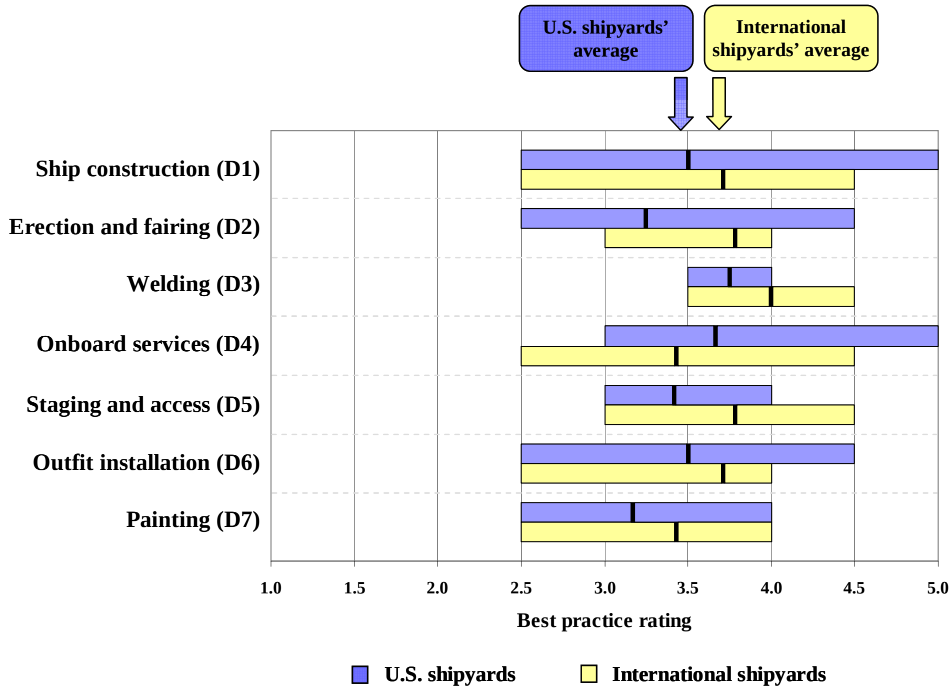

Figure A2.4 – Ship construction and outfitting

D1 Ship construction

Sub-optimal construction facilities are a feature of a number of U.S. yards. This is usually combined with construction cranage which is below capacity for the adoption of a natural block breakdown in all parts of the vessels in the product mix. As a rule of thumb, crane capacity should ideally be not less than $1/50^{th}$ of the erected steel and outfit weight of the largest vessel. The other general issue is that of protection for the workforce at the construction point from the worst effects of climate. A number of yards need to look at ways of providing better protection through the use of temporary or permanent covers and by adopting build strategies which facilitate early closure of internal spaces. The main issues are principally related to yard-specific process development and facilities investment.

Proposed action: No industry-wide collaborative initiatives proposed.

D2 Erection and fairing

A number of yards still have some way to go in achieving better accuracy control in order to improve the efficiency and speed of the block erection process. The achievement of consistent block accuracy is principally a shipyard-specific process development issue. See F8 "Dimensional and quality control".

Accuracy control also has a major impact on work content in block alignment and fairing. Fairing methods that use traditional welded attachments are still widespread although some yards are beginning to make progress with stud welded systems and with alignment and fairing methods which do not require welded attachments. It is felt that an industry-wide study would be of value in this respect to ensure the transfer and implementation of best practice.

Proposed action: No major industry-wide issues other than proposal for non-welded fairing aids study discussed in A10 "Superstructure unit assembly".

D3 Welding

Good progress has been made in the application of more efficient and productive welding processes. More attention to the application of robotics and further mechanization will help to close the gap. The degree of industry-wide welding information sharing is probably sufficient to keep the yards informed of the behavior and benefits of new materials and processes. There may be some specific processes, such as laser welding and friction welding, applicable to thin materials and special steels inherent in warships that would benefit from additional research and development support.

Proposed action: No industry-wide collaborative initiatives proposed.

D4 Onboard services

The range and extent of services that have to be placed on board a vessel after block erection does, of course, depend on the amount of work remaining to be done. Those yards which achieve least in erecting large natural blocks and in pre-erection outfitting, by definition have the greatest amount of work remaining to be done on board, all of which requires electrical and mechanical services. Some yards have made good progress in this respect but there is still much to be done to minimize and improve the arrangement of onboard services. Housekeeping is another area which many yards need to improve. Hoses and cables can often be seen spread around internal spaces in an apparently unplanned and uncoordinated manner. Both these subjects are principally yard-specific process development issues.

Proposed action: No industry-wide collaborative initiatives proposed.

D5 Staging and access

Most shipyards spend excessive hours and cost on non-added value staging activities. There is insufficient thought given to the reduction, and eventual virtual elimination of staging through the application of a natural block breakdown and the planning of pre-erection and post-erection outfitting and painting. It is probably in painting that the yards need to direct the greatest thought and effort.

Proposed action: Investigate available staging systems and industry best practice. Document and transfer technology to lower performing yards (H).

D6 Outfit installation

Some yards have made good progress with the overall process of outfit installation. In some cases, poor implementation of outfitting strategy has limited the amount of outfit installed in the pre-erection stage and consequently pushed outfitting work to the more costly onboard stage. In addition, the lack of a zone-by-stage outfitting methodology makes coordination of the various outfitting trades more difficult to manage. In general, poorly organized onboard outfitting processes are characterized by excessive staging, poor housekeeping, and workers competing for limited working space. The main issues are principally related to yard-specific process development.

Proposed action: No industry-wide collaborative initiatives proposed.

D7 Painting

The approach to painting varies widely across the industry although there are some good applications of the process. In general, the amount of painting achieved at an early stage is closely linked to the overall outfitting strategy employed. The weakest implementations have a limited expectation of outfit installation at the pre-erection stage. In addition, in some yards, the outfitting areas have little protection from inclement weather which further limits the opportunity for early paint application. The problems are principally yard-specific in terms of process development and facilities investment. However, the less advanced yards would benefit from a transfer of technology from the shipyards that have achieved a high level of painting integration in their build strategy.

Proposed action: Industry-wide transfer of technology in terms of the integration of painting into the shipyard's outfitting strategy (H).

