SHIP STEELWORK MANUFACTURE

by

Geoffrey Southern

Ph.D. Thesis

The Department of Management Studies.
Glasgow University.
December, 1978.

ACKNOWLEDGEMENTS

I would like to acknowledge the help of shipbuilding companies and associated bodies with this work, and in particular the British Ship Research Association with whom I spent two years. I also owe a great deal to the guidance of my supervisor, Dr. C.C. Gallagher, and to my colleague, S.K. Banerjee with whom I shared the task of data collection as part of a larger research project. He is examining in detail the ship assembly aspects which follow from the approach used here. Finally I owe the largest debt to my wife Marie whom I met while carrying out the work, and who willingly undertook the task of typing this thesis.

CONTENTS

List of Figures

SUMMARY

The primary aim of the work described in this thesis was to investigate the manufacture of ship hulls. The British share of the world shipbuilding market has fallen from over 50% to under 5% in the last thirty years, although its output in terms of tonnage has remained fairly stable at about one million tons per year. The increase in world demand during this period has been met by overseas shipyards which use production methods akin to those employed in general manufacturing industries. However British shipbuilders have tended to use more traditional shipbuilding methods, and investment in capital plant and improved management techniques has been relatively low. It was therefore intended that British shipyards should be investigated by a person with knowledge of other manufacturing industries.

It became evident at the start of the work that active collaboration with shipyards was essential to achieve meaningful results. Nineteen British shipyards were approached and asked if they wished to participate. Four initially agreed, and a further four companies and two consultant organisations joined at a later date. During a preliminary exercise the four collaborating companies were visited for periods of one or two weeks. Design and production personnel were interviewed, and the areas of ship manufacture which might prove most fruitful on investigation were discussed. It was decided that a detailed study of ship hull steelwork manufacture, its management, and the plant and factory layout best suited for it would be most beneficial. These functions would be investigated and recommendations made to collaborating shipyards on how they might be improved.

The main feature of the work carried out was the compilation and exploitation of a computer data bank describing the design and production features of ship hull components. It became apparent from initial shipyard discussions that difficulties would be met in directly applying production analysis techniques of general manufacturing industries in shipbuilding. The main reason for this is that there is a relative lack of essential production data. In many

shipyards information does not exist on component process routes, component and assembly standard times, and standard costs. In the engineering industry in general an analytical investigation can start with the assumption that this data already exists within the firm. It was thought this problem would only be overcome by collecting information directly from ship steelwork drawings and material lists, and by then using this information to generate production data. The information would also be most economically stored, manipulated, and analysed using a computer.

Component and assembly information was collected from drawings and material lists for selected ships and stored in computer data banks. Each data bank described components and assemblies comprising a complete ships hull. They employed descriptive coding systems which were specifically designed to indicate the manufacturing features of components and assemblies. It was thus possible to overcome the lack of production data by directly recording design information. In addition efficient computer storage, manipulation, and analysis packages were found to be readily available. The data banks were directly analysed to quantitatively investigate raw material standardisation. More important, by using the data banks it was possible to indirectly derive manufacturing methods from design drawings, and to use this to publish statistical tables of ship hull components for use in management decision making. Further investigations were made into work scheduling and shopfloor layout problems in a specific shipyard. In these investigations the non-existence of manufacturing process plans and work content estimates was found to be severely restricting. Computer programs were therefore written to generate these directly from the computer data banks for both component production and assembly. The resulting systems are faster in response and inherently more consistent than manual planning methods. They are accurate enough for scheduling, and they are now available for more detailed investigation of schedule work balancing and shopfloor layouts.

During the period of research a continuing study was made of recent developments in shipbuilding and associated topics. Shipbuilding factors which were investigated include the shipbuilding market, manufacturing methods and shopfloor layouts, and production organisation and information systems. The study endorsed the value of the work by emphasising the need to improve information systems within shipyards, and thus enable production management decisions to be made on a quantitative basis. Should further work be envisaged in this field a study of group technology flowline production systems would be most fruitful. Some work has already been attempted in this area and is described in this thesis. However this was undertaken without the benefit of the work content estimating systems which have now been developed. These will allow more detailed study of flowline work station balancing. A second topic which deserves closer investigation is the relationship between the design and production functions in shipbuilding. It is felt that closer co-operation between these would be most beneficial, particularly in standardisation of material sizes, components, and steelwork details.

World shipbuilding is at present passing through a phase of deep recession and vast overcapacity. British shipbuilding is in a strong position to survive this, partly because of government support but mainly because it is better equipped than its competitors to build the types of ship now required. However shortcomings in shipyard management, particularly in production information systems must be overcome to take advantage of the situation. While British shipbuilding had already carried out significant work in this area a formal, all embracing, and rigorous approach had not been attempted. This work has now introduced many of the production analysis techniques employed in general manufacturing industry to shipbuilding. It has resulted in the application of new computer storage and analysis techniques for ship hull steelwork, and in the development of computer process planning and estimating systems. It is hoped techniques such as these will be accepted by the industry as a means to improve shipyard management in general.

Chapter 1 Introduction

This thesis can be divided into four sections covering present aspects of the shipbuilding industry, the compilation and analysis of a computer data bank for ship hull components, the exploitation of a component descriptive coding system, and a discussion of the research findings.

The description of present aspects of the shipbuilding industry is sub-divided into three chapters. The first of these describes the shipbuilding market with particular reference to its influence on British shipbuilding, and the remaining two chapters describe aspects of ship manufacture and ship hull production management respectively.

The compilation and analysis of a computer data bank describing ship hull components from six British shipyards is described in the next four chapters. The first of these describes the development of a component coding system and compilation of the computer data bank. This was undertaken in collaboration with a fellow researcher who was independently investigating assembly information, the responsibility for designing separate component and assembly sections of the data collection format was divided accordingly. The second chapter in this section outlines the concepts of statistical analysis and the methods used to exploit the data bank. The final two chapters in this section deal with the specific use of the data bank to analyse material and component requirements respectively. Raw material analyses are based on both actual shipyard material orders and requirements estimated from component information, and raw material standardisation is also described. Component analysis methods vary from simple card sorting to the use of sophisticated statistical analysis computer packages. Standard analysis presentations which highlight the dependence of production methods on component configuration are also described. These allow comparison of different ships.

The section covering the exploitation of the component coding system consists of two chapters. Both deal with the determination of component process routes and work content estimations. The first describes the automatic specification of component process routes and work content estimates to enable process and production planning of components at the earliest possible stage. The second describes similar techniques to enable assembly production data to be defined from the shape and size of component parts.

The discussion in the last chapter covers the value of the analyses and information techniques employed, and the influence the research has had on the shipbuilding industry. It ends with specific conclusions which have been drawn from the research findings.

The practical knowledge of shipbuilding which is essential in a thesis of this kind was acquired by collaborating with a number of shipbuilders, shipbuilding consultants, and shipbuilding research associations. The majority of the data was collected from Austin and Pickersgill (Sunderland) and Ailsa Shipbuilding (Ayrshire). Data was also collected from Ryton Marine (Wallsend), Scott Lithgow (Greenock), Camell Laird (Birkenhead), Swan Hunter (Wallsend), and Harland and Wolff. This industrial collaboration, and the contributions made by the companies, is described and acknowledged in Appendix A.

Chapter 2 The Market for British Shipbuilding

2.1 The market history

Many manufacturing industries rely on a strong home market which is often protected by legislative import duties or natural transport costs. However until the second world war ship owning and shipbuilding companies operated under policies of free world trade based on a traditional supply and demand mechanism. This was a result of the commonly held belief that if a nation's merchant fleet was to remain competitive then it must be allowed to buy ships under the most favourable conditions available. This has led to the development of two traditional categories of shipping fleet dependent on their country of registration, these are international fleets and open fleets. International fleets are those of countries which both manufacture and import ships, while open fleets are those of countries who import ships only. International fleets include those of the U.K., Norway, Holland, Denmark, and Sweden. Open fleets are those registered in 'flags of convenience', countries such as Panama and Liberia.

Since 1948 the world policies of free competition have been undermined by legislative protection or financial support given by various countries to their respective shipbuilding industries. Many nations now believe that they can only become or remain an economic or strategic world power if they are capable of producing ships to control their own imports and exports. This has led to the growth of 'closed fleets' which are registered in countries which legally require or financially induce their shipowners to buy internally; the first fleets in this category included those of Japan, Italy, Spain, the U.S.A. and to a lesser extent France.

All shipbuilding nations now provide some degree of financial support for their own industry. It was pointed out in a report on British Shipbuilding published in 1972 (1) that U.K. subsidies compared favourably with all other countries except the U.S.A. The report categorised methods of support into five divisions, these were:-

1 Exemption from indirect taxes and import duties. This was practiced by all countries except Japan where there were (and still are) strong links between shipbuilding and other industries to compensate.

2 Direct subsidies on the price of ships. The U.S.A. (43%) Italy (9%), U.K. (10%), and France (3%) practiced this in 1972, although the size of subsidy has since been reduced in the U.K. and Italy under E.E.C. regulations.

3 Offers of credit to shipowners at rates better than those available commercially. All shipbuilding countries offered this with loans as high as 87% over 25 years at 6-8% (U.S.A.)

4 Direct financial support to shipbuilders by cash grants or subsidised research and development agencies. Direct cash support was used to re-equip shipyards and was significant in the U.K., Sweden, Italy, and Japan. It has increased further in the U.K. since 1972 with shipyard development projects at Cammel Laird, Govan, Harland and Woolf, and Sunderland Shipbuilders leading to government ownership of all four companies after further financial difficulties and finally nationalisation of all British Shipbuilding.

5 Other support. This included demolition premiums to encourage scrapping of older vessels (Japan) tariff protection on imported ships (Spain and Japan), and inflation insurance (France and U.K.). (Inflation insurance became increasingly important in the early 1970's with many countries suffering astronomical inflation rates.)

The report stated (in 1972) that nearly a third of the free world demand for new vessels was not open to international competition. Since then the world shipping slump has accentuated the problem (see section 3 of this chapter).

2.2. Market Influences

Influences on the U.K. shipbuilding market can be divided into those which affect total world needs and those which affect the U.K. market share.

The type and total number of ships required on the world market is influenced by a number of factors, foremost of which are cargoes to be transported, operating conditions, and technical innovations or developments. Cargoes have changed dramatically since the early 1950's particularly in the quantity of 'bulk' cargoes such as crude oil, grain and iron ore which have been moved. The availability of cheap Middle Eastern oil until about 1973-4 encouraged many countries to specialise in building bulk transport ships. Larger oil tankers and the facilities to produce them were developed initially in Japan, then in traditional European shipbuilding centres (W. Germany, Denmark, France, etc.) and finally in the developing shipbuilding countries (Greece, S. Korea, Taiwan, etc.) The tanker market diminished alarmingly in 1975 with large increases in Middle East oil prices, the construction of refineriesat source and development of North Sea oilfields. This has resulted in vast overcapacity. It has been forecast that a similar situation will develop in bulk carrier construction, although the collapse and resulting overcapacity will not be of the same magnitude. Another market development partly induced by cargo availability has been the growth in numbers of small ships needed to carry mixed cargoes to developing nations, although this has been equally influenced by the operating conditions avaiable. The draught of such ships must be such that they can enter the shallow harbours found in many of the developing nations, and they must also be equipped with deck handling gear to compensate for the lack of harbour facilities. Ships in the size range 10,000 - 20,000T d.w.t. are found to be the optimum at this time; an example of such a ship is the SD14, a standard 14,000T d.w.t. cargo vessel which is produced in large numbers. In addition the increased traffic in oil products has led to an increase in the requirement for oil-product tankers as demonstrated by a Cammel Laird series of ships (STAT 35, STAT 45). Ship operation has also been influenced by the size of the Suez and Panama canals, although Suez has been of less significance since its closure in 1968. Economic studies undertaken in the past have led to the design of 60,000 - 80,000T d.w.t. bulk carriers of specific draught and breadth to pass through both canals, and 125,000T d.w.t. crude oil carriers to pass empty through Suez when bound from Europe to the middle east, and full around Cape Horn on the return journay. The closure of Suez (1968) changed the circumstances under which the studies were made and resulted in an acceleration in the development of supertankers.

Technological developments are usually initiated by a market need, but when complete they can in return influence the market. Typical examples of this process are the design of Oil-Bulk-Ore (O.B.O.) Roll-on-roll-off (R.O.R.O.), and container ships. OBO's can carry oil, grain or ore cargoes and although their initial cost is high because extra cargo handling and cleansing equipment is required, their economic efficiency is increased by the resulting flexibility. RORO's are vehicular ferries which have been designed to carry the increase in international road traffic in the last ten to fifteen years, particularly in heavy goods vehicles. They allow vehicles to drive on or off the ship at the stem and stern, thus improving speed of 'turn-round' over traditional single entry ferries. They are employed on short distance routes, such as from the U.K. to Europe and Ireland, and Denmark to Scandinavia. Container ships have also been developed from the need for an integrated shipping-road transport system and use sophisticated equipment to handle containers which may also be transported by lorry. Their use has resulted in faster turn-round of ships due to easier cargo handling, and the introduction of sealed cargo units for import custom purposes. Possible future developments in the field of integrated transport systems are ship carried canal barges (L.A.S.H.)[2], and power 'units' comprising of engine room, steering gear, and crew facilities which may be coupled to a 'cargo unit' in a manner similar to that used for articulated road vehicles.

The share of total world market which any particular nation can expect to obtain is governed by the price and delivery they can offer. The price is dependant on the cost of production, the degree of government support which is available, and the strength of the currency of the manufacturing country. The recent depreciation of the pound relative to other currencies has improved the position of U.K. shipbuilders with potential buyers, but the cost of labour is high compared with that in emerging shipbuilding nations (S. Korea, Portugal, Spain, Taiwan). The delivery period for ships at any specific time is dependent on the availability of shipbuilding berths. Not only is a short delivery period of importance but consistency and accuracy of delivery forecast is often considered imperative. This results in buyers returning to shipbuilders who have delivered on schedule in the past, and eventually results in mutually beneficial trust between specific owners and builders. In addition several joint companies have been formed in the U.K. by the amalgamation of owners and builders in attempts to stabilise ship demand and improve deliveries. Examples are London Overseas Freighters and Austin and Pickersgill, Maritime Fruit Carriers and Swan Hunter, Court Line and Sunderland Shipbuilders. The present overcapacity in the world shipbuilding industry has reduced problems of both scheduling and poor delivery forecasts. However, deliveries may still be delayed by industrial disputes or material shortages, and these have now replaced optimistic planning as the main reason for late deliveries. Industrial relations in U.K. shipbuilding have improved recently although there will be an inevitable time lag before this will be recognised by world markets.

2.3 U.K. performance in the world market

Supply and demand in shipbuilding fluctuates with world trade and is a strong indicator of buoyancy and recession. It can be seen from graphs of ship production since 1948 (figures 1 and 2) that the world shipbuilding market has undergone steady growth with an acceleration in tonnage produced occuring in 1963. The U.K. share of the market has steadily declined from 50% by weight in 1948 to about 5% in 1974 although the tonnage and number of ships pro-

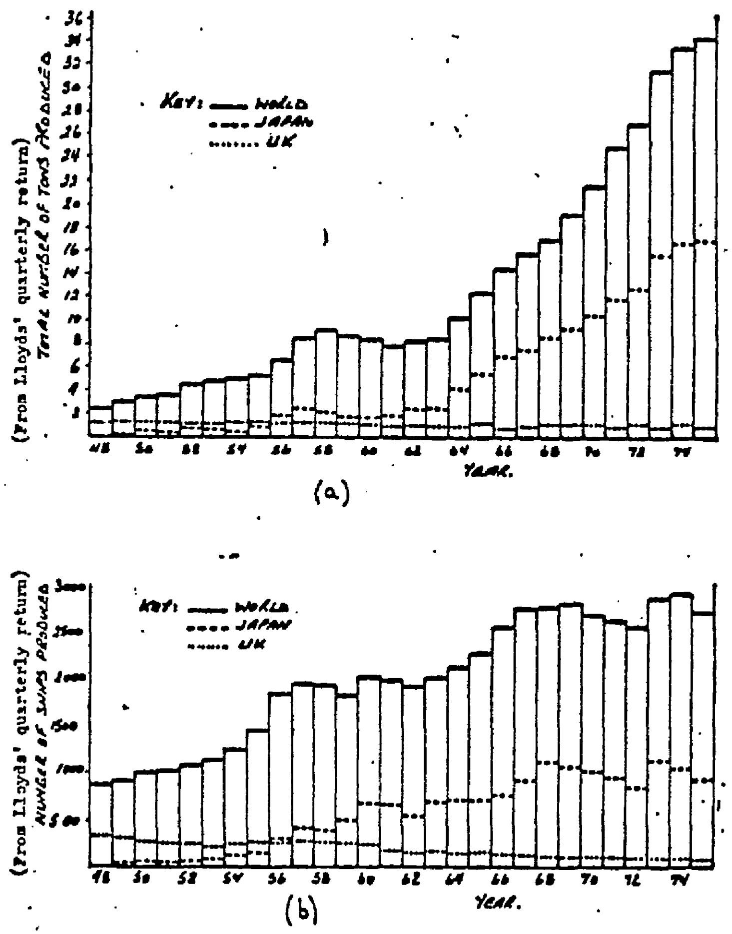


Figure 1 Ship production in the U.K., Japan, and World from 1948 to 1975
a) Tonnage produced each year
b) Number of ships produced each year

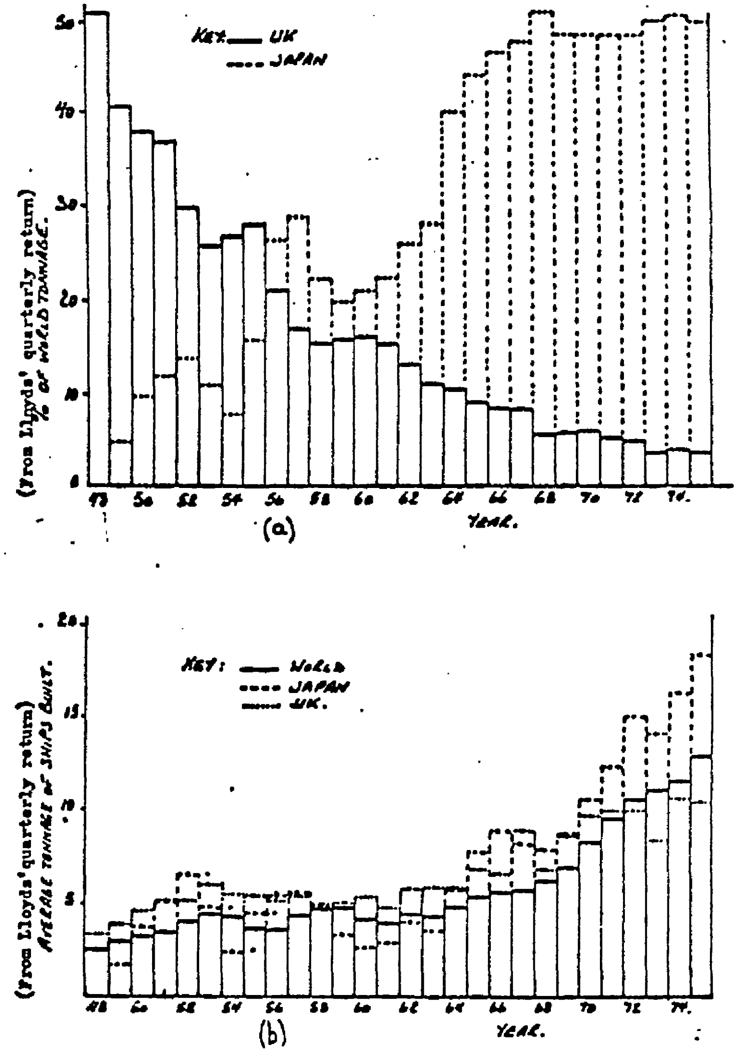


Figure 2 Comparative ship production figureu of the U.K. and Japan from 1948 to 1975
a) Percentage of world tonnage produced each year
b) Average size of ship produced in each year

duced has remained fairly consistent. Thus, although shipbuilding has been a growth market from 1948 until 1974 the U.K. has failed to increase its capacity in proportion but has been satisfied to produce a consistent quantity of ships in well established shipyards. However, the growth in the market has been fully exploited by Japan whose world share has increased rapidly, particularly between about 1960 and 1966 (figure 2a) The difference in the investment policies of the two countries is also reflected in the size of ships they have produced (figure 2b) Until the early 1960's the U.K. produced ships which were well above the average tonnage of those produced in the world and Japan. From the mid 1960's the average size of ship built in Britain has increased by about 150% while Japan's has increased by about 250% from a near common base. This reflects the capital invested by other countries in shipyards capable of manufacturing much larger ships, particularly by Japan for building large tankers. This investment has in turn led to the development of sophisticated management systems and advanced technology to increase production efficiency. British shipbuilding, however, has followed traditional methods of management and manufacture, a policy which has been enforced by the lack of capital investment and a resistance of shipyard labour to change. Attempts have been made recently by a few companies to increase the size of ship which they can build. The first British yard to follow the world trend was Harland and Woolf (Belfast), who were followed by Scott Lithgow (Greenock) and Swan Hunter (Wallsend). Scott Lithgow (Greenock) have increased their capacity to 250,000T d.w.t. by building ships in two halves and welding them together while afloat using an air-tight coffer-dam.

A closer investigation of the ships in production and on order since 1972 shows the effects of the recession in the tanker market on the order books of various countries. Histograms have been drawn of the total weight and number of ships in production, and on order (including those in production) in each quarter since 1972 for the world and selected countries. Graphs of tonnage of ships in production (figure 3a) show a world peak in mid 1975 with the

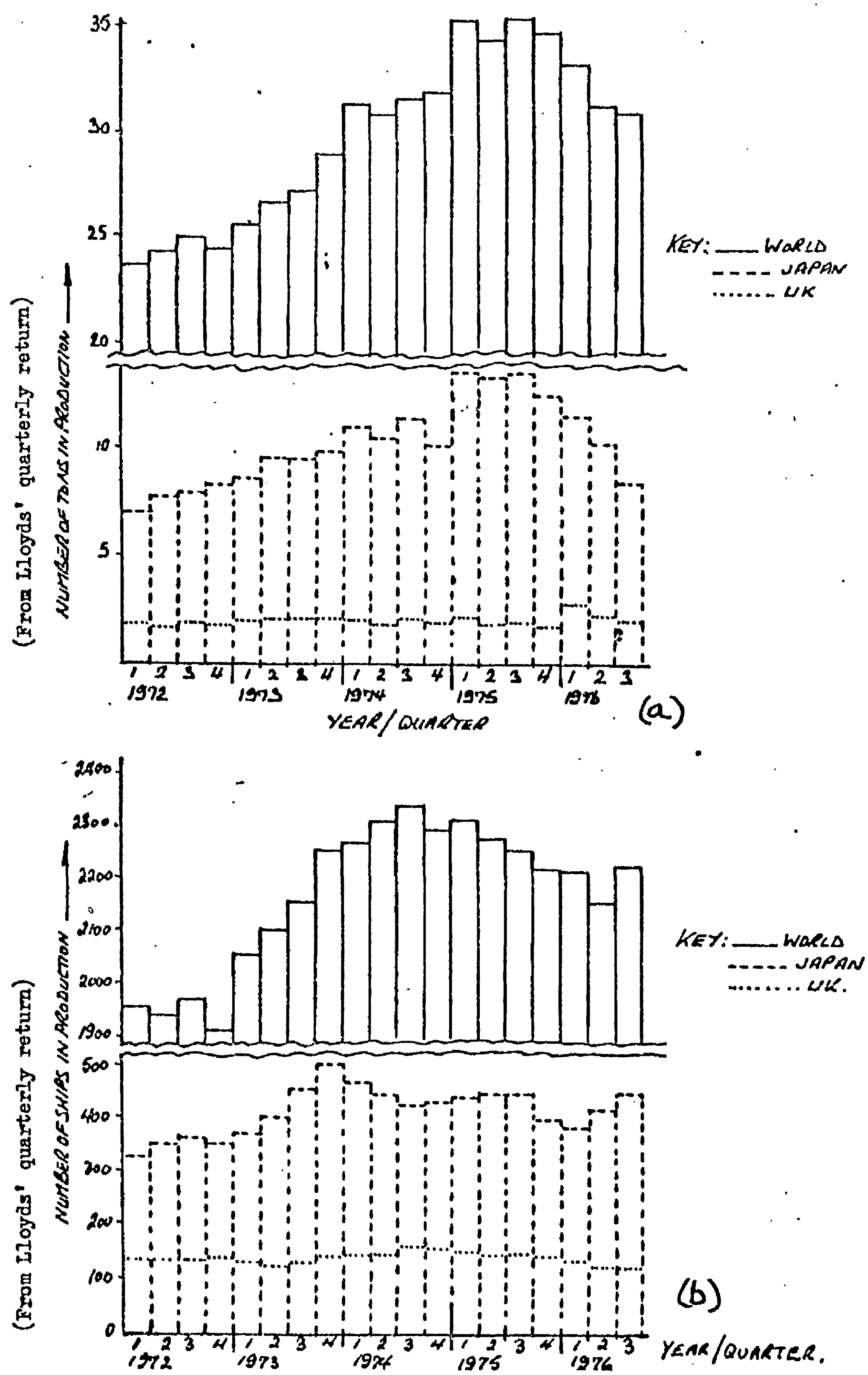


Figure 3 Analysis of ship production in the U.K., Japan, and World in each quarter from 1972 to 1976
a) Tonnage in production
b) Number of ships in production

Japanese tonnage closely following the world trend. The number of ships in production in the world (figure 3b) has not fallen as quickly as the tonnage indicating that smaller ships are being built. Both the tonnage and number of ships in production in the U.K. has shown a steady decline since 1975. Graphs of the U.K., Japanese, and South Korean shares of world tons in production is shown in figure 4. The Japanese share of the world market has fallen dramatically since a peak in 1975 while the U.K. share has remained stable and the South Korean has increased steadily, this accounts for the loss making contracts accepted by Japan since mid 1975.

A study of ships on order indicates the immediate prospects of each shipbuilding nation. A graph of the total world tonnage on order (figure 5a) shows a peak in mid 1974 corresponding to the production peak of 1975 and demonstrating the design - production time lag. A steady decline in world orders has occured since the second quarter of 1973 and this is reflected in the order books of individual countries (figure 5b). The order book of most countries has fallen by about 70%. Graphs of the market share of various countries (figure 6a) shows that the U.K. share recovered after falling during 1974 to show an overall increase of about 1½%, while the Japanese share fell from 47% to 33%

An attempt has been made to indicate capacity utilization for each country based on orders and making assumptions to determine the capacity available. These assumptions are:-

1 That each shipbuilding nation had orders enough to fill their capacity for roughly equal time periods at the peak of total world orders (1st quarter 1974). This is a fairly reasonable assumption as there was a world shortage of berth capacity at that time, and fixed price contracts. Thus each shipbuilder would take care not to overfill its order book when ship prices were likely to rise and not fall.

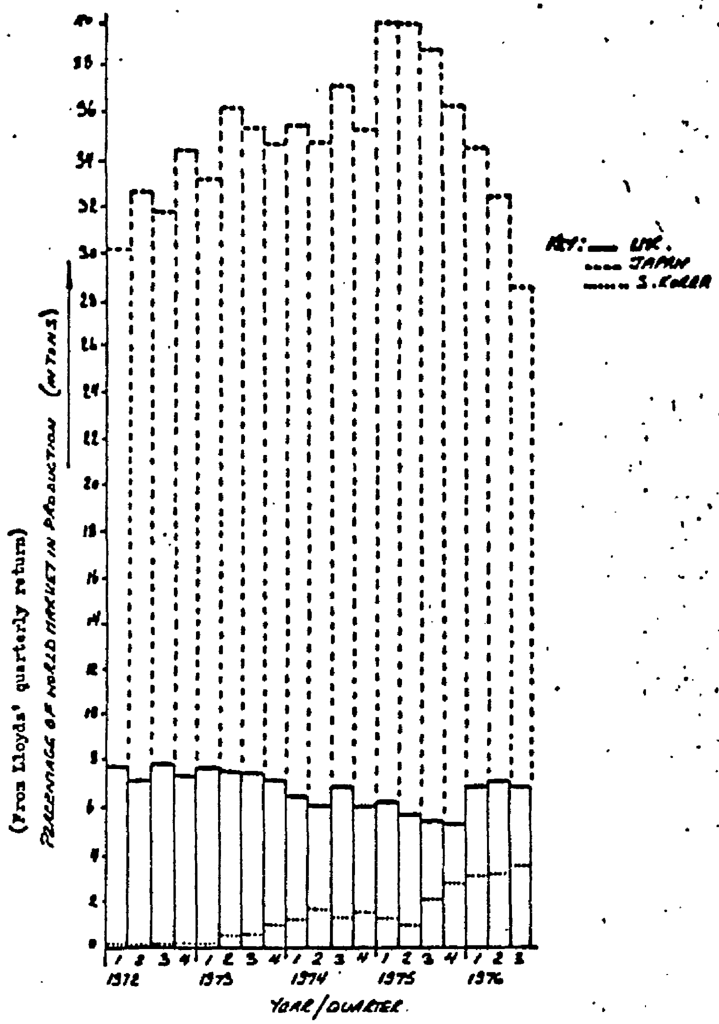
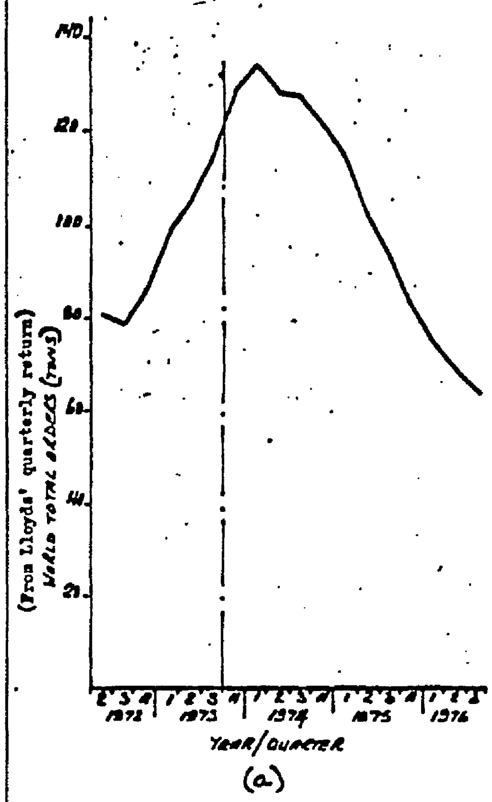


Figure 4 Analysis of world market shares of ship tonnage in production in the U.K., Japan and South Korea from 1972 to 1976



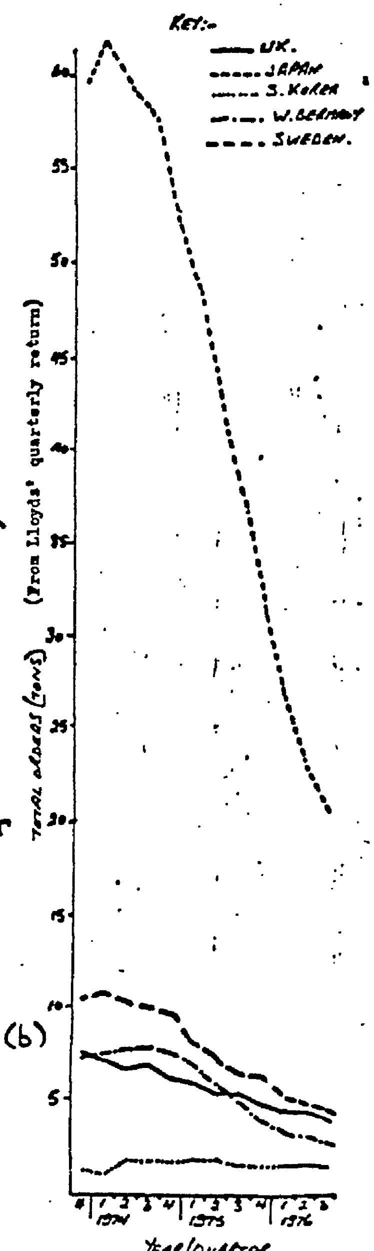


Figure 5

Analysis of ship tonnage on order in each quarter year
a) for world (1972-1976)
b) for the U.K., Japan, South Korea, West Germany, and Sweden (1974-1976)

2 That increases in capacity of shipbuilding nations have been minimal since the peak. This is ill-founded in the case of developing shipbuilders (i.e. South Korea) but is still probably true for established shipbuilders.

Averages were found of three values of tonnage orders before, on, and after the peak of world orders for each country being considered. This was accepted as a measure of the capacity available, and the ratio of successive quarterly tonnage on order against this measure has been plotted for each country (figure 6b). The capacity of South Korea has most probably increased and can therefore be dismissed as failing to comply with assumption 2. The rate of decline of capacity utilization is notably greater for Japan, West Germany, and Sweden than for the U.K., the U.K. is at present operating at about 58% while Sweden, West Germany, and Japan have fallen to 42%, 36% and 33% respectively. It is also noticeable that the resulting order of countries (U.K., Sweden, West Germany, Japan) is the inverse of the way in which the respective currencies have moved in exchange markets.

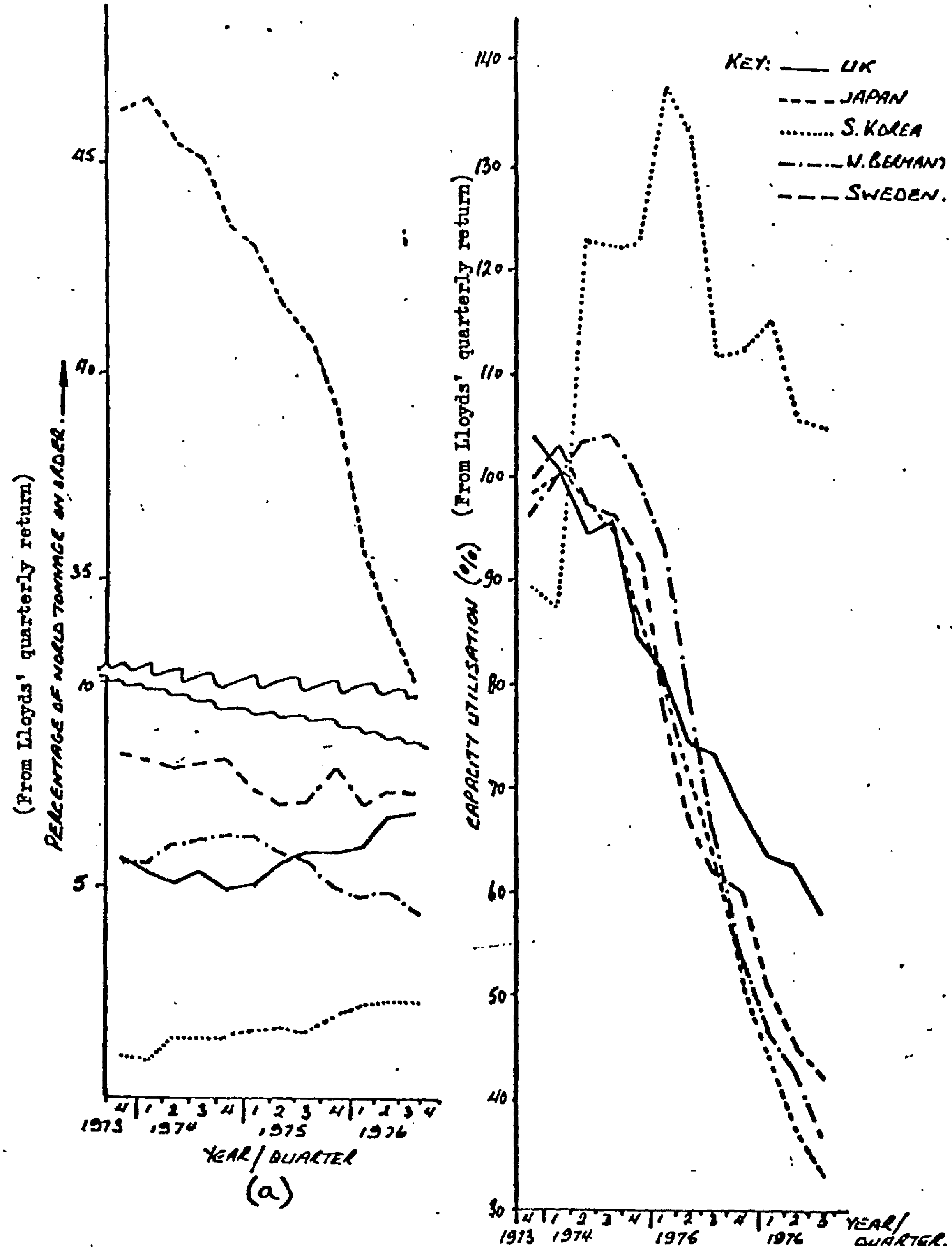


Figure 6 Analysis of comparative success of the U.K., Japan, South Korea, West Germany and Sweden in each quarter-year during the work shipbuilding recession (1974-1976)

a) percentage of world tonnage on order

b) capacity utilisation

Chapter 3 The Shipbuilding Process

3.1 Process Outline

Shipbuilding is in many respects similar to civil engineering. It involves the construction of a single structure at a fixed location over a long time period. It employs planning techniques similar to those used in civil engineering, including, network planning and critical path analysis. It is traditionally a labour intensive process and involves three design and two production stages:-

Design	1	Preliminary design
	2	Design of structural scantlings and shell envelope
	3	Structural detailing and marine engineering
Production	4	Ship hull production
	5	Outfitting and engine fitting

Recent changes in marketing practice have led several shipyards to specialise in series ship production. Here only slight modifications are made to the next ship to be produced, thus the design stages are minimal.

Preliminary design is concerned with the operating characteristics and size of the ship. It usually involves the optimisation of speed, cargo capacity, stowage arrangements, and the deadweight and displacement tonnage. Detailed consideration is given to weight and cost of steelmass, outfit equipment, machinery and fuel. Preliminary checks are also made on stability criteria, these include floodable lengths and freeboard calculations. In the past prospective buyers and shipbuilders have liaised closely at this stage, as ships have often been designed for specific purposes. However with trends towards standard ships preliminary design is now frequently undertaken without owner-builder collaboration.

The shell envelope is based on hull dimensions which are specified in the preliminary design. It is developed using monitored performances of previous ships and model towing tests to evaluate hydrodynamic properties. Structural scantling drawings usually show typical design outlines and indicate plate thicknesses and section moduli to achieve structural strength requirements. The major scantling drawing is termed the 'design midship section' and shows bulkheads, webbed frames, bracket frames, and longitudinal structure positions at midship. This is sent to the relevant classification society to be verified, preferably before structural detailing commences. Ships are designed using box girder type algorithms and the strength is checked using finite element analysis. The structural strength is guaranteed by applying classification society rules (Lloyds,[3] Bureau Veritas) which are based on past experience and updated regularly. Several computer programs[4] are available to interpret classification society rules and find the minimum scantlings required.

Structural detailing involves the application of scantling drawings to the hull shape and results in the design of actual (rather than typical) transverse and longitudinal sections throughout the ship. Each transverse frame and longitudinal feature in the ship is drawn in full. Design information is presented to ship hull production departments in the form of large plans showing structural features (bulkheads, floors, girders, decks, web frames, etc.), or as smaller drawings of structural units to be erected at berth and sub-assemblies for workshop construction. Marine equipment (engines, generators, pumps, piping, etc) is fully detailed at this stage, usually by a separate department. Collaboration with structural detailers is needed to position equipment and design service arrangements (electrical supplies, piping), but the separation of the two functions often conflicts with 'total design' concepts.

The process of ship hull production can be divided into two basic stages:-

a) the production of individual steel components from steel plate and rolled or welded steel section by means of cutting and forming operations

b) the welding of these components into progressive assemblies, and the erection of final assemblies (called fabrication units) at the shipbuilding berth.

The assembly stage may be historically subdivided into pre-berth assembly and berth erection, although this has become less meaningful with the introduction of 'ship factories' having covered berths. Here several fabrication units are often fitted together to form a 'fabrication block' at a suitable site near the berth. Individual steel parts and certain above-deck units (super-structure, hatchways) may be fitted after launch, although this increases costs considerably. A recent trend in the U.K. has been to complete as much assembly work as possible under cover. This has the advantage of weather protection and easier access for workshop services. This is done on covered building berths, or by increasing the size of fabrication units assembled in workshops prior to outside berth erection. Recent developments in hull manufacture are described in detail in the following sections.

Outfitting is concerned with the installation of engines, generators, ventilation fans and ducting, oil and water piping, cargo handling equipment, steering and control gear, and all equipment other than basic steelwork.

3.2 Steel component production

The two raw materials of hull production (steel plate and rolled steel section), are processed in separate production areas. However both undergo similar production operations; marshalling, marking out, outline cutting, drilling and forming.

Material marshalling ensures that plates and section bars are delivered to production areas in the required sequence. Steel plates are particularly bulky and can be up to 15M x 3M in size and of differing thickness. In addition each plate is traditionally ordered to produce specific components. They are usually stored flat in piles, so they must be in the correct sequence for painting and cutting to prevent production hold-ups and excess handling. Section bar sizes are less variable and standards are often used, so they are more easily marshalled and handled.

Raw material is painted before component production. Following their withdrawal from the stockyard plates are passed through straightening mangles directly to 'treatment' plant. In modern shipyards this includes shotblast, steam cleaning, spray paint, and heat drying. It is often positioned on a purpose built conveyor which transports the plates to flame cutting machinery. Section bars follow a similar path through a second purpose built treatment plant.

Plate mark-out can be carried out manually, or by the optical projection of scale slides onto raw material plate for 'tracing'. Plate marking has generally been superceded by optically controlled or numerically controlled flame cutters. However, guillotine cut plates are still marked, as are section components.

Outline cutting is carried out mechanically or by flame burning. Mechanical methods consist of guillotining and roll shearing, they are used to produce small brackets and lugs from fairly thin plate. Flame cutting is controlled by manual, semi-automatic or fully automatic means. Manual cutting methods consist of using hand held torches, although electrically driven torch carriers (which follow manually placed rods) can be used for straight lines. Flame cutting machinery can be categorised by the number of cutting heads, whether edge preparation facilities are incorporated, and the control systems employed. Multi-cutting head machines are used to cut identical or mirror image parts using a single control system, and edge preparation for welding is achieved using three staggered cutting flames. The first flame is perpendicular to the surface and cuts the outline shape, the second and third are at angles to cut the welding bevels required, this is shown diagramatically in figure 7. Control systems consist of straight line manually operated flame planing, profile cutting using optical followers, and n.c. profile cutting. Cutting of section bars to length is usually carried out using hand held flame torches, although flat bar can be guillotined.

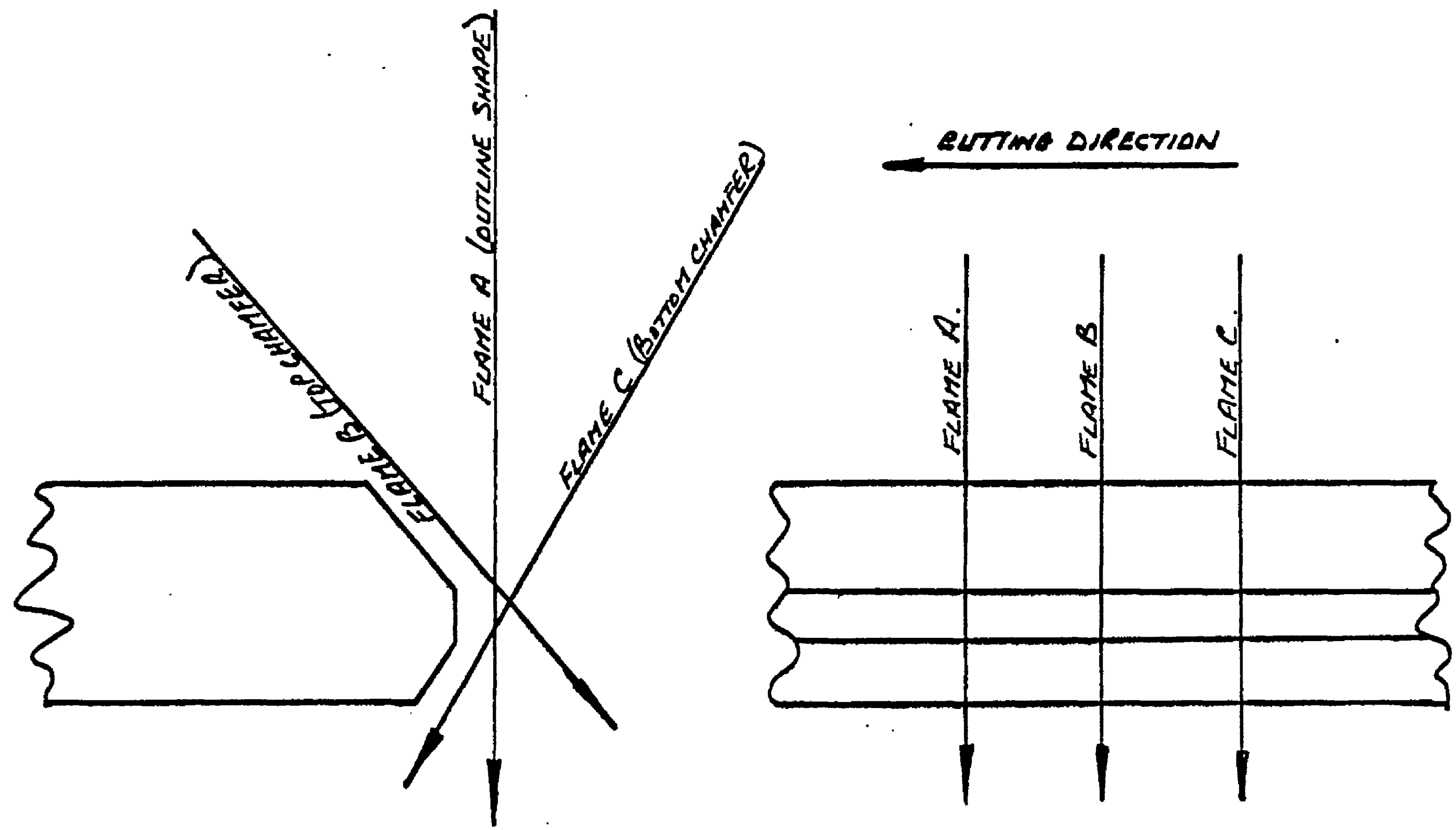


Figure 7 Flame orientation and cutting order for flame cut edge preparation of plate components

Plate forming processes consist of flanging, roll bending, and heat line bending. The latter is very seldom practiced and involves heating a steel plate locally to enable it to be formed, or supported such that its own weight causes bending. Flanging presses are used to flange free edges of small brackets and to swedge or corrugate bulkheads. Corrugations are used on non-structural thinner bulkheads such as accommodation divisions, and swedging is used on major structural bulkheads. Typical flanged brackets and bulkheads are shown in figure 8. Presses are also used to form shell plates by performing a large number of minor flanging operations resulting in a smooth bend. However, the most common method of forming shell plates is roll bending, rolling machines consist of three rolling mandrels which are usually controlled manually and can be up to 2000T capacity[5]. Section bar bending plant consists of cold frame bending machines for angle and bulb flat bar, and roll benders for flat bar when used as face-flats. Cold frame bending involves forming bar to the required shape using a power ram and two fixed clamps. Bars are usually bent in pairs and are placed back to back and clamped as shown in figure 9, long bars are formed by repeated bending operations at increments along the length. Forming is usually controlled manually and wooden templates are used for checking. Operator skill is imperative due to 'spring back', although attempts have been made to control bending using numerical methods.[6] Cold frame bending has now completely replaced the previous costly practice of furnacing then manual forming on slabs.

There have been few recent developments in component production and the fundamental operations have remained much the same since the introduction of welded ships. However developments have occurred in the size of machinery and in the control systems employed, n.c. flame cutting is now used in practically all shipyards. The introduction of tenth scale optical control, and then n.c. flame cutting has minimised marking operations and changed production information formats. It has also led to the adaption of flow line principles for most plate-part production to ensure that costly plant is fully utilised. Forming and

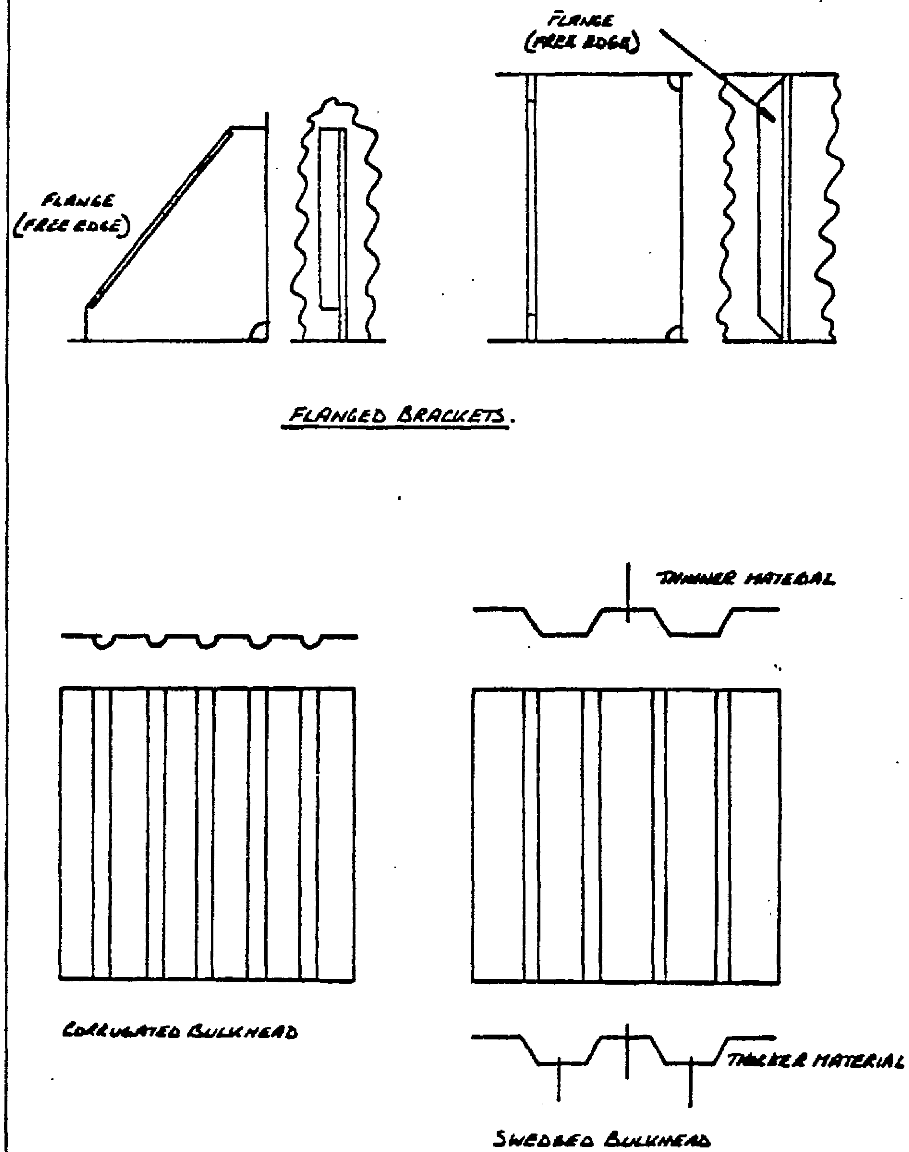


Figure 8 Typical flange formed plate components

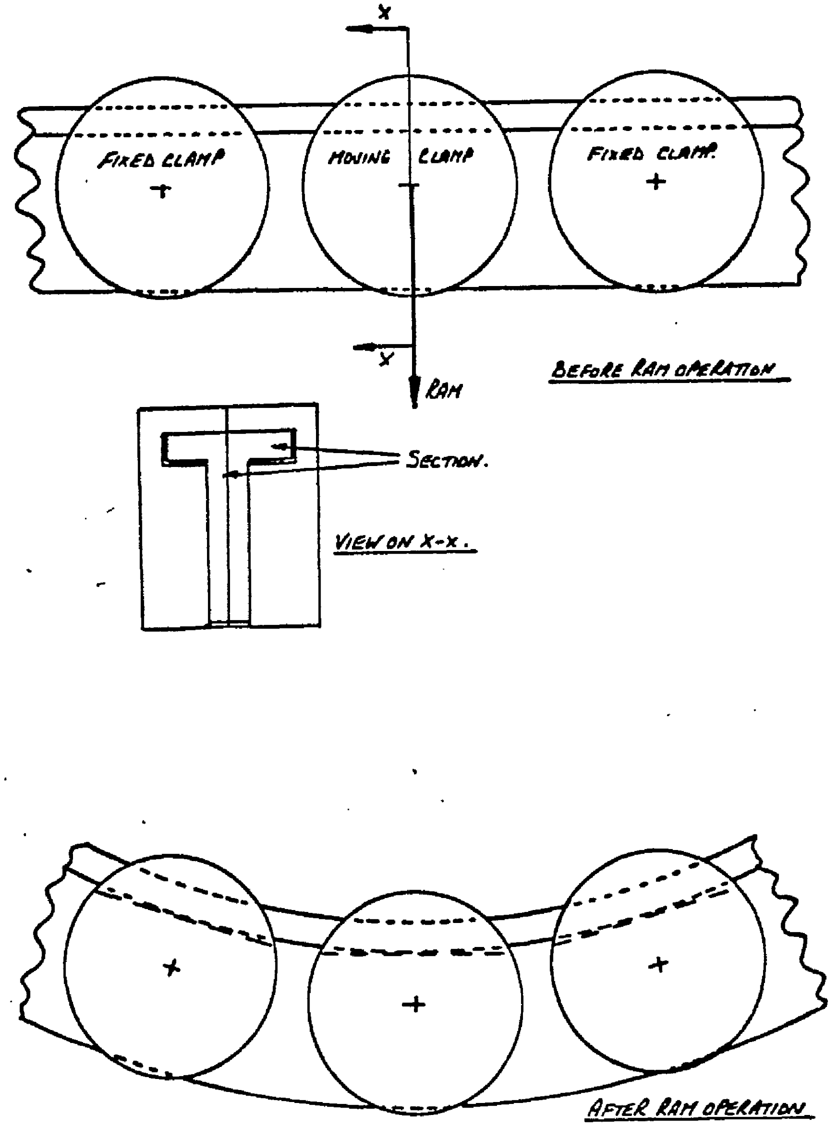


Figure 9 Cold frame bending of section bar components

drilling operations are still process orientated and not treated as part of a production line. Drilling occurs in relatively few components and is considered undesirable in large plate parts. It is often eliminated in design, for example by using studs rather than nuts and bolts to secure watertight covers.

3.3. Assembly methods

British shipbuilding has a historical tradition which has been reflected in its assembly methods and trade demarcations until recently. The hulls of the first iron and steel ships were constructed in a similar manner to those of wooden sailing ships. This involved two stages, first the building of a skeleton or frame for the ship and then the covering of the frame with a skin or shell of plates. These operations were carried out on the building berth using rivets to join overlapped components together. Welding has now replaced riveting but new technical problems have been introduced, these include improved dimensional quality control for abutting joints and the need for electrical supplies and ventilation ducting. It has also brought about a radical change in manpower policies, riveting had been a time consuming process requiring more personnel of a relatively higher skill standard. It became apparent that welding services could be supplied more easily and cheaply in a workshop environment than on a building berth. Also several sections of the ship could be manufactured simultaneously by building in workshop size units, thus reducing berth cycle time and increasing the return on capital investment. In addition workshop assembly was not weather dependant and an improvement in labour relations was theoretically possible. This was particularly important with a trend in the late 1940's and 1950's towards an era of full employment and the availability of more 'comfortable' occupations. Increased costs were found to result in material handling and quality control, but with the development of machine and plant technology these could be justified by higher steel throughput and a reduction in the quantity and quality of shipyard labour required.

Berth assembly methods have changed radically from the practice of fabricating individual components to the erection of large pre-fabricated units, using larger berth cranes. The largest cranes tend to be of the 'goliath' or portal type and are capable of lifting up to 15000 Tonnes (Kochums, Sweden). They are usually designed to service the berth itself and an area at the head of the berth, where workshop fabrication units are joined together into 'structural blocks' prior to erection (see figure 10). Luffing cranes of smaller capacity are still the most widely used, and hammer-head cranes are still found in older shipyards. Other changes in berth design include the increased use of covered berths and launching methods other than slipways. The sheltered working conditions resulting from the use of covered berths have been shown to improve worker satisfaction and increase productivity.[7] The size of ships constructed on covered berths has increased with facility size, although this has been enhanced by 'ship extrusion.' This consists of 'inching' a ship from a covered area into an open day dock or slipway from where it is launched in a conventional way; examples include Arrundell[8] and Cammel Laird[9]. Smaller ships can be completed on covered berths and in recently completed facilities at Sunderland Shipbuilders[10] and Austin and Pickersgill[11] a full ship plus an additional stern half are made together. On completion and launch of a ship the stern half is transferred to the full length berth by floating (Sunderland Shipbuilders) or by mechanical means (Austin and Pickersgill). Ships are launched using traditional greased slipways and by floating from a dry dock. The floatation method allows the ship to be built horizontally and submits the hull to lower launching stresses, although initial shipyard capital costs are considerably higher.

Berth facilities at various British shipyards are as follows:-

a) Swan Hunter (Wallsend)

Luffing cranes (2 x 180T) building on conventional open slipways. Vessel capacity 250,000T d.w.t.

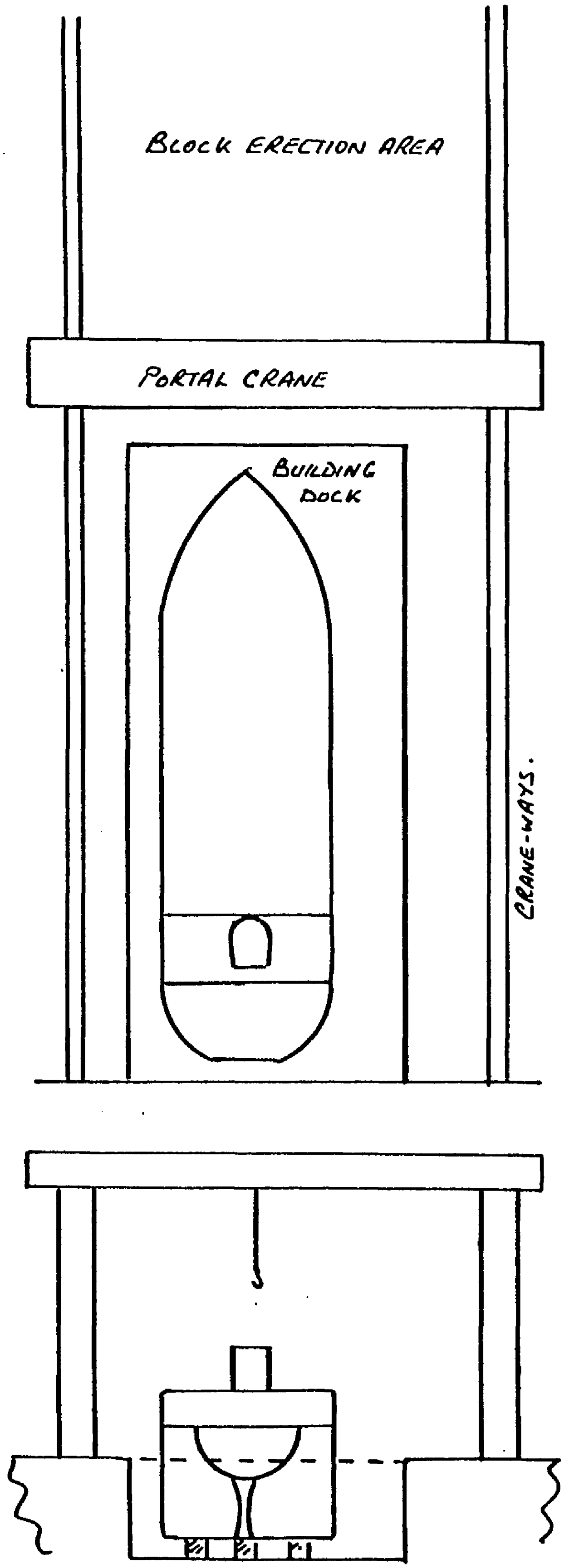


Figure 10 Typical modern berth layout with structural block fabrication area

b) Harland and Woolf (Belfast)

Goliath cranes (2 x 850T) over open dry dock. Vessel capacity 350,000T d.w.t.

c) Sunderland Shipbuilders (Pallion shipyard Sunderland)

Gantry cranes over covered dock to build one complete plus a half ship (transferred by floating)

Vessel capacity about 35,000T d.w.t.

d) Austin and Pickersgill (Sunderland, under construction)

Gantry cranes over slipways to build one complete plus a half ship (transferred mechanically. Vessel capacity 26,000T d.w.t.

e) Cammel Laird (Birkenhead, under construction)

Gantry cranes over workshops from which the ship is extruded onto a slipway, final launch from slipway. Vessel capacity 55,000T d.w.t.

f) Scott Lithgow (Greenock)

Goliath cranes over open conventional slipway. Ships launched in two halves where necessary and joined while floating using watertight collar around ship. Vessel capacity 250,000T d.w.t. plus.

Increased capital expenditure on berth facilities has resulted in the need to build ships faster. This has led to the use of specialised assembly areas and production lines for the manufacture of structure units and smaller assemblies which have features in common. Production times are improved by increased use of downhand welding and implementation of more mechanised repetitive tasks. Downhand welding allows higher rates of metal deposition than vertical or horizontal, which in turn are faster than overhead. Repetitive tasks require a smaller range of skills and reduce the learning curve involved for any manufacturing operation, they can also be mechanised. Attempts to introduce downhand welding and repetitive tasks have taken two forms, both of which require minor modifications to the detailed design of the ship hull. The first is the introduction of flat panel lines and curved panel jigs with one side automatic welding or turnover apparatus. The second is the introduction of specialised assembly lines for brackets, webs, floors, and girders which are designed to be stiffened from one side. Attempts to increase the use of downhand welding have also been made by introducing large rotating jigs which hold previously 'assembly-tacked' structure units and allow presentation of welds in the downhand position.

The use of large flat panel lines has been made possible by the general increase in size of ships and lengthening of parallel mid-bodies. They consist of production lines where plates are welded together, and stiffening section bars are positioned and welded in place (figure 11). Components are mechanically positioned and clamped, and electro-slag welding is generally employed although gravity feed fused arc methods are sometimes used to fix stiffeners. Panel line layouts depend on the control system employed (which can vary from manual component positioning to computer control), and on whether single or double sided welding is employed. Double sided welding requires an operation to turn the panel over but technically it is a simpler process and virtually guarantees full depth weld penetration. Comparative cost exercises have not proved conclusive and companies tend to choose two sided welding with facilities to turn the panel over. Two sided welding without a turnover has been developed [12] using a gas shielded process on the underside and traditional submerged arc on the top, but weld lengths of up to only 680 cm have been achieved and the method has not been adopted by shipbuilders.

Large stiffened flat panel production lines have been installed at the Kingston shipyard of Scott-Lithgow[13] and the Wallsend shipyard of Swan Hunter[14] with smaller installations at Sunderland Shipbuilders and Cammel Laird. Large installations are generally only justified when used to supply a number of shipbuilding berths. The Kingston panel line is used to supply the Scott-Lithgow shipbuilding complex in Greenock and the Wallsend line was planned to supply all of the Swan-Hunter Tyneside facilities. Both are fed directly by automated plate and section treatment lines incorporating shotblast, steam pre-heat (for better paint adhesion), paint and drying facilities. Following edge preparation (if required) the large steel plates are then fed to the panel line, automatically placed and electro-slag welded from one side. They are then turned over using either cranes (Swan Hunter) or a rotating jig (Scott Lithgow) and the second welding operation is carried out at the same work station as the previous one. The large flat unstiffened panel is then moved on conveyors to a second work station where stiffeners are introduced from a single feed as the panel is indexed through it. The stiffeners are then tack welded in position automatically and finish welded by manual or automatic methods at a further work station. In general flat panel lines use n.c. or computer controlled devices for the positioning of plates and stiffeners. Production lines for sub-assemblies are often arranged to feed extensions to the stiffened panel lines where the flat panels are built up into three dimensional modules. The modules, often pre-outfitted, are then transported to the berth where they are then erected onto the ship. In shipyards producing smaller vessels the cost advantages of large flat panel lines are greatly diminished by the comparative lack of parallel mid-body. Panel lines are technically less advanced, although similar flow line principles are adopted. In addition the use of lower technology in panel lines results in less specialisation and it is possible to mix flat panels with others having slight curvature.

Units forward and aft of the parallel midbody and having a larger degree of curvature are generally still constructed in separate work areas. They are manufactured complete from components by building a 'frame' and 'shelling' it out. Jigs consisting of adjustable vertical stems have been devised for the assembly of curved shell panels (figure 12). Pre-rolled steel plates are positioned on the jigs which are pre-set to the required curved shell shape. Pre-shaped stiffeners, floors, or girders are then tack welded in position before the stiffened panel is removed for finish welding. The jigs may be set using n.c. methods although technology at this level has yet to be applied in Britain.

The use of flow production line principles for the manufacture of smaller assemblies such as brackets, webs, flows, and girders, has been widely accepted for some time in Japan and Scandinavia, and is now becoming more common in British shipyards. The Kobe shipyard of I.H.I. Ltd.[15]

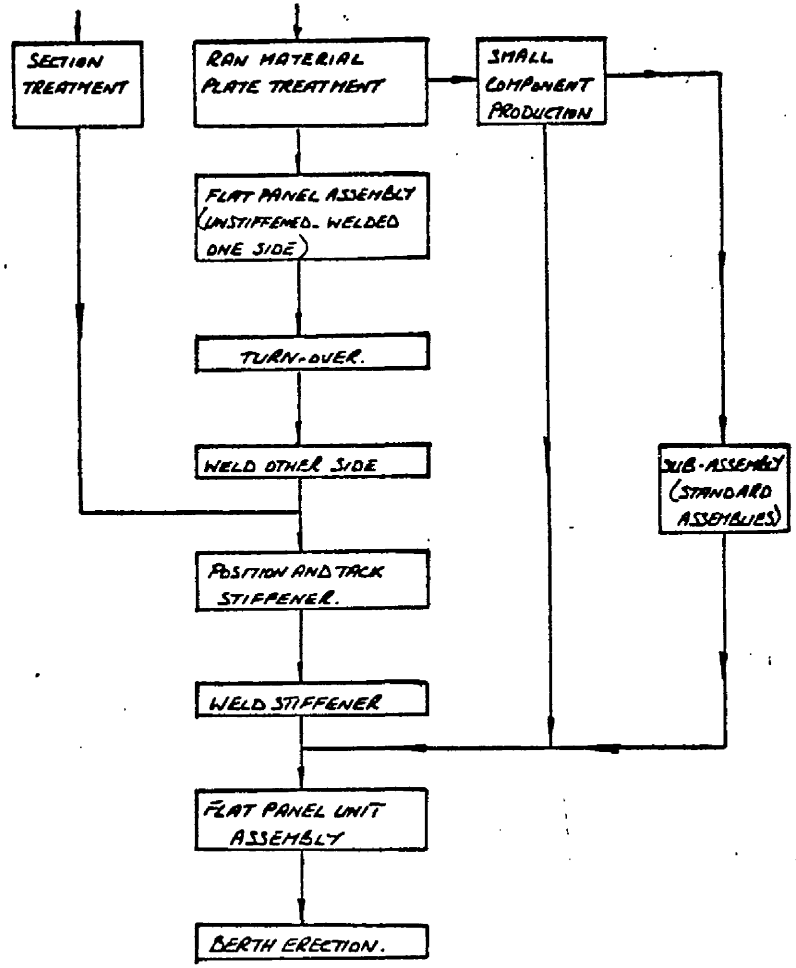


Figure 11   Typical production flowchart for the manufacture of large flat panel assemblies

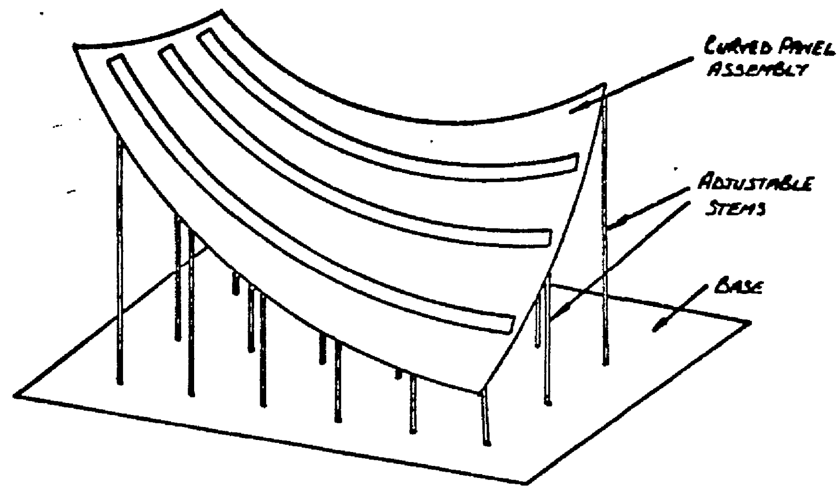


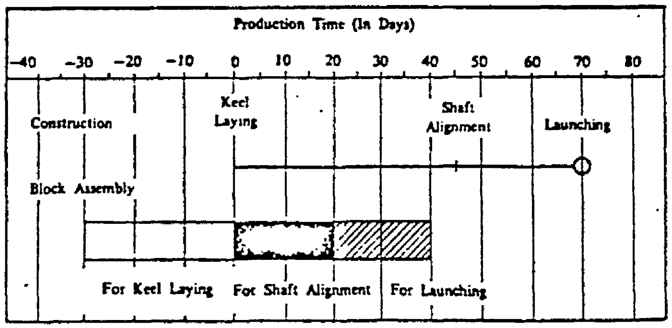
Figure 12   Curved panel assembly jig

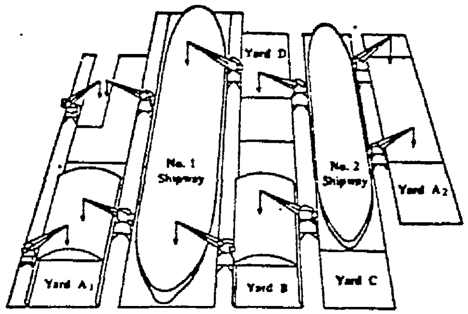
in Japan is organised using flow lines with pre-specified sequencies of assembly, an outline of the production system is shown in figure 13. It has been found that this particular shopfloor layout allows the use of computer production control systems, mechanisation, automation, and n.c. techniques. It has also been possible to install online computer systems on the assembly lines resulting in a more detailed feedback system and real-time data processing. The most recent British shipyard development at Austin and Pickersgill has minor assembly lines producing similar weldments which are then fed to work areas designed to construct specific structural unit types. Downhand welding is made possible by carefully defining the ship breakdown into structural blocks, fabrication units and minor assembly stages. The success of sub-assembly flow line installations depend on the division of a ship hull into assemblies which allow welding without a turnover operation.

Attempts have been made in U.S.S.R. to make this possible by using a classification system for assemblies and structures.(16) Consideration was given to similarity of production process standards, adjustment of equipment, and the size of shape of assemblies and structures; these determine the dimensions of workplaces and the nature of devices necessary for their production. It appears that attempts have been made to apply group technology principles throughout the hull construction process. However, the resulting organization appears to be very similar to that which has been evolved historically in other situations, this includes specialised workplaces and sub-assembly flow lines.

The provision of large rotating jigs to increase the use of downhand welding can only be financially justified where long production runs of vessels which are very similar in design and construction are expected. This was the case at the Mitsubishi Chiba works where the Rotas(17) system was employed for the construction of V.L.C.C. parallel mid-body blocks up to 600 tons. Fore and aft sections of the ship were produced by conventional methods at a separate location and joined to the midbody in a large dry dock after being floated into position. The shipyards using the Rotas system were geared to produce V.L.C.C.'s

Construction and Block Assembly Time





Assembly Yard and Block Distribution

Yard	Block Distribution
A_1	For No. 1 Shipway; 1) All of the bottom blocks of hold part, star-board side of Long. Bhd., Side Shell, and Upp. Deck 2) Upp. Deck and internal structures of Eng. Room
A_2	For No. 2 Shipway; As same as above mention, but port side against star-board
B	For Nos. 1 & 2 Shipway; 1) All of the Trans. Bhd. of hold part 2) Opposite side of Long. Bhd., Side Shell, and Upp. Deck
C	For Nos. 1 & 2 Shipway; Curved shell block of fore and aft
D	For Nos. 1 & 2 Shipway; Double bottom in Eng. Room, three-dimensional blocks of fore and aft

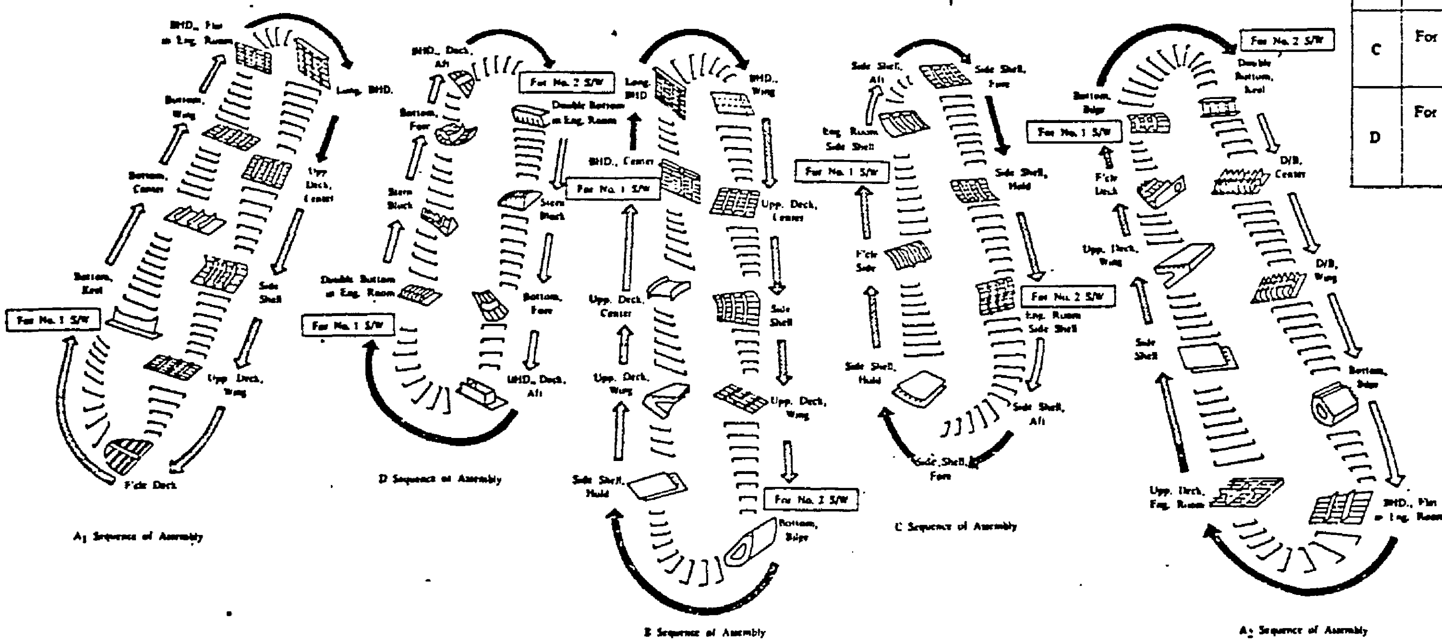


Figure 13 Flow line assembly system at the Kobe shipyard of I.H.I. (Japan)

rapidly using the large assembly jigs and flowline methods made possible by the large flat panels and long production runs of similar components and assemblies. The inflexibility of such a system became apparent later, with the collapse of the V.L.C.C. market, resulting in the under utilisation of expensive capital equipment.

Chapter 4 Current management practice

4.1 Fundamental concepts

Planning and control are of fundamental importance to good shipyard management. Planning must be based on realistic time and cost estimates. It is practiced at three levels; contract planning, operation scheduling, and process planning. Control involves the measurement of time and cost expenditure relative to plan. Accurate cost estimating and control is needed in any industry but in shipbuilding it is particularly important to plan and control production to meet a delivery date. Failure to ensure this will result in loss of faith in the shipbuilder, and will incur price penalties on many contracts.

4.2 Contract planning

Contract planning begins at the tender stage and is concerned with long term berth, machinery and manpower utilisation. For a particular contract it involves estimating labour requirements and steel weight. These are compared with yard capacities of manpower and steel throughout to calculate the time required on the berth and the ship cost. The results are then fitted to the existing contract plans to find the probable delivery date. If the tender is accepted the original estimates are refined and the contract plan finalised. For estimating purposes ship cost is usually divided into steel material costs, outfit material costs, main machinery costs, and labour costs and overheads. A typical distribution is 10%, 30%, 25%, and 35% of total ship cost respectively.[18] Steel cost is found from steel weight, which in turn is estimated from ship scantlings or from similar previously built ships. Labour costs are estimated from historical data of manhours needed to build previous ships. They are categorised into as many as sixteen ship trades which fall into general categories of steel trades and outfit trades. Steel trade labour estimates are again based on steel weights. In many cases the ship is divided into structures of differing complexity and a factor is applied to the steel weight of each to obtain a manhour measure. Outfit material estimates are obtained by identifying and costing each item. They are fairly accurate and most errors result from factors outside the control of the shipbuilder (e.g. inflation).

4.3 Operation scheduling

Shipbuilding follows civil engineering in that a contract might be tendered for and accepted before a detailed plan has been devised. Thus operations are often back-scheduled from a previously agreed delivery date. Network planning techniques are employed to compile a master berth programme from a fabrication erection sequence, estimated weights of fabrication units, and steel throughput capacities. Weekly fabrication programmes are then prepared and are issued together with forward programmes for information purposes. Outfit plans are derived from the fabrication plan. Traditionally outfitting follows steelwork in the schedule, although pre-outfitting of steelwork before berth erection is now common and they are more closely related. Computer packages are widely used to derive network plans from precedence or sequence input, and then provide near optimum schedules for various machines, trades, departments, etc.

Fabrication unit weight estimates and steel throughput capacities are based on analytical calculations and historical information respectively. Historical information mainly consists of work measurement data and is used to forecast work content values. Shopfloor work measurement has generally been confined to welding and fabrication areas and rarely to material preparation and component production. However since component production areas are closely related to assembly areas for work loading and production control their performance is often complementary. Steel throughput is the measure of work used most frequently, it provides a useful indicator of all aspects of component, assembly, and hull production. However, different sections of any ship are of differing structural complexity, hence a tonne of steel in say a double bottom may require fewer production manhours than a tonne of steel in a fore end. In addition some areas of ship are constructed of thinner steel than others, this again leads to disproportionate work contents. Most shipyards overcome this problem by dividing the ship into regional cost centres (or structure groups - fore end, aft end, double bottom) all of which have a discrete work content value per tonne of steel. These cost centres are also employed for steel ordering, batching, loading, and production control purposes. This method of work content measurement is particularly applicable to series ship production (e.g. Austin and Pickersgill, Cammel Laird) where a depth of historical data is available. However, with varying ship types the work content per tonne of steel is more difficult to determine for each structure group. The cost centre breakdown method also provides the basis for calculations of weights of structure blocks and the total ship by empirical rules.

Attempts have been made to introduce more accurate methods of measuring and estimating work content, these include calculation of weld length and weld metal deposited, and synthetics from time study. Weld length automatically caters to some extent for the differing complexity of units. The weld or joint lengths of an assembly are scaled from drawings and used as a direct measure of the work content involved in manufacture. This results in an accurate assessment of the work content of the assembly operations to produce a unit but only an indication of the work content to produce the component parts. A further disadvantage is the time and effort involved in physically measuring weld length. Weld metal deposited is also a good measure of the work content of assembly operations. It entails monitoring the release of welding rod and material from stores, either on a time basis (i.e. relating welding material release to work in production) or on a cost basis (i.e. logging weld material to the ship cost centre used on). It suffers the same weaknesses as weld length measurement when applied to component production but does have the advantage that effort involved in data collection is vastly reduced. However, if used jointly as a work content and incentive scheme it encourages the workforce to waste weld material and thus apparently 'increase' the work content of the assembly unit. Attempts to generate tables of synthetic data based on time study of shipyard operations include exercises at Doxford and Sunderland (now Sunderland Shipbuilders) and Swan Hunter.[19] These were concerned almost entirely with welding operations, and intended as replacements for existing incentive schemes where the incentive element had largely disappeared. They were hindered by the reluctance of the workforce to be time studied, stemming from a long history of poor industrial relations in the industry.

Although many methods of work measurement and estimating have been applied or attempted results have been poor. Most of the methods are based on an approximate measurement unit, and practically all apply to welding assembly operations only. In addition the workforce's deep seated suspicion of time study and the difficulty of applying it in a high variety industry makes the development of a work content estimating system using other indices highly justifiable.

4.4 Process planning

Process planning is the preparation of information required to produce an item or group of items. It is carried out prior to scheduling, loading, and subsequent manufacture of the item and as such must result in a fully comprehensive description of:-

a) the raw material required
b) the finished item
c) the method of manufacture of the item
d) the time required to produce the item
e) the necessary identification marks to prevent loss of the item

The degree of process planning practiced in British shipbuilding at present varies considerably from shipyard to shipyard. The factors influencing the type and complexity of the process planning system a yard uses are also many. The system selected depends upon:-

a) The type, variety, and size of ship produced.

Many shipyards concentrate on a specific type of vessel (Harland and Woolf - Oil tankers) others will tender for and produce any ship a potential customer may require (Robb Caledon). A third type specialises entirely on one product, for example Austin and Pickersgill with the SD14 cargo vessel. Thus the planning system to produce a wide range and variety of ship must be fairly flexible while that to produce one specific model can be rigid and practically self running.

b) The production rate

The productivity measure for a particular ship will not only be a factor of the steel weight, but also the value of the ship which will be related to its complexity. The production rate of ships is determined by the size and type of the ship, the facilities of the yard, and the repetition of the ship (number to be produced). This in turn directly affects the type of process planning system required in the shipyard.

c) The communication system

The communication system within a yard is directly influenced by the size and physical layout of the site; the larger or more complex the site the more formal the communication system required to manage it. The informal communication system in smaller yards often leads to better working relationships between departments and supervisory management. Therefore in smaller shipyards blocks of work may be released onto the shop floor and 'progress chased', in this case the departments will be small and the work in progress manageable. In larger yards, however, the loading of work onto the shopfloor must be more rigidly organised or the amount of work in progress will increase, work will be lost, and control will generally deteriorate.

d) The level of technology

The level of technology is not always directly influenced by the size of a shipyard, although generally only larger yards have the necessary steel throughput to justify the large capital investment required for higher technology. Production facilities range from those which are highly flexible and manpower orientated to those which are fairly rigid, and machine orientated. The planning function for manpower orientated systems is less important than that for systems with a capital equipment bias where a good return on the invested capital must be achieved.

e) The labour force

The level of skill in the workforce influences the degree of process planning necessary; the more skilled the work force the lower the degree of planning required. Most shipyards have a long history with a corresponding depth of inherent skill, but with the recent shortage of building berths new 'total ship factories' have been built which employ mainly semi-skilled and newly trained labour. The planning systems both for these new shipyards will therefore need to be more detailed and explicit than those currently in use. The age and history of the yard therefore also influences the process planning system which is in operation.

Shopfloor distribution of process route cards and workbills for components has generally been neglected in shipbuilding. The process route of a particular component depends on its design features and the manufacturing facilities available. Possible process routes for plate components are shown in figure 14, but the most frequent order of operations is:-

1	Marshalling
2	Painting
3	Marking out
4	Outline cutting
5	Edge preparing
6	Forming
7	Drilling

Operations 3 and 5 are optional and facility dependant, and 5, 6 and 7 are optional and component dependant. Possible routes for section components are shown in figure 15; but the most frequently found are guillotine then roll bend (optional-components dependant) for their flat bars uses as face flats, and flame cut then cold frame bend (optional-component dependant) for other bar cross-sections used as panel stiffeners.

From examples of job cards used at the Southdock shipyard of Austin and Pickersgill (figure 16) it can be seen that route codes are specified very briefly; the codes are:-

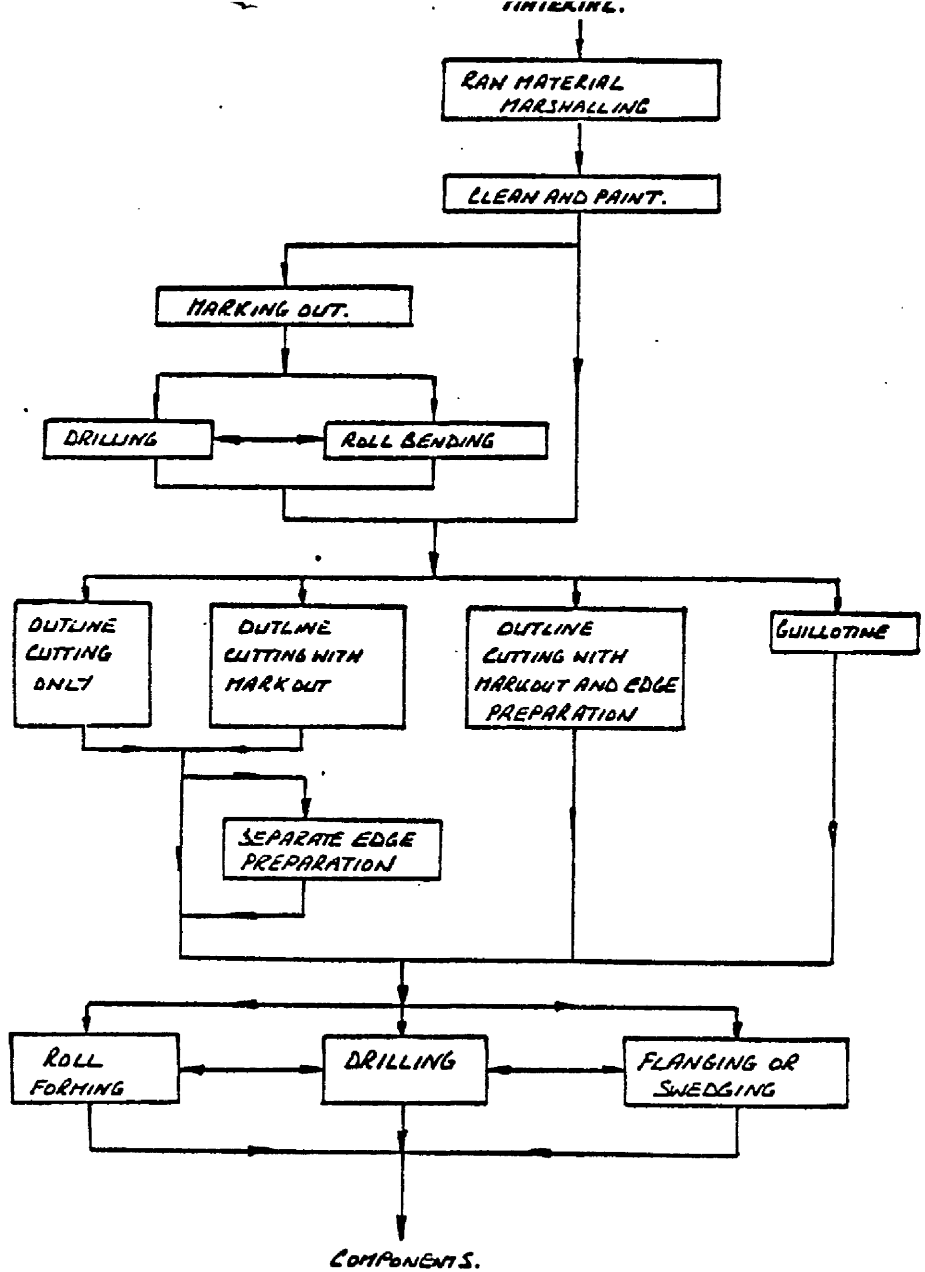


Figure 14 Flowchart for component production from steel plate material

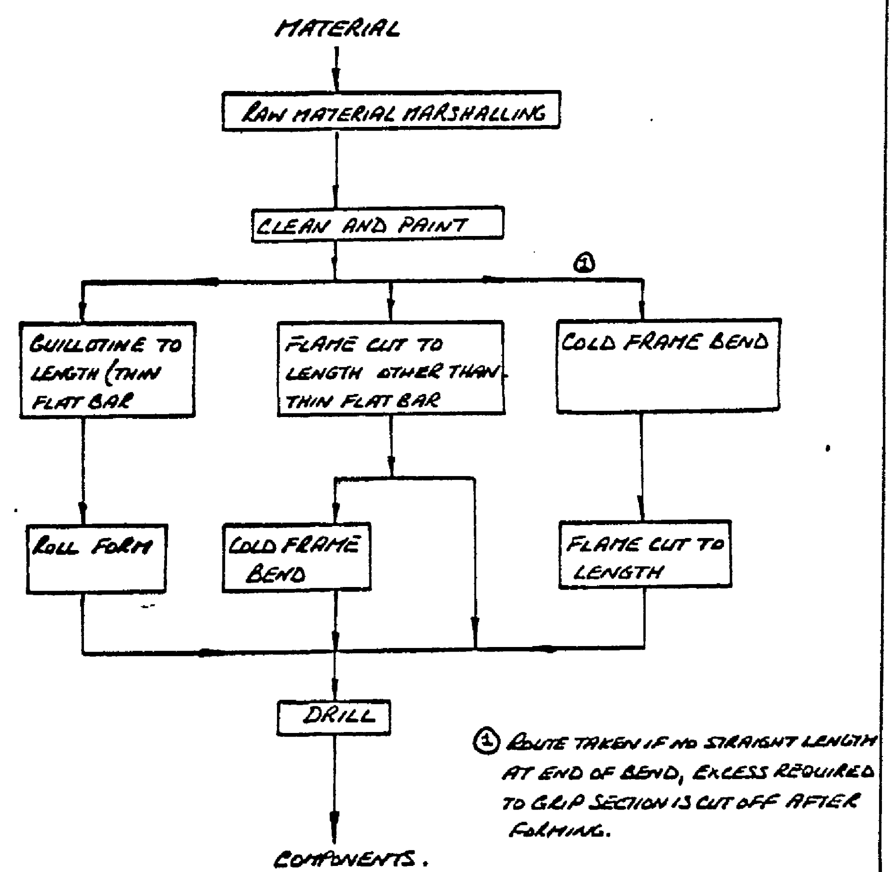
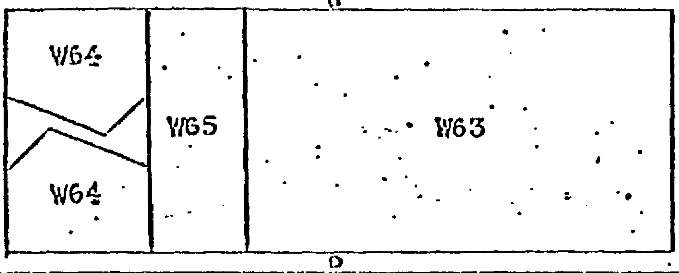


Figure 15 Flowchart for component production from section bar material

~~[illegible] MASTER.~~ ~~RECORD CARD.~~ JOB CARD.

PLATE Nº	Nº OFF.	L.	B.	T.	TYPE.	SHIP Nº	DRG. Nº
FE1. 40.	2	5840 19-2"	1385 5 4½"	7'50 '30"	MS	439	499



TAPE Nº	SLIDE Nº	[illegible] Nº
	104	W / FE

UNIT Nº 148

DATE. STARTED.	DATE. COMPLETED.

FT. MARK.	FT. BURN.	FT. TRAVEL.

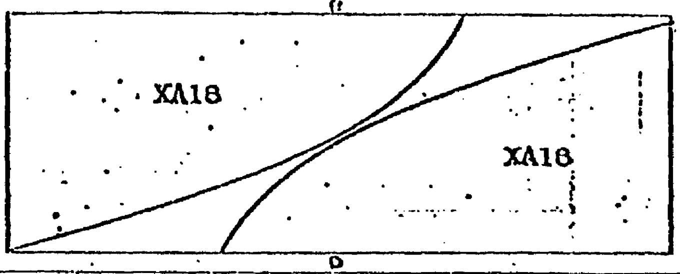
PL. LOCATION.	PART. LOCATION.

ROUTE CODE	OPERATION. INSTRUCTIONS.	NOTES.	PROC. TIME	DEL. TO
MG&SB				
W				
P				
N	W63. ONLY.			

	PART Nº	PART DESCRIPTION	P	N	S	ARCA	DEL	V	DEL	T	DEL	L	DEL	R	DEL
148.	W63	2-6-5-0.OFF.C/L(2ND-UPP.DK) FEF.VENT.TRUNK.168-169.FRS.	1		1					/					
148.	W64	2-6&5-0.OFF.C/L(2ND-UPP.DK) FEF.VT.SIDE.PL.168-169.FRS.	2		2										
148.	W65	2-6-5-0.OFF.C/L(2ND-UPP.DK) FEF.VT.FRONT.PL.168-169.FRS	1		1										

~~SHEET MASTER.~~ ~~RECORD CARD.~~ JOB CARD.

PLATE Nº	Nº OFF.	L.	B.	T.	TYPE.	SHIP Nº	DRG. Nº
FE1. 2.	1	2950 9-8"	1015 40"	19'50 '76"	MS	439	476



TAPE Nº	SLIDE Nº	CATCH Nº
	101	W / FE1

UNIT Nº 147.

DATE. STARTED.	DATE. COMPLETED.

FT. MARK.	FT. BURN.	FT. TRAVEL.

PL. LOCATION.	PART. LOCATION.

ROUTE CODE	OPERATION. INSTRUCTIONS.	NOTES.	PROC. TIME	DEL. TO
MG&SB				
W				
P				
R				

	PART Nº	PART. DESCRIPTION.	P	N.	S	ARCA	DEL	V	DEL	T	DEL	L	DEL	R	DEL
147.	XA18	SHELL.A18. 173½-STEM.	1		1									/	

Figure 16 Sample shipyard component production job-card. (Austin and Pickersgill)

MB and SB	.....	mangle and shotblast
W	.....	optical mark out (projection tower)
P	.....	flame plane
R	.....	roll bend
N	.....	knuckle

No indication of expected operation or set-up times are given and even edge preparation is omitted (components XA18 in the examples have chamfered edges). The information on the job card comprises of the raw material and size, the optical slide number, the component numbers, and the number required. It is copied from a master file (figure 17) which is kept and used at the Southwick shipyard of the same company. At Southdock work is loaded to the shopfloor by fabrication units, but at Southwick more space is available and work is loaded by structure groups comprising of several such units. Here multihead flame cutting equipment can be better utilised and longer 'production runs' are possible, this is highlighted by the increased numbers of components required on the master file (figure 17) to cover several units. The production of a standard ship enables Austin and Pickersgill to have a fairly detailed material and component listing system. Swan Hunter are in a similar situation with a series of 130,000 ton tankers which they are producing at their Walker and Hebburn shipyards. Item lists of steelwork to manufacture these vessels are being filed in computer store and component information lists (figure 18) can be generated quickly and easily.

Component production information supplied to the shopfloor is on the whole very limited, and many production decisions are made by shopfloor supervision. This is particularly so in the case of individual machine loading, which is done with little knowledge of job duration times. This can lead to increased work in progress and loss of control.

4.5 Production control

Production control entails receiving information on work completed, comparing this with a schedule, and taking corrective action to bring work back on schedule. Data is recorded using a variety of methods including graphs and bar

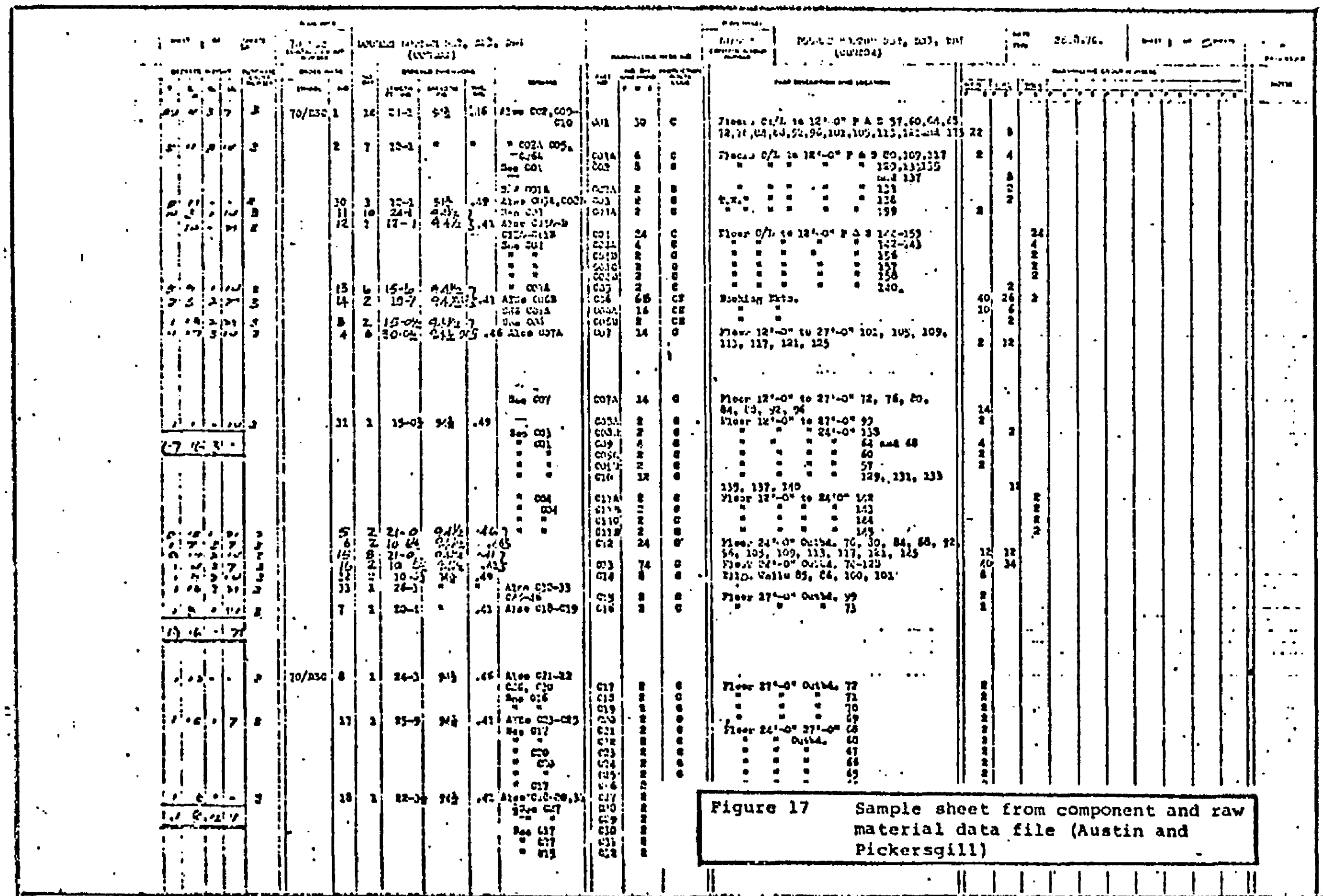


Figure 17 Sample sheet from component and raw material data file (Austin and Pickersgill)

PEPCRT NO. 51101

SHIP	PLAN	SHT
47	5 0 5	1

ITEM LIST

BOTTOM SHELL UNITS P&S

UNITS COVERED. D 8

ISSUE	DATE
1	18/07/74
1	18/07/74

PAGE NO. 1

CO.	DEPT
12	401

ITEM NO.	QTY	PLAN ITEM NO.	PART NO.	COMMENTS	LENGTH MM.	WEB HT/ PLT WIDTH MM.	WB/PL THICK MM.	FL. WTH MM.	FL. THK MM.	TYPE	MAT. GRAD	MODIFICATIONS LAST	NEW	CO./ DEPT
1	2		D 8 648 011		8425	200	12.0				01			
2	6		D 8 648 001		8425	200	12.0				01			
3	2		D 8 415 001		15010	2670	12.0				01			
4	2		D 8 663 001		15025	250	20.0				01			
5	2		D 8 646 005		8425	200	12.0				C1			
6	12		C 8 111 004		11380	2700	12.0				01			
7	4		D 8 613 001		15025	450	12.5				01			
8	2		D 8 641 001		15025	250	20.0	120	27.0		07			
9	2		C 8 408 001		15010	2875	16.5				07			
10	6		C 8 655 001		8400	100	12.6				07			
											01			
11	6		D 8 116 001		9300	1200	11.5							
12	6		C 8 111 006		11380	2700	12.0				01			
13	2		C 8 607 001		15025	450	12.5				01			
14	2		D 8 648 010		8425	200	12.0	120	30.0		07			
15	6		D 8 648 001		8425	200	12.0				01			
16	2		C 8 663 001		15025	250	20.0				01			
17	2		D 8 415 003		15010	2690	12.0				01			
18	2		D 8 111 007		11380	2700	12.0				01			
19	2		C 8 648 003		8425	200	12.0				01			
20	54		C 8 111 002		11380	2700	12.0				01			
											01			
21	54		C 8 111 002		11380	2700	12.0							
22	18		D 8 W02 004		15025	180	20.0				01			
23	2		C 8 402 002		7520	2245	21.0	550	12.0		07			
24	2		D 8 402 001		7520	2245	21.0				07			
25	2		C 8 401 002		7520	1925	21.0				07			
26	2		C 8 401 001		7520	1925	21.0				15			
27	2		C 8 P02 001		15010	2990	21.0				15			
28	2		C 8 P02 002		15010	2990	21.0				07			
29	2		C 8 P02 005		15010	2990	21.0				07			
30	12		C 8 654 002	NOT ORDERED							07			
31	12		C 8 115 001		8780	1950	11.5							
32	12		C 8 654 005	NOT ORDERED							01			
33	18		C 8 111 003		11380	2700	12.0							
34	6		D 8 653 003		9950	220	15.0				01			
35	6		C 8 649 001		8675	250	15.0				01			
36	6		D 8 650 001		10475	240	12.0				01			
37	6		C 8 651 001		9150	230	12.0				01			
38	6		C 8 111 001		11380	2700	12.0				01			
39	6		C 8 652 002	NOT ORDERED							01			
40	6		C 8 652 001	NOT ORDERED										

SHIP	PLAN	SHT
47	5 0 5	1

Figure 18 Sample component information list from computer data bank (Swan Hunter Shipbuilders)

PAGE NO. 1

charts and is compared with planning data to calculate the amount of 'slip' on the contract. Rough guides to progress are available weekly and more accurate reports are prepared each month. However much of the data collected is related to input effort rather than results achieved. Thus information on steelwork may be measured in manhours or steel weight rather than performance to plan. The indices employed are often unreliable and likely delays in key dates may not be recognised until late in the building cycle, resulting in late and possibly misjudged resource allocation decisions. It was found in a survey[20] that 'Progress is generally measured informally, on the basis of work done rather than work to be completed, and it is measured in units related to processes, e.g. tonnage, joint length, number of pipes, rather than planned activities. For accurate control during the building programme a more detailed system of estimating related to the method of building is required. This can then be used with records for each ship section to apply standard volume and cost analysis techniques.