E YARD LAYOUT AND ENVIRONMENT

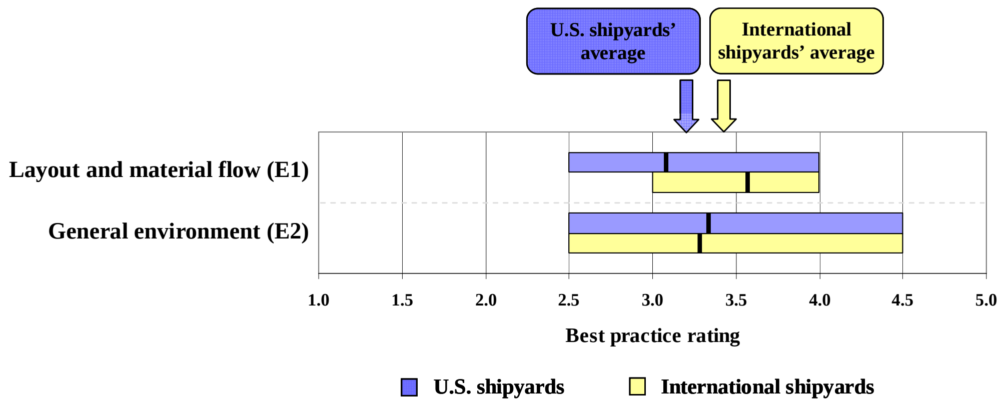

Figure A2.5 – Yard layout and environment

E1 Layout and material flow

The layout and material flow in many shipyards suffers from the fact that the yards have been developed over several decades. In many cases, the size and shape of the site is less than ideal and distances between product centers are sometimes long. Overall material flows are generally unidirectional although flows are often less good in local areas. A feature in many yards is high work-in-progress and this needs to be addressed. Further development in this area is principally yard-specific process development and facilities investment related.

Proposed action: No industry-wide collaborative initiatives proposed.

E2 General environment

All shipyards have a mixture of old and new buildings. Conditions have improved and are generally satisfactory as buildings tend to be well maintained and housekeeping is usually good in most areas. Factory-like conditions have been achieved in the newest buildings. Housekeeping is worst in outside assembly areas, old isolated workshops, ship construction areas and on-board. A continuous focus is required here to improve housekeeping and working conditions. The issues are principally yard-specific process development and facilities investment issues.

Proposed action: No industry-wide collaborative initiatives proposed.

F DESIGN, ENGINEERING AND PRODUCTION ENGINEERING

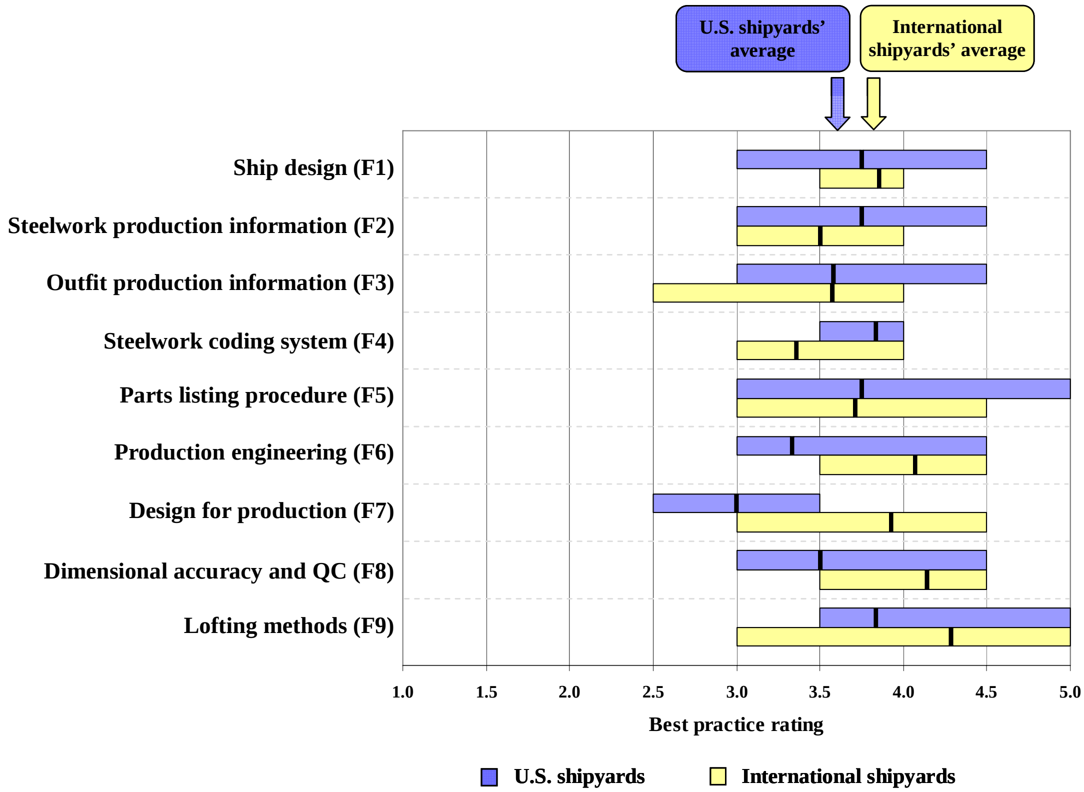

Figure A2.6 – Design, engineering and production engineering

F1 Ship design

In this element, with an average rating of 3.8, the U.S. shipyards achieved a score close to the international yards. However, while the score has been positively influenced by the computer technology applied in U.S. yards, the design process in many is not as effective as in the international yards and design lead times and man-hour expenditure are excessive in U.S. yards. The continuing use of legacy designs has limited the frequency that new design methods and techniques, aimed at reducing lead times and improving the design process, could be introduced. Leading international yards that continually develop designs have more opportunity to implement changes to the design process and to improve the producibility of their designs.

Many shipyards suffer from gaps in their design programs and a consequential loss of design staff that makes it difficult to retain design expertise and build corporate experience. The current naval acquisition strategy also creates engineering gaps with consequent loss of skills and opportunity for continuous performance improvement through the design process. Legacy designs have not been significantly modified and do not, therefore, reflect advances in production and design technology. Shipyards and government continue to carry the productivity burden of these dated legacy designs. Many yards still use a traditional system-oriented design organization and approach and also have difficulty in recruiting and retaining appropriately skilled personnel.

Proposed action: Change current acquisition strategy to maintain design skill base and promote continuous performance improvement (H). Consider more frequent design upgrades to maintain the national design capability, smooth the design load and avoid the productivity burden associated with legacy designs (H). Promote and support the implementation of modern design organization and strategy through appropriate re-designs of legacy vessels (H).

F2 Steelwork production information

At 3.8, the U.S. average rating is slightly higher than the international yard average of 3.5. Some yards have had the opportunity to develop their steelwork production format and content in recent years through activity in the commercial sector and this has significantly improved the overall average. Many yards, particularly those focusing on a long series of naval vessels, continue to use traditional unit-based production information formats.