4.6 Production information

There has traditionally been a lack of conventional production information presented to shipyard workers when compared to general manufacturing industries. This was a result of the labour intensity and inherent skill in the industry. Automated capital equipment needs more detailed production planning to achieve high utilization and an adequate return on investment. In addition the skills of the mould loft and shopfloor workers allowed them to translate design information into complete structures. Output from the mould loft consisted almost entirely of data which either described components or was used for checking them. Methods of manufacture were usually defined by shopfloor supervision. Assembly information traditionally consisted of drawings of structural surfaces or planes on which the divisions into fabrication units for berth erection and component parts were marked. Thus the planar parts of a specific block-type fabrication unit might occur on several drawings. Accurate part-list compilation and breakdown of fabrication units into sub-assemblies was neglected.

The introduction of more sophisticated and capital intensive production techniques, particularly in flame cutting, has resulted in an increase in process planning and production information made available. This has been manifested in advances in nesting technology, tenth scale drawing, and N.C. tape generation. However the practice of issuing job cards has not yet been fully introduced, and operations other than flame cutting are still often defined and carried out using assembly drawings. The use of assembly flow systems has resulted in the definition of detailed sub-assembly breakdowns of ship hulls, particularly in shipyards which have been modernised (Harland and Woolf, Cammel Laird).

The quantity of production information in a company is proportional to the degree of process planning which takes place. This in turn depends on factors which are inherent in that company such as the type and size of ship produced, the production rate, the management system and communications used, the labour force employed, and the level of technology available. The collaborating shipyards varied widely in these aspects, and thus the amount of process planning and production information available differed between the yards.

Component information required to manufacture the hull of a ship can be divided into that which identifies and that which describes.

Component identification is concerned with the raw material source of a component, and where it is assembled into the hull. The use of a meaningful numbering system is of particular importance in specifying the raw material, the component, and the structural block, unit, or sub-assembly into which the component is assembled. Examples of numbering systems are shown in figure 19. The Austin and Pickersgill system indicates the structure group of the component for material ordering and network planning procedures. However this is subdivided into fabrication units for assembly, so while ideal for long component production runs the system is weak when applied to assembly. The absence of a raw material number also generates the need for a separate raw material data file with a cross reference system as shown in figure 17.

Austin and Pickersgill — 70 FE1 W63

- 70 — Ship number, necessary when components for more than one ship are in production simultaneously. (This is the usual case)
- FE1 — Structure block number (F.E. - Fore End)
- W63 — Piecepart number (W specifies the first production operation, this is piecepart description, see later).

Swan Hunter — 67 D8 P02 005

- 67 — Ship number
- D8 — Structure unit number (D-Bottom Shell)
- P02 — Raw material number (P-plate to be used on panel line, this is piecepart description)
- 005 — Piecepart number (5th part produced from raw material numbered P02)

Cammel Laird — A112 3005 09P

- A112 — Ship number
- A112 — Structure unit number (A - Engine Room, 11 - block number, 2 - unit number within block.
- 3005 — Raw material number (3 - profile cut plate, this is piecepart description)
- 09P — Piecepart number (9th part produced from raw material numbered 3005, the P indicates Port side

Figure 19 Examples of numbering systems used at Austin and Pickersgill, Swan Hunter, and Cammel Laird.

Breakdown by control groups — 23 1 20 306

- 23 — Ship number
- 1 — Zone number (Midships)
- 20 — Structure group number (within zone)
- 306 — Plate part number (306)
  A single digit would indicate a control group (i.e. 2 is control group within structure group 120)
  Two digits would indicate an assembly (i.e. 12 is an assembly within structure group 120)

Breakdown by part and assembly — 23 1 A 1001

- 23 — Shipnumber
- 1 — Zone number
- A — Structure group
- 1001 — Component number (1 = plate, 001 = serial number)

Assemblies are also indicated i.e. 5 3 03

- 5 — type of assembly (web or girder)
- 3 — Sub-Assembly
- 03 — Serial number

Figure 20 Numbering systems developed by The British Ship Research Association

The British Ship Research Association (B.S.R.A.) has devised a component numbering system which they hope will become widely accepted in the industry. The system consists of a higher level containing the ship number, zone number, and structure group number (within zone), and a lower level which has two alternative formats. The first indicates control groups and is intended for use in yards which build vessels having a small number of similar components and assemblies (i.e. cargo liners). The second indicates assemblies and is for tanker and bulk carrier builders. The numbering system has been fully documented and a technical memorandum[21] circulated to all member companies, examples of the use of the coding system are shown in figure 20. Although the numbering systems of Scott Lithgow and Harland and Woolf are based on that of B.S.R.A. the cost and inconvenience of changing a system make further applications unlikely. The advantages of the B.S.R.A. numbering system alone will not justify the changeover cost, but if offered as part of a package covering all aspects of shipyard management (data retrieval, design, material planning, production planning and control, etc.) it may become more acceptable.

Various sections of identification numbers are not required at all stages of manufacture; for example the raw material number is only needed until components are cut, component numbers are then substituted. In many companies (Swan Hunter, Cammel Laird) the raw material number forms part of the component number. Although this erases the need for cross referencing it tends to lengthen the number, thus increasing component marking time, making it difficult to mark small components, and increasing the likelihood of errors. Many shipyards also mark components with a brief verbal description, particularly in the case of frames, transverses, shell plates, and deck plates. For example frame section parts may be marked with the frame number (F.M. 67) or shell plates with the approximate frame location and strake number (SHL.PL. B.STR. 67-71) The frame number indicates the position of the component from the stern post (rudder), and the strake number indicates the lateral position of a shell plate from the keel. In one small shipyard visited assembly workshops rely almost entirely on written verbal descriptions with only the structure unit number to enable parts to be marshalled prior to assembly.

The fullest description of a component or assembly is a detailed explanation of the shape, size, metallurgical characteristics, and surface finish. From these the method of manufacture is defined to complete the information necessary to produce it. The design (or Naval Architecture) drawing office produce the overall design, hull shape (as lines plans), and steelwork scantling drawings. These are detailed into fabrication unit assembly drawings for shopfloor use by the steelwork drawing office. The steelwork drawing office is also responsible for generating raw material data to manufacture components, this involves 'nesting' components into conveniently sized plates or sections (figure 21) and listing the generated raw material (figure 22). The overall shape and structure of the ship is translated into a data form suitable for component production by the 'mould loft' However with the development of new data presentation formats the mould loft has tended to become combined with the steelwork drawing office. The methods of presenting information to the shopfloor are as follows:-

a) Full Scale Lofting

Cross-sections of the ship are drawn full scale on an area of floor allowing co-ordinates to be 'lifted' or full scale card or plywood patterns made. This is the traditional way of supplying production information but it requires a large area of floorspace for the full scale drawing (or 'screeve' board) and the patterns are cumbersome, wasteful, and difficult to store for series ships. Adjustable templates are available but they may only be used in certain circumstances and are more cumbersome than conventional patterns. Full scale lofting is still used in smaller shipyards (Ailsa - Troon) but very infrequently.

b) Tenth scale lofting

One-tenth scale drawings are prepared from lines plans

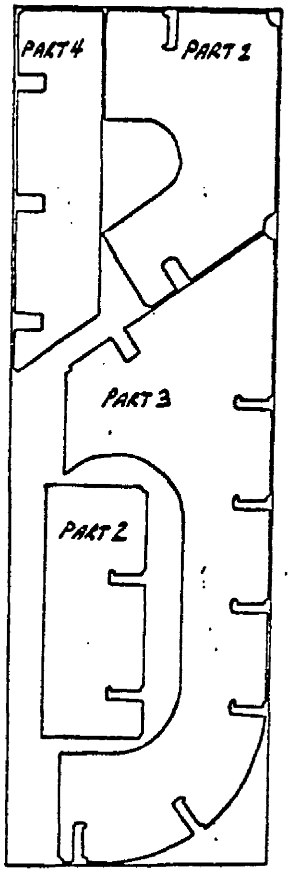
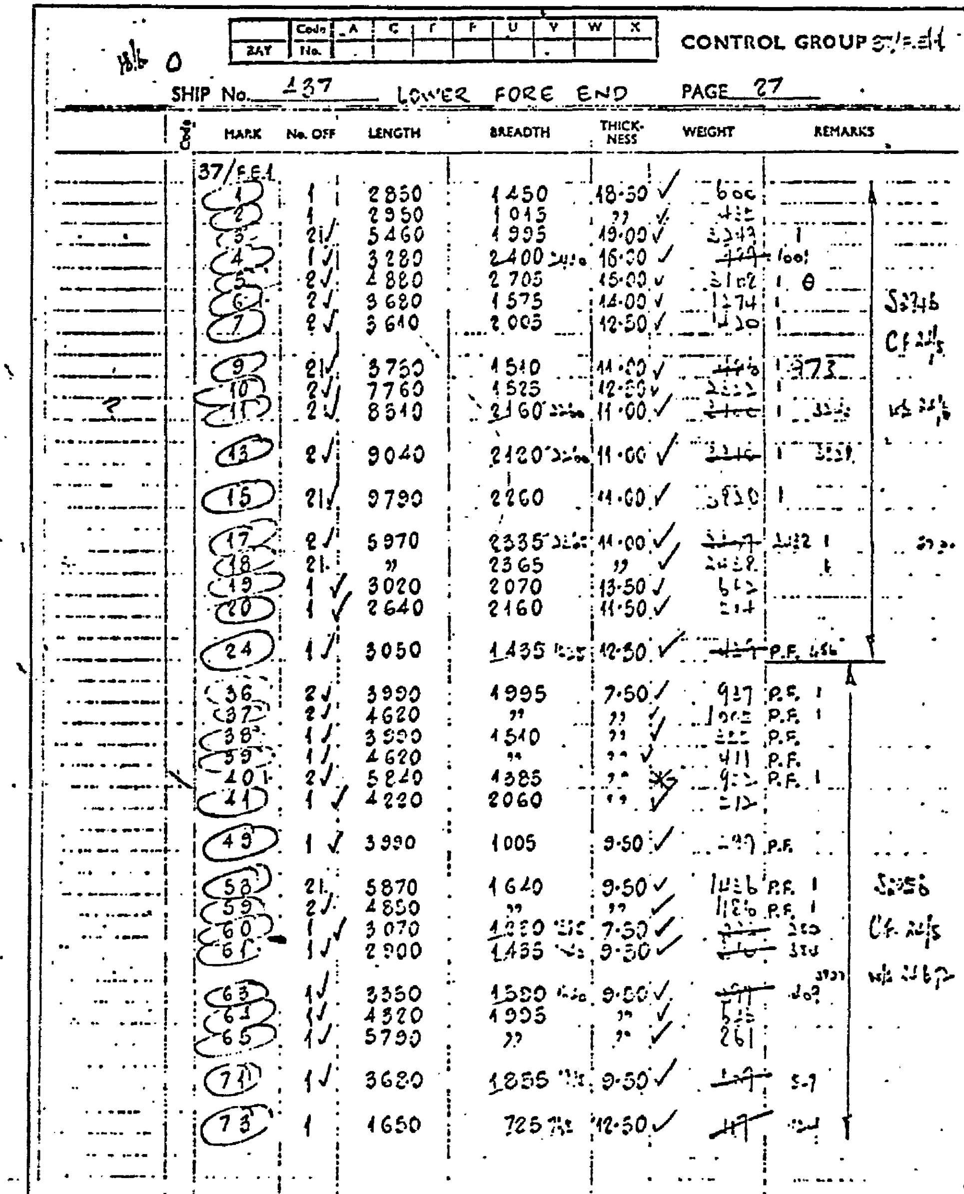


Figure 21 Example of plate component nesting



CONTROL GROUP

SHIP No. 137 LOWER FORE END PAGE 27

MARK	No. OFF	LENGTH	BREADTH	THICKNESS	WEIGHT	REMARKS
37/F.E.1						
1	1	2850	1450	18·50	600	
2	1	2950	1015	"	[illegible]	
3	2	5460	1995	19·00	[illegible]	
4	1	3280	2400	16·00	[illegible]	
5	2	4880	2705	15·00	[illegible]	
6	2	3680	1575	14·00	1274	
7	2	3640	2005	12·50	[illegible]	
9	2	3750	1510	11·00	[illegible]	
10	2	7760	1525	12·50	[illegible]	
11	2	8540	2160	11·00	[illegible]	
13	2	9040	2120	11·00	[illegible]	
15	2	9790	2260	11·00	[illegible]	
17	2	5970	2335	11·00	[illegible]	
18	2	"	2365	"	[illegible]	
19	1	3020	2070	13·50	[illegible]	
20	1	2640	2160	11·50	[illegible]	
24	1	3050	1435	12·50	[illegible]	P.F.
36	2	3990	4995	7·50	[illegible]	P.F.
37	2	4620	"	"	[illegible]	P.F.
38	1	3990	1540	"	[illegible]	P.F.
39	1	4620	"	"	411	P.F.
40	2	5240	4385	"	[illegible]	P.F.
41	1	4220	2060	"	[illegible]	
49	1	3990	1005	9·50	[illegible]	P.F.
58	2	5870	1640	9·50	[illegible]	P.F.
59	2	4850	"	"	[illegible]	P.F.
60	1	3070	[illegible]	7·50	[illegible]	
61	1	2900	1435	9·50	[illegible]	
63	1	3350	[illegible]	9·50	[illegible]	
64	1	4320	1995	"	[illegible]	
65	1	5790	"	"	261	
71	1	3620	1855	9·50	[illegible]	
73	1	1650	725	12·50	[illegible]	

LENGTHS WIDTHS

θ ~ coi
P.F. ~ pi

Figure 22 Sample shipyard raw material list (Used for ordering and checking purposes).

and scantling drawings, and are used with tenth-scale marking and cutting machinery. Optical marking involves projecting scale slides onto raw material plate and tracing the outlines. It is mainly used for straight edged components with no cut-outs which may be easily flame planned with low cost plant. Tenth scale cutters use optical followers to trace the drawings and one or more flame cutting heads to cut components. It is used for more intricate shapes (curved edges and cutouts) but still requires constant supervision to shut off, reposition, and re-ignite cutting heads for new components or cutouts. The advantages of these methods in data storage for series ship production is fairly obvious.

c) Numerical control (N.C.) lofting

This is now used extensively for the production of plate components, either by using punched paper or magnetic tape. Tapes may be prepared manually from lines and scantling drawings or automatically from a data bank held in computer store. It is more accurate than tenth scale lofting and allows subroutines to be used for standard lightening holes and notches.

Obviously very simple parts do not require this degree of description, for example short sectional stiffeners may be verbally described to the fullest detail (flat bar, 12.5 mmx 250 mmx 3000 mm, square ends). Other guillotined plate parts, brackets and small straight sided components, may only require a sketch or drawing. In addition components which have been N.C. or tenth scale lofted will probably not need an additional drawing.

Assembly stage drawings, other than for unit or block assemblies, are at an early stage of development as sub-assembly production lines similar to those used in general engineering have been little used in shipbuilding. Harland and Woolf have developed a fairly extensive system of sub-assembly drawings and lists for the midship sections of their very large crude oil carriers (V.L.C.C.'s) and other shipbuilding companies, particularly those building new 'ship factories' are further developing the use of assembly production lines.

Chapter 5 Computer data banks

5.1 Data handling and storage in shipyards

Data handling problems encountered in the management of ship manufacture are likely to increase in future with attempts to increase steel workshop production rates and thus decrease berth cycle times. In one case (Chapter 8.2) it is intended to reduce the berth cycle time of a 14000T cargo vessel, consisting of about 13000 different components, from twenty weeks to six. Many shipyards attempting to increase berth utilization are constrained by the physical area available for component production and unit assembly. Thus the total output from steel workshops must be increased while keeping the work in progress at about its present level to allow control of the total manufacturing process to be maintained. This implies a decrease in the amount of time-float allowed for individual operations and an increase in the quality of production planning and control. The data banks and feedback information procedure required to maintain these systems will correspondingly be more complex and difficult to generate and update.

Information systems will also need to be more elaborate for the proposed change from structure-unit to structure-group component work packaging (where a structure-group will contain several fabrication units). This will result in the further use of more complex production planning and control procedures to enable the components to be marshalled prior to assembly. A further complication will be the introduction of a complex mix of ship standard parts, structure zone standard parts, and 'special' components. The introduction of tree-structure assembly techniques will also result in complications caused by the greater intensity of production planning required.

The problems of data handling may be lessened by using a central computer held information bank to store and update production data, and manipulate it into forms suitable for presentation to the shop floor. Information in the data bank may be related to, or defined from a Computer Aided Design (C.A.D.) file, as is proposed in the HICASS and FORAN systems described in section 5 of this chapter. Alternatively the information included may be defined from existing design and production data

Two types of data format may be considered:-

- A product breakdown method, listing stages of assembly and all of the components and sub-assemblies which need to be fed into each stage.
- A 'where used' file which lists lower level manufactured items (components, sub-assemblies) and the higher levels into which they are assembled.

and Information to be stored in any data bank will comprise of that which:-

- adequately identifies the component or assembly to allow it to be produced and marshalled to the next production stage.
- adequately describes the component or assembly with reference to the production method necessary to manufacture it.

This information may be used to derive production methods and estimate production times which in turn allow more precise production planning and control procedures to be used. Information which is required by various departments may also be listed using automatic data retrieval methods. In addition the information which is relevent to the department concerned may be automatically selected and directly listed, thus simplifying shopfloor presentation.

This chapter describes the development of methods of collecting information and their use in the compilation of a computer data bank. Sources of production and management information in the industry were located, a classification and coding system for components was designed and two related formats for collecting production information were developed. Using the coding system and data collection formats data banks describing the hulls of different types and sizes of ship were compiled. The 'where used' system of data collection was used; each individual steel component found was allocated one data record and the assembly stages at which it was required was fully documented. In practice only the next stage of assembly needed to be noted as the component concerned was 'lost' following this operation (as far as the shopfloor was concerned). However, detailed information of subsequent assemblies was also noted for statistical analysis purposes.

Simultaneously a record was kept of the complete product breakdown from ship through unit and sub assembly to the initial assembly stage, these were noted as they were established. A third data collection format was developed for recording route information from operation job cards.

5.2 Development of data storage formats

The data storage formats which have been devised allow the use of standard eighty column computer cards. The information each is concerned with is

- descriptive component and raw material data;
- descriptive component and assembly data;
- component manufacturing (process route) data respectively.

The first data collection format allows accurate description of the steel components which comprise a ship hull. It enables the recording of information which is necessary to manufacture components from specified raw material and to marshal them into work packages as required. The information is divided into that which identifies and describes raw material, that which identifies and describes components, and that which identifies the immediate destination of components. However as most shipyards combine identification of the three aspects in a single number (see Chapter 4.4), the data format consists of an overall identification section, and sections for material description and component description. The combining of identification numbers results from the traditional practice of arranging work packages by structural units for component production as well as assembly purposes (see chapter 4.4). Thus a pre-specified block of the raw material number and the component number for all pieces forming a structural unit consists of a unique number identifiable with that unit. In addition the raw material number of a plate is often used as a prefix for numbers of all components derived from that plate. Following an investigation of the part and material numbering systems employed in the collaborating shipyards during short familiarization periods, it was realised that the format of the data record section concerned with identification needs to vary between different companies. However, to allow identical data handling techniques to be used to analyse all information collected identical blocks of digits are allocated to cater for identification and description in the data collection format for all components. Thus the information format within the identification data block varies between shipyards, but the description data block is identically formatted for all companies and allows consistent analysis methods to be employed.

Raw material description is closely related to component description particularly in the case of bar cross-section shape and size, plate thickness, and material type. Additional information describing bar material consists of length, numbers of pieces, and in certain cases an additional cross-section dimension where this cannot be fully included in the component description. Additional information for plate pieces consists of the numbers of pieces required and the length and width of each piece.

Component description consists of a code number derived using the descriptive classification system which has been developed specifically for the purposes of data collection. The code number describes in numerical terms the shape and size of the component, and is designed with particular reference to the production processes necessary to manufacture it. The development of the coding system is described in detail in section 3 of this chapter. Absolute values of component dimensions specified by the coding system are included in the format, and the number of components required in the structural unit and a brief verbal description of the part are noted for reference and checking purposes. The general data collection format employed during familiarisation exercises at Austin and Pickersgill, Ailsa Shipbuilding, Ryton Marine, and Scott Lithgow is shown in figure 23, attempts were made to use this format in all collaborating companies. Information describing components from double bottom units of ships under construction in each of the collaborating shipyards was collected using the format. Double bottom samples were chosen as being most representative of those available throughout the ships hull. The final data collection formats used in two of the collaborating companies are shown in figure 24.

The second data collection format has been developed from the first following initial data collection exercises. Here it was shown that the classification size ranges are well enough designed to give a good indication of individual component size. (see Chapter 5.3) Although it has only been shown that the de-

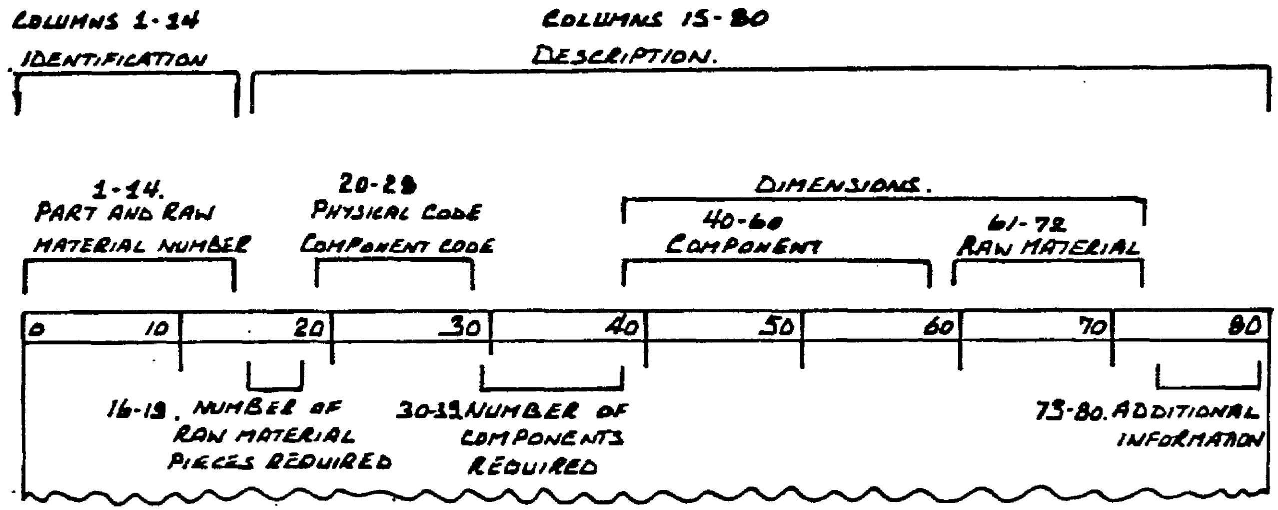


Figure 23 General data collection format for component and raw material information

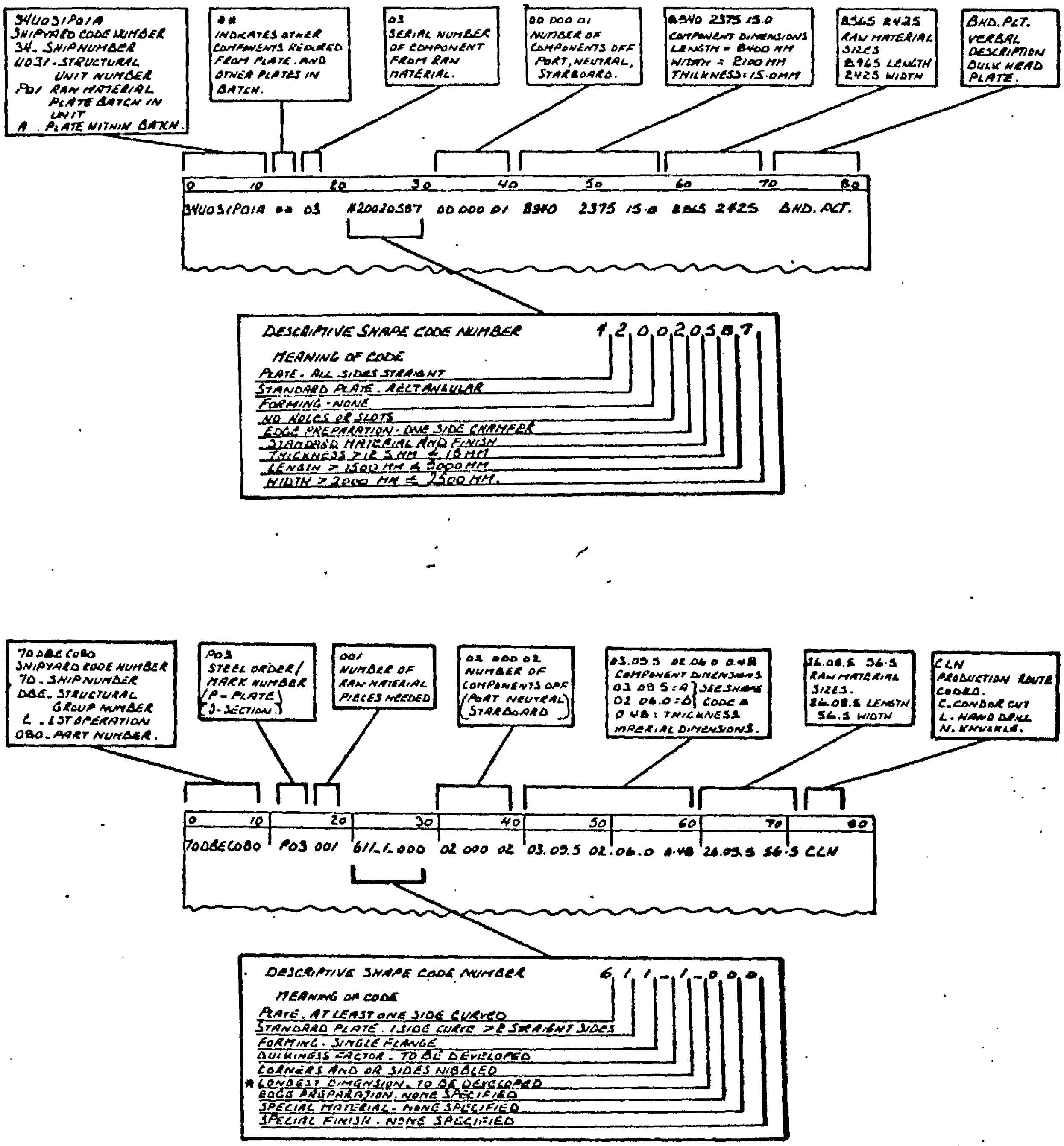


Figure 24 Data collection formats for component and raw material information used at Ailsa Shipbuilding (upper) and Austin and Pickersgill (lower)

scriptive code size ranges are suitable for use in shipyards of a similar size to those participating in the research, shipyard machinery for the manufacture of parts from steel plates and sections does not vary a great deal in larger shipyards. In addition the raw material steel plates ordered from steel suppliers by larger shipyards are limited by the same steel rolling mill sizes which apply to smaller companies. Thus while structural unit size increases component sizes do not increase to a great extent. Thus collection of absolute values of component sizes is superfluous and capacity is released in the first data format to include assembly information.

The assembly data collection format shown in figure 25 is still based on component information, and the initial section of the data record closely follows that described earlier. However, the absolute values of all sizes except thickness are replaced by sequential assembly part numbers describing the assembly route of the component. This includes up to four production stages including the erection of the structure unit at the berth; three sub-assembly stages are allowed in the data record and the fourth stage is the unit assembly (which is indicated in the part number). (A survey showed that the maximum number of assembly stages a component passed through before being completely welded into position (i.e. loosing its 'identity') is three, with most components passing through only one or two stages.) In addition the weld length required to be completed at each assembly stage is recorded as a direct measure of the work content involved at that workstation.

The third data collection format has been devised for use in shipyards where process information is freely available in the form of job cards. The format is shown in figure 26 and covers:-

- The shipyard code number
- The steel order number
- The unit used on
- The drawing number
- The tape or slide used on (for N.C. cutting or optical marking)
- The number of components required
- The production operations in their correct sequence (see below for production code)
- The total number of components per piece of raw material

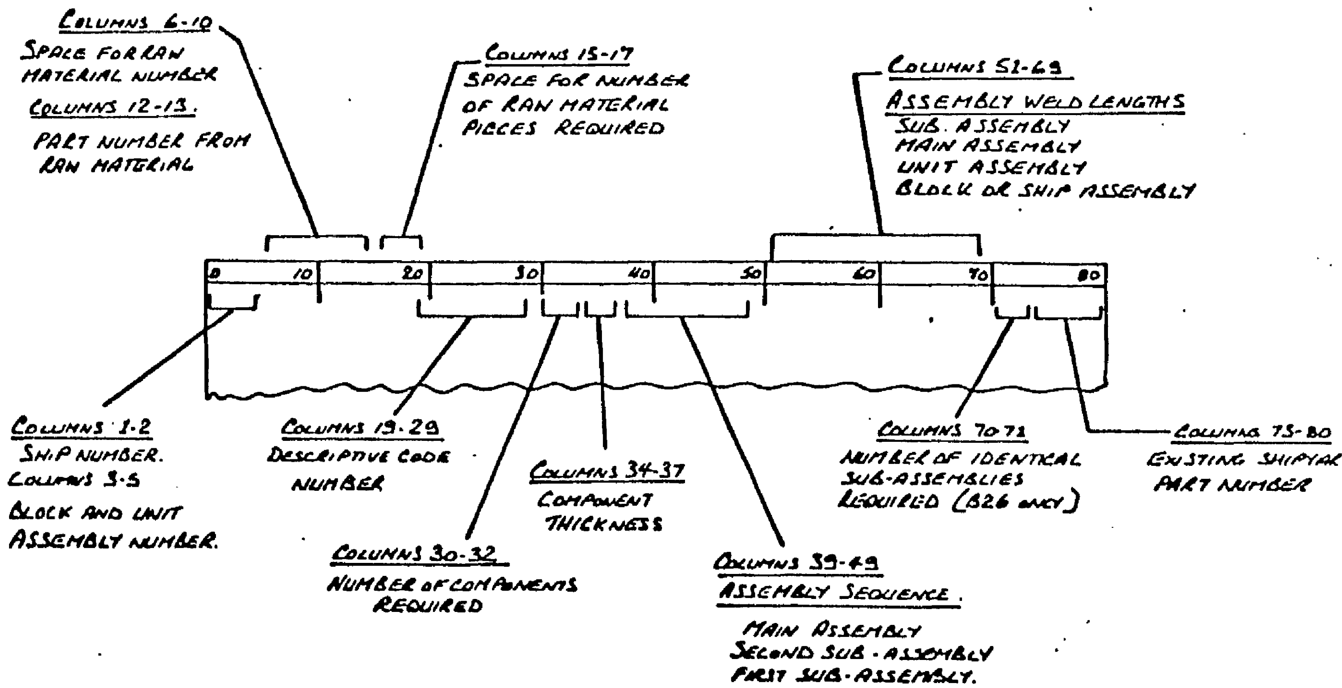


Figure 25 Data collection format for component and assembly information

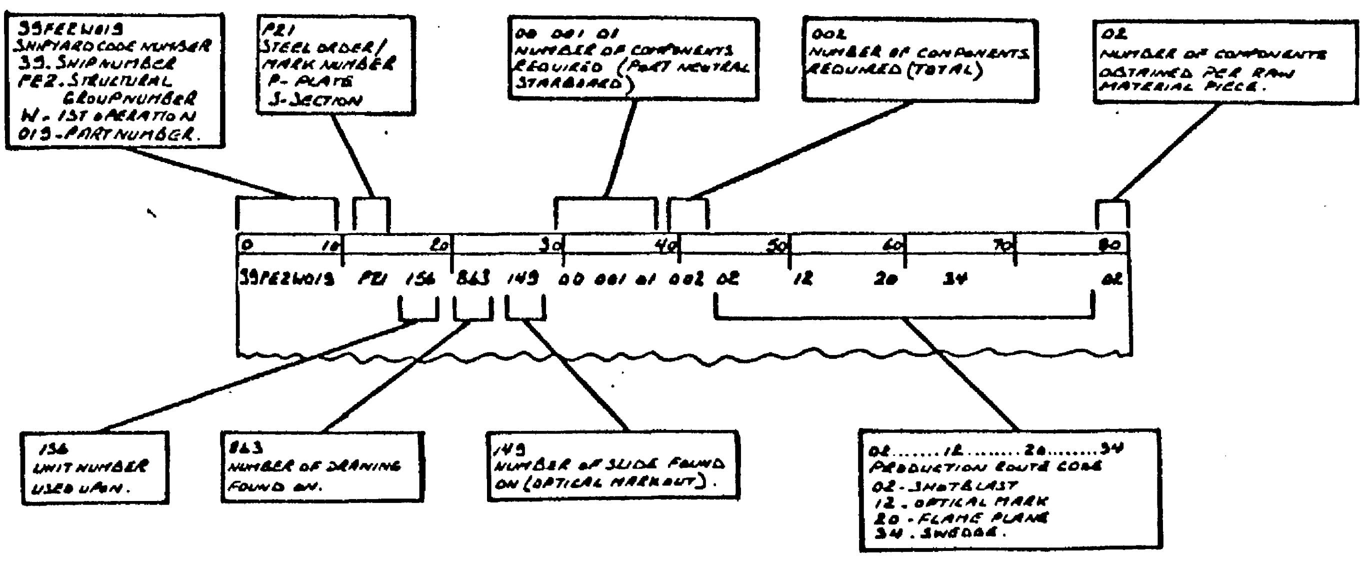


Figure 26 Data collection format for component manufacturing information (process routes)

A numeric production process code has been devised to describe the operations which a component undergoes as follows:-

	Code	Operation
primary operations	02	'shotblast only' stated on job card
	03	shotblast and point
marking operations	10	handwork
	12	optical work
flame cutting operations	20	flame plane
	22	'Monopal' (profile) cut
mechanical presswork	30	Guillotine
	32	Knuckle
	34	Swedge
mechanical rolling work	40	roll

However as previously indicated in Chapter 4 process information is not generally well documented in shipbuilding. Of the collaborating companies only Austin and Pickersgill operate a job card system and use of this data format was limited to collection of information from this source.

5.3 The Component descriptive coding system

5.3.1 Existing coding systems

Component classification and coding requires a description of each component, traditionally a drawing or precise alpha-numeric description. These exist in any industrial situation and are a pre-requisite to any manufacturing operations. It therefore follows that a component analysis following classification and coding may be applied in any manufacturing situation. Components may be coded by shape, by production features, or by a combination of the two depending on the availability of a suitable classification system and the organization concerned. An investigation was made of previous classification and coding systems which might prove useful for directly coding ship structural steelwork, or for designing a coding system suitable for this purpose. Four systems were examined closely, these were the Brisch and

Opitz systems for general engineering, the Aachen-Demag systems for structural engineering, and the British Ship Research Association parts numbering system for shipbuilding.

The Brisch Industrial Classification and Coding System [22] was developed by E.G. Brisch and Partners of London. The system is generally tailored to the needs of individual companies and implemented with the aid of members of the Brisch organisation. It is broadly based and encompasses the entire manufacturing process from raw material to finished product and also includes all facilities and services which are employed in the production process. The area of components assemblies and products is left unexpanded in the overall Brisch system to allow individual companies complete freedom so that they, with the help of Brisch consultants, can devise their own component and assembly coding sub-system.

The Opitz system [23] for general engineering is a pure component classification and coding system and its aim is to describe parts in such a way to allow statistical analyses to be undertaken. It is a nine digit code containing a good basic definition of component shape in the first five digits with a four digit supplementary code covering size, raw material, and accuracy aspects of the workpiece. This system was originally designed for the German machine tool industry and has since become a well established coding system in many countries. The first five digits of the code describe the shape and production features of the part and the remaining four digits cover one important dimension (diameter or length), material, original material configuration, and the accuracy required of the part. The outline of the coding system is shown in figure 27. Adaptation of the system to suit an individual company's requirements is possible only by the use of specific part classes denoted by 5 (for rotational parts) and 6 (for non-rotational parts) in the first digit of the shape code.

The Aachen-Demag classification and coding systems for structural steelwork [24] were devised following collaboration between the Aachen Technical University and the Demag organisation in West Germany. Aachen was also the place of origin of the Opitz coding system for general engineering workpieces and this and the systems for structural steelwork are now proposed as sections of a single larger coding system to cover all facets of industry. Demag is a structural

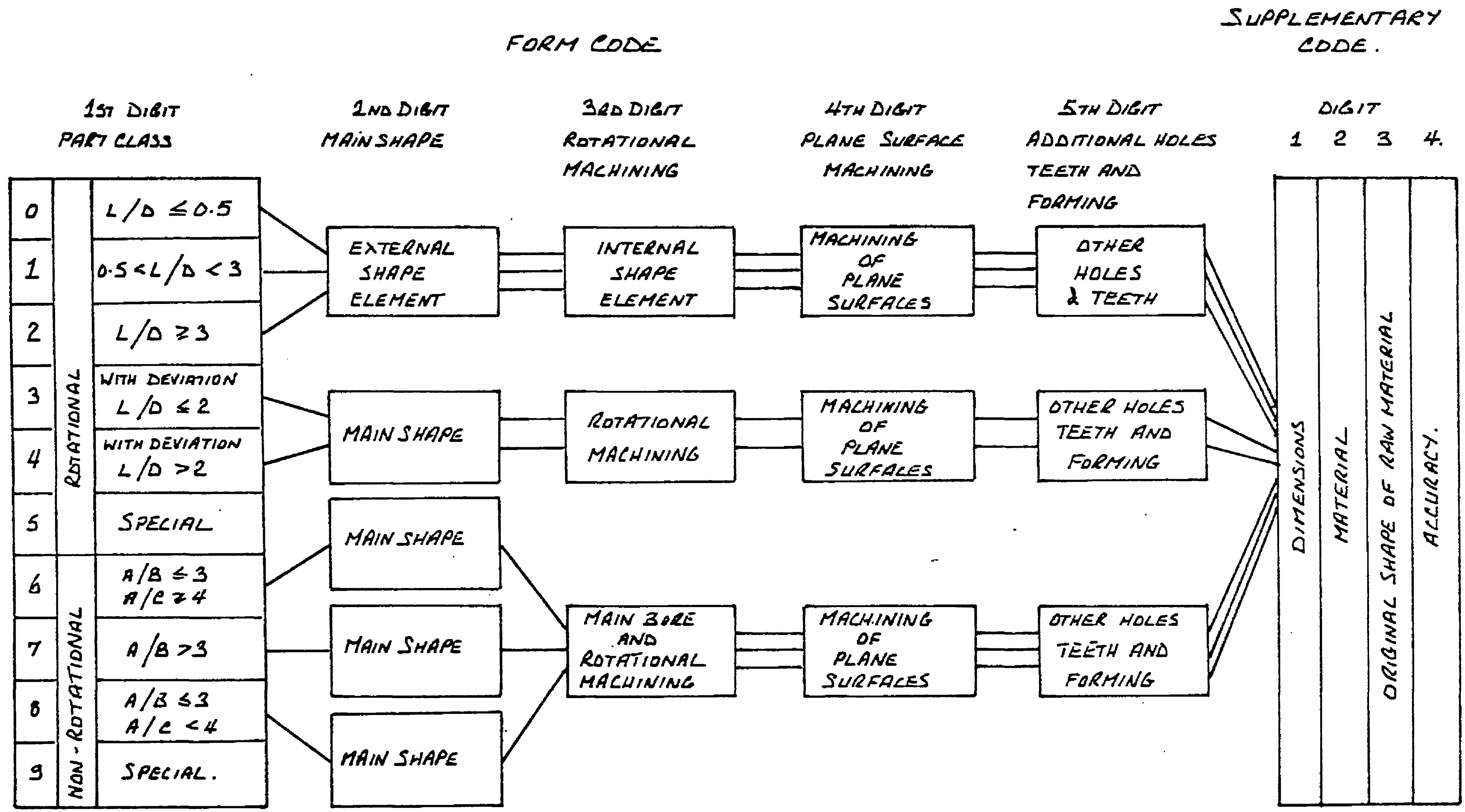


Figure 27 Outline of Opitz classification and coding system for machined components

engineering company who funded the development of the structural steelwork coding systems and subsequently sell it to other potential users on a consultative basis. Although industrial secrecy aspects concerning the use of the coding systems are strictly observed descriptive articles have been published outlining the systems and presenting coding examples. The structural steelwork coding systems cover three separate aspects of structural engineering; components, welded assemblies, and fabricated (non welded) assemblies. In the proposed overall industrial coding system these are each presented as a separate section. The sections concerning components and welded assemblies were of most interest in the development of a classification and coding system for ship steelwork. The basic construction of all sections is practically identical to that used for the original Opitz system with a change in emphasis from machining characteristics to cutting and forming for the component code and structure type for the assembly code. The component code was found useful in the design of a system and at one stage it was considered using it directly for part coding and analysis. It was described by a colleague following a visit to the Demag organisation where the system was explained more fully, the use of it at that time and plans for extending its use in the future were also discussed. Because of the specialised needs of the shipbuilding industry and also the expense of purchasing the requisite parts of this system from Demag, its use was not pursued further. However the basic construction of the system was studied in detail, and its method of approach to the problem found to be of value during the development of the ship hull component code.

The British Ship Research Association Parts Numbering System for Steelwork [21] (described in Chapter 4.4), although having elements of classification is primarily a product based part numbering system. It allows a previously generated ship breakdown (into units, sub-assemblies, and components) to be numbered in a hierarchical structured way. While the importance of systems such as this for material and production control purposes cannot be overstressed it does not allow a detailed indication of the type of work which is involved in the shipyard workshops. The B.S.R.A. Parts Numbering System was therefore not thought applicable for a statistical analysis of components or assemblies.

5.3.2 <u>The design of the system</u>

Initial studies were carried out in the four collaborating shipyards to gather basic information about the processes used, and the types of components produced. The data was collected from both manufacturing sheds and drawings. A major problem at this stage was the necessity for the researchers to become competent to interpret shipyard assembly drawings which differ substantially from traditional engineering drawings.

Shipyard drawings consist chiefly of two types, ship plans and unit drawings. Ship plan drawings consist of sheets of various sizes (but usually long) showing large planar areas of structural interest within the ship, while unit drawings consist of standard size sheets showing all the relevant information necessary to manufacture a single structural unit. Very few instances occur of individual component drawings and in the case of the four shipyards who were collaborating they were practically non-existent, thus parameters of each component had to be interpreted directly from the assembly drawings.

From this work a draft system was developed and refined, the basic features of which are shown in figure 28

The draft classification and coding system was 9 digits long and of the 'fixed' digital significance type, as is the Opitz machined component code. Indeed the format of the system followed that of Opitz closely. The first six digits described the geometric shape of the component in a way which would provide useful information to the industry.

The major segregation made in the first digit between sections and plates was an obvious one to include in order to follow manufacturing practice, other divisions branch from this. In the case of both plate and section components the first two digits were used to describe the cut shape of the component. Section components were segregated by cross-section type; initially by the popularity of the section (judged by shipyard use) and solid bar in the first digit of the code and then by cross-section specification and end of section cut-off shape (shaped or

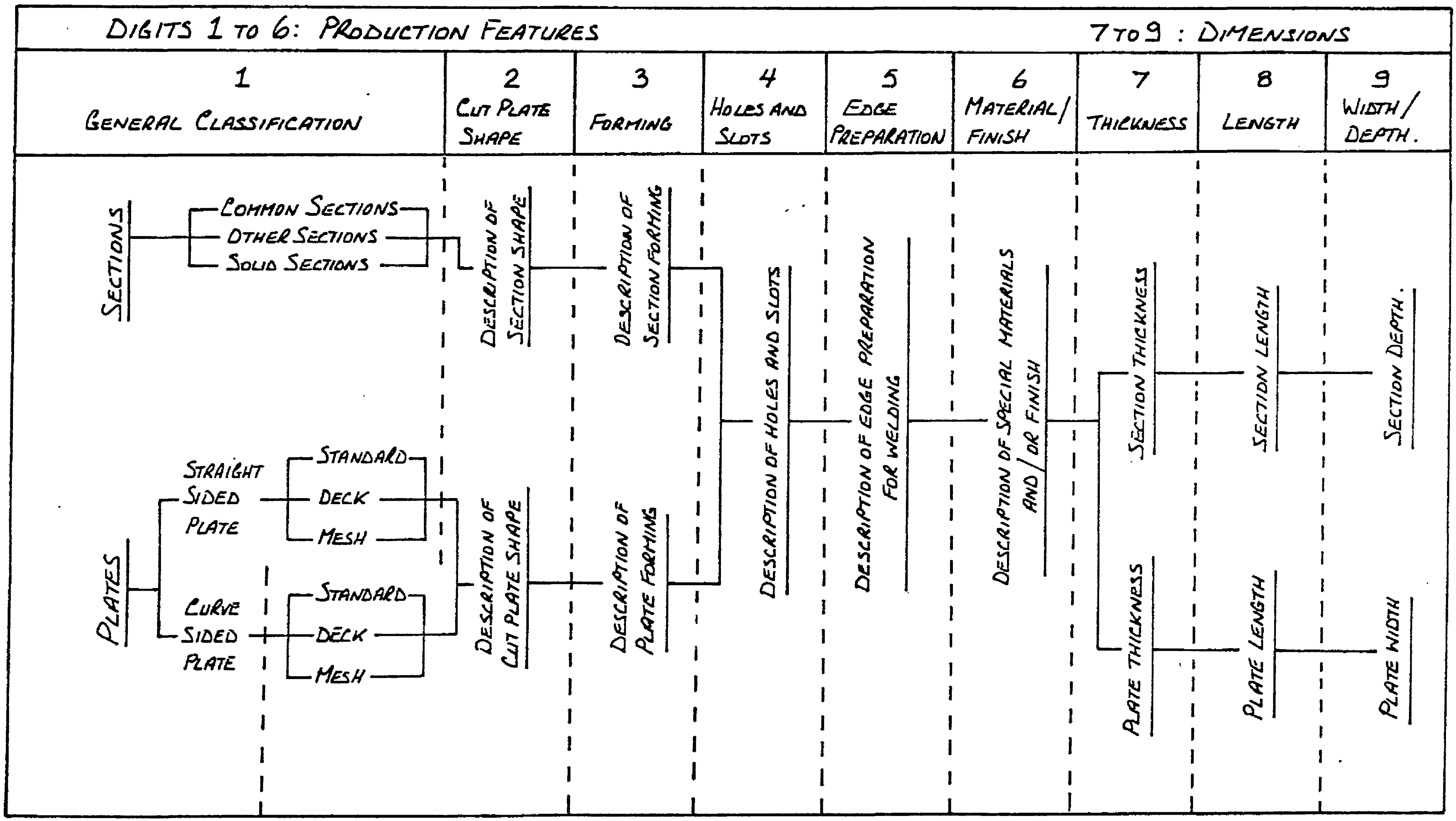


Figure 28 Outline of draft classification and coding system for ship hull components.

square) in the second digit. This followed possible manufacturing practices where square ended sections could be readily cut by flame cutting or mechanical (sawing) methods, but shaped ends were more readily flame cut and in certain cases this was the only production method. Plate components were sub-divided into straight sided plate and curved sided plate components. In both sub-divisions segregations were made between standard plate (plain rolled), deck plate (with a pattern rolled into the surface), and expanded diamond mesh (to cover drained walkways). The major segregation of plate components (straight sided and curved) were then divided by perimeter shape using number of sides (straight and curved) and number of square corners. This again was to give a good indication of the best choice of production method between flame planning, profile flame cutting, or guillotining, and the number and ease of set-up operations which would be required.

The third digit was concerned with forming operations which could have been required for the manufacture of the component. For sections segregations were made between bends, flanges, and combinations of the two; bending included rolling operations for flat bar (defined in the two previous digits) and cold frame bending for other sections, and flanging occured chiefly in flat bar components. Divisions were made for plate components between those having flanges, roll bends, swedges (corrugations), and combinations of two or three of these, again to follow manufacturing practice. Distinction was also made between components (plate and sections) which required single or multiple forming operations, this indicated the difficulty and number of set-ups. For example cold-rolled sections requiring a single bend could be formed prior to end cutting, thus the positioning of the bend would be relatively unimportant, but if the section had more than one bend there would be a relationship between them and this would complicate the set-up and subsequent checking operations.

As indicated the first three digits of the shape code were 'tree' structured and had different meanings for each digit value of the plate and section main divisions. The remaining three digits of this section of the classification systems were assigned the same value meanings for all components. The fourth digit indicated the peripheral operations to produce holes and slots in the component, these included nibbles or mouseholes to aid welding operation or allow drainage, circular or non-circular lightening or access holes, drilled holes, or combinations of these. Attention was given in the design of this section of the code to the relative accuracy which might be required of peripheral features, for example corner and side nibbles required relatively little positional accuracy compared with slots for stiffening cross members. The fifth digit was allocated to the edge preparation required on the part. This was used to distinguish between components having chamfers from one side only, from two sides on one edge, square specifically (machined) and square as flame cut; and also for components having different edge preparations on different edges. The sixth digit of the shape code was allocated to the material composition and surface finish of the component, this digit was left to be expanded and at this stage specified only standard and non-standard material and finish.

The final three digits of the code (seven to nine) were used for dimension ranges giving an indication of the size of any component. Segregation was again made here between plate and section component; thickness, length, and depth ranges were used to dimension section components with different thickness, length, and width ranges for plate components. It was observed from visual inspection of plate parts in progress on the shopfloor and shipyard drawings that component sizes could be classified by size into two categories. One category covered small brackets and the other catered for shell, deck, bulkhead, floor, or girder parts. The initial length and width ranges were therefore designed on this basis and scales similar to logarithmic bases were devised, these are shown in figure 29. By using this system it was found that the length percentage error within any range remained fairly constant. The errors found if the midpoints of the ranges are used in estimating computations and the actual values are on the upper or lower limits are shown in figure 30.

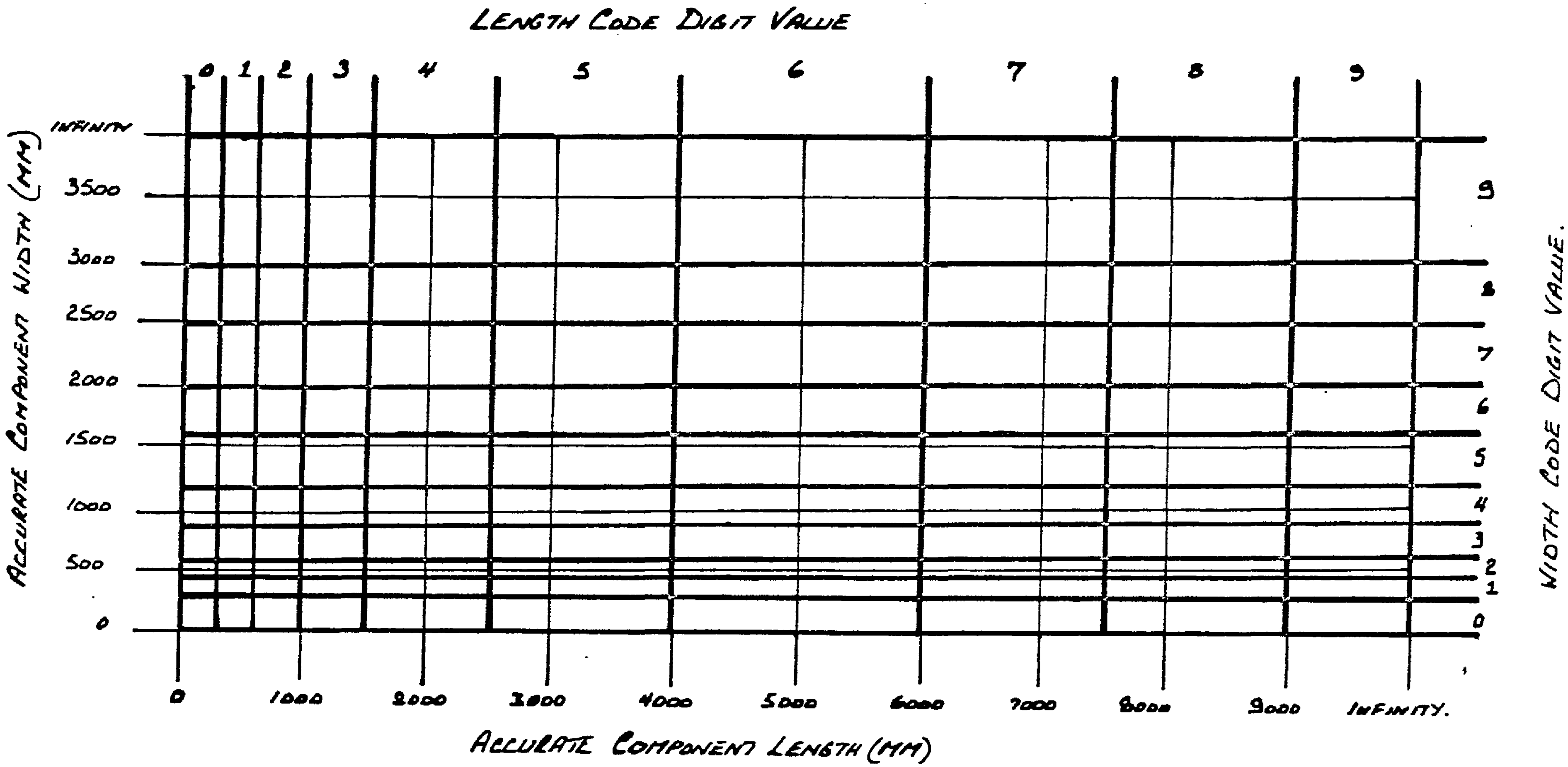


Figure 29 Length and width size ranges of code digit values for components from plate material.

The error values are generally 25% or less with the highest errors occuring in the lowest ranges. The error values given are the maximum possible, and if a straight line distribution of length is assumed then a normal error distribution occurs around each midpoint value. The ranges of the upper values of the size digits (length = 9000mm width = 3000mm) were based on an investigation of the raw material sizes used in the collaborating shipyards. It was assumed that component sizes could not possibly exceed raw material sizes. The designation of the lowest ranges of the size digit (length = 300mm, width = 300mm) were made following a visual inspection of small brackets. It was observed that the smallest of these were generally in the range 200 - 300mm in both length and width, thus using these range values the maximum possible errors were found to be $33\frac{1}{3}$% for both width and length. The errors expected for lower sized parts are also of less importance in the cutting length, weld length, and general work content estimating systems.

The distribution of section component lengths was thought to be much more linear than for plate components. This is a reflection of the chief function of section parts which is to stiffen plate parts, and the dimensions to be stiffened are distributed fairly linearly. The maximum percentage errors found when applying the same assumptions used for plate parts are shown in figure 31. The upper and lower ranges were studied in a similar manner to that used for plate parts, visual inspection for the lower range and investigation of raw material sizes for the upper range. The depth ranges for section parts were again partly based on visual inspection of shopfloor work and shipyard drawings and also in this case an available standard size from the rolling mills. The maximum possible percentage estimation errors for section depth are also shown in figure 31.

A homogenous distribution of component sizes for digit values 1 to 8 was assumed to give an indication of the errors resulting from using the range midpoints. (This was a very theoretical situation and, considering the practical aspects designed into the coding system, a poor case to

CODE DIGIT VALUE.	MAXIMUM LENGTH ERROR (%)	MAXIMUM WIDTH ERROR (%)
0	100	100
1	33.3	20
2	25.0	14.3
3	20.0	20.0
4	25.0	14.3
5	23.1	14.3
6	20.0	11.1
7	11.1	11.1
8	9.1	9.1
9	INFINITY	INFINITY.

CALCULATION EXAMPLE:

CONSIDER LENGTH CODE DIGIT VALUE 3 (1000-1500 MM)

RANGE MIDPOINT = 1250 MM

MAXIMUM ERROR (ON LIMIT) = 250MM

$\therefore$ MAXIMUM % ERROR = $250/1250 \times 100$

= 20%

Figure 30 Possible percentage errors in length and width estimates of plate components using the coding system size range midpoints.

CODE DIGIT VALUE	MAXIMUM LENGTH ERROR (%)	MAXIMUM DEPTH ERROR (%)
0	100	100
1	33.3	20.0
2	25.0	20.0
3	20.0	14.3
4	14.3	11.1
5	11.1	14.3
6	9.1	11.1
7	7.7	9.1
8	6.6	18.4
9	INFINITY	INFINITY.

CALCULATION EXAMPLE:

CONSIDER LENGTH CODE DIGIT VALUE 2 (1200-2000 MM)

RANGE MIDPOINT = 1600 MM

MAXIMUM ERROR (ON LIMIT) = 400 MM

$\therefore$ MAXIMUM % ERROR = $400/1600 \times 100$

= 25%

Figure 31 Possible percentage errors in length and depth estimates of section bar components using the coding system size range midpoints.

show the system size range merits). In this case all size ranges would contain an equal number of components which would be equally distributed over the specific range, i.e. mean actual length at the midpoint of the range and upper and lower quantities situated at half the maximum possible error above and below the midpoint. Thus averaging the maximum errors would result in a mean error for each size code and 50% of component dimensions would be accurage to within 50% of the maximum error. Using this hypothesis 50% of plate components would be 10.4% or less accurate in length and 7.2% or less accurate in width, and 50% of section components would be 7.9% or less accurate in length and 7.4% or less accurate in depth. These figures are for digit values 0 to 8 only.

Thickness ranges, both for section and plate parts, were based on a study of the thicknesses of raw material ordered by the collaborating shipyards. The thickness of components would be the same as that of the raw material they were produced from, and it was more efficient to inspect raw material order lists than component thicknesses.

For all size digits the original values of upper and lower values of ranges were only chosen from brief experience of practical requirements. It was therefore intended that in the early stages of data collection the absolute value of component sizes would be included in the data format. This would allow an accurate statistical analysis of the size ranges to be undertaken to verify or disprove their value, and to redesign them if necessary. It would also allow 'block' changes to be made (if necessary) in the code values using the actual dimension values and computer data processing methods. This would alleviate the necessity to recode large batches of information if the size ranges were found to be impracticable. However when the size code system had been statistically proved it was intended to rely on this as a true indication of the size of components and cease recording absolute values.

At this stage it became necessary to test the code on a fairly extensive scale before attempting to use it to component-code and statistically analyse the parts forming a complete ships hull. To do this the double bottom structures of a ferry, a dredger, and a cargo vessel, each under construction in different collaborating shipyards, were coded. The double bottom section of a ship was thought to contain a representative sample of the components which would exist in the entire ships hull. During coding operations notes were kept detailing ambiguities which existed in the use of the shape code. These were clarified by either changing the classification system to suit, or by defining it more concisely in a coding manual which was compiled at a later date. Notes were also made of structural component features which could not readily be coded. In these cases the classification system itself was changed or enlarged to enable the features to be coded and stored in the data bank. Two instances occurred which required a change in the basic code. The first concerned section parts which were cut and rewelded to enable the section to be knuckled, usually to follow the surface of the panel it was required to stiffen. The second occurred where plate components were both corrugated and flanged, these difficulties were both overcome by using a spare value of the forming code digit. Special attention was given to the distribution of the size code digit values throughout the component population for each ship. Histograms were drawn of numbers of components having specified code values for thickness, width, and length in the case of plate parts; and thickness, depth, and length in the case of section parts. The original design concept of the size codes had been that a compromise should be divided among a number of code digits, but a fairly even distribution should be maintained for the regions outside this peak. For section parts the lower digit values were found to contain more components than higher values, the majority were found to be in the range 600 - 1200 mm (code digit value 1) Digit values about code value 1 were found to have a normal type distribution although for the dredger the distribution was found to be very much flatter than for the other two vessels. There was found to be a fairly even distribution for higher value digits (4 to 9). Three dimensional histograms of numbers of plate components for length and width code digits were drawn and studied, these analyses are discussed in further detail in Chapter 8. In general distributions were found to be similar to that described above for section lengths, that is a normal type curve in one area (0 - 4 for length and width codes, 4 - 6 for depths and thicknesses) with an even distribution covering other digits values. The region which was covered by the normal distribution peak was in all cases divided into smaller ranges than the flat area. It was therefore shown the design policies for the size code had been applied.

During subsequent data collection programmes the advantages of recording assembly information which could be directly associated with a component were recognized. If the types of weld which would be used to assemble the piece-part into a welded structure were noted, then assembly work content values could be estimated from the component data bank. Thus following the initial coding exercise a further digit was incorporated into the classification system to indicate the weld type which would be applied to assemble the component. This was only applied to welds at the edges of the part and not for that of a second component welded to it, for example by a fillet weld (this weld would be included in the description of the second component). The initial division of weld type was into butt and fillet welds, and combinations of these two for different edges. The second division was into continuous and intermittent welding techniques. No attempt was made to define the weld production method (submerged arc, M.I.G., manual electrode, etc.) as this would depend on the assembly area employed and the facilities available within the specified manufacturing shipyard. The welding detail digit was inserted between the previous fifth and sixth digit, following the digit describing edge preparation for welding and preceding the digit describing material and finish. Thus the three digits which are inter-related and closely associated with the assembly process were grouped together, although the edge preparation is also closely connected with the component production methods and may equally be associated with the preceding four digits.

The finalised classification and coding system has now been published by the Department of Management Studies, Glasgow University, (25) and consists of two parts, a summary and a manual. The code now consists of ten digits which can be divided into three distinct sections. The first four digits describe shape parameters of the component which are of importance in the manufacture of the part. Digits five to seven inclusive describe factors involved in both the production of the component and its assembly into a welded structure. The final three digits describe the dimension of the component using distinct size ranges for plate and section parts. The structure of the code is now as shown in figure 32.

The material and surface finish code digit (seventh) is yet to be fully defined, and as yet only standard and non-standard material and finish is specified. The variety of material and surface finish which is employed industry wide is extensive, particularly if different grades of carbon steel are considered. However, individual companies and shipyards will generally have a much narrower range of material or finish standards, depending on the type of vessel manufactured. It is therefore intended that this digit will be expanded by the individual shipyard user based on his own company standards.

The dimension ranges to describe component sizes at present in the code are based on the parts found in two ships hulls (the 5000 Ton dredger and the 14000 Ton SD14) and the double bottom of the 3000 Ton ferry. This size of vessel is produced in small or medium size shipyards and the production equipment employed is only able to deal with relatively small raw material pieces. Few of these shipyards use a modern automatic or semi-automatic panel assembly line designed to fabricate large flat panels. This is because the ships capable of being constructed on their building berths do not have a long parallel midbody and the resulting large areas of flat panel to justify large capital investment. The average size of components occurring in smaller vessels is also less than in oil and products tankers or in bulk carriers. This is particularly true in the case of plate thicknesses and rolled steel sec-

Main Division	Digit Numb	Digit Description
Shape Parameters (component production)	1	General Classification (plate type/section type)
	2	Cut plate/section shape
	3	Formed shape
	4	Holes and slots
Assembly Features (component/assembly production)	5	Edge preparation
	6	Welding detail
	7	Material/finish
Size (dimension ranges)	8	Thickness
	9	Length
	10	Width (plates) / depth sections

Figure 32 Outline of final classification and coding system for ship hull components.

tion thickness and depth as the scantlings of these vessels need to be stronger for classification purposes. The dimension ranges of the code therefore need to be redesigned for larger ships and shipyards employing larger plant and equipment. Different thickness ranges for plates and sections (and depth ranges for sections alone) need to be redesigned for specific types and sizes of ship; and in addition different length and width ranges are required to cater for the shipyard equipment available. The factors involved in the redesign of size ranges are the same as those defined previously. Statistical analyses of raw material can be quickly carried out to find maximum plate sizes and rolled section sizes which are most commonly used in the shipyard, the maximum values will be similar to that found in the statistical analyses described in Chapter 8 and this can be used to define ranges. If this fails a small statistical analysis can be made of the parts themselves.

The code summary allows a quick reference to the classification system, and any specific problems may be solved by consulting the larger manual. It has generally been found that students who are being taught to code require directed tuition for about one or two days. Following this a period of two or three weeks is required with access to an experienced coder, during this time queries occur less frequently and the manual is also referred to less often. Eventually the code summary is used for practically all coding operations and the manual is referred to only for types of part which occur very infrequently. Care must be taken, however, not to make assumptions where any element of doubt as mistakes once made tend to be recurring. For this reason a study of the manual should be made at fairly frequent intervals to act as a 'refresher' course.

5.3.3 Analysis of the coding system

An independent analysis of the use of the classification and coding system was carried out by a final year engineering student at Strathclyde University (26)
The student investigated the difficulties involved in classifying and coding the ship structural components forming the double bottom structure and estimated probable training

time required for coding based on his own experiences.

The greatest difficulties found by the student were locating components from assembly drawings and interpreting drawings in general. As he was not familiar with ship assembly drawings it took up to ten minutes to locate some unique components in a drawing, and this frequently required cross-checking with other drawings to verify that the correct part had been found. In addition it was found that ship draughting procedures were inconsistent when compared with general engineering drawing practice. For example a manhole might be shown in dotted lines usually indicating that it was cut on the berth; but this could also have indicated that the manhole was hidden below the facing panel (deck or bulkhead), or could have indicated access from above. Problems were also found in defining the exact shape and features of components. Many of the parts were found to have one or more sides with slight curvature, usually these were shell plates, or deck plates which were joined to the shell. This curvature, when slight, was not apparent in assembly drawings but a shipyard draughtsman would consult lines plans and shell expansions to check curvature. The student, however, found difficulty in interpreting lines plans and correspondingly he encountered problems in determining the code number to be allocated to the part.

The student kept a log during his project to indicate his difficulties in coding and maintain a record on his progress in learning the code. The first six days were spent in familiarisation exercises with shipyard drawings and the coding system. Days seven and eight were spent coding, the initial rate during these two days was very slow, about thirty components per day. Days nine to thirteen were also spent coding but the rate was increased to about forty parts per day; by the thirteenth day the student was fairly familiar with both the coding system and shipyard assembly drawings. Few difficulties were encountered during days fourteen to eighteen and the experienced coders were consulted less frequently. Coding became a routine job and many of the parts were found to be identical. The coding rate was increased to about fifty per day during days nineteen to twenty four when coding ceased. The student found more difficulty in coding plate parts than section parts, this was to be expected as they are usually found to be of greater complexity. A learning curve (figure 33) was drawn based on the students experience of coding during the twenty four days. He estimated that a coder skilled in the use of shipyard drawings could code 100 - 150 parts per day but that a person with no technical experience would only reach a maximum of about twenty parts per day. These figures were based on his own experience of coding as a person with a technical background but with no experience of shipyard drawings or ship structure.

The student also analysed the coded component data gathered from the same shipyard assembly drawing by the two originators of the code and himself. Inconsistencies were found to exist, particularly in the use of the second and third digit. This was usually due to poor interpretation of the drawings involved and the student suggested that a ship draughtsman was the best person to employ for coding operations and coding was best done at the detail drawing stage. Major differences occurred when a 'snipped' corner was classed as a further side, thus a mistake in coding of this nature would radically alter both the second and fourth digits. Examples of this coding failure are shown in figure 34. The student suggested that differentiation should be made between very short sides and corner snips. It was later decided to define corner snips by purpose, i.e. 'sides' for the purpose of easing welding operations and relieving corner stresses would be classified as snips. A certain amount of discretion and knowledge of ship design is still required of the individual coder, although this has been reduced considerably. Further problems occurred with parts having slight curvature of side which was not clear in the assembly drawings. Moreover for this exercise lines plans of the ship were not available and these would have solved this problem. The student suggested that a manual be prepared to explain the system in greater detail and explain more clearly the points which had arisen during the exercise. This manual

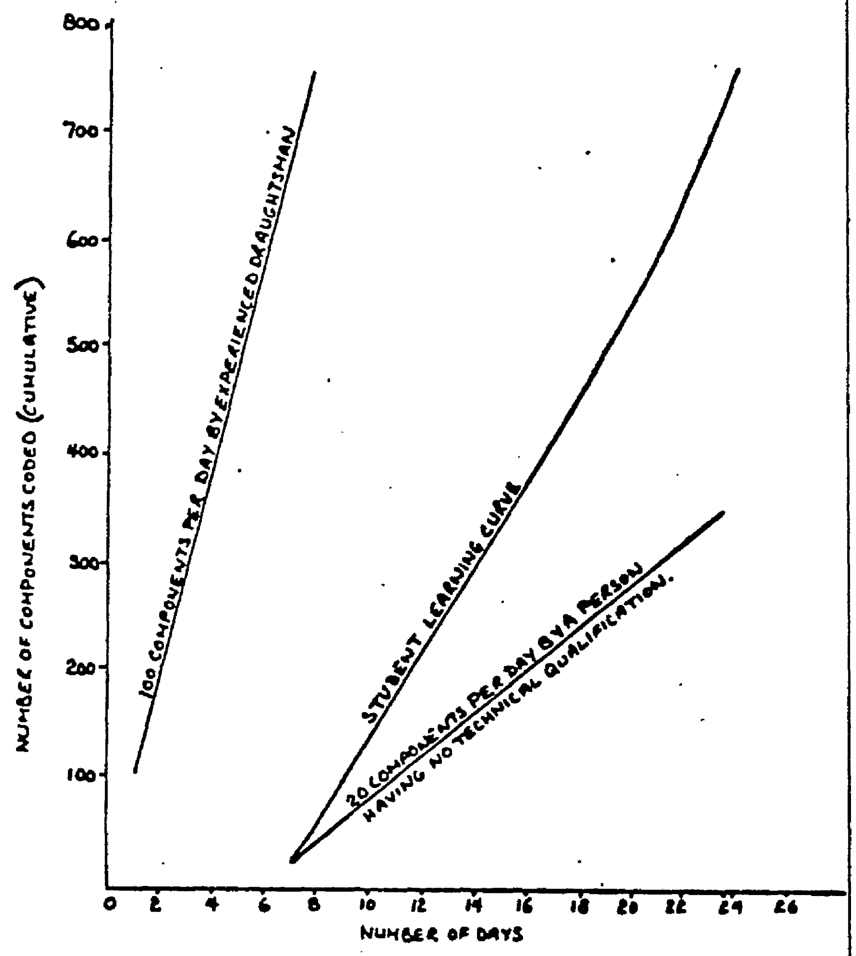


Figure 33 Student learning curve and estimated coding rates for shipyard draughtsman and non-technical personnel

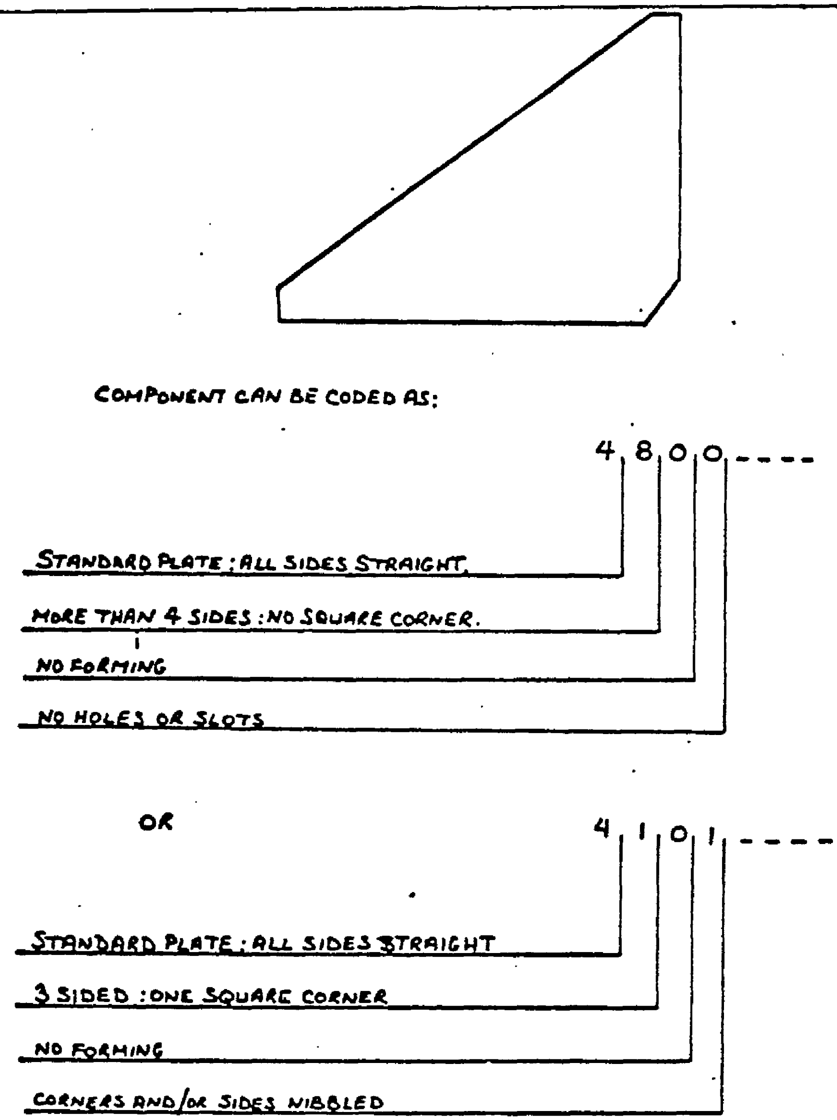


Figure 34 Example of coding inconsistency

could then be referred to by potential coders. These points were noted and acted upon in the design of the final classification and coding system presentation.

5.4 Data collection

Pilot data collection exercises were undertaken at the start of research to ensure that the component descriptive coding system and the data format could be used in all four collaborating shipyards. Sources of production information were investigated and the following areas were of specific interest.

- Drawing procedures and methods; the degree of detail of the drawings, and the parts numbering and coding system used.
- Shipyard planning and production control methods; parts lists, steel ordering lists, and information passed to the shop floor to control production (such as job cards or route cards).

Sample drawings and parts and material lists for double bottom structural units from a ship under construction in each company were obtained. Information describing each component on the drawings was collected using the common data format and punched onto eighty column computer cards. Following successful analysis of the data collected (Chapters 7 and 8) reports were sent to each company proposing to gather a large statistical component sample by examining in detail a whole ships structure, this would then allow a more detailed investigation into manufacturing problems. However, Scott Lithgow rejected the proposal for personnel management reasons, and Ryton Marine went into liquidation before further collaboration was possible.

After presentation of reports on work done during the pilot study periods spent in their shipyards both the Ailsa Shipbuilding Company and Austin and Pickersgill agreed to provide facilities to allow vessels to be component coded. It was agreed that the vessels which were to be coded would be those which had been the subjects of the initial data samples, i.e. the 5000T dredger at Ailsa and the SD14 at Austin and Pickersgill.

Shipyard drawings for the dredger were supplied and processed at the University of Strathclyde. Frequent day-long visits were made to the shipyard to clarify any points which were not clear or understood when interpreting the drawings. Component information was collected onto data sheets as shown in figure 24, and then transferred onto punched cards. The information on the punched cards covered:-

1 Shipyard part number
2 Number of plates/sections ordered
3 The descriptive code number
4 Number of components required
5 Component size i.e length, breadth, and thickness
6 Raw material sizes or nesting information
7 Brief verbal description of the component

The company was informed that the data was available for their use and sample analyses were presented in a second report. The company was also informed of a computer time-sharing system which could be used to exploit the data bank for information retrieval and analysis. A detail cost breakdown for installing and running the system was included in the report to the company and is presented in appendix 8

In order to ease communication problems and collaborate with shipyard personnel the coding and data collection for the SD14 was undertaken in the Southdock shipyard of the company involved. An office was provided in the shipyard and a complete set of ship drawings for a previously constructed vessel were made available. A total of fourteen weeks was spent in the shipyard carrying out a detailed survey of the components forming the hull of the ship. In addition job cards were gathered for a similar ship which had been built previously, and the process information from these was also numerically coded onto data sheets and transferred onto punched cards.

The format used to collect the component information closely followed that used in the previous sample exercise and is shown in figure 24. In addition a brief verbal description of the part was added and the component and raw material sizes were noted in millimetres, this involved a conversion from imperial dimensions but would allow easier data handling. The process was simplified by using a specially graduated scale which allowed direct conversion from ship drawings into millimetres. The information collected onto punched cards covered:-

1 The shipyard code number
2 The steel order number
3 The number of plates/sections ordered
4 The descriptive code number
5 The number of components required
6 Overall component dimensions
7 Raw material sizes
8 A verbal description

The additional process information was collected in a format designed to describe the production route of a component and the unit it was used. This information only described components manufactured from plate. It did not cover the complete vessel as an entire set of job cards was not available, but 47% of the total number of plate components were described. The aim of collecting this additional information was to supplement the component information for subsequent analysis and also to form the basis of a possible automation data retrieval service for the design and production planning departments of Austin and Pickersgill.

A report was presented to the company giving details of the information which was available for their use.

At this time the importance of assembly information in the control of production became apparent. The task of such information in the data banks was overcome by using the data storage capacity previously used for component dimensions (see section 2 of this chapter). Common interest in the collection of assembly data was found to exist with A.P. Appledore who were engaged in the design of new shipyard facilities for Austin and Pickersgill. It was suggested that the SD14 be reprocessed, and the B26 be processed for the first time, with the collection of additional information describing the assembly process to berth erection. This would be of value in the design of assembly production systems, design of assembly work areas, and for the scheduling of work to these work areas. It was further suggested that a coding system in use at Cammel Laird Shipbuilders could be employed, this was closely examined and found to be suitable. Austin and Pickersgill agreed to participate in the exercise and supply necessary ship drawings. The work was carried out at the offices of A. and P. Appledore who advised on the proposed ship breakdown, although the detail breakdown of the vessels into units, main assemblies, and sub-assemblies was undertaken by the researchers who numbered the resulting weldments. The assembly coding system employed consisted of a single alpha character which described the type of assembly. Its use in the project generally followed that employed at Cammel Laird although for some assembly types more explicit definitions were required, and in one case a new value was introduced. The alpha characters with explanations of their meanings are shown in figure 35 .

Data describing both the individual components and their assembly route until erected into the ship on the berth was collected using the redesigned format. There was little difficulty in the coding and collection of component data following previous work, but some problems were encountered with the definition of an assembly breakdown which would comply with the envisaged ship factory design. These difficulties were overcome by discussing the problems with shipyard and A. P. Appledore personnel and making policy decisions throughout the data collection process, and in particular at the early stages of the exercise. These decisions were recorded using a catalogue of welded assemblies defined in the breakdown which numbered each assembly and contained sketches of the assumed method of assembly. A sample from the catalogue is in appendix C

Following completion of this data collection exercise both Austin and Pickersgill and A. P. Appledore were informed that a new data bank existed. Data retrieval and handling techniques using the information were also demonstrated to them, and in the case of A. P. Appledore processed information in a useful form was presented.

CAMMELL LAIRD CODES

CODE DIGIT	ASSEMBLY DESCRIPTION
B [1]	BRACKET ASSEMBLIES AND OTHER MINOR ASSEMBLIES NORMALLY WITH ONE PLATE PIECE PART, BUT A NUMBER OF STIFFENER PIECE PARTS.
W [2]	WEB ASSEMBLIES - GENERALLY LONG SUB-ASSEMBLIES AND TANKER TRANSVERSES, NORMALLY FOR SERIES PRODUCTION AND IN PARTICULAR FOR ADDITION TO PLATE STIFFENED PANELS
S [3]	SUB-ASSEMBLY PRODUCTION FOR THE ENDS OF THE SHIP AND OTHER LESS DEFINED AREAS.
L [4]	PANEL LINE FLAT STIFFENED PANEL ASSEMBLIES
C	CURVED PANEL ASSEMBLIES FROM TELESCOPIC JIGS.
M. [5]	MINOR ASSEMBLY CARRIED OUT IN THE LIGHT PLATE AND STIFFENER BAYS.

ADDITIONAL CODES DEVELOPED FOR CODING

CODE DIGIT	ASSEMBLY DESCRIPTION
E	MATRIX OR EGGBOX ASSEMBLIES CONSISTING OF WEB AND WEB, OR WEB AND BRACKET SUB-ASSEMBLIES. (EG DOUBLE BOTTOM UNITS WITHOUT SKINS)
G	LONG GIRDER ASSEMBLIES REQUIRING COMPONENTS TO BE WELDED FROM BOTH SIDES. INCLUDING BOX GIRDERS.
K.	UNSTIFFENED FLAT PANELS, PLATE PARTS ONLY.
F	TROUGHED BULKHEAD (SWEDGED)

NOTES: 1 DEFINED AS SMALL BRACKETS GENERALLY REQUIRING ONE OR TWO STIFFENERS. NOT INCLUDING DOUBLE BOTTOM FLOORS

2 DEFINED AS BEING STIFFENED FROM ONE SIDE ONLY (IE NOT REQUIRING A TURNOVER OPERATION. TWO SIDED STIFFENING DEFINED AS GIRDERS.

3 INCLUDING WELDED PILLARS AND SEATINGS

4 INCLUDING BUILT UP PANELS (PLATE PARTS ADDED)

5 INCLUDING SMALL STIFFENED BULKHEADS

DEFINITIONS MADE DURING DATA COLLECTION EXERCISE.

Figure 35 Cammel Laird assembly code, and additional codes developed during research

At a later stage Cammel Laird and Swan Hunter Shipbuilders agreed to participate in data collection exercises.

Swan Hunter were in the process of installing a data retrieval system for material and production information flow systems. Components in each unit drawing were numbered sequentially as items, drawing office personnel then listed the components by item number, part numbered the components, and added complimentary information such as raw material numbers and dimensions. The information was recorded and inserted into a computer data bank for manipulation and later retrieval. Unit drawings and item lists were supplied to the researchers by Swan Hunter and students were employed to code the components and record the data in a form similar to that employed in previous exercises. The ship involved was a crude carrier of about 130,000 Tonne D.W.T. which was under construction at the Walker shipyard of the company. Sample item lists from the company system were shown in figure 18. Due to time limitations the sample collected was fairly small but the exercise showed that other data formats could be easily adapted to the project data format and comparative analyses of different vessels could be undertaken.

As previously described Cammel Laird had for some time been using a simple classification system devised to code assemblies by type. This was in preparation for the installation of specialised assembly lines and workplaces in the redevelopment of their shipyard. The shipyard drawings were therefore already both assembly and component numbered and a fully documented product breakdown existed. The researchers were supplied by Cammel Laird with ship assembly drawings and students were again engaged to code parts and collect data. However due to time and cost considerations approximately 70% of the ship hull component coding was completed and entered into the computer data bank after being punched onto data cards. Component data collection was found to be more difficult than with the Swan Hunter documentation, but a product breakdown was already defined in greater detail than in any shipyard who had previously collaborated.

5.5 Simultaneous part numbering and component coding

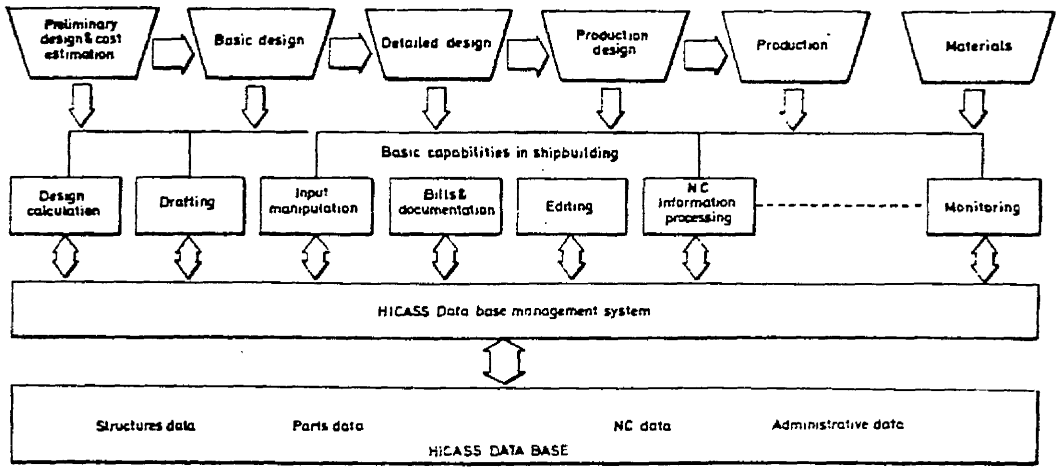
The most difficult task encountered in the coding of components and assemblies was that of locating and identifying the parts themselves from shipyard assembly plans (see Chapter 5.3.3) However this task has previously been executed by the detail design office in order to number parts and compile parts lists for raw material ordering and component production in the manufacturing shops. It can therefore be assumed that the coding operation time required can be drastically reduced by combining the component numbering and coding operations. This would involve a training programme for detail draughtsmen, checkers, or parts listers in the use of the classification and coding system employed. It has been shown that the component classification and coding system devised for the project is easily learned and applied by arts and engineering students. It should be even more easily learned by personnel who are familiar with shipyard drawings and documentation, particularly if the documents concerned are from their own particular shipyard.

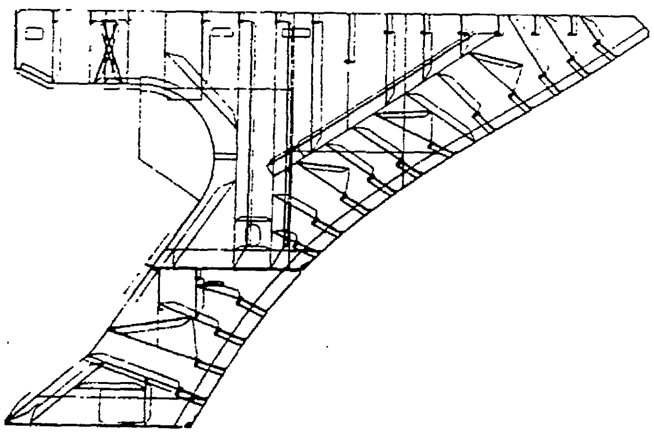
For contour cut components which are produced on N.C. machinery an alternative occasion for coding is at the N.C. coding stage. Here the component concerned is accurately described in a coded language which could be readily interpreted to the type of code described previously. Again a training programme would be required for the N.C. programmers to allow them to either code the component completely or add the elements which cannot be interpreted from the N.C. description. A disadvantage of coding at this point is that the process route for the component has already been devised, it is hoped to define this from the code number.

Any shipyard wishing to component code one of their vessels would be advised to train their own detail draughtsmen in the use of the code rather than employ new personnel who would have to repeat the component location and identification task. This aspect of concurrent part numbering and coding is particularly important where assemblies are concerned. In the case of the SD14 and B26 vessel product breakdowns the simple assembly classification code was used as part of the assembly numbering system as explained previously. It is also important that the complete detail design is developed from the start as a set of assemblies and sub-assemblies, rather than a set of components which are later grouped together to form the required assemblies. The latter method of arriving at a product breakdown is not fully compatible with the concept of assembly production lines for similar types of assemblies. Complete designs developed as assemblies, however, ensure that the product breakdown is compatible with the production system which was devised to manufacture the assembly types. It also ensures an inherent amount of standardisation in the design system by using the assembly code.

Computer aided design (C.A.D.) also has implications in the classification and coding of pieceparts and assemblies in shipbuilding. A recent development (many examples of which are still in progress) in the use of C.A.D. is in the field of structural detailing. Systems such as Foran (Spanish)[27], Hicass (Japanese)[28], and Viking[29] (Swedish) are all based on the application of computers to all facets of shipbuilding from preliminary design to detail draughting and the definition of information for production. The concept of a general shipbuilding information processing computer package built around a data base supporting a management system is common to all these developments. Examples of structural detailing from the HICASS system are shown in figure 36, these include a scantling drawing and a detail assembly drawing which would be developed from a scantling drawing; and also the system outline.

The Ship Structural Design System (S.S.D.S.)[30] under development at British Ship Research Association (B.S.R.A.) uses typical structural views for the development of all necessary assembly sketches. The typicals will be based on minimum scantling programs and will be slightly modified in each case to derive the actual assembly drawings required. These assembly drawings will be shown on a computer graphics display system and parts will be numbered and compiled into lists for marshalling and assembly. The resulting assembly drawings and parts lists will be





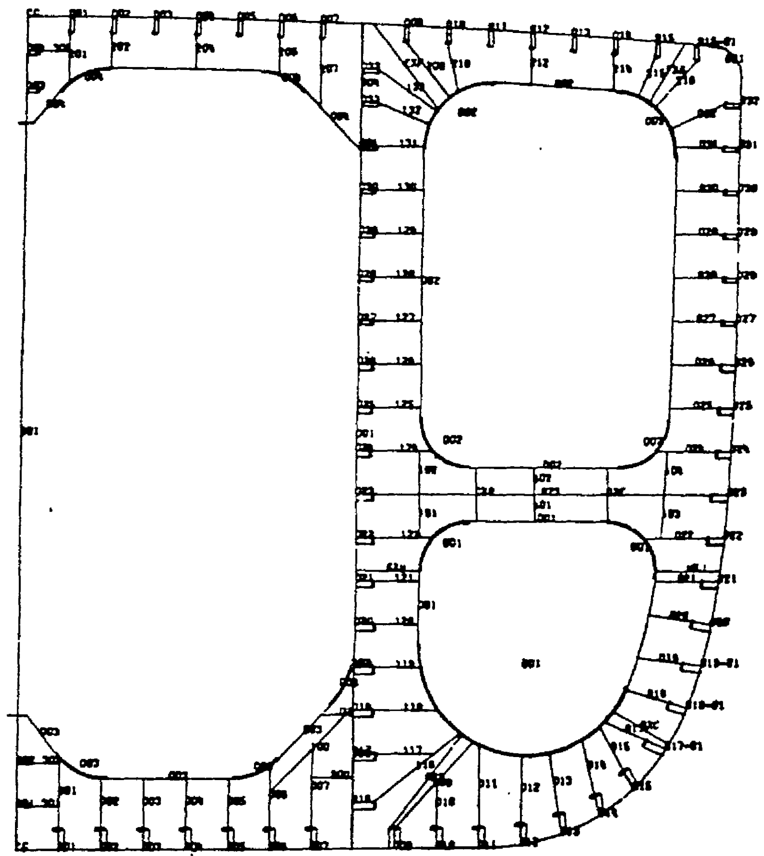


Figure 36 'HICASS' computer aided design system outline, and sample structural drawing output.

stored in the data base to be retrieved for subsequent manufacture. The possibility of coding assemblies and components at this stage will also be investigated, thus the coding operation in this case will be combined with both the detail design and part numbering tasks.

The feasibility of using the data base as a source of information for coding will also be investigated, although it will probably be necessary in this case to devise a further code to better exploit the format of the available data. Using this concept mannual coding operations will become unnecessary as computer procedures may be devised to extract the required data and transpose it. Although the information will already be in existance in the data base this process will convert it into a much more manageable form to apply in statistical analyses and in the investigation of production process design.

Chapter 6 Statistical analysis concepts

6.1 Potential benefits of statistical analyses

The value of statistical analyses in general manufacturing industries for the development and application of improved manufacturing methods and production systems is well proven. Analysis techniques are often employed in association with the introduction of group technology manufacturing systems, although benefits are obtainable from other uses of analyses. Component analyses in general metalworking industries in Germany and the United Kingdom have shown that a high degree of consistency exists among component populations. The statistical results of analyses carried out in various industries have been published for general use within the industries, and also for the benefit of auxiliary industries which offer services to the main one. These analyses have mainly been undertaken by academic institutions or research establishments with close affiliations to the industry involved (31) Alternatively many individual companies have undertaken analyses within their own organizations with the dual objects of standardisation and the introduction of cellular production techniques. The direct results of statistical analysis carried out by individual companies have been less frequently published although exercises concerning the introduction of group technology leading to improvements in throughput times and management systems have been more widely reported. The variety of industries where group technology techniques have been introduced following statistical analysis exercises range from the manufacture of highly specialised products such as friction brake linings (32) to valve gear (33) and structural steelwork industries. (24)

Statistical analyses have generally proved to be of value in the design of production machinery and production systems, areas of specific improvement have been:-

- In the design of production machinery to best suit the components which it is required to manufacture.

- In the reduction of material and component variety by grouping similar components together and allowing closer exploitation of the similarities, and the redesign of components to fulfil several functions.
- In the scheduling of individual machine or process workloads to enable similar components to be batched together, thus minimising down time due to set-up operations.
- In the development of manufacturing cells, each consisting of a group of machines to produce a family of similar components, thus gaining the advantages of lower set-up times, easing shopfloor management problems and limiting inter-process component movement.

A literature survey showed that no substantial analysis exercises had been undertaken or documented in the shipbuilding industry. Two examples were found of small scale analyses carried out for specific purposes. These were a craneage evaluation exercise, and an investigation of plate material passing through various metal cutting operations.

The craneage evaluation exercise was undertaken by a graduate shipbuilding apprentice in an Upper Clyde shipyard in the mid 1950's, and the results were described in a paper (34) presented to the Institute of Engineers and Shipbuilders in Scotland. Since then building methods have changed radically from the erection of numerous section and plate parts with only small assembly units on the slipway, to the modern practice of shed assembly of large structural units prior to berth erection. The chief consideration during the exercise was the crane requirements which would be required in the shipyard involved. It was shown that for 2,340 units comprising a 28,000 ton d.w.t. ore/oil carrier the average weight was 2.3 tons and only 15 units were greater than 20 ton. In addition 2100 ton of miscellaneous individual plates and sections were lifted to the berth of a total steel weight of 7500 ton Because of the changes in methods employed in the industry and the increase in scale of berth lifts, as well as the narrow objectives of the exercise the results of the project bear little relevance to modern shipbuilding management or techniques.

A survey carried out at Harland and Woolf was undertaken by the Systems Planning Manager and a systems specialist, and was documented within the company only. The report was published in 1974 and was only discovered when collaboration took place with Harland and Woolf in the later stages of research. It was therefore not available for reference during the coding and data collection exercises. The analysis concerned second stage preparation only; second stage preparation is a general term used by the company for all metal cutting, rolling, and shaping operations. The number of plates burnt by the various types of plate cutting machine employed in the shipyard were investigated using figures compiled from loft sheets for a tanker in production. The analysis was divided into seven sections corresponding to different cutting operations, these were;

a) plates burnt on single bed sicomat profile cutting machine with N.C. burning tape.

b) plates burnt on single bed Sicomat profile cutting machine with optical following head.

(These machines have no edge preparation facility, parts requiring edge preparation must be transported elsewhere for this to be achieved)

c) Plates burnt on double Sicomat profile cutting machine incorporating edge preparations facilities on burners. Used to burn components of full plate size.

d) Plates burnt on flame plane machines with edge planing facility and intended for panel line assembly. Used to burn components of full plate size.

e) Plates burnt on flame plane machines with edge planing facility and not intended for panel line assembly. Used to burn components of full plate size.

f) Plates burnt on flame plane machines without edge planing facility. Usually used for small plate superstructure components where edge preparation is not required.

g) Plates hand marked for burning on 'quicky' machine. Usually on pre-corrugated superstructure plates.

For each of the seven analysis sections the ship was divided into functional zones and thence into structure groups to follow material and production control and manufacturing practice. A table of the following statistics were prepared and presented for each functional zone:-

1. Structure group number
2. Number of weldments (fabrication units) in structure group.
3. Overall number of plates used in structure group.
4. Overall number of nests used in structure group
5. Number of plates with all edges planed used in structure group
6. Number of nests with all edges planed used in structure group
7. Number of plates with no edges planed used in structure group
8. Number of nests with no edges planed used in structure group
9. Number of plates with some edges planed used in structure group
10. Number of nests with some edges planed used in structure group
11. Total number of parts from plates with some edge planing
12. Number of parts with edge planing from plates with some edge planing
13. Percentage of parts with edge planing from plates with some edge planing.

For several of the analysis sections all of these categories were not applicable as the process from which they were derived did not allow edge preparation. A sample statistical table for a burning tape Sicomat machine for zone 1 of the ship is shown in figure 37 the summarised results are reproduced in figure 38. The exercise was concerned only with raw material size plates

SICOMAT MACHINES CONTROLLED BY BURNING TAPE (ZONES 1,2)

STRUCTURE GROUP	Nº WELDTS	Nº OVERALL		ALL EDGES PLANE		NO EDGES PLANE		SOME EDGES PLANE			PARTS E/P
		PLATES	NESTS	PLATES	NESTS	PLATES	NESTS	PLATES	NESTS	ALL PARTS	
1B	14	123	15	33	6	40	7	42	2	210	42
1D	24	99	12	76	7	23	5	–	–	–	–
1E	21	130	45	91	37	28	5	11	3	239	26
1G	20	171	21	76	86	36	7	10	3	74	18
1H	30	119	39	5	2	60	21	54	16	334	112
1K	28	258	56	177	39	73	16	8	1	24	8
1L	34	291	36	76	14	213	21	2	1	10	8
1V	18	94	11	70	7	16	3	8	1	24	8
1W	16	137	24	32	3	37	18	8	3	40	10
1X	18	89	15	36	6	37	5	16	4	32	16
1T	2	52	2	26	1	26	1	–	–	–	–
ZONE 1	225	1583	276	697	133	707	109	159	34	9873	248
%				44.6	48.1	45.2	39.6	10.2	12.3		25.1

Figure 37 Sample statistical table from an analysis of plate cutting operations carried out at Harland and Woolf (Belfast)

SUMMARY.

The plates for 1693 are burnt on the following machines:-

Sicomat		3437
B/T	2816	
O/D	621	
Double sicomat		819
Flame plane		1159
A/W (Panel line)	375	
A/W	540	
M/Y	244	
Hand marking & burning		254
All (excluding Multisec and Statsec)		5569

Rolling and shaping is mainly carried out on parts burnt on the Double Sicomat machine from which 61.2% of parts are rolled and 21.4% shaped.
Edge preparation is only important on those machines which do not have edge prep. facility, incorporated into burning heads, i.e. Sicomat machines.

on the Sicomat machines:
35.5% of plates have all parts edge prepared
50.2% of plates have no parts edge prepared.
14.3% of plates have some parts edge prepared.

The level of edge preparation is higher on the zones 4 - 7 than for the parallel midboby.

Figure 38. Summary results of an analysis of plate cutting operations carried out at Harland and Woolf (Belfast).

which were processed by cutting operations and not with the size and numbers of individual components which were produced. Thus only a simplified indication of the production volume passing through the machines, particularly the Sicomat machines, was achieved. In addition components produced from rolled steel sections were not considered. The scope of the analysis was correspondingly narrow although useful indications of the volume of work to be loaded on certain processes resulted.

It was proposed that statistical analysis exercises be undertaken with three objectives; to benefit the British shipbuilding industry in general, to benefit the specific shipyards who were collaborating, and to benefit the manufacturers of shipbuilding machine tools. Benefits to the British shipbuilding industry will chiefly stem from a statistical comparison of the steelwork components which comprise different shiphulls. This will enable a comparison to be made of the workload involved in building various ships using more reliable indices than at present. The measure of workload which is presently employed to gauge shipyard efficiency most often is steel tonnage throughput. However, ships are of varying complexity and therefore steel weight is not always a good indicator of work load even when an empirical weighting factor is employed. The number and shape complexity of parts required will present a more accurate assessment of the workload on the steel preparation shops. It will also give a better indication of the assembly shop workload as this is directly influenced by the number and complexity of the components forming the assemblies. Efficiencies of individual shipyards may then be compared using a common measurement unit, this will become increasingly important with the development of a national shipbuilding policy. The improved workload measurement will also assist in the development of improved cost estimating and cost control systems using correlation and regression techniques based on historical costs and associated workloads. In addition statistical descriptions will be of value in the investigation of the effects of producing various mixes of ship type and size on the productivity of an individual shipyard. It will also allow shipyards to investigate production facilities and manufacturing resources required to produce any mix of ships which may be proposed, and to plan accordingly. In the case of individual ship tenders the publication of standard sets of statistical tables describing the hulls of a variety of ships will allow shipyards to compare proposed ships with vessels previously built. This will result in a more accurate assessment of the time and cost it will take to build proposed vessels.