Through discussions, it appears that virtually all those yards using unit-based production information are currently in the process of developing new engineering strategies based on the development of product-oriented information. However, it is possible that inexperience in the field of preparing production information of this nature may lead to an increase in engineering man-hours and difficulty in maintaining design traceability.

Proposed action: Define modern steelwork production information development methodology (H).

F3 Outfit production information

In the area of outfit production information, the U.S. yards scored a little higher than the international yards. However, discussions indicated that all the U.S. shipyards adopt a block and zone-based composite format for information rather than one based on product-oriented concepts.

With respect to levels of design maturity and advanced outfitting definition, U.S. yards typically place a high reliance on production feed-back over a series of vessels to progressively develop and improve the production information, whereas the international yards achieve similar levels of production information on the first-of-class. Most U.S. shipyards surveyed were currently midway or nearing the end of a long series of vessels in the same class and it is believed that, given the approach to developing production information, this may partially account for the closeness in the scores.

Proposed action: Develop a general methodology to re-format outfit production information to provide information specific for all stages of construction with a minimum level of ship lifted information on new designs (H).

F4 Steelwork coding system

At 3.8, the average rating in this element is considerably higher than in the international yards at 3.4 and most shipyards do not need significant development in this area. However, in terms of future industry developments and a progression towards product-oriented operations similar to those applied in other manufacturing and assembly industries, then the coding systems currently in use need to be changed.

The structure of the coding system in some shipyards does not support the definition of interim products in a manner that would allow full implementation of workstation organization including automated scheduling, information generation and performance feedback.

Proposed action: Develop a consistent relational coding structure that can be independently developed into yard-specific coding systems whilst maintaining sufficient common structure to facilitate industry-wide cooperative applications. The coding structure should enable clear definition and relationship of parts, interim products, systems and personnel to production workstations and shipboard zones (H).

F5 Parts listing procedure

The U.S. yards are on a par with the international yards. In most U.S. yards, the parts listing procedures are a mixture of CAD extraction and manual enhancement. Although developments could be made by making a greater use of CAD system capabilities, this would not make any difference unless it was part of an overall coding methods development program.

Proposed action: No industry-wide collaborative initiatives proposed.

F6 Production engineering

With an average rating of 3.3 compared with 4.1 in the international yards, production engineering was weak in the U.S yards. International shipyards regard the production engineering function as the principal lead in all performance improvement and facility development activities. Overall, it embraces product, methods and industrial engineering and, for continuous performance improvement, it is essential to develop the production engineering function to cover all aspects of ship construction, establishing an effective link between technical and production departments. The objective of production engineering is to ensure the most effective operation of the facilities in the manufacturing and assembly of the shipyard's product mix.

U.S. yards generally have been ineffective in the introduction of production engineering principles into the design and production areas. It tends to be a secondary problem-solving activity rather than an innovation leading activity and the inability to develop a strong and effective production engineering function is a major contributor to poor performance.

Proposed action: Promote the development of production engineering principles through training seminars and workshops and the preparation of generic production engineering application manuals (H).

F7 Design for production

As a principal part of the production engineering function, design for production, with an average rating of 3.0 in U.S. yards against 3.9 in international yards, also scored badly. The design for production function is given a low priority when compared with international industry norms. It is fair to say that as a high proportion of legacy designs are being built, it is more difficult to realize the full benefits of design for production. However, discussions on the subject indicate that U.S. yards do not fully appreciate the importance of capturing production knowledge and formally defining facility constraints and attributes. Without this knowledge it is very difficult to define design parameters that result in optimum production performance.

Continued use of legacy designs over a number of years has minimized the opportunities for applying design for production principles and methods. High turnover of staff in many yards means there is often a loss of design for production knowledge during gaps in design activity.

Proposed action: Consider more frequent design upgrades to facilitate the development of design for production guidelines and to maintain the national design knowledge base (H).

F8 Dimensional and quality control

Although there has been a recent focus on the implementation of accuracy control and quality control procedures in U.S. shipbuilding, the U.S. average of 3.5 compares poorly with the international average of 4.1 which indicates that there still remains a significant gap in the use of best practice. Most shipyards have firmly established AC and QC departments. However, a low level of confidence in the statistical evidence in production results in the continuing practice of added material and the subsequent high levels of rework.

By comparison, leading international yards have adopted a total quality approach and no longer have dedicated AC and QC departments. AC and QC requirements are fully integrated into all pre-production and production activities with cross-functional teams meeting at regular intervals to discuss problem areas.

Proposed action: Promote awareness of the true costs of non-added value work through training, seminars and workshops for all levels of management (H). Instill, in production management, confidence in the capability of accuracy control procedures to successfully eliminate inherent process rework (H).

F9 Lofting methods

While the U.S. shipyards have almost totally integrated the lofting functions with CAD systems, there still remains some use of traditional techniques and a transfer of information between systems. In the main, this is a result of the continuing use of legacy designs and results in the relatively low average rating of 3.8 in comparison with 4.3 for international yards.

All the U.S. yards appreciate the shortfalls and are actively developing their CAD systems and design methods to fully integrate lofting activities in the engineering process.

Proposed action: No industry-wide collaborative initiatives proposed.

G ORGANIZATION AND OPERATING SYSTEMS

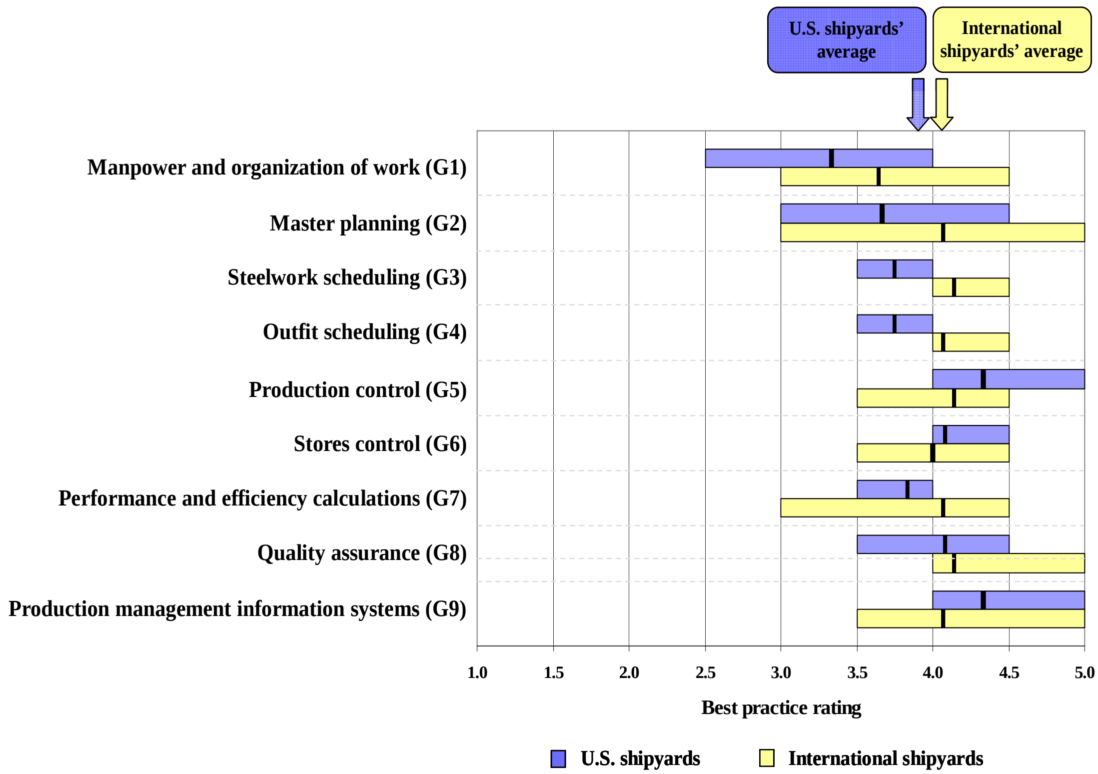

Figure A2.7 – Organization and operating systems

G1 Manpower and organization of work

There has been a notable change in human resources (HR) policy over the last few years with yards making much more effort to retain and get the best out of their people. The importance of a stable workforce is understood but the nature of the naval workload makes this difficult to achieve. Although there are some very good examples, the use of best practice applied across the U.S. yards is variable and the industry generally lags behind the international group.

Individual yards still feature some or all of the following: difficult labor relations, blame culture, trade demarcation, limited multi-skilling, and limited training for flexibility. Workstation organization is not fully implemented and there is a lack of true area management controlling multi-disciplinary teams. The public image of the industry appears generally to be poor and some yards are not particularly attractive places to work. Unsurprisingly, there has been a serious reduction in new entries into higher education for shipbuilding. One of the reasons for the high level of subcontracting in some of the international yards is the desire to maintain a stable core workforce when the workload is variable. These yards tend to develop a stable core and a flexible workforce and then subcontract the peak loads.

Proposed action: Government/Navy needs to level load the shipyards to assist in skills retention (H). Develop methods to more effectively share work and labor between yards (M).

G2 Master planning

In general, the planning systems and methodologies applied in the international group were much simpler and required much less operational effort than those in the U.S. shipyards. There is a hierarchical approach in the U.S. but often too much detail is created too early in a contract and there is a disproportionately high number of people involved. It is often labor intensive and time consuming to change schedules. There is evidence of poor schedule adherence in many yards but this is compounded by Navy change orders. Many planning systems are not responsive to change and often create excessive inventory.

Proposed action: Develop model planning processes centrally to provide guidance for those in industry who are currently developing new systems and/or wish to upgrade current systems (H). The Navy should seek solutions to limit the number of change orders and operate realistic time fences for change orders (H).

G3 Steelwork scheduling

See comments and proposed action in G2 “Master planning”.

G4 Outfit scheduling

See comments and proposed action in G2 “Master planning”.

G5 Production control

There are weaknesses in the planning systems in some yards which are being compensated to some extent by a huge effort in production control. In many cases, improvements in the planning processes will reduce the effort required.

Proposed action: No industry-wide collaborative initiatives proposed.

G6 Stores control

Stores control in most yards tends to be part of the computer-based material control systems. There are some pull systems.

Proposed action: No industry-wide collaborative initiatives proposed.

G7 Performance and efficiency calculations

Many U.S. yards collect a wide variety of performance metrics. However, they often tend to be known only to the department to which they apply and are not part of the routine management reports. Although several international yards are also weak in this area, the U.S. industry could do much more to use metrics to help plan and deliver improved performance. There is also a high degree of focus on achieving the budgets on a particular vessel rather than measuring productivity in a more generic way by process. Performance improvement targets tend to be set by ship rather than on the basis of an ongoing process improvement effort.

Proposed action: Identify output and process measures to be used in the industry and provide guidance on their application. Output measures quantify the overall productivity of a process (such as man-hours per ton); process measures quantify the aspects of a process that if improved will intrinsically improve the output measure (H).

G8 Quality assurance

The shipyards all operate an accredited quality assurance system. Most yards are using the system to assist performance improvement. Not all yards include repetitive work that is an inherent part of the shipbuilding process in their definition of rework.

Proposed action: No industry-wide collaborative initiatives proposed.

G9 Production management information systems

Although most of the information is available to those who need it in an appropriate format, there is generally a huge amount of information gathered and generated and it is questionable whether or not this has a value to the organization. Not all of the information is generated automatically and manual rework is often required to translate data into a meaningful format. It would useful to include the area performance measures in the routine reporting arrangements.

Proposed action: Potential for a small industry-wide project to review the types of information required to operate a shipbuilding business effectively (L).

APPENDIX 3 – THE FMI BENCHMARKING SYSTEM

1 INTRODUCTION

As is well known, benchmarking is a tool by which a company can compare its practices with those of others to determine its strengths and weaknesses with a view to improving performance.

There are several ways to do this. Perhaps the most simple is to visit another company and review its practices. Proprietary benchmarking systems, however, provide a more structured approach which generally make a comparison against a scale of reference. Some systems can be applied to industry in general; others are more specific.

The First Marine International (FMI) benchmarking system is shipyard specific and its full application includes the following elements.

1. Evaluate the applied technology and practices against international best practice.
2. Assess the shipyard's current best practice rating.
3. Identify the gaps and imbalances in the applied technology.
4. Identify the areas that require attention if overall performance is to be improved.
5. Establish the shipyard's current performance and competitive position.
6. Determine product focus and required performance through market analysis.
7. Set future performance targets.
8. Define the overall characteristics of the shipyard that will allow it to compete in chosen markets.
9. Describe the processes and practices that will yield the required performance.
10. Generate a prioritized performance improvement plan.

Formulating a performance improvement plan using this methodology ensures that the plan is driven by market requirements and that the shipyard will succeed in its chosen markets - hence the term "Market-Led Benchmarking".