Benefits to a collaborating shipyard will result from analysis of its own shiphull data. The results will be of value when investigating workload fluctuations. The analyses will be considered in collaboration with workshop and berth schedules to compute the workload on various building facilities at any one time. This may be done for a specific ship over the building cycle, but for best results all ships under construction at any time must be considered and the individual workloads superimposed to find the total. By using this analysis method imbalances in workload on specific facilities can be highlighted and work-scheduling plans can then be modified to ensure a nearer optimum use of machinery and manpower. Analysis will also enable a company to plan its facilities and plant layout more scientifically with a thorough knowledge of production requirements. It will indicate the type of flame cutting equipment required, and also the type of guillotine, flange forming, and rolling machinery needed. Indications will also be given of the size of equipment and the number of machines required. It will also be possible to investigate the feasibility of employing different manufacturing techniques and systems in the shipyard concerned. These techniques might include the setting up of component manufacturing cells under group technology principles, or in the use of flowline principles.

Benefits to machinery manufacturers will result from publication of statistical tables following the analyses. These will be presented with particular reference to the size of the components and one set of tables will be presented for each production process. They will therefore be of value to the designers and manufacturers of machine tools in general in the design of construction and size of their products, and in particular in the specification of machine bed sizes.

6.2 Statistical analysis methods

6.2.1 Range of analysis methods employed

Information was collected on data sheets and then transferred to punched cards, as described in the previous chapter. Four data analysis methods have been employed to investigate the material and component parts described in the resulting data bank. They range from simple punched card sorting in the early stages to the use of a specialised computer data analysis package to carry out a full statistical analysis. In addition Fortran computer programs were developed to use in conjunction with the data analysis package and another statistical analysis technique based on a commercial data manipulation and retrieval package was developed. The complexity of the analysis methods reflect the stage at which the specific analysis was undertaken and the experience of the author in data processing techniques at that time.

6.2.2 Data manipulation and retrieval packages

Initial data analyses were carried out by mechanical card sorting methods, but this was found to be tedious and often required the data card set to be duplicated. Although the technique has these drawbacks it was found to be a useful tool in early analysis exercises while investigating more advanced analysis methods. It also gave a good indication of the methods needed to produce analysis results which would be meaningful and of value to the shipbuilding industry, and in particular to the collaborating companies.

Two data manipulation and retrieval packages were examined for possible use in data analysis exercises. These were the Store and Manipulate package by Honeywell, and the Composit 77 package by Comshare Limited. Store and Manipulate (S.A.M.)(35) is a Honeywell software package which was installed on the Strathclyde University Time Sharing Programming System (T.S.P.S.). It was freely available for research and access was possible by using a remote terminal and internal telephone lines. It was employed to carry out analysis exercises on the component descriptive data banks available at that time. Data was stored on disc file in the computer and was freely available for interogation using the S.A.M. package. Thus by using commands (count, display) and comparison codes the S.A.M. package presented both a powerful file editing facility and a useful tool for the retrieval of specified data. It fully replaced the card sorting procedures which had been employed initially in analysis exercises. The advantages over card sorting were that data could be continually processed without renewing data cards, the retrieval operation itself was more speedy, and listings of required information were available immediately on the remote terminal. The major disadvantage that it was only possible to count data records rather than numbers of components required was retained. Thus the only advantages which resulted were that the process was easier to use and quicker in response.

Composit 77,[(36)] a program similar to S.A.M. was used by A. P. Appledore for their further data analysis needs. It is a package supplied by Comshare Ltd., a computer bureau service, which allows data collections and storage, information retrieval, information analysis, reporting results, and data control. The data in store on the Strathclyde Honeywell computer was transferred to storage on the Comshare time sharing system using magnetic tape. Thus A. P. Appledore were able to independently examine the data bank information as required. This exercise was part engineered by the researchers who explained to the company the fundamentals of the system following initial contact with Comshare and approximate costing.

6.2.3 Statistical Package for the Social Sciences

The Statistical Package for the Social Sciences (S.P.S.S.) (37) is a collection of computer programs developed at Stanford University to describe and analyse social science data. The system consists of a control program, general service routines, and a number of associated statistical subprograms. It is Fortran based and therefore easily understood and used by technologists who are familiar with that language. The control cards used to describe the data and the procedure to be carried out are written in a quasi-natural language and have a simple layout. They consist of operating commands requesting the statistical programs required, and data definition cards which specify the format of the input information and assign full names to numbered variables. These may be required to ensure that output information can be directly interpreted by the layman. General service routines are available throughout a job and at any stage between analyses; they provide facilities to recode, transform, or generate variables and sample, weight, and select cases. Before carrying out statistical procedures data may need modification either by a transformation operation or by grouping values of continuous variables into discrete categories or some other recoding operation (see ref.37) The most useful of the subprograms were found to be Codebook and Crosstabs. In particular Crosstabs allowed consideration of the size of components (length and width for plates, and length and depth for sections) for each production process. The process itself was determined by the shape characteristics of the parts, (shown by example in figure 39).

S.P.S.S. was available on the University of Strathclyde computer, and later on the Edinburgh Regional Computing Centre (E.R.C.C.) facilities using Glasgow University periferal devices. The data banks which had been processed using the previously described analysis methods were transferred to magnetic and disc storage files on the Glasgow facilities. In addition ship hull component data which was collected in the later stages of the exercise was directly input to the Glasgow facilities using standard eighty columns data cards. Data files were set up for each structure group of each ship to allow them to be analysed individually using S.P.S.S. They could also then be grouped into larger structure zones, or even complete ship hulls, for various collective analysis exercises.

In a number of cases where S.P.S.S. could not provide the desired analysis a short Fortran program was written. However, the writing and debugging of a program is time consuming and so was kept to a minimum. In most cases

FILE NONAME (CREATION DATE = 03/13/75)
SUBFILE B261 B262

* * * * * * * * * * * * * * * * * * * C R O S S T A B U L A T I O N O F * * * * * * * * * * * * * * * * * * *

VAR009 LENGTH BY VAR010 WIDTH
CONTROLLING FOR..
VAR002 CUT PLATE SHAPE VALUE = 3.00

* PAGE 1 OF 1

VAR009 (COUNT / TOT PCT) \ VAR010	LT.300MM 0.0	300-450MM 1.00	450-600MM 2.00	600-900MM 3.00	900-1200MM 4.00	1200-1600MM 5.00	1600-2000MM 6.00	2000-2500MM 7.00	2500-3000MM 8.00	GT.3000MM 9.00	ROW TOTAL
0.0 LT.300	14	1	0	0	0	0	0	0	0	0	15
	2.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
1.00 300-600MM	34	35	0	0	0	0	0	0	0	0	69
	6.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3
2.00 600-1000MM	3	4	38	5	0	0	0	0	0	0	50
	0.6	0.8	7.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7
3.00 1000- 1500MM	0	14	15	99	16	1	4	0	0	0	149
	0.0	2.7	2.9	19.1	3.1	0.2	0.8	0.0	0.0	0.0	28.8
4.00 1500- 2500MM	0	6	16	4	4	7	3	46	0	0	86
	0.0	1.2	3.1	0.8	0.8	1.4	0.6	8.9	0.0	0.0	16.6
5.00 2500- 4000MM	2	3	0	6	4	3	3	0	5	4	30
	0.4	0.6	0.0	1.2	0.8	0.6	0.6	0.0	1.0	0.8	5.8
6.00 4000- 6000MM	2	3	2	6	2	2	4	16	15	3	55
	0.4	0.6	0.4	1.2	0.4	0.4	0.8	3.1	2.9	0.6	10.6
7.00 6000- 7500MM	0	2	0	0	0	3	8	2	11	4	30
	0.0	0.4	0.0	0.0	0.0	0.6	1.5	0.4	2.1	0.8	5.8
8.00 7500- 9000MM	0	2	0	0	0	2	0	0	0	0	4
	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.8
9.00 GT.9000MM	0	0	0	0	0	4	16	8	2	0	30
	0.0	0.0	0.0	0.0	0.0	0.8	3.1	1.5	0.4	0.0	5.8
COLUMN TOTAL	55	70	71	120	26	22	38	72	33	11	518
	10.6	13.5	13.7	23.2	5.0	4.2	7.3	13.9	6.4	2.1	100.0

CHI SQUARE = 1163.56659 WITH 81 DEGREES OF FREEDOM SIGNIFICANCE = 0.0

Fig. 39 Sample S.P.S.S. output; cross tabulation of length by width for all plate components which are straight-sided (subfiles B261 and B262 previously created) and foursided with one or two square corners (VAR002, cut plate shape = 3).

the program was used to rearrange the data file so that the S.P.S.S. package could give the desired results. This technique was also used to economise on computing costs as it was found that the running costs for the package were high. By reducing the size of the working file before beginning S.P.S.S. the running costs of the system were correspondingly reduced.

Chapter 7 Raw Material Analysis

7.1 Potential material cost savings

Analysis of raw material can result in the reduction of shipyard costs by both direct and indirect means. The cost of raw material can be divided into direct steel cost and indirect (or stockholding) costs which includes handling, storage, and depreciation costs.

Direct steel costs consist of the basic cost of the steel and additional increments which the supplier adds in an attempt to persuade the customer to order in size ranges which suit the manufacturing and distribution process. For shipbuilding quality rolled steel plate the basic price of the steel is given in pounds per tonne for a basic size; sizes other than the basic may carry additional extra price penalties which are again in pounds per tonne. Typical price zone tables for British Steel heavy rolled steel plate are shown in figure 40 (as at March 1976).[38] Steel costs may be lessened by either reducing the weight of raw material purchased, or by ensuring that raw material sizes are within economical zones of the price structure employed. It is theoretically possible to increase the weight of a plate and decrease its price, and the British Ship Research Association (B.S.R.A.) have developed a computer package (Steel Plate Ordering Technique - S.P.O.T.)[39] to exploit these anomalies in the steel pricing system. The input to the package consists of raw material plate sizes which have been previously defined using traditional shell and deck plating and component nesting techniques. These sizes are increased to decrease the total steel cost, the technique also involves the grouping of smaller size raw material plates onto larger areas. The technique has been used by Robb Calledon of Dundee to optimise their steel plate ordering on a total cost basis. However, economic advantages gained from a study of these aspects are fairly small, chiefly because the size penalties are small compared to the basic price. Thus the advantages occur only in size tolerances very close to the range divisions and under the present price system an investigation has little scope for making savings.

Extra £ per tonne

Width – mm	15 to 20 mm thick						over 20 to 30 mm thick						over 30 to 40 mm thick					
	Length																	
	mm 1500 to under 3000	mm 3000 to under 4000	mm 4000 to under 8000	8000 mm to & incl. 12.0 m	over 12.0 m to 16.0 m	over 16.0 m	mm 1500 to under 3000	mm 3000 to under 4000	mm 4000 to under 8000	8000 mm to & incl. 12.0 m	over 12.0 m to 16.0 m	over 16.0 m	mm 1500 to under 3000	mm 3000 to under 4000	mm 4000 to under 8000	8000 mm to & incl. 12.0 m	over 12.0 m to 16.0 m	over 16.0 m
450 to under 600	20·00	18·00	16·00	17·50	18·50		21·00	19·00	17·00	19·00	21·00		22·00	20·00	18·00	20·00	22·00	
600 to under 800	17·00	15·00	13·00	14·50	15·50		18·50	16·50	14·50	16·50	18·50		21·00	19·00	17·00	19·00	21·00	
800 to under 1000	14·00	12·00	10·00	11·50	12·50		16·50	14·50	12·50	14·00	16·00		18·50	16·50	14·50	16·50	18·50	
1000 to under 1300	11·50	9·50	7·50	9·00	10·00		14·00	12·00	10·00	12·00	14·00		17·00	15·00	13·00	15·00	17·00	
1300 to & incl. 1600	10·00	8·00	6·00	7·50	8·50	10·50	12·50	10·50	8·50	10·50	12·50	14·50	15·00	13·00	11·00	13·00	15·00	17·00
over 1600 to 1800	8·50	6·50	4·50	6·00	7·00	9·00	11·00	9·00	7·00	9·00	11·00	13·00	12·50	10·50	8·50	11·00	13·00	15·00
over 1800 to 2100	7·00	5·00	3·00	4·50	5·50	7·50	9·50	7·50	5·50	7·50	9·50	11·50	11·00	9·00	7·00	9·50	11·50	13·50
over 2100 to 2250	5·50	3·50	1·50	3·00	4·00	6·00	8·00	6·00	4·00	6·00	8·00	10·00	10·00	8·00	6·00	8·00	10·00	12·00
over 2250 to 2500	4·00	2·00	Basis	2·00	3·00	5·00	7·00	5·00	3·00	5·00	7·00	9·00	10·00	8·00	6·00	8·00	10·00	12·00
over 2500 to 2750	5·50	3·50	1·50	3·00	4·00		8·50	6·50	4·50	8·50	8·50		11·00	9·00	7·00	9·00	11·00	
over 2750 to 3000	7·00	5·00	3·00	4·50	5·50		10·00	8·00	6·00	8·00	10·00		12·00	10·00	8·00	10·00	12·00	
over 3000 to 3250		6·50	4·50	6·00	7·00			9·50	7·50	9·50	11·50			11·00	9·00	11·00	13·00	
over 3250 to 3500		8·00	6·00	7·50	8·50			11·00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
over 3500 to 3750		9·50	7·50	9·00	10·00			12·50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
over 3750 to 3950		11·00	9·00	10·50	11·50			14·00	12·00	14·00	16·00			17·00	15·00	17·00	19·00	

Notes:—1. The length is defined as the greater dimension, the width is the lesser.
2. The maximum dimensions should be confirmed with the Works before orders are placed.
3. Sizes not included in these tables may be supplied subject to special arrangement.

Figure 40 Sample British Steel heavy rolled steel plate price chart

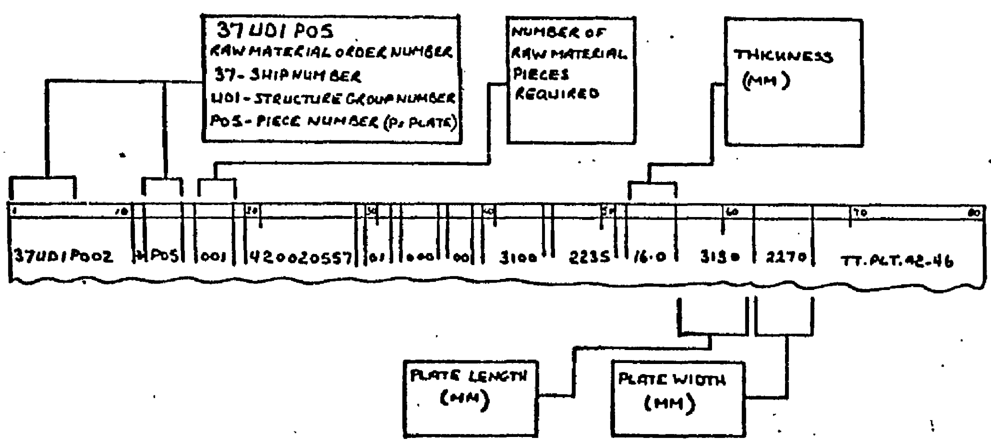


Figure 41 Data collection format (emphasising raw material information for plates)

Stockholding costs consist of handling, storage, and depreciation costs. The historical system of ordering a raw material piece with individually specified dimensions to produce a specified component or group of components increase the management problems which occur in ensuring that the correct raw material is available for production when required. This system requires the storage of different size raw material pieces in stacks (usually by fabrication unit) because of the space limitations. This in turn results in restacking operations to ensure that individual raw material pieces are available when required. Thus handling and storage costs can probably be reduced by introducing or increasing the use of standard size raw material. The introduction of material size standards can also result in a decrease in the total amount of steel required to be held in stock. This is possible because of the increased flexibility allowed in the manufacturing operation achieved from the interchangeability of raw material. Thus stockholding and depreciation costs are also reduced by the increased uses of raw material standard sizes. A raw material analysis can be undertaken to define the most economic standard sizes and thus reduce handling, storage, and depreciation costs. However, the degree of standardisation possible can be constrained by the increase in ship weight which may result, this is discussed further in the next section.

Raw material analyses which have been carried out have been concerned with information from two sources. These are directly collected information from existing raw material records, and raw material requirements generated from data describing components which must be produced from the material itself. Data collected from existing raw material lists is more accurate than that generated from component data in that the latter is estimated information while the former is factual. Existing information is easily collected and analysed as all shipyards must prepare lists of raw material in order to buy the steel from the producers. These lists can be readily translated into core-stored data so that computer data processing and analysis techniques can be employed, this can therefore be achieved without any reference to the component information. However the existing information is defined and collated by production planners and steel ordering personnel from the original component definition, there may therefore be more economical methods of nesting and ordering the material. Raw material requirements traditionally defined from component information require systems to estimate values of the area of plate or length of section. They require further factors to compensate for scrap percentages involved in nesting the components and 'green' material from edges of plates and ends of section lengths.

7.2 Standardisation of plates

An exercise has been carried out to investigate the possibility of standardising raw material plate sizes, and hence ease probable stockyard layout and material control problems for SD14 production. This was possible because of the availability of the original data bank which was collected during the early stages of research. The data collection format, with raw material information emphasised, is shown in figure 41 and consists of the raw material mark number and the size of the plate or section. The raw material mark number was referenced to the structure group into which it was eventually incorporated by means of the structure group number. The raw material piece number within the structure group was therefore noted in the data record format only, the structure group number which was necessary to identify individually the raw material piece could be found from the individual component number. The prefixes P for plates and S for sections were also added to the raw material piece number to aid identification and data processing. In addition the difficulty caused by the fact that several components might be manufactured from a single raw material piece was overcome by, where possible, noting raw material sizes for one component record only, and also by noting the number of raw material pieces required only on the record in which the sizes were noted.

The data bank was initially reduced by deleting component records which had no reference to raw material piece numbers required or size, i.e. which had blanks in the relevent data card blocks. This was accomplished by using the Store and Manipulate (S.A.M.) computer package which is fully described in Chapter 6.2.2. An investigation was then made into the variety of raw material sizes which existed in the steel plate lists at that time, this was again accomplished by using the S.A.M. computer package. The raw material plate data file was fully listed and the total number of raw material thicknesses was then extracted manually, and the individual thicknesses noted. The 'print all' command was the employed to produce lists of all plates of the same thicknesses in ascending order of thickness until all plates had been listed. The counting mechanism available in the package was then used to ensure that all plate data records had been listed. This allowed visual investigation of the pieces according to thickness and was kept for reference purposes.

It was decided to attempt to reduce the variety of raw material sizes by reducing the number of thicknesses and reducing the number of different widths; this would involve the definition of both thickness and width 'standards'.

a) Definition of thickness standards

The total range of plate thicknesses was listed together with the number of raw material pieces which resulted is shown in figure 42. A visual inspection of the table showed that several thicknesses of plate required relatively few raw material pieces to be ordered. Thicknesses of plate can only be standardised by increasing the present values if they are decreased the 'scantlings' or structural strength of the ship can be adversely affected. It was therefore necessary to replace the thicknesses which were not often required by increasing them to the next 'popular' size. However an increase in ship weight would result which would be detrimental to the operating performance of the completed vessel. The weight increase would also result in a higher steel

TABLE I

STEEL PLATE STANDARDISATION - THICKNESS (BELOW 25.5 mm)

Thickness (mm)	Number of Plates	Total Weight (Tonne)	Thickness Increase (mm)	Resulting Extra Weight (Tonne)	Alternative Thickness increase (mm)	Resulting Extra Weight (Tonne)
6.0	7	1.29	0.5	.107		
6.5	170	88.76	Standard			
7.0	12	9.06	0.5	.647		
7.5	131	90.71	Standard			
8.0	32	25.95	Standard			
8.5	15	11.73	0.5	.690		
8.7	13	13.79	0.3	.476		
9.0	40	32.44	Standard			
9.2	4	2.35	0.3	.076		
9.5	62	52.13	Standard			
9.7	1	1.17	0.3	.036		
10.0	208	215.42	Standard			
10.2	13	12.84	0.3	.378		
10.5	86	112.33	Standard			
11.0	152	133.98	Standard			
11.5	69	94.72	Standard			
11.7	4	5.83	0.8	.399		
12.0	12	13.70	0.5	.571		
12.2	8	7.80	0.3	.192		
12.5	145	156.05	Standard			
12.7	47	48.01	0.3	1.134		
13.0	42	62.40	Standard			
13.5	32	46.30	Standard		0.5	1.73
13.7	6	5.64	0.3	.123		
14.0	70	126.68	Standard			
14.5	14	18.81	0.5	0.648		
15.0	84	188.40	Standard			
15.2	1	1.73	0.8	0.091		
15.5	8	12.09	0.5	.390		
16.0	32	53.51	Standard			
16.5	6	5.33	1.0	.323		
17.0	12	32.01	0.5	.941		
17.5	50	155.15	Standard			
18.0	62	168.34	Standard			
18.5	16	24.42	Standard		1.0	1.320
18.7	1	1.52	- 0.2	- .016	0.8	0.060
19.0	13	12.76	0.5	.336	0.5	0.340
19.5	7	21.00	Standard			
20.2	1	2.12	0.3	.031		
20.5	2	3.10	Standard			
25.0	1	0.35	0.5	.007		
25.5	15	30.94	Standard			
Totals	1706	2102.47		7.580		

Original number of thicknesses	=	42
Proposed number of thickness standards	=	21
Increase in steel plate weight	=	0.36% of steel plate

Figure 42 Proposed standard plate thicknesses and resulting weight increases

cost and increased labour costs where labour bonus systems are based on steel weight throughput. Before defining standard thicknesses a check would have to be made that the steel weight was not excessively increased.

Two fortran programs were devised to calculate the total weight of plate of a specified thickness and the increase in weight of plate caused by increasing a specified thickness by a specified amount. The formula used in the first program to calculate the total weight value of a specific weight record is given by:-

W = volume of plate x density x number of plates required (where volume = length x width x thickness)

The individual plate reoord weights were summed to result in a total weight for that thickness.

The second program for calculating the extra weight caused by thickness increase requires a data subset. of the plates required of the thickness to be increased. Temporary data files were prepared for each thickness by duplicating the raw material file and then deleting all records other than those of the required thickness. The temporary files were then used as input for the weight calculation program. Following development of the individual thickness data subset the thickness increases required were input into the program. The program was then repeatedly run. Output consists of the weight increase for each raw material plate record and the total weight increase for the specified thickness increase. The complete table showing present thicknesses, plate numbers, and proposed standard thicknesses, together with present weights and weight increases is shown in figure 42 It can be seen that the total number of thicknesses can be reduced from 42 to 21. This is achieved at an extra cost of 7.580 tonne of raw material plate or (deducting 15% scrap) 6.445 tonne finished ship weight, an increase of 0.4% An alternative set of standard thicknesses were also considered which reduced the number of thicknesses further to 19 at a further steel weight cost of 3.45 tonne, these are included in the table. As already stated material thickness has been increased only, but it may also be possible to decrease that of certain low stressed parts (i.e. partition bulkheads, auxiliary seats) thus reducing the proposed weight increase. It may also be possible to increase the number and size of lightening holes where material thickness is increased. Both these exercises can only be carried out under the guidance of a naval architect as they affect the structural stability of the ship.

b) Definition of width standards

Programs were also devised to aid in the definition width standards and thence to determine the weight increase which would result. The first program allows the user to print out plate orders for material of a defined thickness in width size ranges which have incrementally increasing limits. The thickness is specified by the user who changes the relevant statement before running the program, thus listings are produced with each program run for one thickness only. The width limits of each range are generated by the program itself. The initial range is defined as 500 - 600 mm and with each operation of a program loop these are increased by 100 mm an upper limit of 3000 mm is imposed on the lower range boundary. The ranges are initially printed and any raw material orders which fall into the range category and are of the thickness specified are printed under the range limits. A listing was produced for each thickness of plate which was present in the raw material data collected. It was noted that the lists gave a good indication of plates which could be grouped together on a length or width basis in order to increase the size of the raw material piece. For example the plates below could possibly be combined before any standardisation program begins:-

DH4P26	size	2740 x 925 x 6.5
and DH4P17	size	3660 x 1080 x 6.5
combined to give	size	5400 x 1080 x 6.5.

(Care should be taken in this procedure to ensure that the material pieces are from the same structure group, otherwise practical problems of storing the resulting components for long periods between cutting and erection will occur.)

The listings were then inspected visually for indications of possible useful standard width sizes which were just larger than a large group of 'natural order widths'. Following inspection arbitrary widths were selected as standard for each thickness. This was done for each thickness, as raw material stockpiles are required for different thicknesses. The width standards were therefore within the previously defined thickness standards (or vice versa), by using this procedure the resulting increases in steel weight were less than those occuring when the same standard widths were applied across the total steel order system.

A program was then written to find the increase in weight which would result by using these standards widths. The basic principles employed in the program were that the data record specified width was compared to an upper and lower standard width and if it fell between them the data record was listed the weight was calculated and added to a running total. The weight of the plate when the width was increased to the upper standard was also found and added to a second running total. Following investigation of each data record the total weights of the original and the proposed material orders were printed.

The program originally envisaged employed the full raw material data bank and selected a pre-specified thickness of raw material, however it was soon realised that this procedure was expensive in terms of computer running time. Therefore prior to running the program it was proposed that the user would reduce the size of the data bank by creating a temporary duplicate data bank and deleting records other than those of the thickness required. This process has been described previously.

Following the development of the programs described in this chapter it is possible to closely analyse the existing raw material plate orders for a series ship. It is also feasible, where material orders are prepared at an early enough stage of the production process, to carry out a similar analysis for one off or short series ship production. From these analyses attempts at standardisation or order sizes using the existing plating and nesting arrangements are feasible. The existance of a full data bank with component and raw material information is not necessary to attempt the analysis and standardisation procedure. However the raw material orders must be prepared in a form which allows computer data processing techniques to be employed. The general procedure which it is envisaged will be employed will be that first plate thicknesses will be standardised using the programs described in section (a) and then within these widths will be standardised using the programs described in section (b). The standardisation of plate lengths has not been investigated as it was assumed that the machinery employed in steel rolling mills (flying shears) would allow varying lengths of plate to be purchased with little difficulty, however the problems of stockholding and marshalling will still arise.

A full analysis of the SD14 was not carried out but the feasibility of employing standard plate thicknesses was looked at in depth and the full weight extras involved were calculated, these included scrap and ship weight proportions. A further exercise involving plate thickness value 6.5 mm was completed to standardise plate widths, and the increase in scrap weight was calculated. It was thought that a full analysis should be undertaken by shipyard personnel with first hand knowledge of the practical problems involved. A summary report (appendix D) was therefore prepared and distributed to the two U.K. shipyards who were building or preparing to build the SD14 vessel, these were Robb Calledon (Dundee) and Austin and Pickersgill (Sunderland)

The abbreviated data bank containing raw material information only (both plate and section) was also used to prepare data for a South American company who were to produce the SD14 under licence. This data was prepared to enable early bulk steel ordering from countries outside that of the manufacturing company to overcome the problems involved in transporting it. The data was listed categorically (by thickness and width for plate, and section type and size for sections) and supplied to A. and P. Appledore who were dealing with the commercial aspects of the licencing agreement. It was possible to do this quickly and efficiently using computer data processing techniques available on the Strathclyde University Honeywell time sharing system, and a remote terminal situated in Newcastle upon Tyne with a G.P.O. telephone connection. The exercise proved the value of a computer stored data bank for ease of processing and the speedy retrieval of information when required quickly.

7.3 Estimation of Section Material Requirements

Raw material analyses have been carried out for section material for both the SD14 and the B26 vessels, both now under construction at the Southwick shipyard of Austin and Pickersgill. The analysis served three purposes:-

i) The estimation of the amount and type of section material required for ordering purposes.

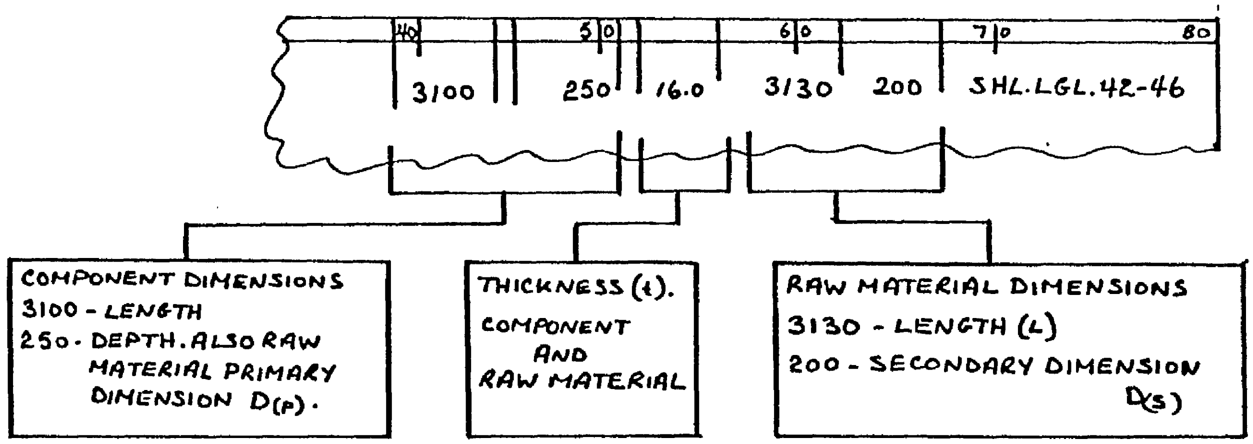
ii) An estimation of the extra steel stockyard requirements for section storage caused by an increase in production rates (i.e. faster building cycle).

iii) The calculation of the transport and material handling facilities required for handling section material in a new shipyard design.

The approaches taken when analysing the raw material requirements for the SD14 and B26 vessels varied with the differences in content and format of information available in the respective data banks. A full listing of the information covering existing section raw material orders was available for the SD14 in the data bank which was collected in the early stages of the project. This described section components and the raw material they were derived from in a manner similar to that described for plate parts in the previous section. In addition the absolute values of three cross-section dimensions was available, these included the thickness and the primary dimension from the component size description, plus a secondary dimension from the raw material size description. The thickness, primary and secondary size definitions varied between types of section and examples for more common cross-sections are shown in figure 43. In many cases (flat bar, bulb flat) the secondary dimension was not necessary and so the primary dimension was repeated in the raw material size, this eased later analysis exercises. Thus a detailed analysis of the section raw material requirements for the SD14 was possible.

The data bank describing the hull of the B26 contained component and assembly information, but no raw material data. At the time of data collection the B26 was still at the pre-production stage; one vessel had been built several years previously and the ship drawings were available but the material lists were not at hand and in any case would probably have been misleading due to metrication of order sizes. The component information was stored using the descriptive classification and coding system which was developed during the project. The number of components required in the relevant assembly, the number of assemblies in the ship, and the absolute thickness value of the material were also available in the data bank. By aggregating the products of the number of individual components required in each section of ship the total number of individual components could be arrived at.

The section dimensions available from the B26 data bank consisted of the absolute thickness and an approximate depth and length only. The latter information was available from the size range digits included in the classification code, an approximate value of the thickness was also available from the code but this was made redundant by the absolute thickness available elsewhere in the data record. The analysis for the B26 was therefore based on component information from which material order lists would later be devised in the traditional shipbuilding method. The ana-



SECTION OF COMPONENT DATA RECORD SHOWING RAW MATERIAL SIZE SOURCES. SEE BELOW FOR DEFINITION OF t, $D_{(P)}$, AND $D_{(S)}$.

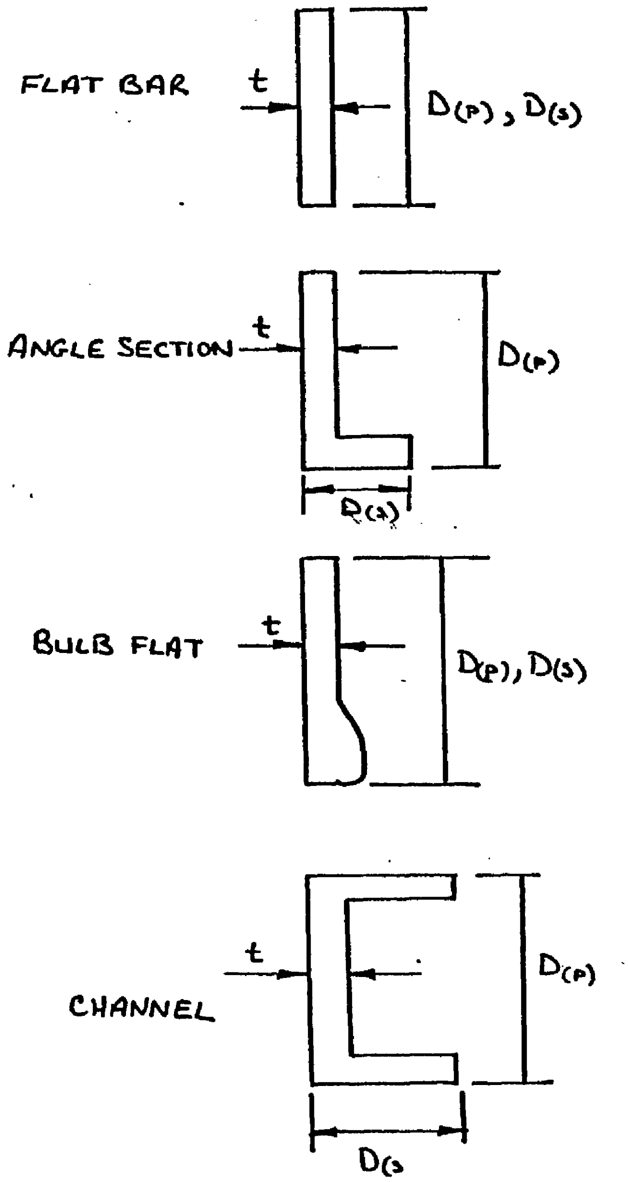


Figure 43 Data collection format (emphasising raw material information for sections)

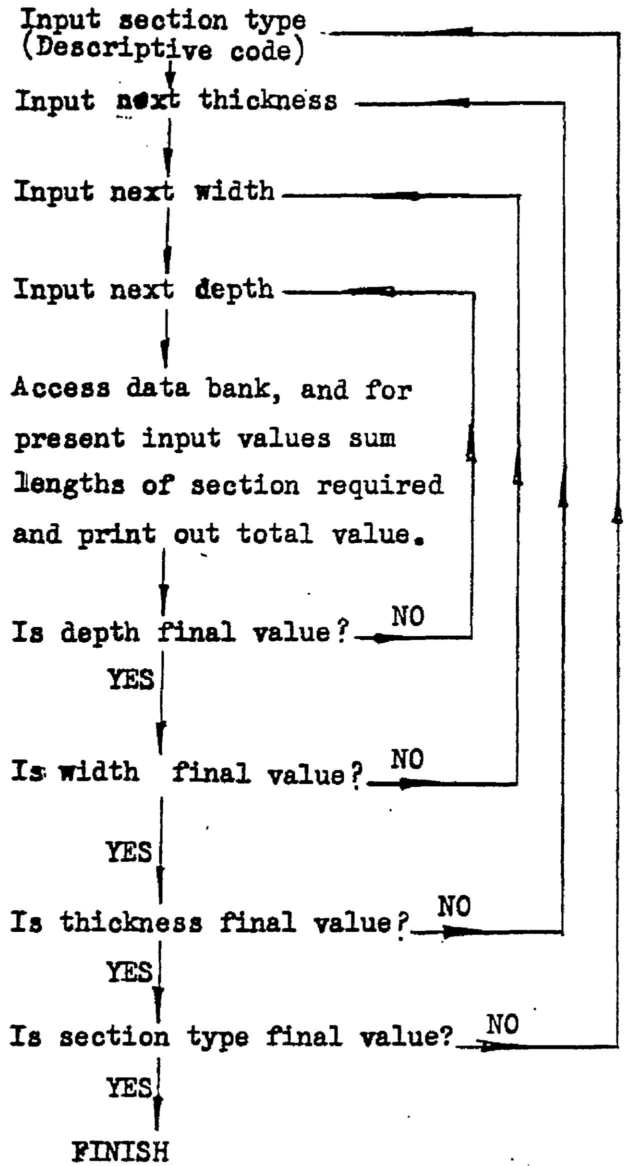


Figure 44 Flow diagram of computer program to analyse section bar raw material

Section type	Total number of section sizes	Number of section sizes using less than 20 metres	Number of section sizes using less than 20 metres
Flat bar	68	37	17
Bulb flat	31	10	3
Angle section	72	34	22

Figure 45 Section bar raw material analysis showing low usage of certain sizes (S.D.14 Cargo vessel).

lysis was less detailed than that for the SD14 because less accurate descriptons of section sizes were available, however by this method options to standardises material sections at a later data were still possible.

a) SD14 section analysis

A full analysis of the existing SD14 section material lists would have been possible in a manner similar to that described for plates (section 2 of this chapter). However it was realised that with the proposed change in building method and fabrication arrangement (unit breakdown) the raw material section requirements might change radically. The section cross-section types and sizes would still remain the same to achieve the same structural strengths in the ship, but the lengths of section raw material pieces might change with the alteration of unit boundaries and corresponding length of units. However the total length of each section type and size would remain the same although a different number of pieces of different length might be ordered. It was therefore decided to present section material information as total lengths required for cross-section sizes within cross-section types. Fortran programs were written to sum the raw material length for different combination of section type, thickness, width, and depth. The flow diagram for the process is shown in figure 44 and the results of the analysis are shown in appendix E

From the listings of section sizes it can be seen that several fractional metric sizes are requested (i.e. flat bar 6.4 mm, 10.2 mm, 12.7 mm), this is most probably caused by a direct conversion from imperial to metric units at some time previously. There is also a wide range of stiffening sections employed many of which require a total length of less than 20 M, the table in figure 45 shows the extent to which this occurs for flat bar, bulb flat bar, and angle sections less than 25 mm thick. It is therefore obvious that scope is present for standardisation of section including in certain cases the replacement of one section type with another of similar modulus or strength characteristics. This may involve slight modifications to panel stiffening arrangements where a section of higher or lower modulus is applied, but in all cases the total weight for equivalent assembled panel or member strength will be the governing factor. The listing of total length of material needed highlights the sections which may be replaced and forms the basis for standardisation following more detailed structural analysis by a Naval Architect.

Following compilatation of the total length of each type and size of section required an estimate of the number of section material pieces to be stocked during the building of the ship can be carried out. This can be achieved by dividing the total lengths by the average length of raw material pieces, this may be derived historically or by investigating the longest stiffening lengths required from the unit breakdown which is proposed. This was done for the SD14, where the immediate production process following section treatment was also derived from the descriptive code number. Thus the number of raw material section pieces required from the stockyard and the workshop areas to which they are despatched is found. The results of the exercise is shown in figure 46.

b) B26 analysis

A similar analysis was carried out for the B26 bulk carrier which was about to be produced by Austin and Pickersgill. A similar technique was employed to that used earlier for the SD14, however as previously specified the descriptive code number of the components and number of each component required was available. The total length of section required for each type of section was found using the flow chart previously shown in figure 44, but in this case code digit values for section depth rather than absolute values were input into the process. The midpoints of the length ranges were used to estimate the length of each individual component and these were then aggregated, the accuracy involved when using the range midpoints is discussed in section 5.2.3. Thus the values obtained were comparable with those for the SD14 for section type and thickness, but were not as accurate for depth and length where size ranges and midpoints were employed.

An analysis was carried out for each structure group of the B26 (this can also be done for the SD14)

The total length of section involved for each structure group was divided by the length in which it was proposed to purchase the material to give the number of section lengths to be bought, stored, and transported. The analysis was made while the component data bank was still in process of being collected and was required urgently to enable material handling facilties in the proposed shipyard workshops to be designed. Estimates based on samples were therefore used for three structure groups for which the data banks had not been completed. The resulting table which was presented to A.P. Appledore for use in the design of the new shipbuilding facilities for Austin and Pickersgill is shown in figure 47

7.4 Influence of standardisation on design

Analyses described so far have been chiefly concerned with existing raw material and component lists for the SD14. However in order to achieve the greatest benefits from raw material standardisation efforts must be made to use standard sizes in the detail design of a ship. This must be attempted particularly in the definition of fabrication arrangements and specification of plating arrangements for large panels, and in the nesting of both plate parts into rectangular sizes and section parts into specified lengths.

The correct selection of standard sizes prior to their incorporation into the design system is necessary to ensure that maximum advantages are obtained. Factors to be considered can be divided into manufacturing constraints which

STIFFENER PREPARATION FACILITIES

FROM AN ANALYSIS OF THE STIFFENERS IN THE SD14 AND TAKING A TARGET LEVEL OF PRODUCTION OF 18·5 SHIPS PER YEAR, THE FOLLOWING OVERALL MATERIAL FLOW FOR STIFFENERS EMERGES:-

STIFFENERS PER SHIP.

	NUMBERS.
FROM STOCKYARD TO FRAME BENDER (ANNEX)	524.
FROM STOCKYARD TO STIFFENER BURNING MACHINE (BAY H)	924
FROM STOCKYARD TO UNIVERSAL MACHINE (BAY H.)	249
FROM STOCKYARD TO PIECEPART LINE (BAY H)	379
FROM STOCKYARD TO OUTFIT STEEL (BAY D)	363
TOTAL STIFFENERS PER SHIP	2500

Figure 46 Analysis of flow of section bar material from the steel stockyard (SD14 cargo vessel)

STRUCTURE GROUP	NUMBER OF RAW MATERIAL (SECTIONS)
A	120 (ESTIMATED FROM SAMPLE)
C	160
D	104
E	16
F	95
J	19
K	270
M	300
B	45 (ESTIMATED)
T	100 (ESTIMATED)
TOTAL	1229

FIGURES FOR STRUCTURE GROUPS C, D, E, F, J, K, & M. ARE CALCULATED FROM ACTUAL MATERIAL CODING. STRUCTURE GROUPS A, B, & T ARE ESTIMATED FROM THE INFORMATION AVAILABLE TO DATE.

Figure 47 Analysis of section bar material requirements using component information (B26 cargo vessel) apply specific limits to the standard sizes and cost aspects which must be optimised. Shipyard constraints will generally define upper limits of standard sizes which are feasible in a particular shipyard, they include:-

a) Stockyard material handling facility limitations (weight, length, width allowed)

b) Shotblast and paint treatment plant capacity (usually convey or width)

c) Flame cutting machinery bed size

d) Roll bending, forming and guillotining machinery size limitations

Cost aspects will be general to the shipbuilding industry and will include:-

a) Steel suppliers pricing system (see section 1 for British Steel price zoning)

b) Extra welding costs incurred by using smaller plate sizes

c) Possible savings by bulk buying of standard sizes made possible by having fewer but larger stock piles (after depreciation and/or inflation considerations)

Having investigated shipyard constraints which apply certain limitations to the selection of standard sizes, cost exercises must be undertaken to optimize the standard sizes chosen. The standard sizes must also be frequently checked for updates which may be necessary due to either changes in constraints, such as the addition or modification of plant and equipment, or changes in steel market conditions.

The specification of plating arrangements using standard size plates is preferably decided at the fabrication arrangement definition stage, when the ship design is broken down into structural units which may be constructed and welded in workshops and then transported to the berth where they are assembled onto the ship. Here the unit size should be designed so that incremental numbers of standard plate and section lengths and plate widths can be used in the assembly of the panels forming the unit itself. Factors which seem to have been of prime importance previously have been the design of a unit which is a 'natural' transverse ship division of flat panel or box structure, and an integer factor of a functional area of ship for longitudinal division. In the case of many of the 'natural' transverse units it is necessary to design their length such that they are self standing when being erected. Such units include upper deck units which must stretch between or balance upon bulkheads to avoid the use of support fixtures on erection. However many transverse units (such as double bottom, bilge or hopper tanks, or possibly side shell units) are naturally self supporting on berth erection and so do not need to be designed as an integer factor of hold length. The units defined using these principles have then been checked against lifting capacities within the shipyard and in certain cases have been combined where possible within the assembly workshops.

A major move has been made in the last ten years to increase the unit size to be erected on the ship to the maximum practically possible in an attempt to ensure that as much assembly work as possible is completed in workshop areas, here it may be done more economically than on the berth. However this trend has conflicted with the traditional idea of using an integer factor of hold length and keeping all transverse units the same length to achieve neatness of fabrication arrangement. As a result of these conflicts it has been very difficult to utilize standard sizes of plate length and width when plating arrangements for the panels are defined, even when standard sizes are previously specified.

The outline of a proposed system of using standard size plates in the definition of fabrication breakdowns for the holds of cargo vessels and tankers is as follows:-

1 Define transverse unit breakdown using natural unit boundaries (changes of stiffening arrangement, flat panels, and box structures) and various plating arrangements using standard plate widths. The best plating arrangement is selected, i.e. that which results in minimum scrap or requires least number of weld seams.

2 Define longitudinal unit length for each transverse ship division using the largest possible standard length of plate. This must also be within the maximum possible unit length constrained by the lifting and transport limitations of the shipyard.

An example of fabrication definition for the double bottom units of a cargo vessel is shown in appendix F. During the first stage of the procedure outlined above several plating arrangements for both the shell and tank top will be defined by or automatically presented to the designer. This will be done using computer programs which will investigate the possible combinations of standard plates across or around each complete double bottom surface (between apexes) and will point out the overlap or scrap resulting. The designer will then select the plating arrangement which he prefers and will then derive the breakdown of the complete double bottom cross section into transverse units based on the plating arrangement. He will then calculate the maximum length of unit possible within the shipyard constraints and will select the greatest practical length which will contain an integer number of standard plate lengths within this. This will possibly result in differing lengths for what would previously have been similar port and starboard units due to different lifting capacities across the berth width. Other factors such as pre-outfitting and changes in plate thickness or material will be considered. Pre-outfitting considerations in cargo holds will chiefly concern the maximum length of unit within the shipyard lifting constraints, and not the definition of unit length within this. Thickness and material changes will possibly determine certain seams in transverse panels, in practice sub-dividing them into smaller panels. In general however the area of thicker or stronger material may be slightly increased to cover a previously defined standard plate width.

Work is continuing at the British Ship Research Association on the development of interactive computer design systems to define fabrication breakdowns using standard steel plate sizes. Computer programs are being developed which will present the detail designer with information to aid in his decision making, although the final decisions will be tempered with his judgement and practical knowledge.

The use of standard plates in definition of nesting arrangements for plate components differs from panel plate arrangement in that the parts themselves are usually predetermined by structural boundaries. Thus items which are to be nested are of a definite shape and size and must be grouped together to result in steel plate orders in the most economical way. Traditional nesting techniques are mainly manual and involve the positioning of scale templates of the necessary parts within an encompassing rectangle. This function is usually undertaken by the Mould Loft department who will then produce dimentioned raw material plate drawings for hand mark out and flame planed or guillotined parts, or a tenth scale drawing or N.C. tape for profile cutting. The traditional cost measurement used when comparing nesting arrangements is nesting efficiency, which can be defined as

$$\frac{\text{area of components}}{\text{total area of material plate}} \times 100\%$$

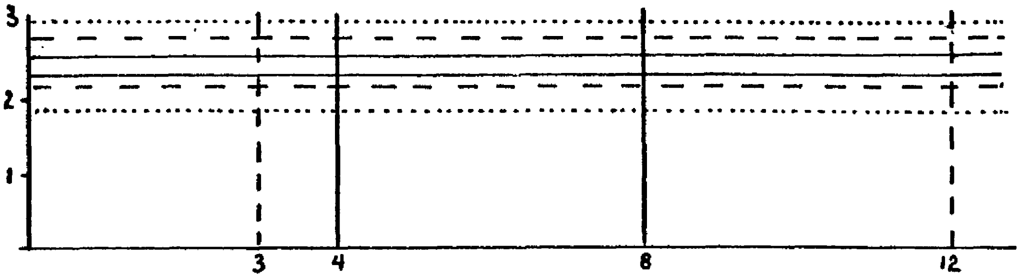
Thus the benefits obtainable by exploitation of steel purchasing systems and standard sizes are not considered.

Computer developments include the automatic production of tenth scale drawings or N.C. machine tapes from previously determined nesting arrangements which are recorded using a reference point on each component contour and an orientation of component. This system is employed in most computer design systems including Britships (B.S.R.A.)(40) and Autokon(41). These systems retrieve pre-specified N.C. descriptions of each component which is to be nested from a data bank and positions them on the 'plate'. The nesting operation, however, is still manually orientated although the accuracy of the final description is improved by the use of computers. An alternative nesting technique, Compunest,[42] developed by Compuwise Inc. of New Jersey U.S.A. is a fully automatic nesting technique which has shown good results with rectangular parts in structural engineering, but which has not generally been as efficient as manual nesting. The system does however allow the definition of a maximum length and width into which the parts are allowed to be nested. Further work in Japan and the U.K. have concentrated on man/machine interactive methods, using the machine to arrive at a 'near optimum' solution and adopting human intuition and experience in the system to improve nesting efficiency. The Japenese systems involve the use of component and nesting data files as employed in the Britships system. From a survey of nesting system it was therefore concluded that the intuitive human aspects involved cannot be totally replaced, and that interactive computer nesting systems will continue to be developed in the future.

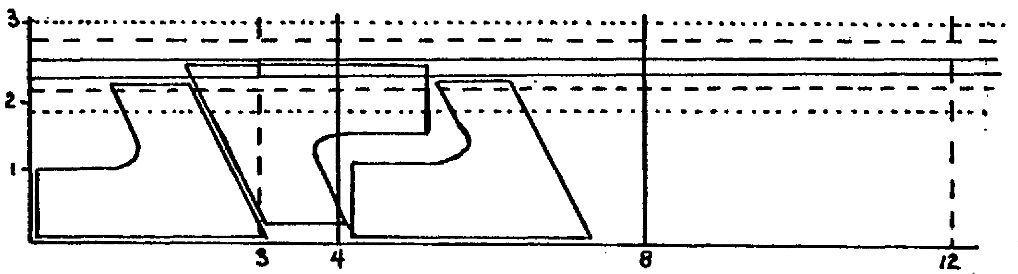
The traditional method of measuring nesting efficiency ofcomparing the used material with total area employed (including scrap), as already stated, does not always achieve the aim of optimising cost aspects. It is therefore proposed that two steps should be introduced in nesting operations to achieve this aim, these are the use of a cost template to nest into, and the use of total material cost rather than used area percentage as a measure of nesting efficiency.

a) Cost template

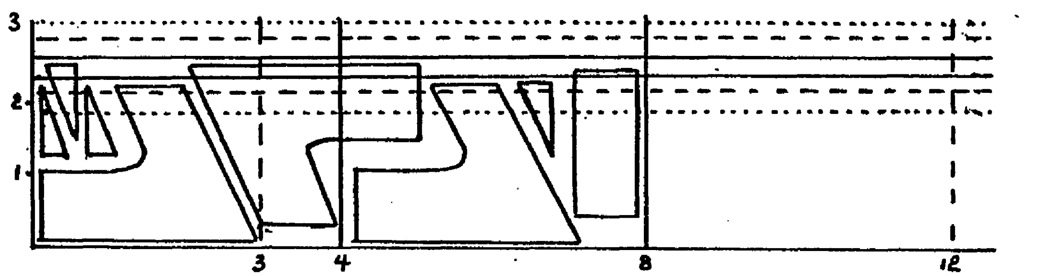
As specified in section 1 of this chapter the cheapest size of raw material plate from British Steel is one which is between 2.25 and 2.5M wide and 4.0 and 8.0M long, the price extras chart is shown in figure 40 It is therefore proposed that where possible components are nested just within the lowest (or basic)size rectangle, the nesting procedure employed is demonstrated in figure 48 Where it is impossible to nest within this rectangle due to the dimensions of one of the components then the limits of the next price zone should be used as the rectangle to be nested into. Thus the higher limits of the price zone system above the basic sizes will become standard sizes.