The benchmarking system has been applied in more than 150 shipyards world-wide and has formed the basis of industry studies in the USA, Japan, South Korea and Europe. This provides a significant database for comparative purposes.

This appendix explains the system and explains what is involved in a full benchmarking study.

2 THE SYSTEM ELEMENTS

The FMI system is applicable to shipbuilding, ship repair and conversion. Different elements of the system are used in each case and where a yard is involved in more than one activity, shipbuilding and repair for example, on appropriate mix of elements is employed.

The table below shows the groups of elements available in the FMI benchmarking system and how they relate to each sector.

Section	**Sector**	**Group**	Number of elements
A	Shipbuilding	Steelwork production	11
B	Shipbuilding	Outfit manufacture and storage	6
C	Shipbuilding	Pre-erection activities	6
D	Shipbuilding	Ship construction and outfitting	7
E	Shipbuilding	Yard layout and environment	2
F	Shipbuilding	Design, engineering and production engineering	9
G	Shipbuilding	Organization and operating systems	9
H	All	Human resources	8
I	All	Purchasing and supply chain	10
J	All	Marketing	7
K	Repair/conversion	Commercial	8
L	Repair	Production infrastructure and equipment	8
M	Conversion	Production infrastructure and equipment	3
N	Repair	Production methods	9
O	Conversion	Production methods	11
P	Repair	Organization and operating systems	4
Q	Conversion	Organization and operating systems	2
R	Conversion	Design/technical	9

Table 1 – Groups of elements

The benchmarking system describes five levels of use of best practice in each element of each group. An example of the description of the levels in one of the human resources elements is shown in Table 2.

	Description
1	*No formal training plan or budget. Training is mainly in response to requirements of regulation or legislation and is carried out only as required. Skills' training is ad-hoc and limited in scope and employees follow no specific training program.*
2	*The shipyard recognizes the benefits of training and has gone some way to putting a training scheme in place for new employees. This may not include off- the- job training and is likely to involve the trainee being assigned to a skilled man for training on the job. Responsibilities for training have not been formally assigned within the management team.*
3	*Apprenticeship scheme, or equivalent, in place. Some skills training for mature shop floor workers and management training for supervisors but probably no middle and senior management training. Small training budget. Probably some students and graduate trainees on site. Management responsibilities for training identified and assigned. Regular formal appraisals of employees and required areas for improvement identified.*
4	*Skill requirements defined in the business plan. Individual training needs analysis carried out for each employee to ensure that the overall business requirements are met. To some extent learning is self-directed. Employees are released from normal duties for training purposes. Training materials and library available on site. Appraisals lead to identification of specific training needs and a personal action plan.*
5	*More than 5% of each employee's time devoted to training, with strong emphasis on quality. Structured post-training assessment and evaluation procedures in place. Continuous personal development of all employees is company policy. A high proportion of learning is self-directed, with support from the management team.*

Table 2 - H2: Training and education policy

In broad terms, the levels of use of best practice correspond to the state of development of leading shipyards at different times over the last thirty years. Those yards that are less advanced remain at the level of technology of an earlier period. On the basis of interviews and inspections carried out during the survey, a "level of technology" mark is assigned to each element. These are aggregated, first, for the individual groupings, and second, for the whole yard.

Each element reviewed is rated according to the description that most closely matches its situation. If it falls between two descriptions, an intermediate mark is given, leading to nine possible scores: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5.

It is important to note that the higher levels of technology are not intrinsically "better". The highest technologies often imply a high capital cost and, where wage levels are low or savings limited, their application may not be appropriate.

Many shipyards do not need to score 5 to be competitive. The important thing is to have a balance of technology across all of the elements at the level dictated by the shipyard's cost base and target market. In general, having isolated areas at a significantly higher level than others is not good. The adjacent areas may not adequately support the higher technology areas and thus the investment in the high technology areas alone may not yield the intended benefit.

3 LEVELS OF TECHNOLOGY

The broad definitions of the levels of technology relating to shipbuilding are as below. The same principles apply to the ship repair and conversion yards.

Level 1: reflects shipyard practice of the early 1960s. The shipyard has several berths in use, low capacity cranes and very little mechanization. Outfitting is largely carried out on board ship after launch. Operating systems are basic and manual. In summary, the yard is characterized by the most basic equipment, systems and technologies and outdated ways of working.

Level 2: is the technology employed in the modernized or new shipyards of the late 1960s and early 1970s. There would be fewer berths in use, possibly a building dock, larger cranes and a degree of mechanization. Computing would be applied for some operating systems and for design work. Level 2 is better than basic but is significantly below world industry norms.

Level 3: is good shipbuilding practice of the late 1970s. It is represented by the new or fully re-developed shipyards of that time in the US, Europe, South Korea and Japan. There would be a single dock or level construction area with large capacity cranes, a high degree of mechanization in steelwork production and more extensive use of computers in all areas.

Level 4: refers to shipyards that have continued to advance their technology during the 1980s and 1990s. Generally a single dock, with good environmental protection, short cycle times, high productivity, extensive early outfitting and integration of steel and outfit; together with fully developed CAD/CAM and operating systems. Level 4 is better than industry averages but not up to leading standards.

Level 5: represents state-of-the-art shipbuilding technology. It is developed from level 4 by means of automation and robotics in areas where they can be used effectively, and by integration of the operating systems, for example, by the effective use of CAD/CAM/CIM. There would be a modular production philosophy in design and production. The level is also characterized by efficient, computer-aided material control and by fully effective quality assurance. In summary, state-of-the-art use of technology and industry-leading business processes, facilities, systems, management and workforce.

The marking of each element is based on a combination of what the consultants/assessors see (e.g., activity on the shop-floor or examples of planning and engineering outputs) and what they are told. The scoring system does not necessarily reflect effectiveness or productivity, except that level 5 is concerned with the effectiveness of the technology in use, as well as the hardware and software in place.

4 OVERALL PERFORMANCE

The overall measure of financial competitiveness used for shipbuilding yards is break-even cost per CGT. In this case, break-even cost is defined as the amount of income that the yard needs to break even after it has purchased equipment, materials and other bought-in items. Man-hours per CGT is used as the overall measure of productivity. The man-hour calculation includes hours spent by all direct and indirect staff and employees who contribute to the shipbuilding effort.

These measures allow the performance of individual shipyards to be compared even though they may be building different types and sizes of ships. They also allow the performance of a yard to be easily related to the current and future requirements of the market.