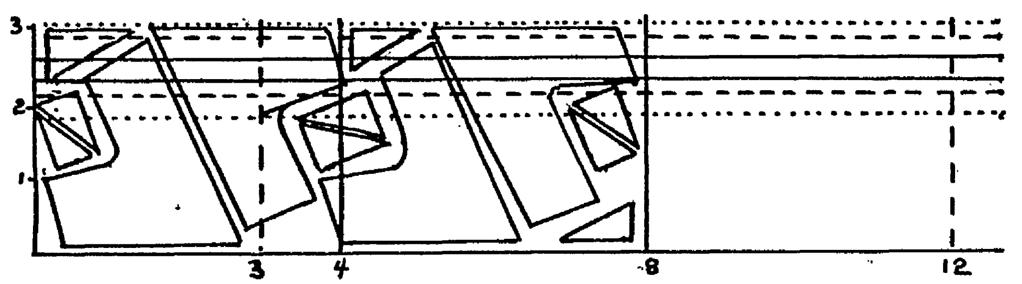
1 DISPLAY SIZE 'TEMPLATE' FOR NESTING OPERATIONS



2. NEST 'MAJOR' COMPONENTS UNTIL MOST ECONOMIC SIZES ARE ABOUT TO BE EXCEEDED



3. NEST 'MINOR' COMPONENTS USING GAPS TO MOST ECONOMIC PLATE SIZES. DELETE NESTED COMPONENTS FROM REQUIREMENTS FILE AND CONTINUE UNTIL ALL PARTS HAVE BEEN NESTED.



4. DEVELOP ALTERNATIVE NESTING ARRANGEMENTS FROM START AND COMPARE ON A TOTAL MATERIAL COST BASIS.

Figure 48 Nesting procedure using a standard size template and total steel costing system

b) Total costing system

This will involve the calculation of total material cost for the nesting of all parts forming a work batch for release to the shopfloor. This will include both the material cost from the steel mills plus the cost of setting up the total batch on machines minus the price gained for scrap.

Thus:-

Total Cost	=	Material Cost (sum of each plate cost)	-	scrap return (% of total)	(number of plates x Set up cost per plate)

The total cost will be easier to calculate than finding the scrap percentage for each raw material plate and will result in a more accurate efficiency indication. It will also allow a comparison of cost of nesting arrangements for entire component work batches; the optimisation of nesting arrangement for individual plates does not necessarily result in an optimum arrangement for the total requirements.

These proposals may be implemented for both traditional manual nesting methods and the interactive computer nesting systems which are still in process of development. Further developments are proposed as part of the Structural Ship Design System (S.S.D.S.)[30] project at B.S.R.A. into the design of nesting systems based on these principles. The approach taken here is to quickly develop several alternative nesting arrangements which can then be cost analysed using computer systems, the least costly will then be selected.

Chapter 8 Component analysis exercises

8.1 Types of analysis

Three types of component analysis were undertaken; complete ship hull analysis, ship hull analysis by manufacturing structure groups, and analysis of the ship hull with consideration given to the work scheduling of components. The methods used for the first two types were similar and only the scale of analysis was different, for this reason these were termed Macro and Micro analyses respectively. The third type of analysis employed the results of the second type and a building program for the relevant ship to calculate the amount of work on the shop floor at any one time.

The results of the Macro analysis are chiefly of value to the British Shipbuilding Industry and the machine tool manufacturing companies who supply shipbuilding equipment. They enable comparisons to be made of different types of ship and the effort involved in building them. Micro analysis results are of value in the design of steel preparation workshops for the building of specific areas of the ship, this is particularly important with the development of ship factories and specialised piecepart and assembly lines (see Chapter 3) They are also necessary to carry out the third type of analysis which is of value to investigate work scheduling and loading over the building cycle of the ship, and which leads to more even work balancing.

An analysis was also undertaken to find component families which can be manufactured using group technology methods.

8.2 Complete ship hull analysis

Initial analyses of the components comprising a total ship hull were undertaken for a 5000T DWT dredger from Ailsa Shipbuilding and Engineering (Troon) and a 14000T DWT cargo ship (the SD14) from Austin and Pickersgill (Sunderland). The results of the analyses were made known to the companies and the results from the dredger were described more fully in a paper presented at Strathclyde University, Glasgow (43). An analysis of the components comprising individual manufacturing structure groups of the dredger was carried out simultaneously to the complete hull analysis, this was included in the paper and is described further in the next section. In the later stages of research an attempt was made to devise a standard set of statistical tables which would follow general manufacturing practices and be of direct value to the industry. These tables will be compiled for each ship for which a component data bank becomes available, to date they have been prepared for two ships.

a) 5000T DWT Dredger analysis

In the analysis of parts for the Ailsa dredger it was found that 8532 parts existed and that 54% of these were produced from plate with 46% from section. Further analyses are segregated into those dealing with plate components and those describing distributions of section pieceparts, this is to follow normal manufacturing practice where different production techniques are involved. In each case shape features are investigated as a direct indication of the production processes which will be involved in manufacturing them. The main operations which were indicated by the shape code digits were cutting, forming, and drilling.

All plates were analysed for similar characteristics of their 'shape before forming' and figure 49 gives the results for the entire ship together with thickness and length distributions. Figure 50 shows the percentage distributions of shape after forming and auxiliary operations for both orthogonal plates and those having curved sides.

The main production features of the plates have been divided into five categories according to their shapes before forming:-

a)	Three sided plates	)
b)	Four sided plates	) all sides straight
c)	More than four sided plates	)
d)	One side curved	) at least one
e)	More than one side curved	) side curved

The number of three sided plates was very low (0.3%) and most of these were used for brackets and supports made as required during assembly by welders. They therefore have

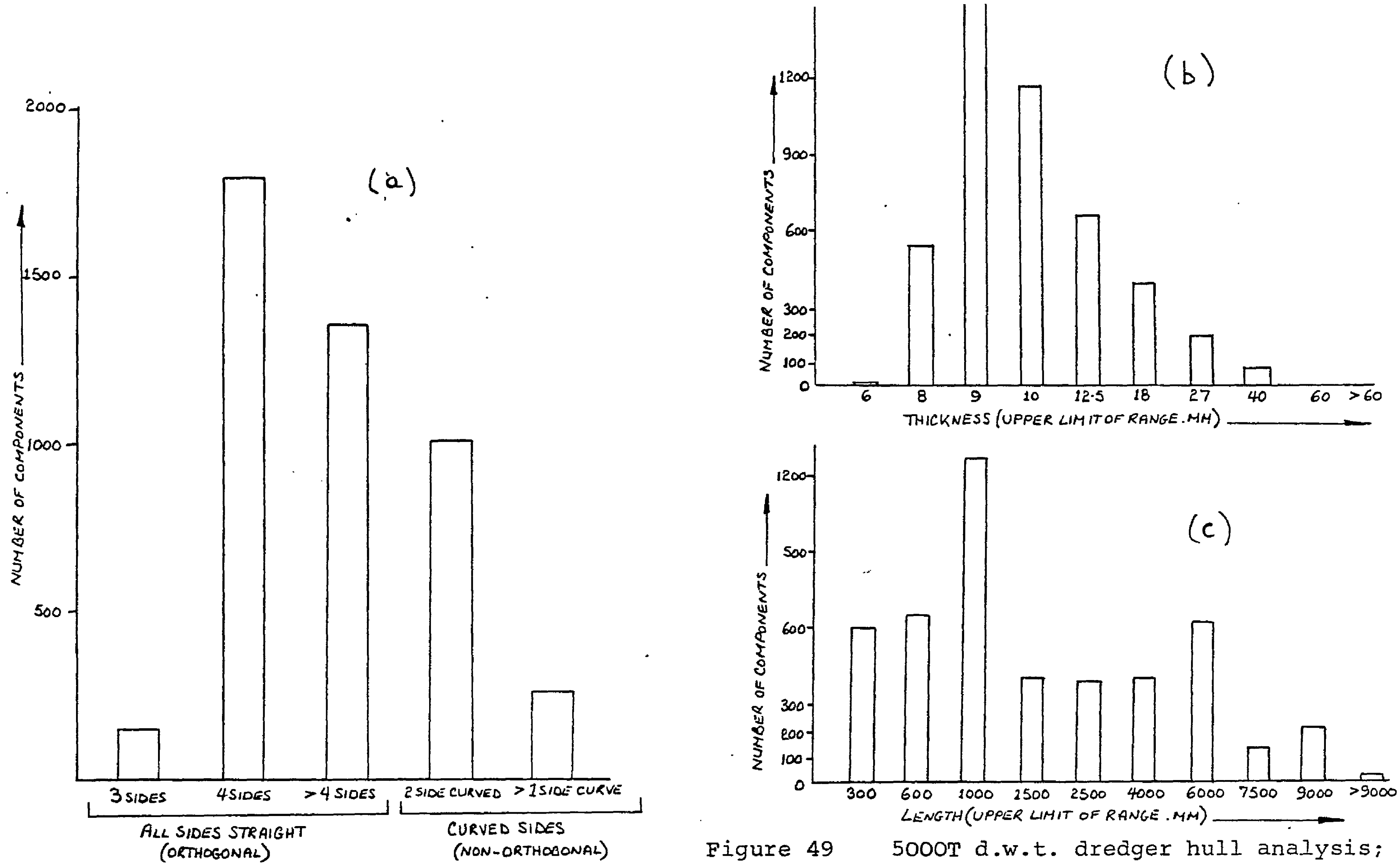
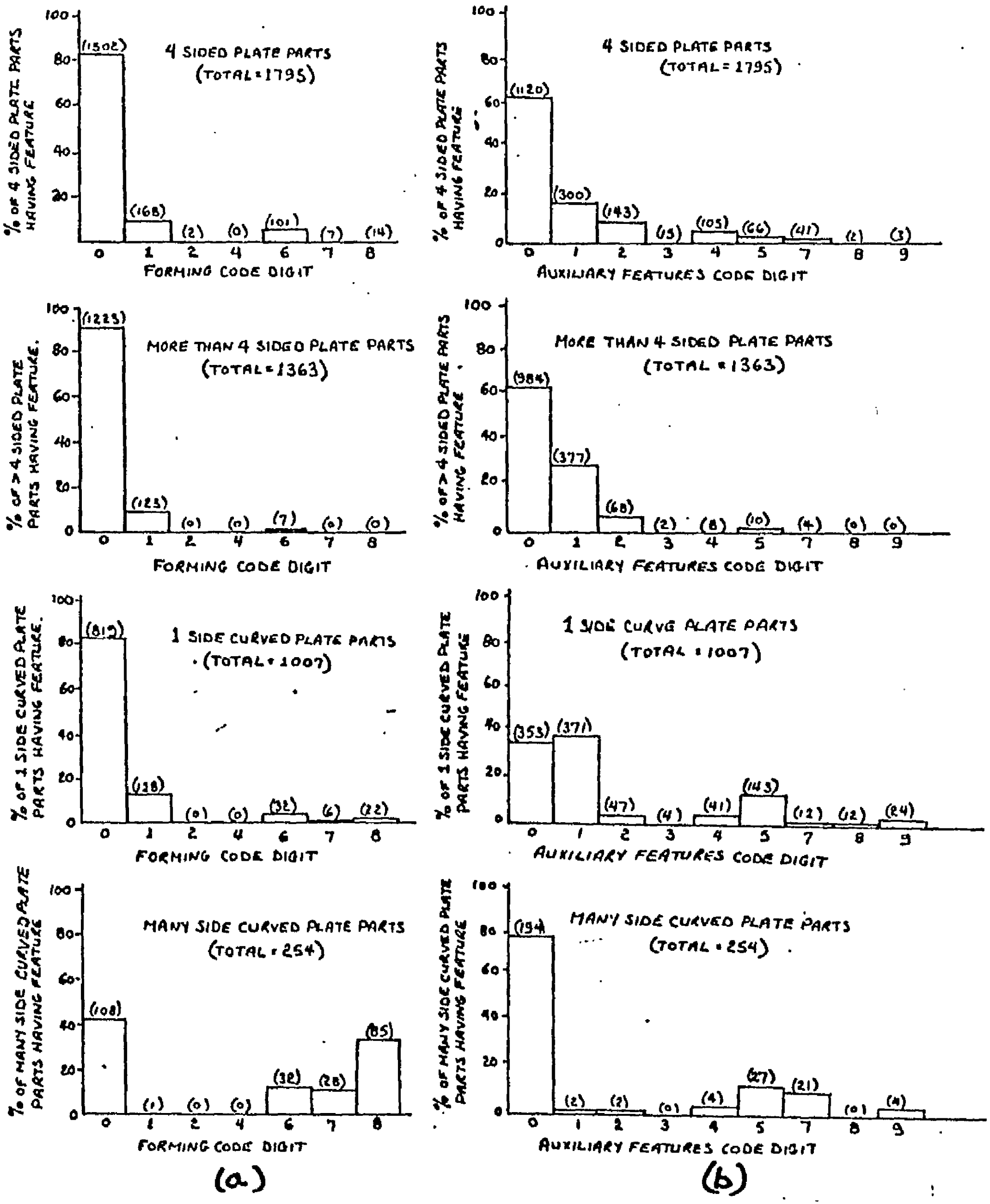


Figure 49 5000T d.w.t. dredger hull analysis; distribution of:-

a) Cut shape of plate components (before forming)
b) Thickness of plate components,
c) Length of plate components.



FORMING DIGIT VALUES: 0. NO FORMING, 1. SINGLE FLANGE, 2- MULTIPLE FLANGE, 4. CORRUGATED, 6- ONE LINE BEND, 7. MULTIPLE BEND, 8- MULTIPLE BEND CROSSED.

AUXILIARY DIGIT VALUES: 0. NO HOLES OR SLOTS, 1. NIBBLED, 2. SLOTS, 3. CIRCULAR BURNED HOLES, 4. NON-CIRCULAR BURNED HOLES, 5. 3 OR 4 WITH 1 OR 2, 7 MACHINED HOLES IN PATTERN, 8 MACHINED HOLES NO PATTERN, 9. 7 OR 8 WITH 1, 2, 3, OR 4.

Figure 50 5000T d.w.t. dredger hull analysis; distribution of:-
a) forming and auxiliary operations for orthogonal plate components,
b) forming and auxiliary operations for non-orthogonal plate components.

an insignificant effect on production organisation.

Four sided straight plates were the biggest single group comprising 39% of the total. This group included rectangular plates, plates with one or two square corners, and plates with no square corners. Of these only 16% were formed and 38% required auxiliary features such as holes and slots. Therefore at least 50% of the four sided plates or a minimum of 20% of the total number of plates in the whole ship had no forming or auxiliary features.

Plates with more than four sides made up 30% of the total number of plates for the ship. Once again forming was only required on 10% and auxiliary features on 35% of these. Thus again at least 55% of these plates or a minimum of 16% of the total plates for the complete ship do not require any forming or auxiliary operations.

Curved plate analysis showed different figures. In the case of plates with only one curved side 18% were formed and 64% had some auxiliary features. Therefore a smaller percentage required no forming and no auxiliary features. Plates with more than one side curved comprised only 5% of the total number of plates, and of these 57% were formed and 24% had auxiliary features. Therefore the number of plates with more than one side curved, but no forming or auxiliary features, is insignificant.

An analysis of the two important categories of plates, orthogonal and non-orthogonal, gives the following figures:-

	Total No. of Plates	No. of Plates formed	No. of plates with auxiliary features
Orthogonal	73% (3294)	11%	35%
Non-orthogonal	27% (1261)	25%	65%

It can be seen that although the total number of non-orthogonal plates was only 39% of the orthogonal, their work content in terms of forming and auxiliary features is nearly the same. The number of plates requiring crossed bending is also much higher in the case of non-orthogonal shapes. Only 8 orthogonal were cross bent compared to 103 non-orthogonal shapes. The making-off work content of the non-orthogonal plates was also substantially more than that of the orthogonal ones.

From the thickness and length distributions for the whole ship (figure 49 b & c) it can be seen that over 85% of the total number of plates are less than 12.7 mm (0.5 in) thick. In addition at least 80% of the plates are less than 3600 mm (12'0") long and over 25% of plates are less than 600mm (2'0") long. As many of the latter components are brackets and stiffeners these sizes and percentages can be an aid in the evaluation of machine tool capacity requirements, such as the bed length of a guillotine or an edge preparation machine. Such data can also help to determine the type and capacity of mechanical handling equipment requirements between work stations. It can also be used to calculate floor space requirements for storage between operations.

Sections were analysed by type and then each type was individually investigated, the distribution of section type is shown in figure 51. Figure 52 shows the length distribution of the three main types of section and the section profile distribution for the complete vessel. Tables in figure 53 give the percentage breakdown of sections before and after forming respectively.

Figure 51 gives an analysis of all sections in the ship by their respective types. It can be seen that flat bar, bulb flat bar, and angle make up 98% of the total, and other sections such as channels, solid sections, and pipes account for the remaining 2% Flat bar is the most widely used type of section, accounting for 57% of the total number of components, with angle 23% and bulbflats 18% The number of auxiliary features such as holes and slots required on all types of sections is very small; less than 4% of the total number of components required some form of auxiliary operation.

Tables in figure 53 show that 40% of flats have non square corners and 11% require forming. In the case of bulb flats 56% have non square corners and 37% require bending, with similar figures of 32% and 6% for angles. The number of bent components from bulb flats is much higher than that for flats and angles, and the work content in itself is also greater. Bending of flat bar can be carried

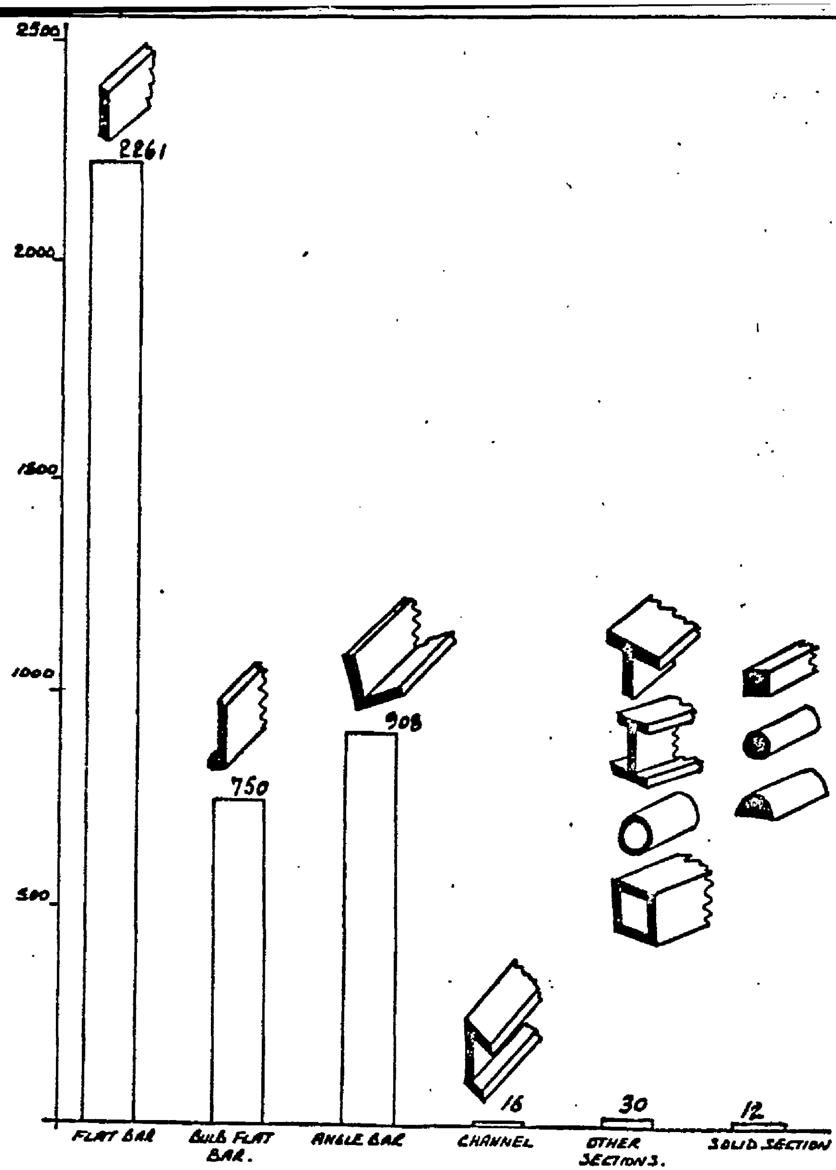


Figure 51 5000T d.w.t. dredger hull analysis; distribution of types of section bar components.

TYPE OF SECTION	TOTAL NUMBER	ENDS SQUARE	ENDS NOT SQUARE
FLAT BAR	2261	1361	900
BULB FLAT BAR.	750	356	394
ANGLE SECTION	908	558	350

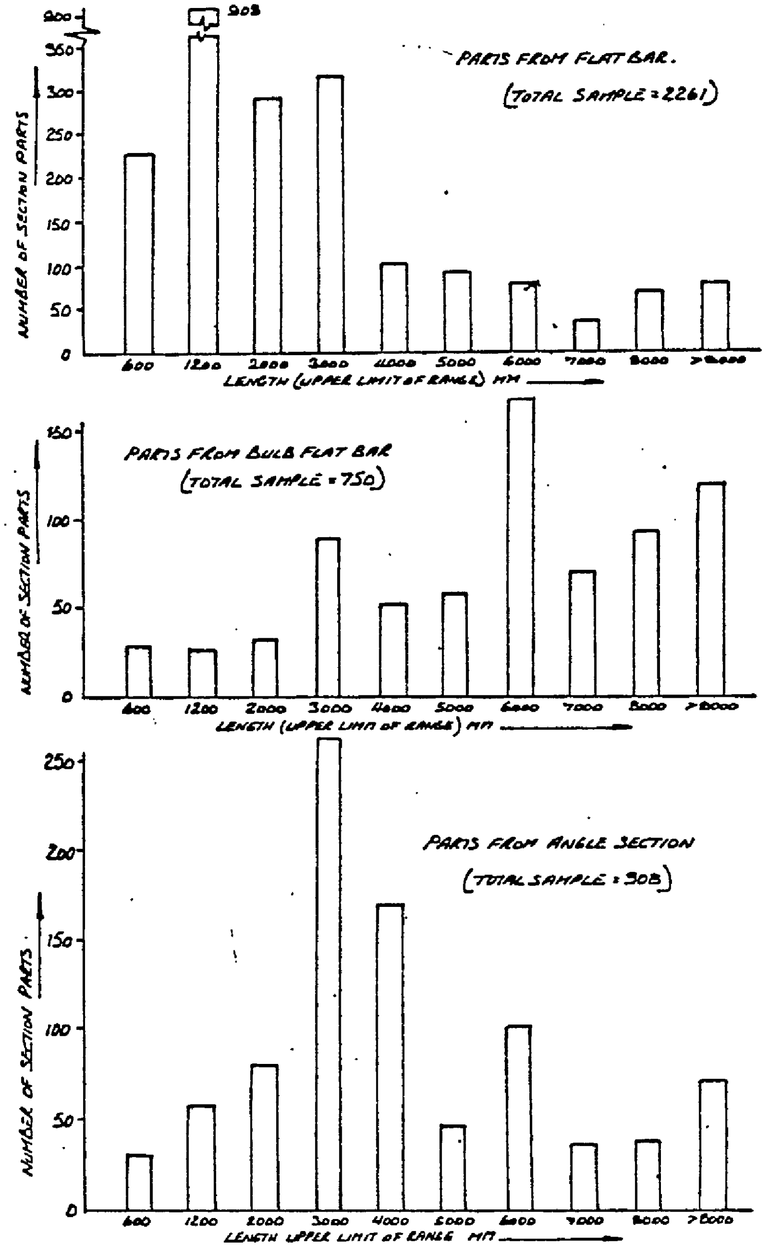
TABLE 1. BREAKDOWN OF SECTIONS BEFORE FORMING.

TYPE OF SECTION	TOTAL NUMBERS	NO FORMING	ONE BEND	MULTIPLE BEND	FLANGED
FLAT BAR	2261	1996	215	40	10
BULB FLAT	750	470	250	30	0
ANGLE SECTION	908	850	58	0	0

TABLE 2. BREAKDOWN OF SECTIONS AFTER FORMING.

Figure 53 5000T d.w.t. dredger hull analysis; distribution of:-

a) Numbers of section components with square ends,
b) Forming operations for section components.



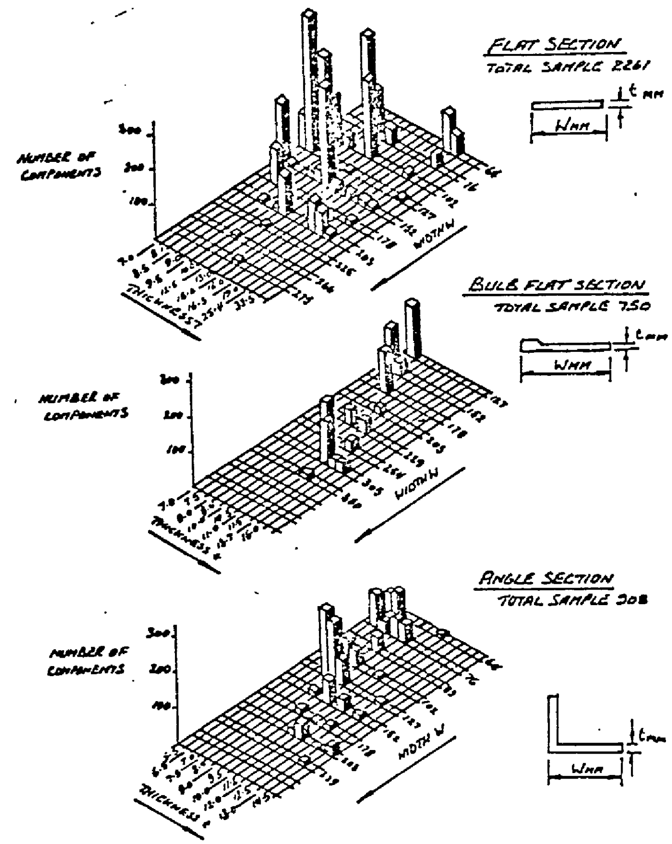


Figure 52 5000T d.w.t. dredger hull analysis; distribution of:-

a) lengths of popular section components,
b) size of flat bar, bulb flat bar, and angle components.

out on a benching roll press whereas bulb flats and angles require a special cold frame bender. Therefore it is possible to divide all sections into two categories:-

a) Flats and other sections, and

b) Bulb flats and angles

All sections require some simple marking-off, and cutting is simpler than for plates.

An analysis of the dimensions of components made from flat section showed that 70% are less than 2000 mm (about 7'0") long and over 75% are less than 152mm (6") wide and 12.7mm (0.5") thick. A similar analysis for bulb flats gives figures of 24% (less than 2000mm long) and 39% (less than 152 mm wide) with 88% and 48% respectively for the heavier and longer sections and as most bending is also carried on bulb flats their work content is correspondingly higher. This basic data, as for plates can aid the selection and organisation of machine tools, material handling equipment, and the allocation of floor space.

The analysis was undertaken in the early stages of research using card sorting techniques and the S.A.M. package. Although production influences were considered to some extent, the outline shape, the auxiliary features, and the edge preparation of the part were treated as separate factors and investigated as such. This was probably justified in the shipyard involved which employed low technology production processes including hand burning, here the outline shape could be cut independently of slots, holes, nibbles etc. It was later found that in higher technology shipyards the interaction between outline shape, holes and slots, and edge preparation defines the complexity of the cutting path required, and hence determines which of the alternative cutting operations normally available will be employed. Shortly after the analysis Ailsa Shipbuilding invested in a tenth scale optical cutting machine which would radically influence the manufacturing function, and would have altered the analysis techniques used. In addition square cornerd plate parts are easier to set up for flame planing or guillotining than non-square cornered parts, this was not reflected in the analysis. In later analyses greater emphasis was placed on consideration of combinations of outline shape, auxiliary features, and edge preparation as indicated by digits 1, 2, 4, and 5 of the descriptive code, this is described in detail later. However, the analysis was of value in the development of analytical techniques and methods of presentation of results.

b) 14,000 Ton D.W.T. cargo vessel (SD14)

The initial analysis of the SD14 cargo vessel was made known to the company in a report following full ship hull data collection and investigation. In addition to the statistical analysis attempts were made to divide the total component population into families having similar characteristics. This would enable investigations to be made later into the feasibility of setting up manufacturing cells in order to produce similar components under group technology principles (see 8.5). This is reflected in the presentation of results and in particular in figure 54.

The analysis techniques used were similar to those employed on the Ailsa dredger, this involved initial segregation into plates and sections to follow manufacturing practice. The total number of pieceparts which form the hull of an SD14 was found to be 12,951 of which 51.3% are made from plate and 48.7% from section, a summary of the statistics is shown in figure 54. The type of sections used are summarised in figure 55 and it can be seen that numbers of components made from flat section, bulb flat section, and angle section are roughly in the same proportion (about 30% each). However, it is found that bulb flat and angle have twice the probability of being formed than flat sections. Other rolled sections make up 4.5% of the total number of section parts, with solid bars accounting for only 0.6%

77.4% of all plates have straight sides (orthogonal plates), of these 14.3% were formed and 43% had auxiliary features (such as holes and slots). Of the remaining 22.6% of plates having at least one curved side, 17.8% were formed and 62% had auxiliary features. Thus the curved sided or non-orthogonal plates are generally more complex than the orthogonal. The breakdown of types of forming carried out on plates are shown in figure 56, together with the breakdown of auxiliary features. Most forming consists of a

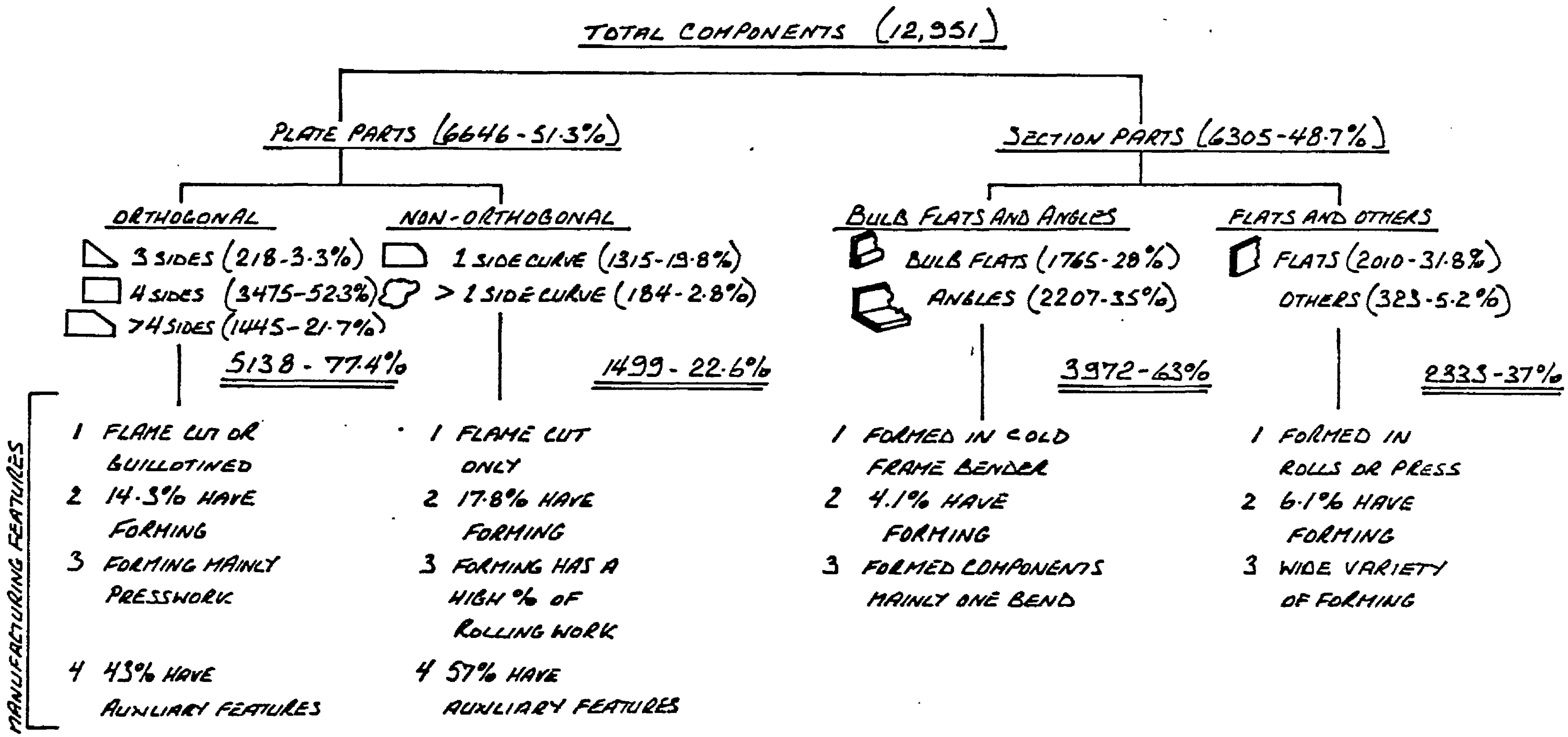


Figure 54 14000T d.w.t. cargo ship hull analysis; distribution of all components.

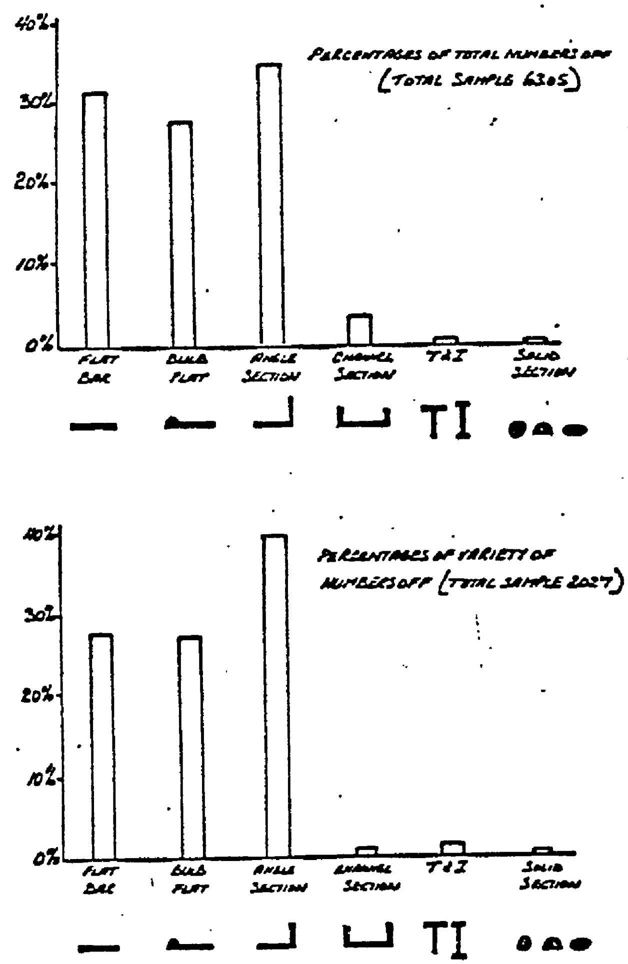


Figure 55 14000T d.w.t. cargo ship hull analysis; distribution of:-
a) section component types by numbers,
b) section component types by variety.

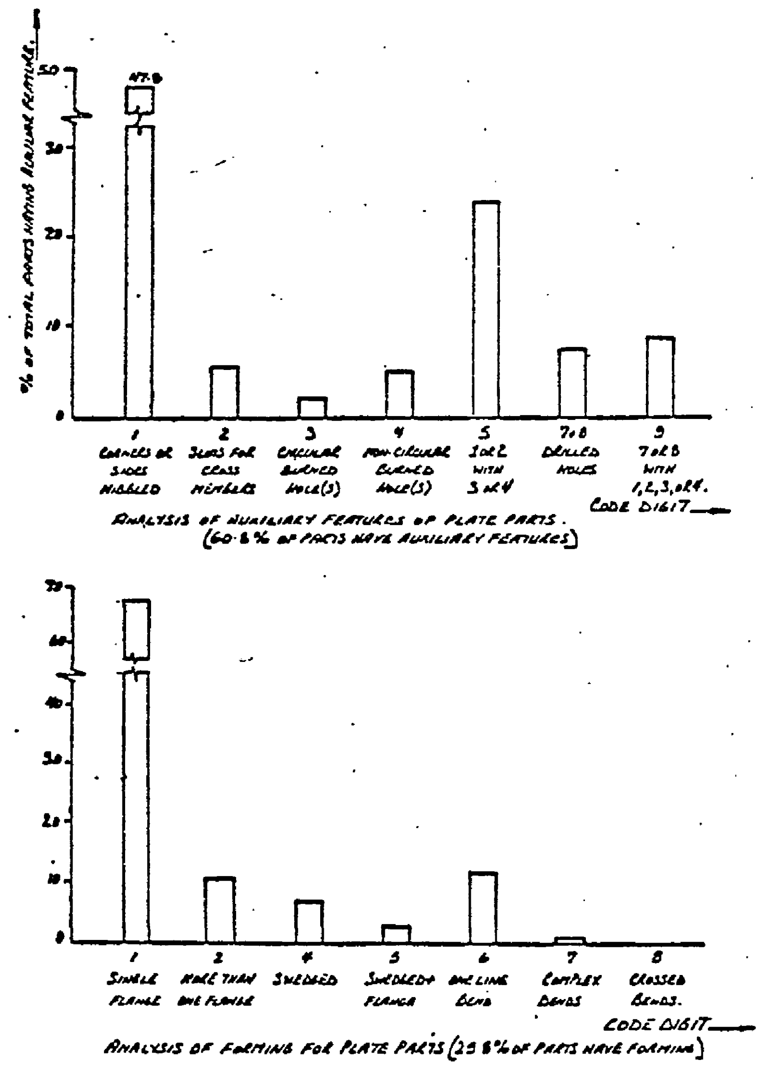


Figure 56 14000T d.w.t. cargo ship hull analysis; distribution of:-
a) Plate component auxiliary features,
b) Plate component forming operations.

simple flange and components found having this are usually beam knees and stiffening brackets. Many formed components have more than one flange (10.8%) and a similar number (12%) have a bend of single roll line (these are of course, shell plates). Most of components having auxiliary features consist of either small water ducts (side or corner nibbles 29%) or large burned holes (30.7%) for a manhole or pipe ducting.

The results of the initial SD14 analysis have only been summarised here as a later, more detailed analysis was carried out. This followed further refining of the steelwork code and greater consideration of production factors. This led to the development of a standard set of statistical tables based on the intereaction of component shape and possible production methods. The development of these standard tables is described in the following subsection.

c) Standard statistical tables

Standard statistical tables have now been devised to present a macro-analysis for any ship where a component data bank has been compiled in a form similar to that devised in the research project. The data analysis method used to compile the statistical tables was the S.P.S.S. package which is described in Chapter 6.2.4. This was used to find the number of components which existed in each category, these were then presented as percentages of the total number of parts comprising the ships hull by using a short Fortran program.

The statistical analysis results are presented in such a way that the relationship between the final component shape and the best manufacturing method is emphasised. Although the component descriptive code is shape based, consideration was given to this manufacturing relationship during its development. In practice in many cases literally the only method of manufacture can be determined from the shape of the component. In other cases all possible methods of manufacture will be determined by the component shape. With the most economical method then defined by the shape complexity or size. As an example, consider plate component shape cutting. There are four fairly standard shipyard methods - guillotine, flame plane, profile cut, and hand burn. The method, or combination of these methods used to produce the cut shape of a component will be determined by the overall perimeter shape of the component (digits one and two of the code), the number and type of holes and slots (digit four) and possibly the edge preparation (digit five) depending on the facilities of the individual shipyard. A simple rectangular plate component with no holes or slots or edge preparation will be flame planed or guillotined depending on its thickness and surface sizes, while a curved sided plate component with holes and slots but no edge preparation will be profile cut or hand burned.

Thus although the analysis has been based on the shape and size of components, the results are presented in such a way that a shipyard manager or designer may align it to the production methods used in his specific shipyard. The possible methods of manufacture of the parts are defined in the analysis with the probable most economical method stated, but the final choice of manufacturing method is left with the individual manager.

In the case of general component features (type of section, section holes and slots, section forming, and orthogonal plate shapes) a table is presented of the number of components required having each feature, and the percentage of the ship component population of these numbers. Where the size of component has an important influence on the method or difficulty of manufacture the numbers of components required are further broken down by the size ranges used in the descriptive coding system. A table of the descriptive code size ranges is included with the statistical data for each ship. Length and depth are of prime importance for section components, with length and width of equivalent importance for plate components. The breakdown into size ranges gives an indication of the production method, where it is influenced by size and the size of machine necessary to produce the component parts. When possible a histogram of each table is included to allow a visual inspection of the size 'profile' for that particular feature.

A full description of the statistics and their use was published in the Naval Architect(44) tables 1 to 8 describe section components. The first table indicates the number of components required from various types of section material and tables 2 to 6 give the numbers of components required from common sections (flat bar, bulb flat, angle, channel) on a length/depth matrix. Tables 7 and 8 indicate production operations other than cutting to length (holes and slots and forming). The remaining tables are concerned with plate components, table 9 giving the numbers of orthogonal shapes by type. Tables 10 to 12 to give numbers of components for cutting methods (guillotine, flame plane, hand burn, profile cut) on a length/width matrix, the cutting methods being determined from the shape code. Table 13 details the numbers of plate components requiring various edge preparations and tables 14 to 16 give numbers of plate components having forming operations (flanging, swedging and roll bending) again on a length/width size range matrix. A full list of tables is detailed in the contents of each data set.

Appendix G shows the standard statistical tables describing the components forming the hulls of two ships which have been coded and analysed. These are the SD14 (a 14000T d.w.t. cargo vessel) and the B26 (a 26,000T d.w.t. bulk carrier), both of which are produced by Austin and Pickersgill. The percentages of parts produced from plate and section are about the same (57% plates for SD14 and 54% plates for B26) although the further breakdown of plate and section parts differ. The numbers of parts produced from bulb flat bar are similar for the B26 and SD14, but the percentage of flat bar parts employed in the B26 is three and a half times that in the SD14 and the inverse of this is found for the ratio of angle bar employed.

The percentages of orthogonal (straight sided) parts for the SD14 and B26 are 47% and 40% respectively although this is reversed for non-orthogonal (curve-sided) plate parts, where figures of 10% and 14% result respectively. Comparison of the perimeter shapes of orthogonal plate parts show that percentages of rectangular parts are about the same the percentage of triangular parts having a right angle is much greater for the SD14 than the B26 (x10) although the percentage of four sided parts with one or more square corners is halved. Similar percentages of parts having more than four sides and one square corner are found (9% -B26, 7%-SD14) while the number of parts with many sides and no square corner for the B26 is twice that of the SD14 (8% and 4%)

This analysis will enable a comparison to be made of the work content of various ships for the measurement of shipyard efficiency and for the development of cost estimating and control systems. The most widely accepted shipyard measure of work content and efficiency is steel throughput. However, ships vary widely in their complexity and therefore steel weight, even when an empirical complexity weighting factor is employed it is not always a good measure of work content. A data bank which records the number and complexity of parts required can be used to present a more accurate assessment of the workload on the steel preparation shops. It will also give a better indication of the assembly shop workload that is directly influenced by the number and complexity of the components forming the assemblies. Having obtained a better measure of workload, the efficiencies of individual shipyards may be compared and more accurate overall cost estimating systems developed. The publication of a standard set of tabulated statistics describing the hulls of a variety of ships also allow a shipyard to compare a proposed ship with a vessel previously built in that yard. This can also enable a more accurate assessment to be made of the time and cost which will be incurred in building the proposed ship.

8.3 Control group analysis

For purposes of shipyard component production control a ships hull is divided into various sections which are termed structure zones, structure groups, control zones, or control groups. A structure group represents a controllable work unit which is generally used for cost control and analysis purposes, it also contains similar structure throughout and thus similar components may be found in it. For purposes of assembly the control groups are subdivided into fabrication units which can be constructed and erected into the ship hull on the berth. The size of structure groups and fabrication units vary between shipyards and ship designs, and in many cases the structure groups can themselves constitute fabrication units. Structural units and fabrication units can themselves be the subject of component statistical analyses. Such analyses indicate the type of production operations required in the manufacture of parts comprising the work package, or indicate the work content involved. These exercises have been termed micro-analyses, and have been undertaken for the Ailsa dredger, and for the SD14 cargo ship using both an existing and a proposed control group breakdown.

a) 5,000T Dredger Structure group analysis

The ship was divided into seven control groups for component production purposes. The number of components found in each control group is shown in figure 57. The control group component population has been segregated into parts produced from plate and from section and the relative percentages, and percentages of the total population are shown. It can be seen from the table that the percentages of plate parts for most structural groups fall between 50% and 60%. However the plate cutting facilities will probably be relatively overloaded when manufacturing the hopper side (69% plate parts) and underutilised when the double bottom is in production (37%). The inverse occurs for section parts. In addition an indication is given of the work content involved in each structural group by the percentage of the total number of parts which exist for each group. Although in some structure groups (decks and shell units) the average size of parts will be larger than in others (double bottom, and fore and aft ends) the number of parts will result in a better indication of work content than steel weight.

More detailed analyses of plate parts have been undertaken and the results are shown in figures 58 and 59. The initial breakdown into three sided, four sided, and more than four sided plate parts, and curved sided plates is shown in figure 58. Figure 59 shows analyses of four sided and more than four sided straight sided plates and curved sided plates; holes and slots, and forming operations are investigated. The breakdown of section parts for four structure groups into the type of section from which they are

STRUCTURAL GROUP	TOTAL NUMBER OF COMPONENTS	PLATES		SECTIONS		PERCENTAGE OF TOTAL NUMBER OF COMPONENTS.
		NUMBER OFF	PERCENTAGE	NUMBER OFF	PERCENTAGE	
1 DOUBLE BOTTOM	1839	674	37	1165	63	21
2 AFT END AND ENGINE SEATING.	689	382	55	307	45	8
3 FORE END	499	289	58	210	42	6
4 MAIN DECK	784	430	55	354	45	9
5 HOPPER SIDE AND BULKHEADS	1403	964	69	439	31	17
6 SIDE SHELL	1192	762	64	430	36	14
7 SUPERSTRUCTURE	2162	1054	50	1072	50	25
COMPLETE VESSEL	8532	4555	54	3977	46	100 %.

Figure 57 5000T d.w.t. dredger structure group analysis; distribution of plate and section components.

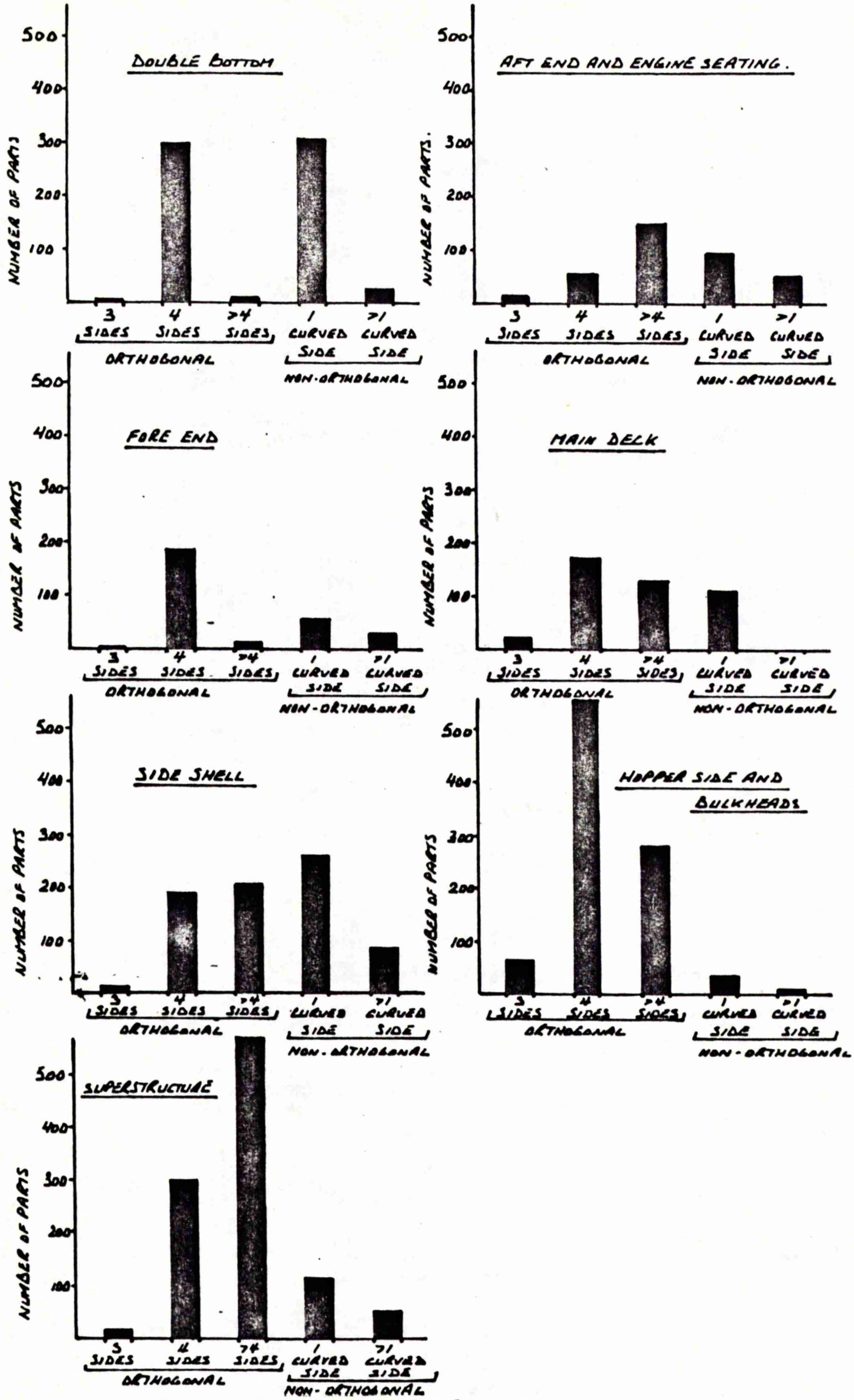
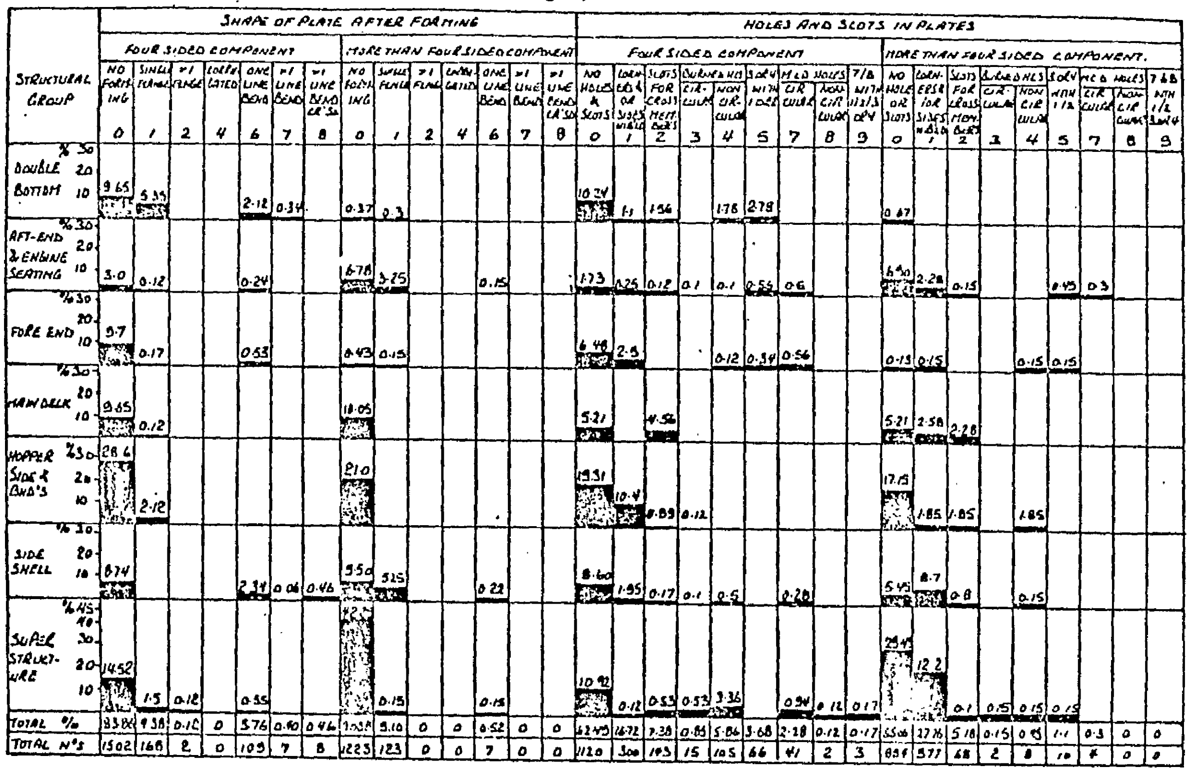


Figure 58 5000T d.w.t. dredger structure group analysis; distribution of plate component outline shapes.