CGT is a normalized measure of work content that is calculated by multiplying the gross tonnage by a factor that is representative of the complexity of the vessel. Ships that have a low level of complexity, such as bulk carriers, have lower factors than more complex vessels such as cruise ships and navy combatants. The system has been developed and refined over more than thirty years by leading shipbuilding organizations under the umbrella of the OECD. Factors have been developed for the main ship types but when a yard has been building unusual vessels, new factors may need to be calculated to support the benchmarking process.

In general, the performance assessment is based on aggregated output over a three-year period. However, in some cases, it is not possible to do this and the performance achieved on an individual ship is calculated and taken to be representative of the performance of the yard as a whole.

As these measures are inappropriate for ship repair and conversion, overall performance for these sectors is expressed in terms of a number of measures that relate to a yard's competitiveness and profitability. The choice of measures is influenced by the availability of data for comparison purposes. The measures address output, enquiry response times, customer service, tariffs, manpower issues and overall profitability. They include such factors as:

- labor cost;
- charge out rates;
- time taken to prepare bids;
- cost of carrying out a range of routine work;
- time taken to carry out routine work;
- key financial ratios;
- utilization of manpower;
- output;
- delivery reliability;
- quality;
- customer satisfaction;
- time taken to prepare invoices;
- ability to keep within budget.

5 THE BENCHMARKING SURVEY

An FMI team will visit the shipyard to gather data and assign the benchmarking scores. Individual members of the team visit the relevant offices and facilities and interview department or area managers and/or their nominated representative. Some of the interviews are done while walking around the yard, others are office based. Interviews may last up to 30 minutes, depending on the subject.

The yard is sent a proposed timetable prior to the visit together with a description of the scope of each survey element and a suggestion of the person in the shipyard the team would like to discuss each element with. The survey normally begins with a short presentation on the project (about 40 minutes including discussion) to senior managers and other appropriate staff. This is followed by a guided tour of the facility that allows the team to orient itself, before splitting up to carry out the individual interviews.

A confidential questionnaire is used to collect the information required to calculate the overall performance of the shipyard. The yard usually completes this in advance of the survey so that the team can collect it while they are in the yard. In some cases it is necessary for the yard to complete an additional questionnaire that will allow CGT factors for unusual ship types built by the yard to be validated.

The survey normally takes one or two days with a team of two to four people depending on the size of the yard. Subject to receiving the required information in good time, FMI submit the benchmarking report within three to four weeks of completing the visit.

No information acquired by FMI relating to the shipyard is disclosed to any other party and the shipyard report is considered to be wholly company confidential.

6 THE SURVEY REPORT

Clearly the contents of the report are dependent on the scope of work carried out by FMI. However, the benchmarking survey report usually combines graphical representations of the survey results with commentary on the processes used. Typically the report contains:

1. Best practice rating by individual technology element, organizational area, and overall.
2. Overall performance in terms of man-hours per CGT and cost ($) per CGT.
3. A short written interpretation of the results.
4. Comparison between the yard's best practice / performance rating against international standards.
5. Suggestions for improvements that will yield benefit in the short term.

If appropriate, the yard is positioned on the graph shown in Figure 3 in Section 7. The graph used to present the benchmarking scores is shown in the Figure 1 below. This is an example for the design, engineering and production engineering group.

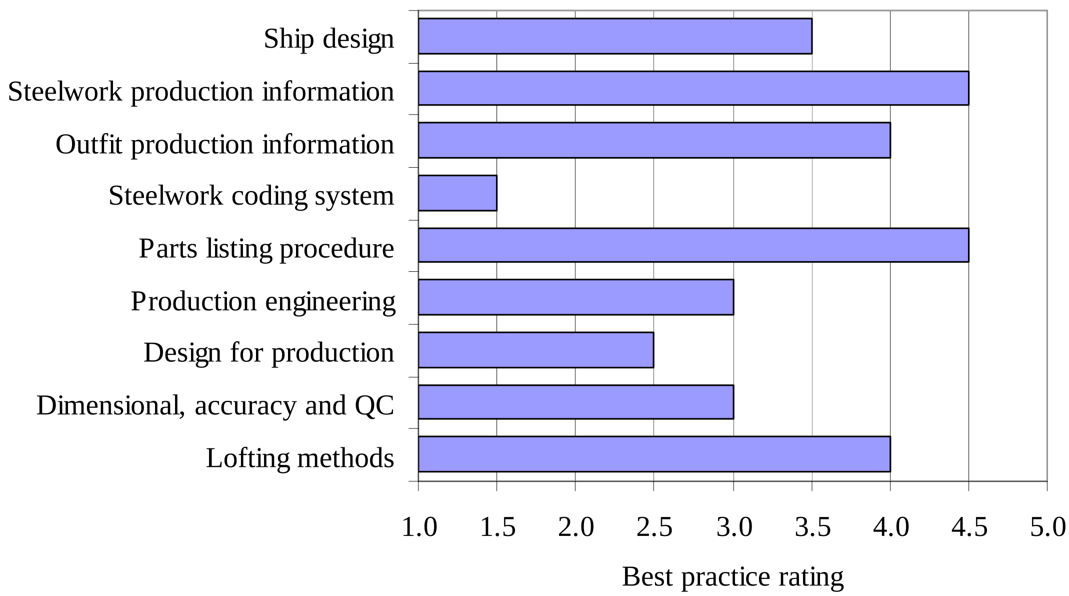

Figure 1 – Presentation of the results for one group of elements

The strengths and weaknesses in the use of best practice and the balance across the group can be clearly seen from this representation. Figure 2 shows a typical example of the results across all the groups in a shipbuilding yard.