(a)



(b)

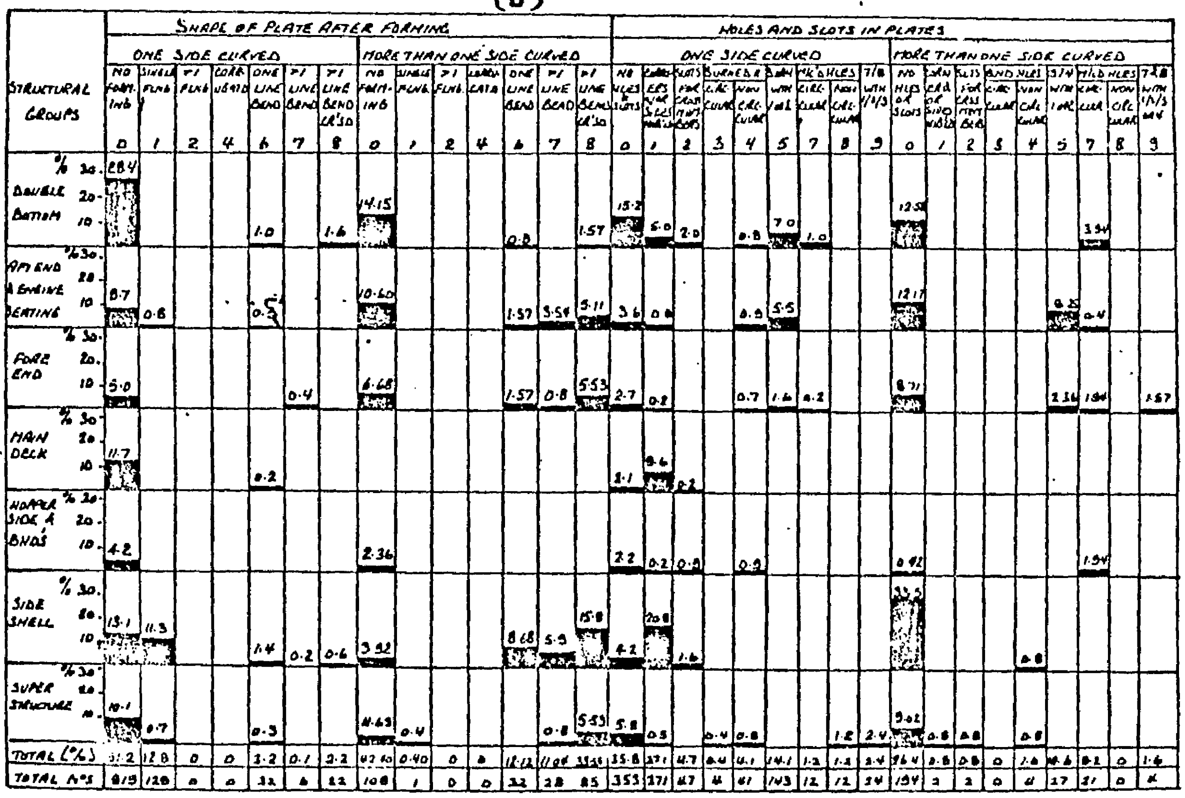


Figure 59 5000T d.w.t. dredger structure group analysis; distribution of:-
a) plate component forming operations,
b) plate component auxiliary features.

produced are shown in figure 60. It can be seen that flat bar is used predominantly in all four structure groups but that bulb flat is used chiefly in the double bottom and angle in the main deck and superstructure. Channel T, I, hollow round, hollow square, and solid sections are not generally employed.

b) SD14 cargo ship structural group analysis (present structure groups)

For material ordering and component cost control purposes in the shipyard of Austin and Pickersgill this vessel is divided into a large number of structural groups. The shipyards of Austin and Pickersgill and Ailsa at the time of the analysis had similar berth cranage capacities (about 15 ton maximum lift) although the slipways were of differing dimensions, thus Ailsa were unable to launch ships of the same size as Austin and Pickersgill. For the smaller ships under construction at Ailsa a functional ship zone (say double bottom or side-shell) could be employed as convenient material and cost control work package. For the larger ships being produced at Austin and Pickersgill (Sunderland) a functional zone was found to be too large to use as a work package, so each zone was further divided into several structure groups for this purpose. It was also found the structure groups themselves were defined differently in the two shipyards. For example a double bottom at Ailsa was completed in the unit assembly sheds with both the shell and inner bottom plates attached, but at Austin and Pickersgill the stiffened bottom shell panel was first laid on the berth and the matrix assembly (girders and floors) complete with inner bottom was the assembled and joined to the shell on the berth. This resulted in two structure group types existing at Austin and Pickersgill where one was employed at Ailsa. In addition the designs of the two ships were fundamentally different; the cargo vessel had two decks and the dredger only one. This was considered an advantage to the analysis as differences were needed for comparison purposes.

The analysis was carried out using the S.A.M. data manipulation package (see Chapter 6.2.3) to list all the data records associated with a named structure group, this

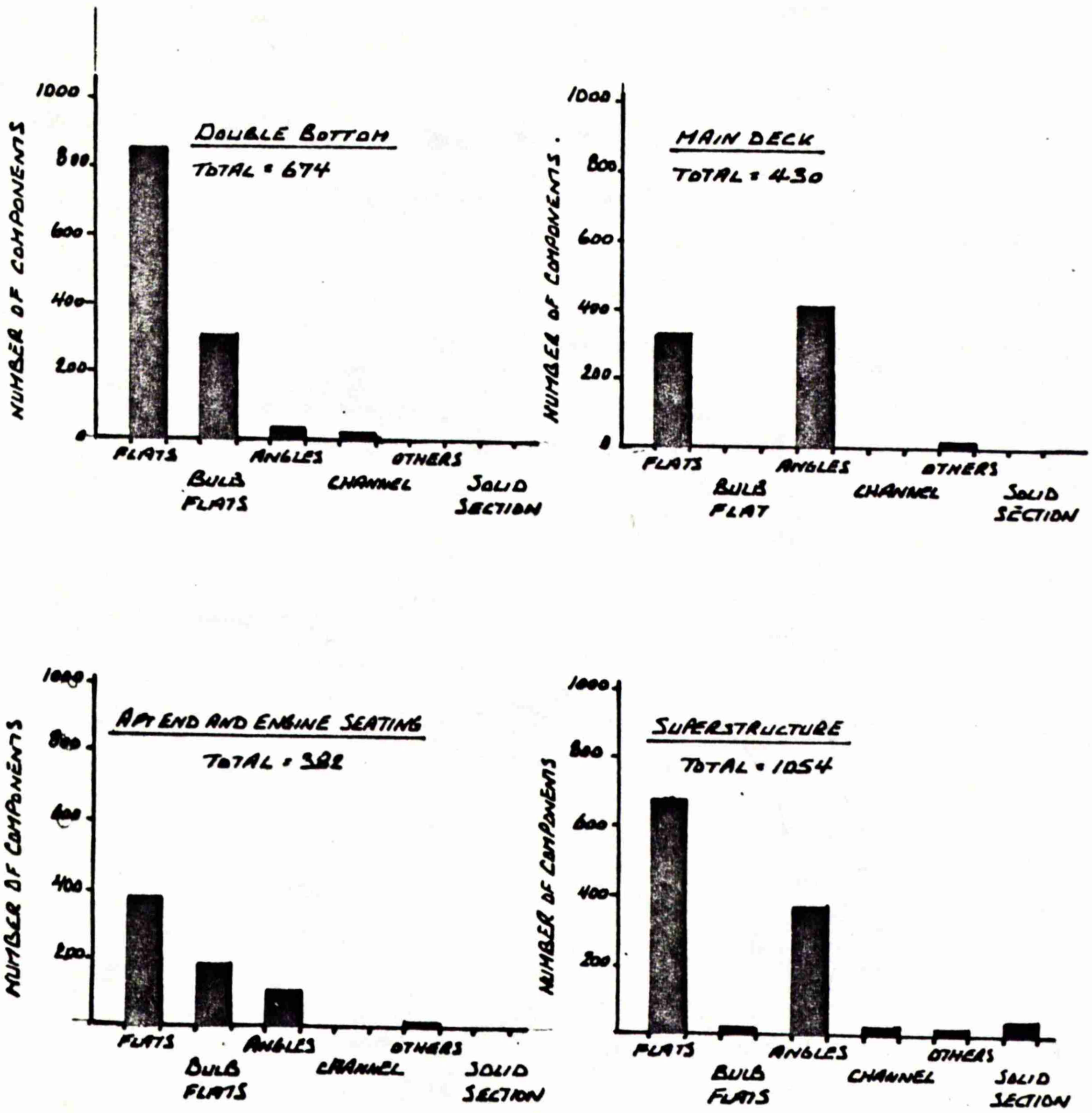


Figure 60 5000T d.w.t. dredger structure group analysis; distribution of section component types.

was specified in the program statement by using the component number. The number of plate components having any particular shape or production feature were then manually counted for each structure group and the results were entered on a standard summary sheet, an example is shown in figure 61. The manual counting exercise was time consuming and prone to errors but was made necessary by the absence of facilities to weight data records by the number of parts required. This problem was overcome in later analysis exercises by using the S.P.S.S. package (see section C). The summary sheets were not used directly for micro-analysis purposes but they were of great value in an investigation of shopfloor loading and work balancing, this is described in detail in the next section. However the total number of plate components required for each structure group was used for comparative analysis with the 5000T d.w.t. dredger which had been investigated previously. In addition the total number of section components needed for each structure group was found, again by listing and a manual count.

A complete list of structure groups used for material control purposes is shown in figure 62 with the total number of components produced from both plate and section material. The control groups in the table have been categorised into seven cost areas to follow the manufacturing practices employed at Austin and Pickersgill and allow a more meaningful summary table to be derived. It can be seen in cost area 1 that the bottom shell (SB) has been divided into two structure groups and the double bottom (DB minus shell bottom) into five. Structure groups DB1, DB2, DB3, DB4 and DBE represent physical zones of the ship while DBC represents a group of parts which are produced using one specific cutting machine (a Condor N.C. profile cutter) and may be found throughout the double bottom, this explains the fact that these are no components made from section in this group. The summary table for the cost areas (i.e. structural group categories) is shown in figure 63a, it includes relative percentages of plate and section parts and the percentage of total number of components required in the ship hull for each cost area. The categorising of structure groups into cost areas for this table

STRUCTURE GROUP: DBE — TOTAL NUMBER OF PLATES 365

MAIN SHAPE \ HOLES & SLOTS	0 NONE	1-2 EDGES CUT	3-5 BURNED HOLES	7-9 DRILLING	TOTALS
ORTHOGONAL	75	5	140	17	237
NON-ORTHOGONAL	34	12	54	28	128

FORMING		EDGE PREPARATION		LENGTH	
0 NONE	325	WITH EDGE PREPARATION	26	<1000	84
1-2 FLANGE	24				
4-5 SWEDGE	0			>1000 <4000	61
6-7 BEND (SIMPLE)	16	WITHOUT EDGE PREPARATION	339		
8 BEND (COMPLEX)	0			>4000	220

Figure 61 14000T d.w.t. cargo ship structure group analysis (existing breakdown); standard summary sheet example.

COST AREA	CONTROL GROUP	PLATE COMPONENTS	SECTION COMPONENTS
1	SB1	36	108
	SB2	28	58
	DB1	132	15
	DBE	365	173
	DB2	355	462
	DB3	267	396
	DB4	376	142
	DBC	220	0
2	MB1	57	66
	MB2	89	45
	TB1 (TDB1)	81	12
	TB2 (TDB2)	32	16
	CLT	17	58
	CLB	48	47
3	FE1	378	319
	FE2	242	222
	AE1	34	45
	AE2	225	231
4	SS1	304	190
	SS2	110	76
	SS3	208	126
	BW	74	52
	TDF	0	228
5	UD1	464	201
	UD2	312	127
	UD3	193	82
	MD1	325	280
	MD2	511	286
	EF1	58	44
	EF2	30	8
	EF3	34	67
6	MH	282	263
	DH1 (MDH1)	159	237
	DH3 (MDH3)	106	170
	DH4 (MDH4)	93	172
	DH5 (MDH5)	38	86
	DH6 (MDH6)	28	33
7	MP1	39	4
	HW	158	809
	AS1	362	149
	HS1	238	82
	CR1	20	8
	ST1	26	3
	SN1	17	0
	GL1	0	132

Figure 62 14000T d.w.t. cargo ship structure group analysis (existing breakdown); numbers of plate and section components in each structure group.

SHIP AREA (STRUCTURAL GROUP)	TOTAL NUMBER OF COMPONENTS	PLATES		SECTIONS		PERCENTAGE OF TOTAL NUMBER OF COMPONENTS.
		NUMBER OFF	PERCENTAGE	NUMBER OFF	PERCENTAGE	
1 DOUBLE BOTTOM (FORE OF ENGINE ROOM)	2303	1224	53	1079	47	20
2 AFT END AND DOUBLE BOTTOM IN ENGINE ROOM	1337	844	63	493	37	12
3 FORE END	1183	642	54	541	46	10
4 DECKS	2988	1883	63	1105	37	25
5 BULKHEADS	563	319	57	244	43	5
6 SIDE SHELL AND BULWARKS	1454	1010	69	444	31	13
7 DECK HOUSES AND MAST HOUSES (SUPERSTRUCTURE)	1721	726	42	995	58	15
COMPLETE VESSEL	11549	6648	58	4901	42	100%

a

COST CENTRE	TOTAL NUMBER OF COMPONENTS	PLATES		SECTIONS		PERCENTAGE OF TOTAL NUMBER OF COMPONENTS.
		NUMBER OFF	PERCENTAGE	NUMBER OFF	PERCENTAGE	
1 SHELL AND DOUBLE BOTTOM	3097	1801	58	1296	42	23
2 BULKHEADS AND PROPELLOR TRUNK.	563	319	57	244	43	4
3 FORE AND AFT ENDS	1726	909	53	817	47	13
4 SIDE SHELL AND BULWARKS	1454	1010	69	444	31	10
5 DECKS AND ENGINEERS FLAT	2988	1883	63	1105	37	22
6 MAST AND DECK HOUSES	1721	726	42	995	58	13
7 HATCHES AND STOWAGES AND MISCELLANEOUS	2013	838	42	1175	58	15
COMPLETE VESSEL	13562	7476	55	6076	45	100%

b

Figure 63 14000T d.w.t. cargo ship structure group analysis (existing breakdown); distribution of:-

a) Numbers of plate and section components in cost areas,

b) Numbers of plate and section components in cost areas which have been ammended for comparison with those of the 5000T d.w.t. dredger.

closely followed the Austin and Pickersgill practice of building in 'layers' of deck or shell levels rather than in three dimensional blocks as at most other shipyards. On further investigation it was found that the table in figure 63a could not be compared with that compiled previously for the 5000T d.w.t. dredger shown in figure 57. The structure groups were therefore regrouped into 'ship areas' similar to the structure groups employed in the Ailsa dredger to allow a direct comparison to be made. The summary table for the regrouped information is shown in figure 63b and is directly comparable with figure 57 for the 5000T d.w.t. dredger.

The structural differences in the two ships are highlighted by the percentage of total component population found in each category (structure group for dredger, ship area for SD14). Decks in the SD14 comprise 25% of the total and in the dredger comprise only 9%, this reflects the area of deck found in each ship. The opposite is found for category 7 showing that the superstructure of the SD14 is relatively small when compared with that of the dredger. The fore and aft ends are generally found to contain more components in the SD14 than in the dredger. This possibly reflects the difference in purpose of the two ships: the SD14 is a sea-going vessel required to be fairly streamlined for efficiency while the dredger will spend relatively long periods of time stationary while collecting sand and gravel from coastal seabeds or discharging cargo, it may therefore be relatively 'stumpy'. The hopper side and bulkheads (category 5 in each case are not directly comparable. The hopper sides in the dredger serve a functional purpose (storing gravel) while the SD14 bulkheads are included chiefly for structural and compartmentation purposes to satisfy classification rules. Correspondingly the hopper sides in the dredger are functional necessities while the bulkheads in the SD14 can be termed necessary evils, this is reflected in the number of parts in the category for each ship.

Although difficulties are found in presenting information for comparative analysis of ships which are different in design and are constructed using different methods it is useful to be able to compare these differences in a quantitative manner. The brief comparative analysis presented here was achieved by categorising structure groups which were devised to suit the production facilities of one shipyard, to ones which would suit those of another. Thus a direct comparison of the differences in operation times and work content involved in building the two ships in the second shipyard could be made. A different regrouping philosophy might be required for each shipyard who might wish to undertake a similar exercise, but the regrouping process is achieved with relative ease if a similarly structured data bank is available for each ship.

c) SD14 Cargo ship structure group analysis (proposed structure groups)

It was proposed with the development of improved shipbuilding facilities at Austin and Pickersgill to replace the existing ship breakdown into structure groups and fabrication units with a new arrangement to suit the new yard practices. An analysis similar to that carried out previously for existing structure groups was undertaken using the proposed structure groups. This involved the renumbering of all components in the ship hull and in certain cases recoding where a part was altered by the new fabrication breakdown. This was completed for the structural hull of the ship only (i.e. minus superstructure, hatches, deck gear, and machinery seatings) it was known these would not change.

It was possible to complete the analysis more quickly by using the S.P.S.S. computer package which was not available previously. This allowed a subfile system to be set up and then allowed each or any combination of subfiles to be analysed concurrently or consecutively. Thus a subfile was opened for each of the proposed structure groups and each was investigated. The format of the data summary sheet used for the previous exercise was employed. For graphical presentation histograms of numbers of components requiring the production operations shown in figure 64 were drawn shape codes used to indicate the processes are also shown. The resulting histograms are shown in figure 65. In addition tables are presented in figure 66 to

HISTOGRAM	VARIABLE (PRODUCTION PROCESS EMPLOYED)	SHAPE CODES USED TO INDICATE PRODUCTION PROCESS EMPLOYED
1 FLAME CUTTING	FLAME PLANE.	ORTHOGONAL [DIGIT 1 = 4] WITH NO HOLES AND SLOTS [DIGIT 4 = 0]
	PROFILE CUT (OUTLINE SHAPE ONLY)	(ORTHOGONAL [DIGIT 1 = 4] WITH EDGE CUTOUTS [DIGIT 4 = 1 OR 2]) OR (NON-ORTHOGONAL [DIGIT 1 = 7] AND NO BURNED HOLES [DIGIT 4 < 3])
	PROFILE CUT (OUTLINE SHAPE + BURNED HOLES)	BURNED HOLES [DIGIT 4 = 3 OR 4 OR 5] AND PLATE MATERIAL [DIGIT 1 > 3]
	PROFILE CUT AND DRILLED	PLATE MATERIAL [DIGIT 1 > 3] AND DRILLED HOLES [DIGIT 4 > 6]
2 FORMING.	NO FORMING	DIGIT 3 = 0
	FLANGED	DIGIT 3 = 1 OR 2
	SWEDGED	DIGIT 3 = 4 OR 5
	SIMPLE BEND (ROLLED)	DIGIT 3 = 6 OR 7
	COMPLEX BEND (ROLLED)	DIGIT 3 = 8

Figure 64 14000T d.w.t. cargo ship structure group analysis (proposed breakdown); code numbers indicating production operations.

STRUCTURE GROUP	NUMBERS OF COMPONENTS WITH EDGE PREPARATION	NUMBERS OF COMPONENTS WITHOUT EDGE PREPARATION
A	102	743
B	122	708
C	161	597
K	280	1473
D	63	247
T	70	484

TABLE OF EDGE PREPARATION REQUIREMENTS.

STRUCTURE GROUP	NUMBERS OF COMPONENTS IN LENGTH RANGE :-		
	LESS THAN 1000 MM	1000 MM TO 4000 MM	MORE THAN 4000 MM
A	378	312	160
B	428	240	162
C	88	455	215
K	1207	200	352
D	144	63	103
T	322	160	72

TABLE OF COMPONENT LENGTHS.

Figure 66 14000T d.w.t. cargo ship structure group analysis (proposed breakdown); tables of:-
a) plate components with edge preparation
b) plate components falling in specified length ranges.

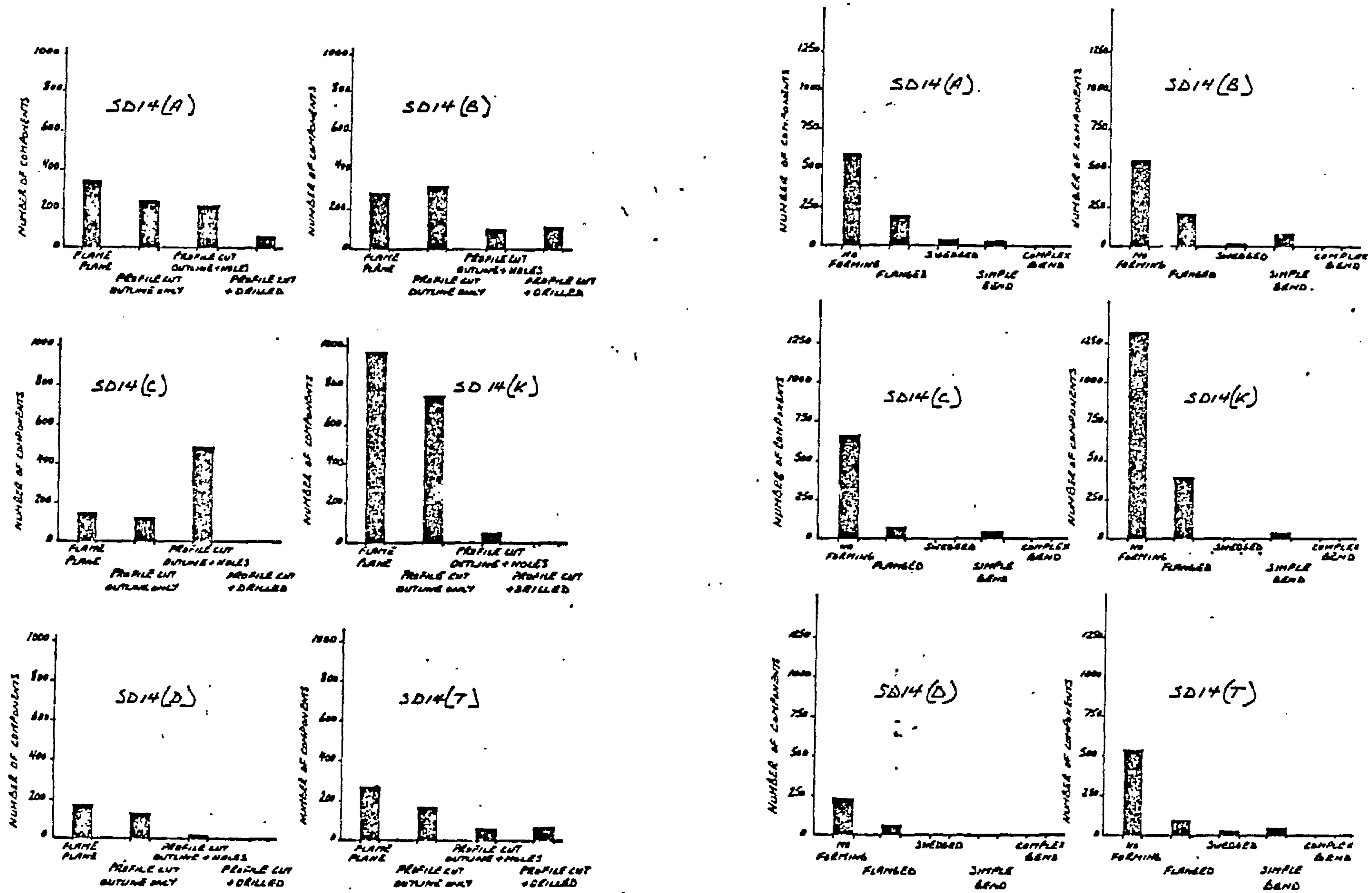


Figure 65 14000T d.w.t cargo ship structure group analysis (proposed breakdown); distribution of:-
a) components having specified plate cutting operations
b) components having specified plate forming operations

indicate the amount of edge prepared plate and the range of sizes found in each structure group.

A more detailed analysis has been made of the sizes of plates and sections, and also of section forming and notching operations. The analysis was undertaken using the S.P.S.S. package and the results are summarised using histograms in appendix H

Twin histograms have been drawn of the number of plate components having a specified outline shape which fall into length and width ranges. These histograms have then been superimposed using the same axial scales for comparison purposes and they are then presented for each of the proposed structure groups. While the histograms are not of great practical value in the calculation of production process loading requirements (this was discussed earlier), they give a strong indication of the range of shape and size of plate components which will have to be handled in the steel workshops. For instance it is found that structure group C contains a large number of plate parts having width between 900 and 1200 mm and length either between 1000 and 1500 mm or greater than 9000 mm. However similar shaped plates in structure group B cover a wide range of lengths and widths with a fairly even spread. Thus an indication may be obtained of the material handling requirements needed to feed plate parts to any specialised assembly area.

Similar analyses of a specified section part shape, size, or production feature, for each proposed structure group are presented for comparison purposes. Histograms are shown of numbers of components falling in length and depth ranges for each main type of section (angle bar, bulb flat bar, and flat bar), with the number having square ends outlined in each case against the total number required. Further histograms are included for forming operations for each type of section, and also for additional cutting operations such as edge nibbling or hole cutting or burning.

It can be seen that the above analysis is based more on production methods-component shape relationships than on purely shape considerations as before. This follows the general trend found during the analysis of a greater awareness of these relationships with the increase in knowledge of manufacturing methods obtained by the author. This trend was also reflected in the progression of total ship hull analyses leading to the development of standard tables which were highly process dependant. The analyses described previously were presented to A. and P. Appledore (who were the chief consultants to Austin and Pickersgill) for possible use in arriving at the new shipyard design using a more quantitative approach.

8.4. Work scheduling analysis

An analysis (45) was made of the workload existing on the component production shopfloor at anytime during the building cycle of a ship from the components being manufactured for that ship, and for the shipyard when considering all ships in manufacture. Analyses were undertaken for total numbers of parts in production and also the number of parts requiring specific manufacturing operations. These were made possible by the availability of a computer listing of activity schedules created from the network plan to build the ship in conjunction with the analyses which had been carried out for structural groups of the 14,000T d.w.t. cargo vessel. The analyses of the structural groups are described in detail in section 3 of this chapter and the summary format sheet is shown in figure 61. Cutting and forming operations are categorised in the summary sheet, and edge preparation and plate lengths are also investigated. The summary sheets for all the structural groups were available for analysis on a time base. The loading of structural groups was available from the computer listing based on the network plan. The manufacture of components and assembly of units was divided into a number of network activities, each of which was assigned a duration, earliest start, latest start, and latest finish. The resulting total float was also listed on the computer listing together with a description of the activity itself. The description of the network activities did not comply with the definition of the structural groups, however it was possible by using the verbal description and the associated frame position of the 'activity' to find the group or part of group which it represented. In some cases it was found that a structure group was subdivided into two network activities, in these cases the numbers of components in the group were divided in proportion to the number of ship frames over which each activity extended; it was assumed that the size of a similar structure type would be proportional to the number of components in that structure.

From the network listing and the structural group analyses a table was completed which summarised all the information available in a form which was easily punched onto data cards for automatic data handling, a sample is shown in figure 67. The resulting data cards were then used as input to programs devised to compute the number of parts which were in production on every day of the building cycle of the ship, this was possible for all components or those requiring specified operations or having specified features by defining the data card column to be employed. Components 'in production' comprise those which are between raw material issue and the erection of an assembled unit at the berth. The number of components in production could also be found when loaded by earliest start or latest start using the devised programs.

The number of components in production was plotted in histogram form over the whole building cycle of a ship, the unit of time employed was one day, and the total span of a building cycle was found to be about twenty weeks. The exercise has been carried out only for components produced from steel plate; steel sections usually have an independent production route and may therefore be dealt with separately.

Two hypothetical sets of conditions were considered:-

a) That all components were loaded by latest start and latest finish. Here the minimum amount of work in progress is allowed and no flexibility is permitted in work loading by shopfloor supervision.

b) That all components are loaded by earliest start and latest finish. Here the maximum amount of work in progress (allowed by the network plan) is in the workshops at any one time and shopfloor supervision is permitted maximum flexibility in work loading.

STRUCTR. GROUP NUMBER	EARLIEST START	LATEST START	LATEST FINISH	TOTAL NUMBER PARTS	PARTS WITH EDGE PREPARN	LENGTH <1000 MM	LENGTH >1000 <4000 MM	LENGTH >4000 MM	FORMING NONE	FORMING FLANGE	FORMING SWEDGE	FORMING BEND	PLATE CUTTING FLAME PLANE	PLATE CUTTING PROFILE CUT	PLATE CUTTING BURNED HOLES	DRILLED
DB1(1)	3·6	7·0	8·4	132	29	21	74	37	82	32	0	18	22	27	47	36
DBE(1)	4·8	4·8	7·2	183	13	42	31	110	164	12	0	8	38	26	97	23
DBE(2)	2·0	5·4	7·8	183	13	42	30	110	164	12	0	8	38	26	97	23
EF1	4·6	8·0	9·0	58	0	29	9	31	50	8	0	0	25	35	0	0
DB2(1)	2·0	5·4	7·8	237	54	28	83	59	103	56	0	10	60	44	134	0
DB2(2)	2·0	6·0	7·2	118	27	14	41	30	52	28	0	5	30	22	67	0
DB3(1)	5·0	7·4	9·4	167	32	9	121	37	131	29	0	8	29	11	4	120
DB3 2	5·0	7·6	8·8	100	20	6	72	22	78	17	0	4	18	7	[illegible]	72

Figure 67 14000T d.w.t. cargo ship structure group analysis (existing breakdown); summary information sheet format used for workload investigations.

a) Components loaded by latest start

Figure 68 shows histograms of components which are in work (i.e. between raw material and completed structural unit) on any particular day during the building cycle. Figure 68 (a) shows the work load by variety of components and figure 68 (b) the work load by total number of components required. The two histograms are very similar indicating that the number off-variety ratio is fairly constant over the building cycle. A further histograms of the average number off per component (figure 69 shows that this is true over the mid-part of the building program, but that the average number off varied widely in the later stages when hatch details and auxiliary seats were being manufactured. During the first 75% of the building cycle, however, the average number off was fairly constant between 2 and 2.5 so the advantages of large batch production do not exist in this case.

More interesting is the shape of the histogram. The shipyard under investigation has two adjacent shipbuilding berths which are both employed to erect the same type of ship. Therefore although the building cycle for the ship is about twenty weeks the launch cycle of the shipyard is only ten weeks. Thus a curve as shown in figure 70(a) would ideally balance the required work load and give a fairly constant total capacity requirement. The actual curve (figure 68b is far from the ideal. Loading by latest start would result in negligible work being available on the ship in weeks nine and ten. Assuming that the ship under construction on the second berth follows the same network plan as that on the first, and that work begins on it when that on the first berth is half completed then two work load charts may be super imposed to give the overall shipyard capacity requirement (figure 70b) This again is found to be very irregular and can obviously not be a true representation of what actually happens on the shop floor.

Consideration has also been given to individual process operations. Components which may be flame planed or profile cut (orthogonal; i.e. straight sided) were easily distinguished from those which can only be profile cut (non orthogonal; i.e. those which have curved sides or intricate cutouts) by using the shape code of the component classifi-

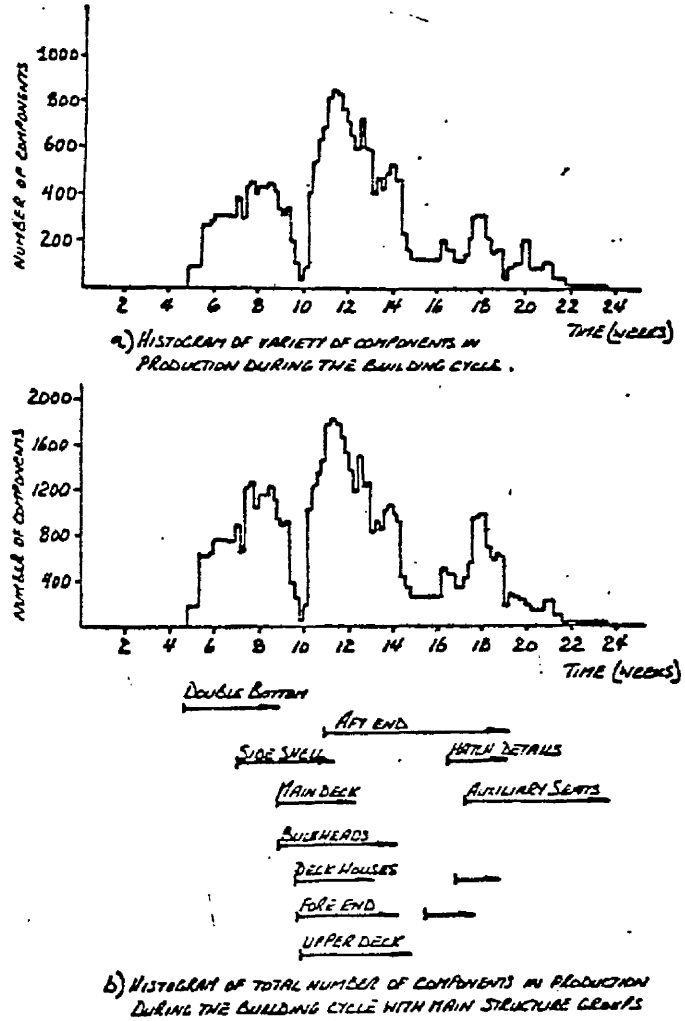


Figure 68 14000T d.w.t. cargo ship workload analysis; distributions of:-
a) variety of plate components,
b) total numbers of plate components in work over the building cycle, loaded by latest start

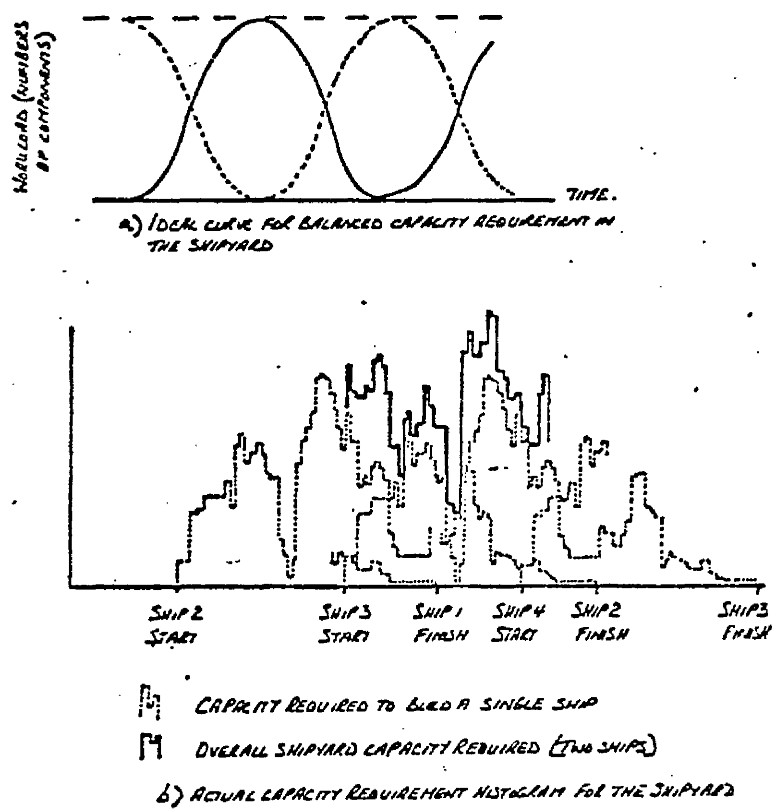


Figure 70 14000T d.w.t. cargo ship workload analysis;
a) ideal curve for balanced capacity requirement over the building cycle
b) actual curves of numbers of plate components
in production over the building cycle, loaded by latest start

Figure 69 14000T d.w.t. cargo ship workload analysis; distribution of average number required per plate component type in work over the building cycle, loaded by latest start.

cation system. These were then automatically counted using data processing equipment. The results of this exercise on plate cutting are shown in figure 71. The shape of the orthogonal plate histogram (solid figure 71a) closely resembles that of the total number of components (figure 68b) However, the non-orthogonal plate production (or profile cutting workload) is slightly higher in weeks six to ten when the double bottom area of the ship is in production. The solid lines in figure 72 show the number of plate components in production during the building cycle requiring burned and drilled holes. Again it is noticeable that comparatively more plates require these operations during weeks six to ten and again an unbalanced workload is highlighted.

A similar exercise has been carried out to investigate forming operations and the results are shown in figure 73 The histogram of plates requiring flanging (solid line, figure 73a is closely related to that showing the total number of components in production (figure 68b, but those showing swedging or 'smooth' bending (solid lines, figures 73b and 73c differ significantly. Most swedging occurs during bulkhead and deckhouse production and more bending occurs during double bottom, fore and aft end production periods. Further analyses for edge preparation and component length distribution were also undertaken. The edge preparation histogram (solid line, figure 74) showed that plates requiring chamfers occured less frequently in the later stages of the building cycle, although in the first two thirds of the programme the curve closely followed that of total component production. The component length distributions were drawn (figure 75) for parts falling into three length ranges; 0-1000mm, 1000-4000mm, and greater than 4000mm. It was generally found that the average size of parts decreased during the building cycle, this can be seen from the relative positions of the three histograms.

b) Components loaded by earliest start

Loading by earliest start introduces the maximum allowable network float into the work load charts and thus the amount of work in progress is also at a maximum.

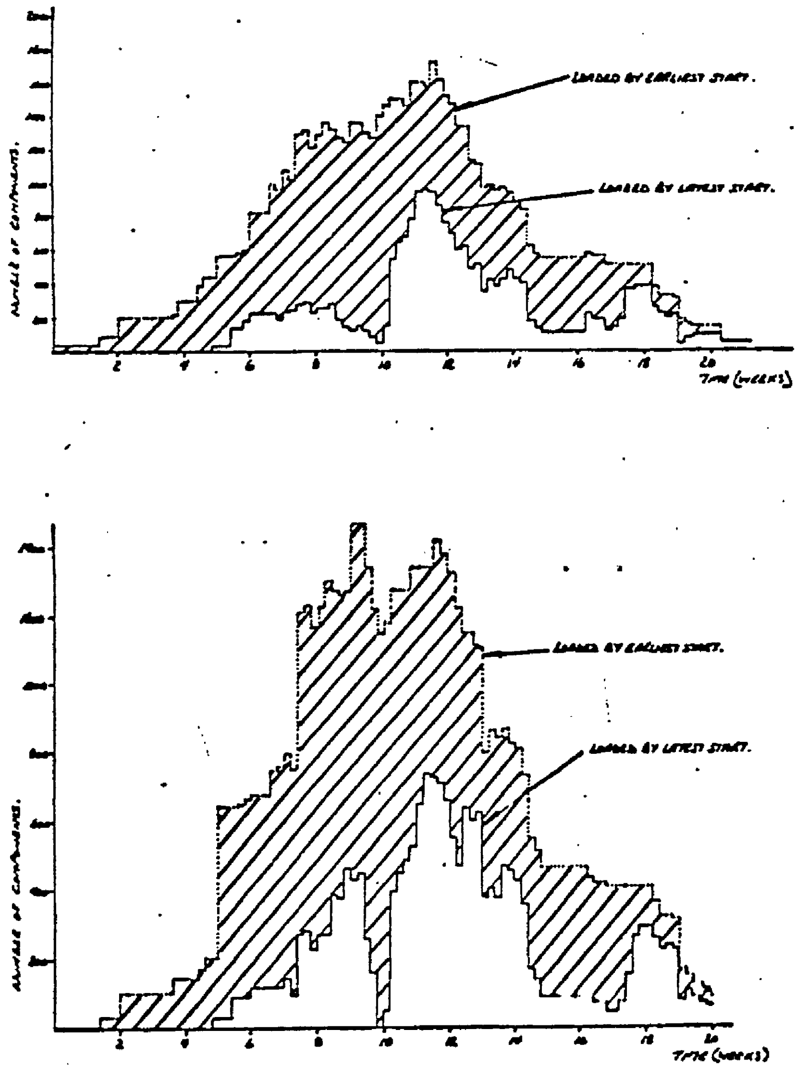


Figure 71 14000T d.w.t. cargo ship workload analysis; distributions of:-
a) flame planed plate components,
b) profile cut plate components,
in work over the building cycle, loaded by earliest and latest start.

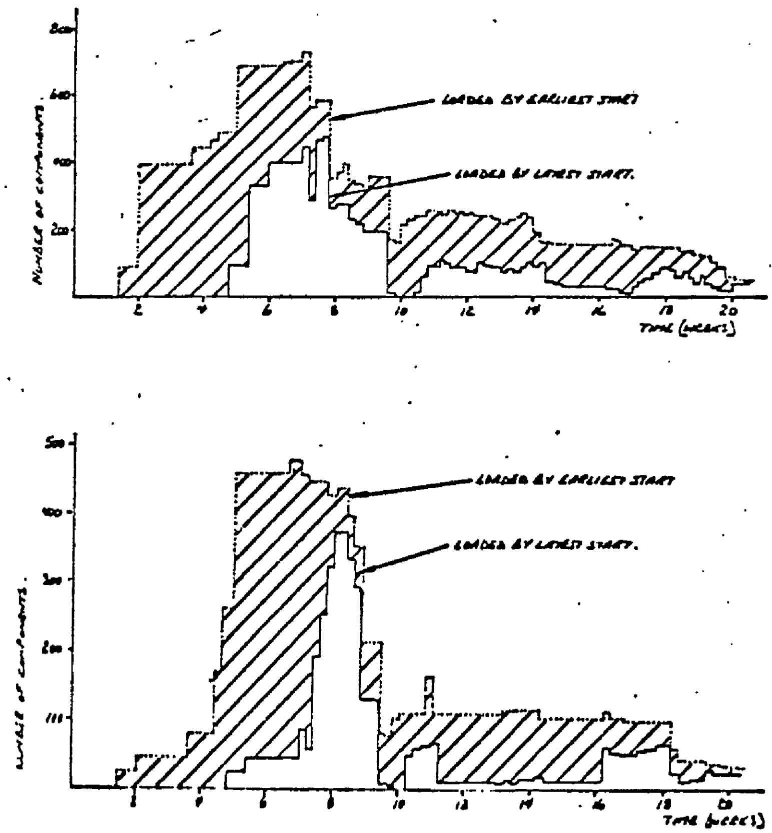


Figure 72 14000T d.w.t. cargo ship workload analysis; distributions of:-
a) plate components with burned holes
b) plate componunts with drilled holes
in work over the building cycle, loaded by earliest and latest start

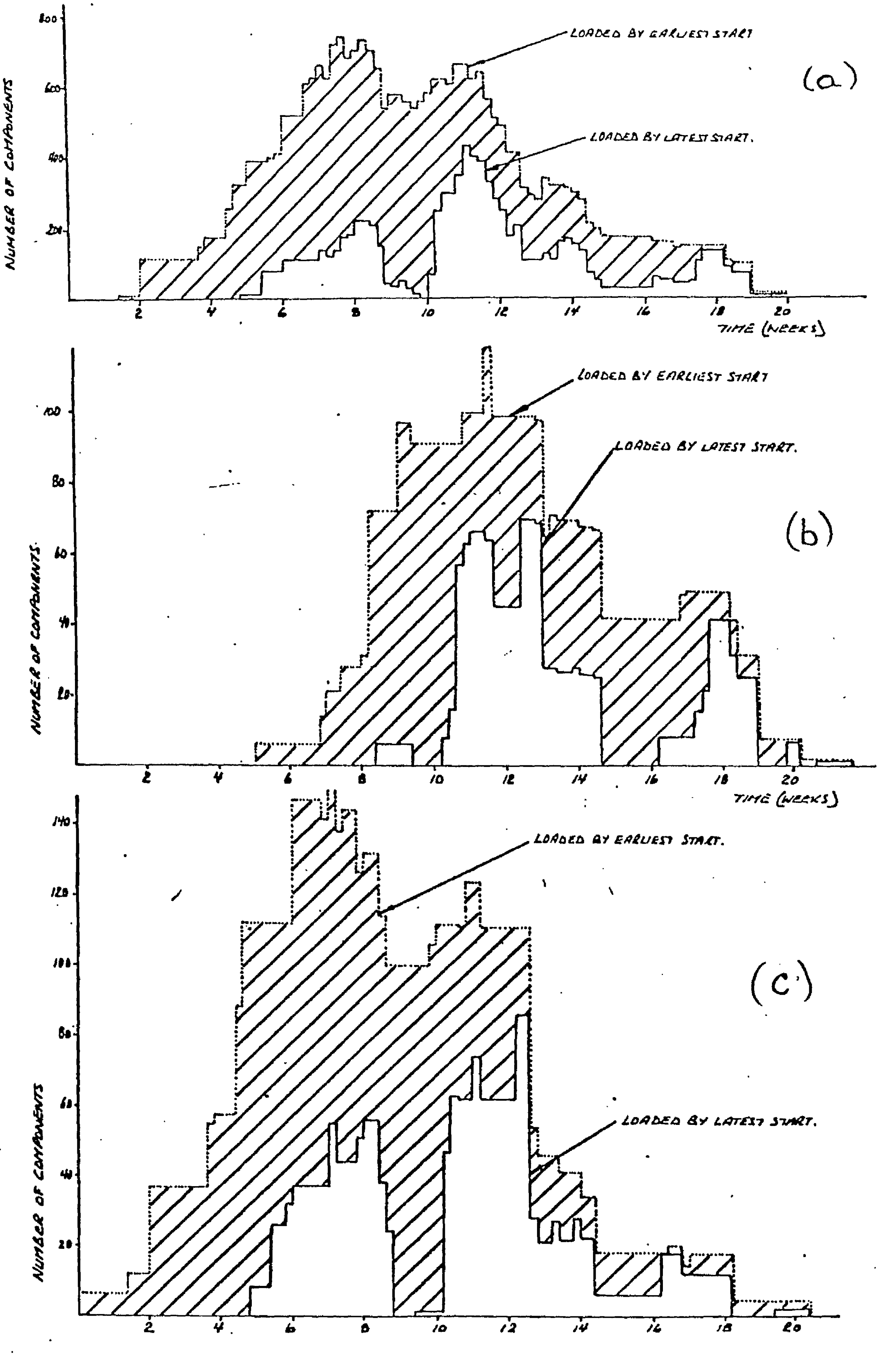


Figure 73. 14000 T d.w.t cargo ship workload analysis; distributions of
a) plate components which are flanged
b) plate components which are swedged
c) plate conponents which are rolled

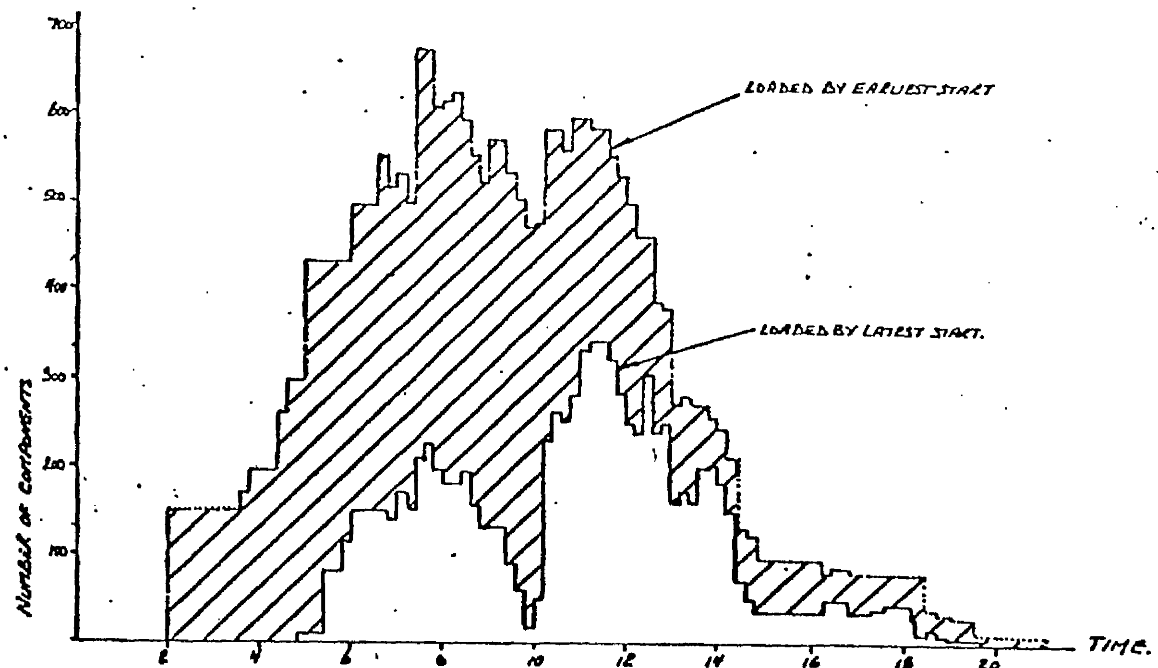


Figure 74 14000T d.w.t. cargo ship workload analysis; distribution of plate components with edge preparation in work over the building cycle, loaded by earliest and latest start.