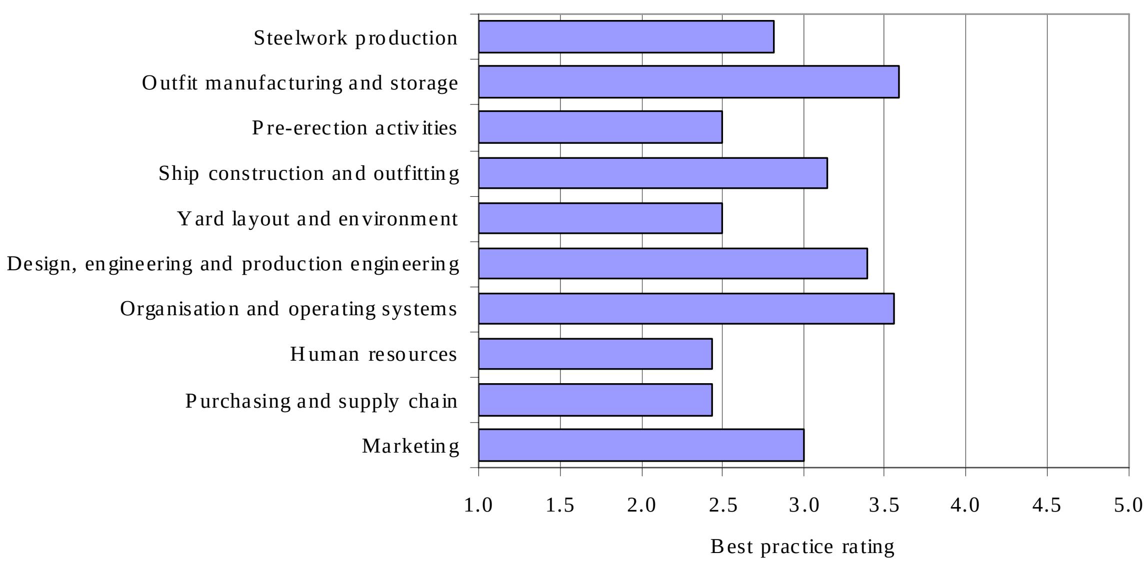

Figure 2 – Presentation of the results for all groups

7 BEST PRACTICE AND PROFITABILITY

Past competitiveness studies have established a correlation between use of best practice, output performance and profitability. One of the most thorough of these was the 1992 EC Study of the Competitiveness of European Shipyards carried out by KPMG (UK) and FMI. This study proposed that each yard must maximize its use of resources by ensuring that it is using best practice as appropriate to its size, type and individual business objectives. The research program and analysis demonstrated the link between the use of best practice and output performance. The results are shown in the figure below, together with the results from subsequent studies.

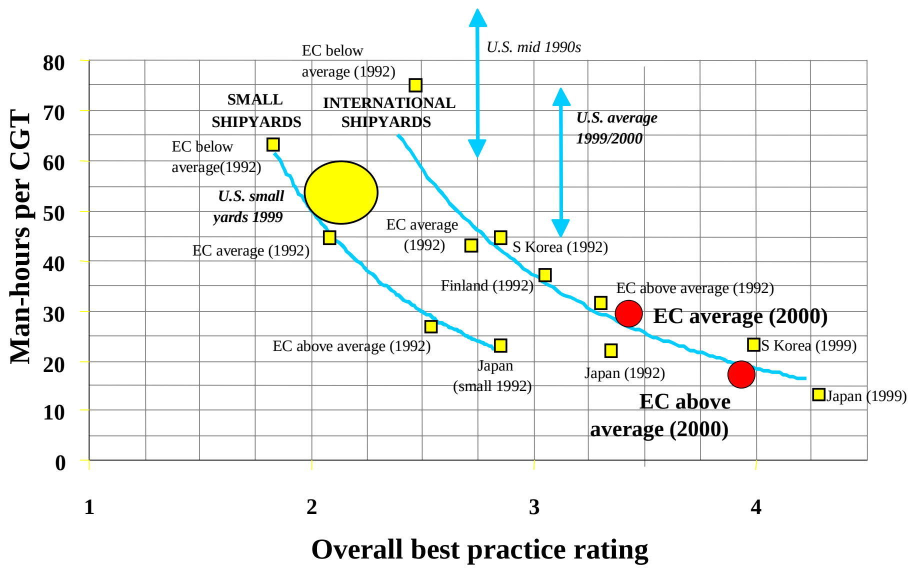

Figure 3 – International competitive performance

The figure shows that there is different relationship between the use of best practice and overall performance for large and small yards. In general terms, for a large yard to be internationally competitive it must be operating close to the right hand line. There may be another line that is appropriate to the builders of naval vessels. This is the subject of current work with the UK Ministry of Defence and European warship builders.

The 1992 study also showed a clear relationship between use of best practice, performance and profitability. Although this table relates to newbuilding, the principle applies also to ship repair and conversion.

Shipyard type	Best practice measure	Performance measure	Profitability measure
EC Above Average	117	150	91
EC Average	96	105	70
EC Below Average	88	65	23

Table 3 – Relationship between best practice, performance and profitability

8 SETTING FUTURE TARGETS

The overall method used to determine the required target performance for a shipyard and define the characteristics that will allow it to reach the required level of performance is shown in Figure 4. A key element in this part of the work is the application of relationships, such as those shown in Figure 3, which have been derived from the assimilation of data gathered from previous benchmarking studies.

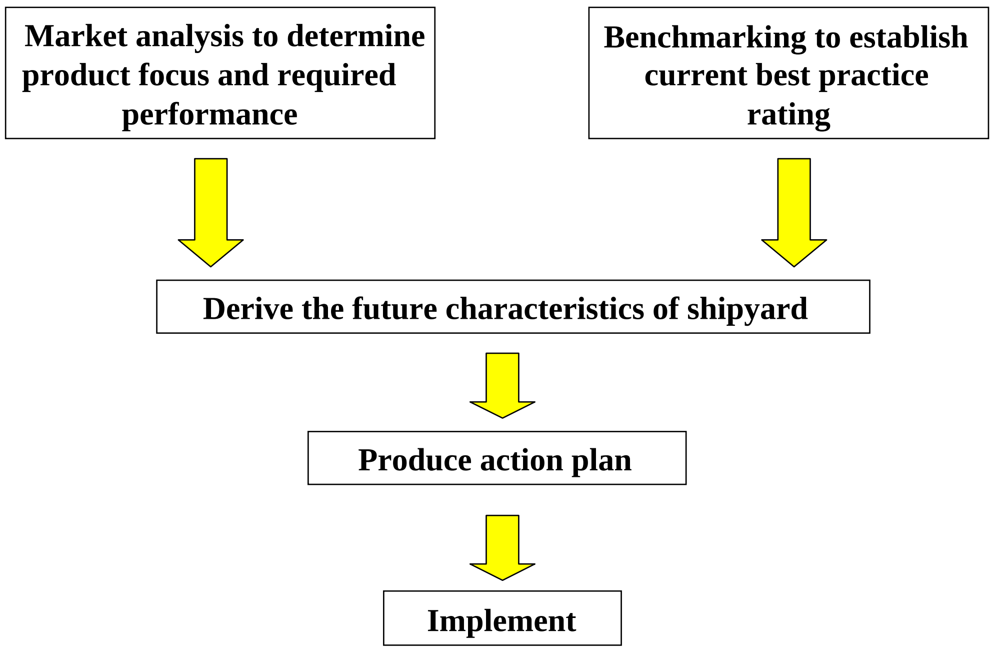

Figure 4 – Overall methodology

This is an integrated approach with each stage building on the results of the previous stage. Although these modules are complementary, they can be carried out in isolation. FMI is able to provide expertise to assist with all stages of this process. However, some yards choose to carry out part of the work themselves. A description the procedure applicable to shipbuilding is given below. A similar procedure is followed for ship repair and conversion.

A market study or market review is undertaken to identify a compatible product mix, the prices for ships in target market sectors and hence the levels of performance that have to be achieved to succeed in these sectors. It is essential that shipbuilding facilities are matched in a technical sense with the chosen market sectors. Choice of technologies and equipment must be clearly related to the size and type of ships to be built.

In the commercial market, performance targets are specified in the form of added value per unit of work ($/CGT); where added value is defined as price less equipment, material and other bought-in items and the unit of work used is compensated gross ton (CGT). In effect, this unit specifies the available income per unit of work to cover shipyard labor, overhead and profit.

The benchmarking system is used to establish the current use of best practice and the break-even cost in terms of $/CGT that is currently achieved by the yard. The gap between this value and the added value available in the target market is known as the "performance gap". The objective is to develop and implement a performance improvement program to close this gap and subsequently stay ahead of the main competitors.

The shipyard should be configured to be capable of profitably building the ship in the product mix that has the lowest level of added value ($/CGT). Using the relationship between the use of best practice and overall productivity shown in Figure 3, and the cost structure information gathered from the shipyard, the added value per CGT for incremental changes in the use of best practice is determined. The minimum required use of best practice occurs at the point where the break-even added value that can be achieved by the yard is the same as the added value that is available in the market sector. This is illustrated in Figure 5.

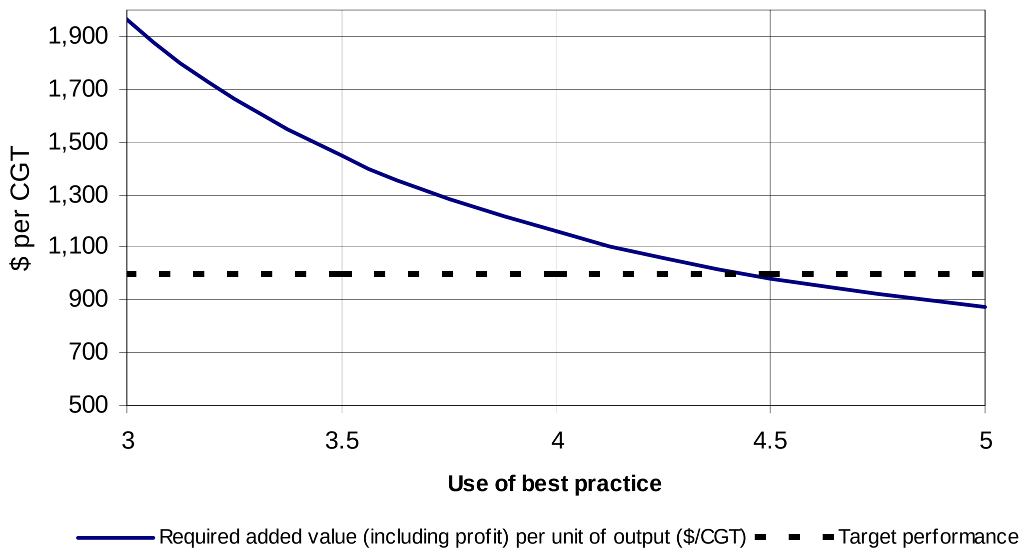

Figure 5 – Minimum use of best practice

The minimum level of use of best practice, required performance, manning levels and high level financial targets are determined by running different product mix and financial scenarios on a computer-based model that takes the following factors into account:

- Output.
- Wage rates.
- Facility related costs.
- Operating expenses.
- Current best practice rating.
- Current performance.
- Incremental cost of improving the best practice rating.

The gaps between the current levels of use of best practice and the required minimum can been seen by marking the minimum use of best practice onto the results of the benchmarking survey, as shown in Figure 6.

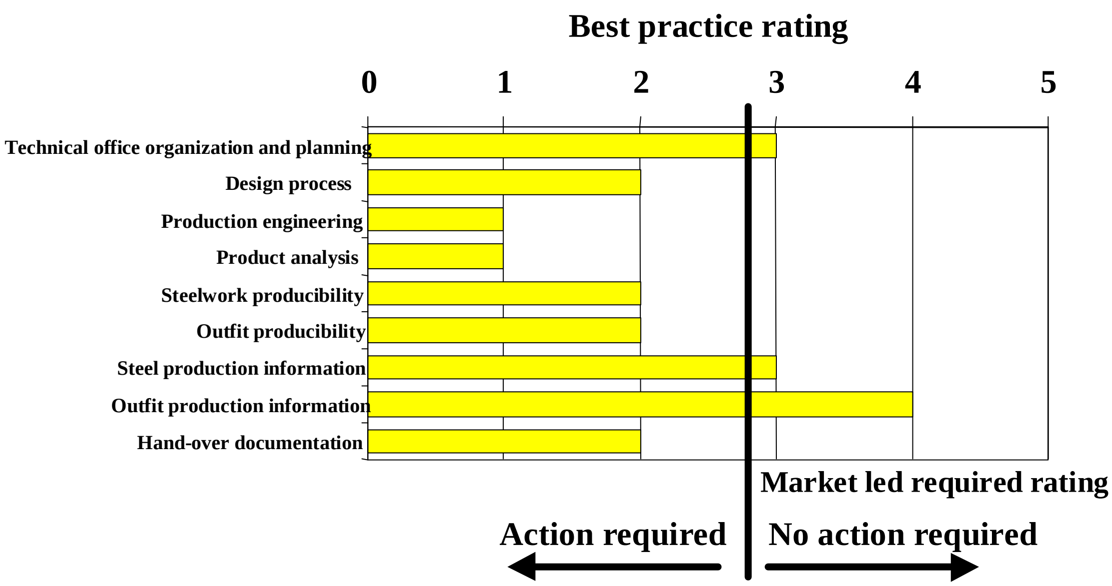

Figure 6 – Identifying the gaps in the use of best practice

This identifies the deficient areas of the organization and gives a clear indication of the focus areas for the performance improvement effort.

A description of the processes and procedures that will yield the required level of performance is then written. This is generated by overlaying the minimum required use of best practice onto the descriptions of the levels of use of best practice in the benchmarking system. This gives an extremely useful high level indication for shipyard managers of the required physical characteristics of the shipyard and the systems, methods and technology which should be applied in order to reach the necessary performance level.

The next step is to develop a performance improvement program to close the gap.

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