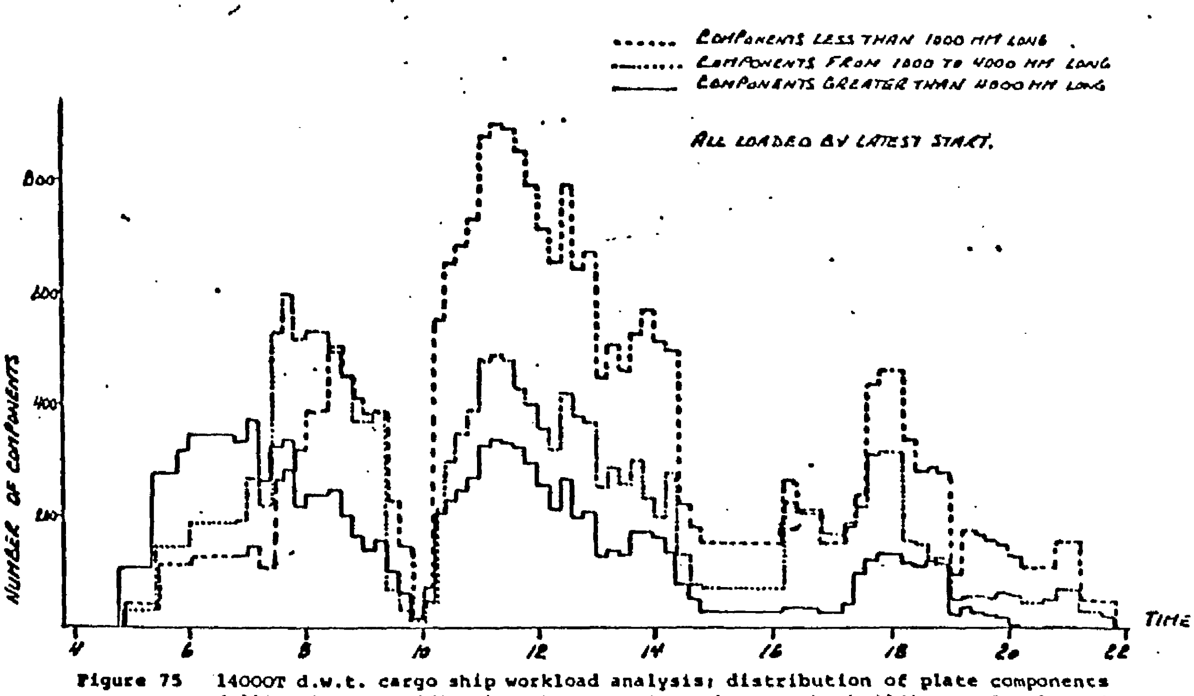


Figure 75 14000T d.w.t. cargo ship workload analysis; distribution of plate components falling into specified length ranges in work over the building cycle, loaded by latest start.

Figure 76 shows the new histogram of numbers of components in production loaded by earliest start, together with the original histogram of number of components by latest start. The shaded area between the two histograms is an indication of the allowable excess work in progress, this is shown to be at least twice that of the essential work in progress. The curve has been greatly "smoothed" by the additional work in progress and approaches the ideal shown in figure 70(a). However, control has now been transferred from the planner and production controller to individual shop floor supervisors. The individual supervisor may use his management skills to work within the shaded "excess work in progress" area of the histogram to balance his own capacity require requirements, the degree of his skill and physical space available limiting the work in progress. Thus the apparent absence of work in week nine will never be noticed at shop floor level.

The shipyard in question allows a great deal of network float on their activities, an average float of 3.6 weeks on an average activity duration of 1 - 2 weeks. It seems therefore that the planner and production controller give shop floor supervision great flexibility in the management of work loads in their areas, but only at the risk of excessive raw material stocks and extravagent work in progress.

Histograms of earliest start distributions have also been superimposed in dotted lines on those described earlier for latest start distributions of parts having various production processes or shapes. These are shown in figures 71 to 74. It was generally found that the curve smoothing which occured for the total component population histogram also applied to individual process graphs. This would have the same effect as previously described of balancing shopfloor workload but would transfer control from the production planning department to shopfloor supervision. The previous comments about excessive raw material costs and extravagant work in progress still apply to individual operations.

Thus the availability of both a ship component data bank and a network plan allows an analysis to be made of the shopfloor workload over the building cycle of a ship,

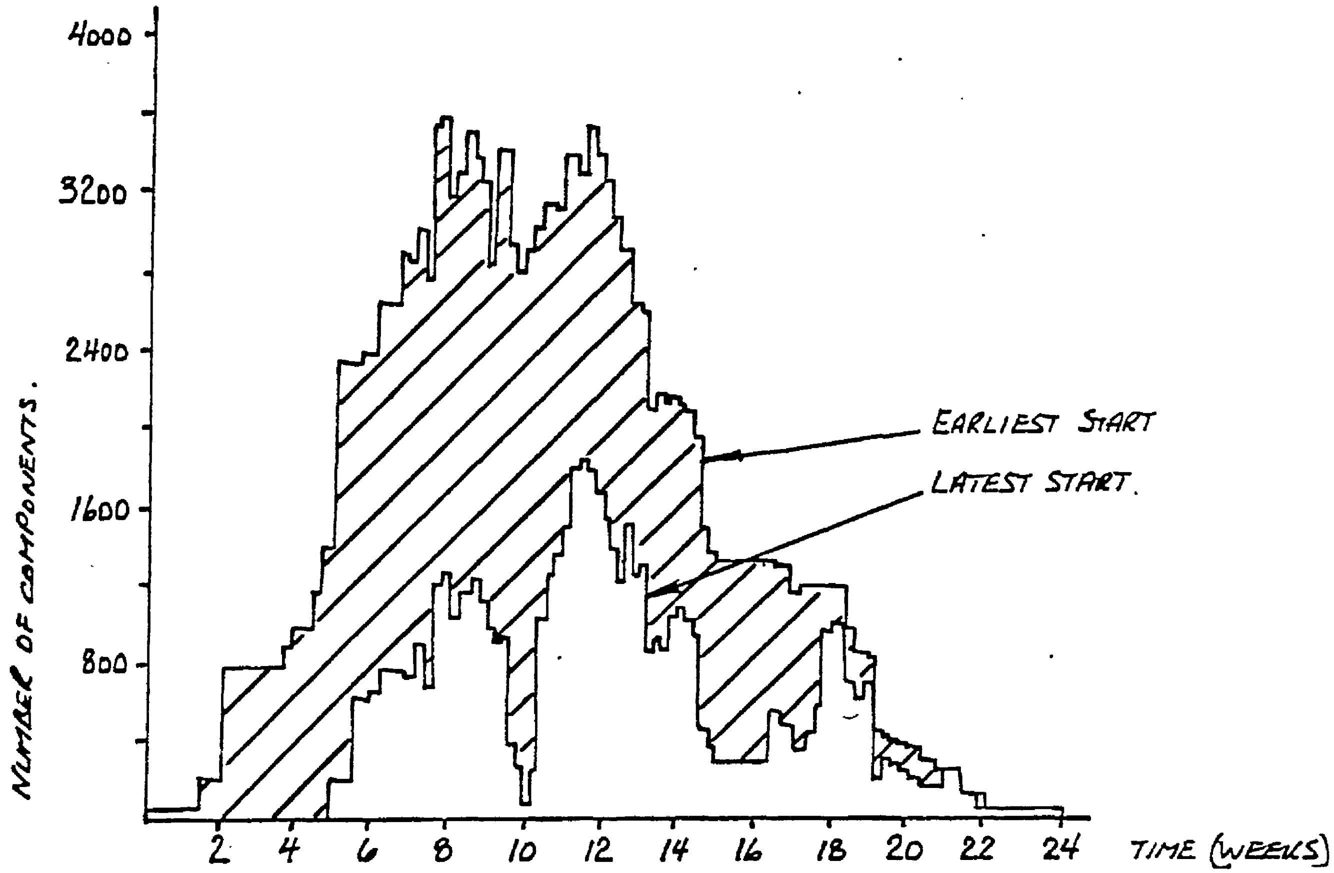


Figure 76 14000T d.w.t. cargo ship workload analysis; distribution of plate components in work over the building cycle, loaded by earliest and latest start.

and over a specified period of manufacture. In this specific analysis inbalances in the basic network plan were highlighted. These were overcome in this case by the use of network float at the expense of work in progress. However there are now plans for a radical redevelopment of the shipyard which was studied here which will reduce the building cycle from about twenty weeks to six. Excess work in progress will not then be practicable and the load charts from the network plan will have to be smoother and resemble more closely the ideal curve.

The redevelopment will also involve an examination of the present method of building the ship and possibly result in a new ship breakdown and network plan. The statistical data gathered on the components will then be used to compare the existing and proposed methods of ship production, both at overall plant and individual process levels. It will also prove useful in the design of the production planning and control systems needed to manage the new facilities.

8.5 Analysis for group technology

Attempts have been made to define families of components having similarities, and then to investigate the possibility of forming machine families or production cells to exploit these similarities. Component similarities in general manufacturing industries have previously been determined by studying process routes or manufacturing methods (Production Flow Analysis-P.F.A., or Component Flow Analysis-C.F.A.); or by studying basic material, shape, size, function, or combinations of these factors. The method employed in the research was governed by component and production information availability, and was chosen following initial studies in collaborating shipyards. These have shown that the level of process planning practiced is low, and frequently consists of specification of cutting operations only. The inherent requirement in shipbuilding to manufacture components from raw material plates and sections leads to the practice of nesting components into raw material pieces as economically as possible. The size of raw material plates also results in the release of relatively small work packages to produce a specific fabrication unit, especially in shipyards having little capacity for storing component parts. This policy also allows components to be painted easily in the raw material form prior to cutting operations, thus preventing subsequent surface deterioration The cutting-out operation is therefore fundamental to all ship hull components and subsequent operations are not specified in detail but are left to shopfloor personnel to define from assembly drawings and mould loft instructions. The most important methods of communicating manufacturing information to the shopfloor are:-

- material bills specifying sizes of raw material and the components to be produced from them;
- numerical control tapes, tenth scale drawings, and optical slides to control flame cutting machines, these are traditionally prepared by mould loftsmen who are skilled in the interpretation of ship hull shape definitions;
- bending templates prepared by mould loftsmen, usually of light wood construction;
- assembly drawings which are used to find details of components as well as for fabrication purposes.

The inherent skill in shipbuilding enables this information to be used to produce component parts and fabricated assemblies without a rigidly implemented process plan or manufacturing information specification. It was therefore decided that component similarities could best be studied by direct investigation of shape, size, and raw material. This approach has allowed the use of assembly drawings as the source of component information, and these are presented using similar formats in all collaborating shipyards. It has therefore been possible to employ common data collection formats and analysis methods in all participating companies.

Initial division of components into those manufactured from plate or section is an obvious decision and is normal practice in the industry, thus attempts at defining similarities for exploitation have been undertaken within these categories.

Plate components were initially subdivided into those having all straight sides (termed orthogonal) and those having at least one curved side (non-orthogonal). It was assumed that the primary operation (cutting), differed for these categories, and that orthogonal components were flame cut or guillotined while non-orthogonal components were profile cut. Analysis of a ship hull showed that 77% of plate components were orthogonal and 52% were both orthogonal and four sided; practically all the remaining 23% non-orthogonal plate components had one curved side. Further analysis of forming operations showed that 30% of all plate components were formed, and that orthogonal plates were chiefly press formed while non-orthogonal plates were rolled. In addition 43% of orthogonal and 57% of non-orthogonal plate components required additional holes or slots. Orthogonal and non-orthogonal plate components were easily recognised using the descriptive coding system (Chapter 5.3)but doubts to their value as component families were soon raised. The main doubt was that orthogonal plate components with holes or slots would be profile cut rather than flame planed in most middle and higher technology shipyards. (Ryton Marine and Ailsa Shipbuilding, who were the first shipyards to collaborate, did not possess profile cutting equipment but relied on flame planners and hand held cutting torches. When work began with Austin and Pickersgill the importance of profile cutting machinery was recognised.) The second doubt was concerned with the difficulty of distinguishing between guillotined and flame cut components.

Recent attempts to establish plate component families have concentrated on primary cutting operations rather than outline shape alone. Cutting operations have been established for components by considering the descriptive code number. This resulted initially in the definition of three categories:-

1 parts which are flame planed or guillotined (depending on size), or profile cut at far greater expense. These are orthogonal components with no positionally important burned holes or slots and having descriptive code numbers 4**0..., 4**1...(with corners or sides nibbled, 4**7... or 4**8... (both with drilled holes).

2 parts which are profile cut, or flame planed and subsequently hand burned for holes and slots. These are orthogonal components with positionally

important holes and/or slots and having code numbers 4**2... (slots for cross members), 4**3... and 4**4... (burned holes), 4**5.. (burned holes and slots), and 4**9... (burned and drilled holes).

3 parts which are profile cut only. These are non-orthogonal parts having code numbers beginning with 7.

The percentages of hull components found in these categories for two vessels were as follows.

Vessel \ category	1	2	3	Total
1	39.5	7.2	10.2	56.9
2	26.1	13.7	14.3	54.1

A detailed analysis of the size distribution (length by width) of category 1 components to indicate which can be guillotined has shown two distinct peaks for both ships. Large numbers of small components (600 mm x 600 mm) are small brackets and connection lugs, and it is noticeable that no category 2 or category 3 components fall into these size ranges. The second peak, although less pronounced, was found to lie at about 7000 mm x 2500 mm; and from visual studies these consist of shell plates, deck plates, and main bulkhead plates. Thus category 1 components have been subdivided by size into guillotinable components (less than 600 mm long), and flame planed components. The re-specified categories and percentages of components are therefore as follows:-

Vessel \ category	1	2	3	4	Total
1	25.2	14.3	7.2	10.2	56.9
2	11.7	14.4	13.7	14.3	54.1

Analysis of subsequent operations has shown that most edge preparation is applied to orthogonal plate components, these are mainly shell, deck, or major bulkhead plates which do not have holes or slots. In many shipyards, including the one constructing the ships analysed, this can only be achieved on flame planing machines, thus further justifying category 2 as a component family. It has also been shown that the majority of rolled plate components are larger than 2500 mm by 1600 mm; these are practically all used in shaped shell sections and therefore have no holes or slots but require edge preparation. Swedging occurs on components in the middle size ranges (1500 - 4000 mm x 900 - 2500 mm), these are generally used for deckhouse compartment bulkheads and require few cutouts apart from doorways and access holes. Thus a manufacturing cell for category 2 components will require plate rolling and swedging facilities, in addition to a flame planing machine with edge preparation facilities.

Analysis of the size distributions of flanged components has shown that a large number of guillotined components (category 1) are subsequently flanged. However the spread of sizes for flanged components is even and wide, and few indications of flanging requirements for other cutting categories is evident. It has been assumed from background knowledge that flame planed components (category 2) which are flanged comprise of major corrugated bulkhead plates and are relatively few in number, and that flanging is frequently used to stiffen free edges (i.e. not welded) of components in categories 3 and 4. Thus manufacturing cells to produce the four component categories will require the following production operations:-

operation \ category	1	2	3	4
Main operation	guillotine	flame plane (with edge prepn)	flame plane or profile cut	Profile cut (or hand burn)
Ancilliary burning operation		hand burn (for corner and side nibbles- not positionally important	hand burn (for holes and slots- positionally important	
Subsequent forming operations	flange	roll bend, swedge, and flange (few only)	flange (edge stiffen)	flange (edge stiffen)

Category 3 components can be manufactured with those from category 2 or category 4. It is therefore possible to implement only three group technology cells; say cell A for category 1, B for 2, and C for 4. Components from category 3 can then be manufactured in cell B or C, depending on workload; but will most probably be made in cell C using the less labour intensive profile cutting process. The resulting families and percentage of total number of components undergoing each operation is as follows for the two ships analysed.

Cell / Operation.		A (cat.1)	B (cat.2)	C (cat.3+4)	Tots.
Main Operation for A guillotine B flame plane C profile cut	Ship 1	25.2%	14.3%	17.4%	56.9%
	Ship 2	11.7%	14.4%	2.8%	54.1%
Edge preparation	Ship 1		7.1%	1.9%	10%
	Ship 2		4.1%	0.8%	4.9%
Flanging	Ship 1	3.9%		8%	11.9%
	Ship 2	0.7%		9.7%	10.4%
Swedging	Ship 1		0.6%		0.6%
	Ship 2		0.7%		0.7%
roll bending	Ship 1		2.2%		2.2%
	Ship 2		1.7%		1.7%

Section components were first subdivided into those which were manufactured from:-

- flat bar
- bulb flat bar and angle bar
- solid section bars and channels (W, I, H, etc.)

Flat bar is chiefly used to stiffen plate edges and is therefore cut in fairly short lengths using flame cutting, drawing, or shearing techniques; and is normally formed by rolling or flanging methods. Bulb flat and angle bar is chiefly used for panel stiffening and is therefore cut in a larger variety of lengths using flame cutting or sawing techniques; and is normally formed using cold frame bending equipment. Solid section bars and channel is seldom used, but it is best cut using a mechanical saw. For all bars the method of cutting is often dictated by the end shape required, square ends can be guillotined or sawed (depending on the cross section), while scalloped or shaped ends must be flame cut.

Analysis of a vessel showed that 63% of section components were from angle or bulb flat bar (with 4% of these formed), 32% were from flat bar (6% formed), and 5% were from solid section or channel. Section usage was found to depend on shipyard policy and to vary from ship to ship. However, because of the differences in manafacturing methods the categories specified here can be used as component families to devise group technology cells.

More detailed analysis of the components forming two ships hulls has shown that relatively few operations are necessary following the primary cutting process, the figures are as follows:-

Category / Operation	1 Flat bar		2 Angle bar and bulb flat bar	3 Channel and other sections	Totals
cutting out	Ship 1 Ship 2	8.0% 28.5%	33.1% 17.2%	3% 0.2%	44.1% 45.9%
burning (holes and cutouts)	Ship 1 Ship 2	0.7% 0.2%	16.7% 1.9%	0 0	17.4% 2.1%
drilling	Ship 1 Ship 2	0.2% 0	4.8% 0	0 0	5% 0
bending	Ship 1 Ship 2	0.1% 0.3%	5.8% 2.7%	0 0	5.9% 3%
flanging	Ship 1 Ship 2	0 0	0 0	0 0	0 0

After initial cutting the main operation is the cutting out of side nibbles and cutouts, this occurs chiefly with bulb flat and angle bars and may then be combined with the initial cutting operation. Differences occur between the two ships and these may present difficulties in balancing group technology cell workloads. They may cause many shipyards to consider combining section categories 1 and 3 (flat bar and channel).

Although it has been shown that component families can be specified, the implementation of group technology manufacturing cells is difficult to justify. Problems include the economics of component nesting for steel ordering, the introduction of two or four bed n.c. profile cutting machines, and the relatively small number of machines of any type which are employed, particularly in smaller shipyards. Nesting can be done most economically if all components of the same thickness are available as input into the procedure. If the proposed plate component families are accepted then either smaller guillotined components will not be available, or they will have to be manufactured subsequent to flame cutting from 'scrap' material. The first alternative will increase raw material costs while the second will increase handling and production control costs. In addition if guillotined components are manufactured in a separate cell then flame cutters or roll shears will be needed to cut heavy steel plates into guillotineable widths. Alternatively the raw material input form can be charged to narrow flat panels (incurring cost extras from steel suppliers), or coiled strip (requiring decoiling machines and having a maximum thickness of 9 mm)

The introduction of two and four bed n.c. profile cutting machines results in an 'anti-trend' (from mass production, and hence group technology principles). They are capable of cutting shapes from n.c. descriptions both in the as-coded version and a mirror image, thus catering for 'opposite-hand' components from part and starboard fabrication units. This results in the manufacture of parts in pairs and work batches governed by fabrication units.

The relatively small number of forming machines presently found in smaller shipyards is also detrimental to setting up group technology cells for components manufacture. Primary cutting operations can easily be segregated to form the basis for cells, each being fed from a single raw material treatment plant. Indeed the division into flame plane and profile cut is already well established in most shipyards by historical development.

However in most shipyards (Ailsa, Austin and Pickersgill) only one roll forming machine, one cold frame bender, one plate portal press, and one guillotine (or combined press/ guillotine) is available; and these are capable of dealing with the full workload. Thus group technology cells cannot be introduced by re-arranging existing equipment with the addition of only a few low cost machines as in other industries, but requires greater capital investment. for secondary operations. Most British shipyards are also on well established sites with workshop space at a premium. The combination of extra work in progress and the shape size of both components and raw material will result in more cramped working conditions and be detrimental to productivity. For these reasons group technology will best be introduced into component manufacturing areas in 'green field' shipyard developments. Here the problems of working with existing plant and equipment will not be applicable, smaller guillotines and forming machines can possibly be used, and shortage of workshop space will be less of a problem. However the possibility of such a development under present economic and market conditions is very unlikely.

Chapter 9 Process Planning

9.1 Process planning requirements

The data required for components manufacture may be divided into four areas, component information, process routes, operations, and work content.

a) Component information

This was explained in Chapter 4 section 4 and comprises of component definition and component description. The definition of raw material, component part, and assembly into which the component is welded is adequately catered for in most ship part numbering systems. The method of describing components, particularly those manufactured from plate, is passing through a transition stage with numerical control descriptions being used more frequently. Full scale screiving is now almost extinct, but tenth scale lofting and verbal descriptions are still widely used. In general this aspect is also well catered for.

b) Process route

This defines the manufacturing path a component must pass through from raw material to finished part. It is influenced primarily by the shape and size of the finished component and secondly by the form of the available raw material. Process routes have been discussed in detail in Chapter 3.

c) Operation Data

This is the information necessary to carry out the operations specified in the process route, it covers main plant, equipment, and manufacturing data. The first and subsequent choice of plant or machinery will be stated with any necessary auxiliary equipment (tools, cutters, jigs, measuring devices. Machining data will include special features of the component (i.e. edge preparation) together with various cutting speeds and feeds to produce the part most economically.

d) Work Content

This will consist of set-up times, operation times, and contingency allowance for each operation. A detailed breakdown of estimated times is only required at shopfloor level if used as part of an incentive scheme, otherwise publication of the information is unnecessary and may damage industrial relations. Data will still be required, as a compiled sum, for work group bonus systems and production scheduling and control. In this case a total job duration time only is required for the shopfloor labour and supervision to gauge the'size' of a job.

The documents used to present manufacturing information to the shopfloor in general engineering are the Process Route Sheet and the Operation (or Job) Card. The route sheet accompanies the item in work through the factory and is usually itself accompanied by a 'book' of tear-off job cards, one for each operation. Examples of route sheet and operation card layouts used in general engineering are given in figure 77

The route sheets are presently used in shipbuilding but they contain much less information than in general engineering. A suggested layout for a route sheet is shown in figure 78 (a). All details of raw material, component, and assembly marshalling number are given with the process route which is itself more detailed than at present. Each operation on the route sheet will require a job card similar to that suggested in figure 78 (b). This contains more detail of the individual operation requirements and also gives the basis of the estimated operation time (only with a fairly accurate estimating system). The production scheduling and control functions will require summary sheets, probably by production batches to aid production scheduling and subsequent loading. A suggested possible layout for this is shown in figure 79.

At present production decisions are made manually either by process planning engineers or in situ on the shopfloor, and are based on information which is not necessarily complete. The degree to which this information can be supplied from a data bank and, using empirical rules, subsequent production decisions automatically made will be described.

ROUTE SHEET

Part Name: End Plate
Part Model: A
No. per Model:
Economic Lot Size:

Material: Aluminum.
Unit Weight:

Part Number: A-68
Drawing Number:
Date Effective:
Replaces issue of Sheet ____ of ____

Oper. No.	Dept. or Prod. Center	Description of Operation	Machine	Tools, Jigs, etc.	Std. Time		Oper. Spec.
					Setup Min.	Prod. Min.	
A68-1	Lathe	Face surfaces, drill, bore, and ream hole to 1-1/4".	#25 LeBlond, 19" Lathe.	Center drill and chuck, 1" T.S. drill, 3/4" boring bar, 1-1/8" T.S. reamer, 5/16" R.H. round nose tool bit, 5/16" R.H. side facing tool bit, 8" smooth file, .025" set block 4-jaw independent chuck.	30	24	
A68-2	Mill	End mill bosses.	#55 Milwaukee Mill.	3/4" dia. end mill, 1" set block, 8" smooth file.	30	18	
A68-3	Drill	Drill 4 holes 11/64". Drill 1 hole 11/32" x 29/32" deep, spot face 4 holes. Drill 2 holes 1/8", tap one hole, 1/8" pipe thread.	#133 Delta Gang Drill.	17/64" T.S. drill, 11/32" T.S. drill, 1/8" or #30 twist drill, drill chuck, 1/2" C'bore with 17/64" pilot, 1/8" pipe tap, Jig #A-68-3.	12	21	
A68-4	Mill	Counterbore 1-1/4" hole, 1/8" deep, cut oil pocket 3/16" wide, 7/8" deep.	#55 Milwaukee Mill.	1-1/4" C'bore with 1-1/8" pilot, #13 Woodruff key cutter, #808 American Std. cutter holder.	12	12	
A68-5	Arbor Press	Press bushing in end plate.	#29 Greenerd Arbor Press.	8" Smooth file.	9	18	
A68-6	Drill	Drill holes designated on jig.	#133 Delta Gang Drill.	#20 twist drill, #30 or 1/8" twist drill, #43 twist drill, drill chuck, #8-32 tap. Jig #A-68-6.	6	18	
A68-7	Drill	Drill two holes 3/16", countersink oil hole.	#121 Avey Drill.	3/16" S.S. Extra Long Drill, extra long C'sink, drill chuck.	3	3	

END PLATE

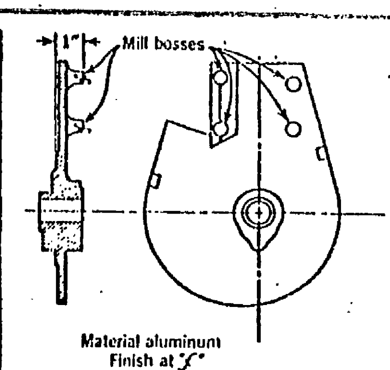
OPERATION NO. 2 TOTAL OPERATIONS

MACHINE Milling
MACHINE NO. Any

TOOLS:
3/4" dia. end mill.
6" scale or 1" set block.
Vertical milling attachment.
8" smooth file.
Suitable parallels.
Bolt and wrench.

JIGS:

FIXTURES:



ITEM	OPERATION ROUTINE	STANDARD TIME
1.	Assemble vertical milling attachment on machine overarm.	
2.	Fasten cutter in attachment spindle.	
3.	Adjust speed to give 200 surface feet per minute.	
4.	Clamp work to table.	
5.	Set cutter to correct height from finished surface.	
6.	End mill bosses as per drawing.	
7.	Have first piece inspected.	
8.	Complete lot.	
9.	File off all burrs and clean work.	

Figure 77 Examples of route sheet and operation card used in general manufacturing industries (from ref 46)

ROUTE SHEET

Part number 37FE1W064 Dwg. No. 449
Number req'd. 2
Raw material Plate mark: 37FE1P40.
Size: 5400x1385x7.5
Number off: 2

Op.No.	Operation	Machine (altve)	Tools Jigs	Est. times SU	Est. times OP	Make with.
1	Straighten	Mangle rolls				
2	S/blast & paint	Treat-ment.				FE1W065 FE1W063 (1 off each per plate)
3	Mark-out	Optical tower	Slide 104			
4	Flame-plane	F.P.2 (hand)				
5	Knuckle	Press No.3	Flanger No.3			

JOB CARD

Part number 37FE1W064 Dwg.No. 449.
Number req'd. 4
Operation number 4 Machine FP2
Jigs: cutting head 62

Operation	Description	Details
1	Flame plane to marking out	Thickness=7.5 mm Cutting speed=***

Estimated times
cutting length=
operation time =

estimated weight =
set up time =

TOTAL OPERATION TIME=

Figure 78 Examples of route sheet and operation card for use in shipbuilding.

ESTIMATED WORK CONTENT SUMMARY

SHIP NUMBER..................
ASSEMBLY UNIT NUMBER...............

COMPONENT IDENTIFIER.			ESTIMATED JOB DURATION TIMES (MIN)												
COMMON	RAW MAT'L	PART	STRAIGHT	S/BLAST & PAINT	MARK. OUT			CUT TO SHAPE			FORM			DRILL
					MANUAL	OPTICAL	OTHER	FLAME PLANE	PROFILE CUT	GUILLOT-INE	FLANGE	SWEDGE	ROLL	
TOTALS														

Figure 79 Example of estimated work content summary sheet for use in shipbuilding

9.2 Process route generation

Process routes for components have been generated using the descriptive code of the part and a series of planning decision rules. The development of the system to generate these process routes consisted of three distinct steps. The first step was the definition of the planning decision rules based on shopfloor production equipment and methods, these were then to be used in the second step to draw a logical flow chart. In the final step a computer program was written based on the flow chart.

Process decision rules are recorded interpretations which a process planner applies when deciding how a component will be made while he is studying a working drawing. For instance for a plate component the cutting method decision is influenced by:-

a) The perimeter shape of the component, is this a series of straight lines or is one or more sides curved?

b) The size of the component, is it too thick or large to be guillotined?

c) The intricacy of holes and cut outs, can these be quickly and more economically achieved by hand cutting following perimeter cutting?

d) Edge preparation of the component

e) Available machinery, what type of machinery is available (flame planners, guillotines, profile cutters, mechanical edge planners, etc.)?

f) Economic factors, how economical is each piece of machinery ?

g) Scheduling. How fully loaded is each piece of machinery? Should an alternative process be given?

Factors a) to d) are concerned with the component, while e) to g) are concerned with shopfloor methods.

The decision rules vary with each individual shipyard and a study must be made of the facilities available in each yard before automatic process route planning can commence. The decision rules which have been used here are based on the steel component production shop of Austin and Pickersgill Ltd., Southdock shipyard. The equipment available is as follows:-

Section piecepart production

a) Section shotblast and paint
b) Roll bender (flat bar)
c) Cold frame bender (other sections)
d) Flanging press
e) Hand mark out and flame cut
f) Drilling machine
g) Hand flame cut holes and slots

Plate piecepart production

a) Plate shotblast and paint
b) Optical tower mask and system
c) Flame planning machine with edge preparation facilities
d) Hand mark out systems
e) Guillotine
f) Profile cutting machine (using 1/10 scale slides or drawings)
g) Drilling machines
h) Flanging press
i) Swedging press
j) Plate rolls

Based on this equipment a set of rules governing the method of manufacture of components was compiled. Examples of decision rules covering cutting methods are:-

Straight edge plates (orthogonal) less than 10mm thick and 1000 mm long and 1200 mm wide will be hand marked and guillotined

Straight sided plates with edge preparation will be optically marked out and flame planned

All plates having curved sides and/or intricate cut outs (slots for cross-numbers) will be profile cut, if they also have edge preparation this will be done subsequent to the main cutting operation.

Plate components other than those listed above (larger straight sided plates) will be optically marked out and then flame planned.

At present rules such as these are not generally recorded, and their application relies to a great extent on the experience of the individual process planner or shopfloor foreman. As the experience of the individual varies so the planning systems presently in use have a tendency to be inconsistent, particularly over long time periods, due to changes in personnel or shopfloor methods. With a standardised recorded set of decision rules and an automated system of applying them their consistency can be guaranteed and accuracy subsequently improved. In addition changes in shopfloor production methods or the introduction of new plant or equipment can be quickly introduced into the planning system by altering the decision rules and adapting the base automatic route planning system program.

The flow chart to produce a process route based on the equipment at Austin and Pickersgill (Southdock) is shown in figure 80. It consists of a series of questions with yes/no answers, the answer from each question dictating the next question to be asked. At decision points, where a decision on a production process has been reached, then the decision is stated (printed out) before the series of questions is continued. The flow chart may also be divided into horizontal sections by the general production process (marking and cutting, drilling, and forming), although this is less defined with section components as they are often formed before cutting (to allow a better 'grip' in the cold frame bender). This aids in the writing of a computer program to execute the flow chart as that may be divided into similar sections.

A fortran computer program has been written which prints a meaningful listing of process routes based on the decision rule flowchart and the descriptive coding system. Before entering the logical decision section of the program a data record containing the component identification number, the descriptive code number, and other relevant production information is read and printed for identification purposes. For example the following line could be listed,

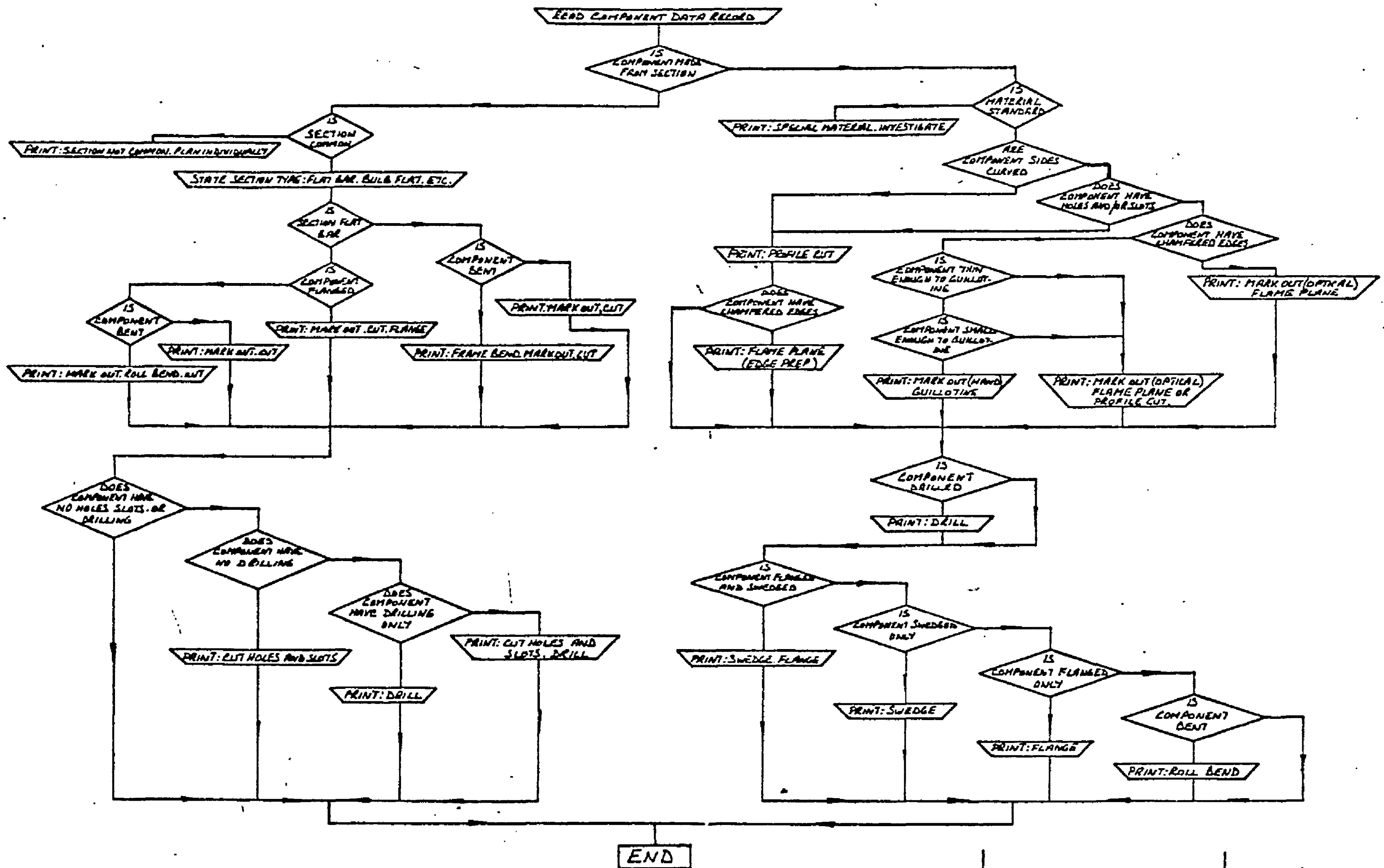
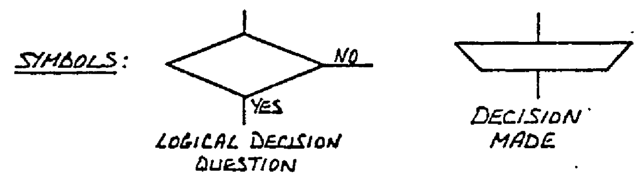


Figure 80 Flow chart used to define process route from descriptive code number



55/A112/3005/09, 4463020344 001 10.0

- 10.0 — THICKNESS
- 001 — NUMBER REQUIRED
- 4463020344 — DESCRIPTIVE CODE NUMBER (see section 53)
- 55/A112/3005/09 — Shipyard part number

The decision making part of the program consists of a series of logical 'IF' statements. By using a series of these statements the flow chart is followed and the process decisions are listed out (appendix I) During the initial stages of the automatic process route planning system development the input information and output format has been kept simple and without great detail. However the method may be used with a much more complex shopfloor layout and the output may be enlarged to cover individual machines, jigs, fixtures, etc. In addition sub routines may be called at the decision points to estimate the work content involved in the individual process operation, again using the descriptive code number of the component.

9.3 Work Content Estimations

Work content may be estimated by using the descriptive code number and empirical rules which are described in the following sections. The estimations are generated process by process for all stages of component production treatment, mark-out, cutting, forming and drilling. Emphasis has been placed on plate cutting operations, and in particular on the estimation of cutting length and errors involved in this. This is justified by the prominence of plate cutting operations in shipbuilding.

9.3.1 Treatment

The straightening, shotblast, and painting of raw material can be regarded as either a pre-steel shop process or an in-steel shop process depending on its proximith to the steel shops in a specific shipyard. As a pre- steel shop activity the unit of work content need not be precise; tonnage, number of raw material pieces, total length of section or area of plate will probably suffice. If regarded as an in-steel shop activity the work content unit needs to be more precise and will possibly be allocated to each piecepart.

For section components the approximate length of section are found from the descriptive code number and this, multiplied by the work content per unit length gives a work content estimate for the component. The work content per unit length varies with different cross-section and size of section, this again is found from the descriptive code number. Scrap wastage must be taken into account.

Thus if:

T_s = Average treatment time for a raw material section (may be categoriesed by shape and size)

L_s = Average length of raw material section

L_{sc} = Average length of scrap per raw material section

L_c = Length of component

then the treatment time for a component is given by

$$T_c = \frac{L_c T_s}{(L_s - L_{sc})}$$

where L_s, L_{sc}, and T_s are found historically and L_c is estimated from the descriptive code.

For plate components the approximate area of plate is found using the shape code with the length and width of the component. The formulae for finding area based on the shape code are shown in figure 81 and their derivation is discussed in Appendix J . Allowance is again made for scrap percentages and difficulty in nesting of components, the latter was considered in the derivation of approximate areas. Thus if:-

T_p = Average treatment time for a raw material plate

A_p = Average area of a raw material plate

A_s = Average area of scrap per plate

A_c = Estimated area of component

SHAPE CODE.	SHAPE	% OF PLATE TOTAL SD14	B26	AREA FORMULA	COMMENTS
40	3 SIDED:- NO SQUARE CORNER	0·2	0·5	$A = WL/2$	NOT EMPIRICAL
41	3 SIDED:- 1 SQUARE CORNER.	9·0	0·6	$A = WL/2$	NOT EMPIRICAL
42	4 SIDED RECTANGULAR	30·3	31·2	$A = WL$	NOT EMPIRICAL
43	4 SIDED; 1 OR 2 SQUARE CORNERS	16·0	7·4	$A = 0{\cdot}65\,WL$	±30% AT EXTREMES
44	4 SIDED: NO SQUARE CORNERS	7·7	3·2	$A = 0{\cdot}58\,WL$	ROUGH ESTIMATE ONLY.
46	MORE THAN 4 SIDES: 1 LONG SIDE.	0·2	0	$A = 0{\cdot}6\,WL$	ROUGH ESTIMATE ONLY.
47	MORE THAN 4 SIDES: AT LEAST ONE SQUARE CORNR.	12·2	16·2	$A = 0{\cdot}6\,WL$	ROUGH ESTIMATE ONLY.
48	MORE THAN 4 SIDES: NO SQUARE CORNER.	6·6	14·4	$A = 0{\cdot}8\,WL$	ROUGH ESTIMATE ONLY
70	1 SIDE CURVED, 2 STRAIGHT SIDES.	10·9	2·7	$A = 0{\cdot}8\,WL$	+10%, -5%, AT EXTREMES.
71	1 SIDE CURVED, MORE THAN 2 STRAIGHT SIDES.	4·3	21·7	$A = 0{\cdot}84\,WL$	+20%, -10%, AT EXTREMES
72	MANY SIDES CURVED.	2·6	2·6	FOR $L < 1000$ $A = \frac{\pi W^2}{4} + W(L-W)$ FOR $L > 1000$ $A = 0{\cdot}85\,WL$.	NOT EMPIRICAL ROUGH ESTIMATE ONLY.

Figure 81 Formulae for plate component area estimation from descriptive code number.

then the treatment time for a component is given by:-

$$T_c = \frac{A_c T_p}{(A_p - A_s)}$$

where A_p, A_s, and T_p are found historically and A_c is estimated from the descriptive code.

9.3.2 Marking Out

The marking out process is similar to raw material treatment in that the input and output from the operation is generally raw material sized plates or sections, the exception to this being sections which are first formed and then marked relative to the forming operation. Thus the overall handling time in mark-out may be attributed to an individual raw material piece or it may be allocated to each component derived from that raw material (as for treatment). In addition marking out operation times may be summed to give the total mark out time for the raw material piece from which they derive.

Section mark out consists of length mark out and forming mark out. Length mark out time is estimated from the descriptive code number which describes the type and size of cross section and whether the ends of the component are square or scalloped. Thus the degree of difficulty in marking out is found and a corresponding time estimate generated. Mark out for forming is more difficult, as sections, particularly bulb flat, angle, and channel often require some mark out after bending where the required bend is near the end of the component. This is to allow a cold-frame bender to 'grip' the part. The number and type of bending operations are found from the descriptive code number and hence a marking out time is estimated.

Thus:-

Component Mark Out time	=	Length Mark Out time	+	Forming Mark Out time
and				
Raw material M.O. time	=	Raw material Section M.O. time	+	Component M.O. times

The times of mark-out for various sections and forming operations is found historically and recorded in a data bank for use automatically.

Plate marking out is usually done only for orthogonal shapes and consists of contour mark out and forming line mark-out. It may be done by hand, by using an optical tower, or on a tenth scale or N.C. marking machine. The tenth scale or N.C. marking machine is similar to that used for profile cutting and is very often a dual purpose machine, although the marking operation is speedier than cutting. A similar approach is used to generate tenth scale or N.C. marking work content as for profile cutting (see next section). Marking is rarely done on one of these machines except in case of extreme work overload, or when forming lines must be shown on non-orthogonal plates. This is achieved as part of the profile cutting operation.

Hand-marking involves more work than optical tower marking and is mainly employed for smaller and simpler webs and brackets. In both cases the important features affecting the work content involved are:-

1 The number of sides (lines to be marked)
2 The geometry of shape (complexity of marking)
3 The amount of 'nibbling' (complexity)
4 The number and type of formed features (lines to be marked)

The geometry is of lesser importance in optical tower marking, which is a simple copying operation, as are the positioning of forming lines. All the features are examined using the descriptive code and by using historical data work content information is generated for each component. The collective work content data can again be summed for the components forming a raw material plate or batch for use in shop loading and possibly incentive schemes.

9.3.3 Cutting operations

The work content involved in cutting to length section components is divided into handling time and operation time. The handling time is a function of the length, the depth and thickness, and the type of cross-section of the component, all of which are found from the descriptive code number. The operation (or cutting) time is a function of the type of cross-section and the required shape of the component ends (i.e. square or scalloped), again these are indicated by the descriptive code. Standard values of work content can be tabulated both for handling and cutting various types of section from work measurement data. These tables can then be incorporated in a data bank and used in collaboration with the descriptive code to find work content estimates.

The work content involved in cutting operations on plate components varies widely between flame cutting processes and guillotining operations, for flame cutting it depends on handling time, cutting speed, and total cutting length.

a) Handling time

The handling time required for a component is a factor of the surface sizes (length and width) and the weight of the component, which itself is a factor of thickness and surface sizes. Therefore size alone (length, breadth, and thickness) can be used as factors to estimate work content. A fairly accurate indication of the sizes of the component is again found by using the descriptive code number of the component. The factors necessary to convert the sizes into a work content measurement are generated by work study sampling methods or using pre-determined time systems. Alternatively an overall handling time percentage contingency can be added to the operation time (cutting speed x cutting length) of the component. This is again found by work study (random sampling) and statistical methods.

b) Cutting Speed

The cutting speed to produce a flamecut plate component depends on three factors, cutting method, thickness, and edge preparation. The cutting method is defined by the process route generation system explained in section 3 of this chapter. It can vary between profile cut, flame plane, and hand cut. Each uses different cutting heads and therefore has a different cutting speed for the same material. The thickness of the workpiece and edge preparation required is taken directly from the descriptive code number of the component held in a data bank. The factors required to convert these into cutting speeds are pre-determined by the cutting method and are recorded in standard books and a corresponding computer data bank.

c) Total cutting length

The total cutting length is comprised of the basic outer shape perimeter of the component plus additional increments to cut holes and slots. Each of these has been considered in turn and then combined. Estimating errors have been considered in detail, by doing this the systems can be evaluated and improved.

The outer perimeter of the component can be estimated using the overall shape of the component from the first two digits of the descriptive code, and the length and width of the component from the last two digits of the code. These are used, the shape to define a suitable empirical formula and the sizes as factors in that formula, in estimating the perimeter cutting length. The methods of derivation of empirical formulae to estimate the perimeter of various shapes of plate component are described in appendix J , a summary table of the derived formula is shown in figure 82 (a) Particular attention was paid when deriving formula for component shapes which occurred most frequently in two ships (the SD14 cargo vessel and the B26 bulk carrier). The particularly important shapes are tabulated in figure 82 (b) it can be seen that about 80% of components are in this category from which an absolute formula (not empirical) can be achieved for rectangles and right angled triangles (about 40% of total). Dimensions in the descriptive code are coded in ranges, for calculation purposes the midpoint of each range is chosen as representative of that range. The ranges and midpoints are given in figure 83. With code digit values 0 and 9, both for length and width, the midpoint is not representative of the component dimensions in the range, there are few very small components (say less than 150 mm length or width). Therefore for digit value 0 it was proposed in the initial stages of development to carry out a combined sampling and error investigating exercise at a later date to compensate for this, and for digit value 9 a figure an initial estimate based on raw material order sizes was used.

Shape Code	Description	SD14 Number off	SD14 % of tot. number	B26 Number off	B26 % of tot. number	Cutting length formula	Accuracy estimate
40	3 sided with no square corner	10	0.2	35	0.5	$P = 1.7L + 1.55W$	Maximum 16% but generally L.T. 5%.
41	3 sided with 1 square corner	452	9.0	42	0.6	$P = L + W + \sqrt{L^2 + W^2}$	Absolute.
42	Rectangle	1530	30.3	2177	31.2	$P = 2L + 2W$	Absolute.
43	4 sided:- within rectangle	805	16.0	518	7.4	$P = 2L + 1.65W$	Maximum error 16% generally L.T. 6%
44	4 sided:- no square corner.	392	7.7	224	3.2	$P = 2L + 1.3W$	Generally L.T. 8%
46	More than 4 sides: one side long	9	0.2	0	0	$P = 2L + W$	Generally L.T. 5%
47	More than 4 sides: one square corner	619	12.2	1131	16.2	$P = 2L + 1.3W$	Generally L.T. 8%
48	More than 4 sides: no	338	6.6	1002	14.4	$P = 2L + 1.3W$	Generally L.T. 8%
70	1 side curved, 2 sides straight.	548	10.9	187	2.7	$P = 1.9L + 1.4W$	Generally L.T. 5%
71	1 side curved. More than 2 sides straight.	219	4.3	1478	21.2	$P = 2L + 1.5W$	Generally L.T. 8%
72	Many sides curved	130	2.6	181	2.6	For $L < 1000$: $P = \pi L + 2(L+W)$; For $L > 1000$: $P = 2L + 1.5W$	
		5052	100	6975	100		

Shape Code	Description.	SD14 Number off	SD14 % of tot. number	B26 Number off	B26 % of tot. number	Accuracy Estimate.
41	3 sided with 1 square corner	452	9	42	0.6	Absolute
42	Rectangular	1530	30.3	2177	31.2	Absolute.
43	4 sided:- within rectangle	805	16.0	518	7.4	Maximum error 16% generally L.T 6%
47	More than 4 sides: one square corner.	619	12.2	1131	16.2	Generally L.T. 8%
70	One side curved, 2 sides straight.	548	10.9	187	2.7	Generally L.T. 5%
71	1 side curved: more than 2 side straight.	219	4.3	1478	21.2	
		3973	82.7	5533	79.3	

Figure 82 Formulae for plate component outline perimeter estimation from descriptive code number:-

a) All shapes

b) Commonly found shapes.

LENGTH				WIDTH.			
CODE NUMBER	RANGE MINIMUM	RANGE MAXIMUM	MIDPOINT	CODE NUMBER	RANGE MINIMUM	RANGE MAXIMUM	MIDPOINT
0	0	300	150	0	0	300	150
1	300	600	450	1	300	450	375
2	600	1000	800	2	450	600	525
3	1000	1500	1250	3	600	900	750
4	1500	2500	2000	4	900	1200	1050
5	2500	4000	3250	5	1200	1600	1400
6	4000	6000	5000	6	1600	2000	1800
7	6000	7500	6750	7	2000	2500	2250
8	7500	9000	8250	8	2500	3000	2750
9	9000	∞	11000	9	3000	∞	3000

Figure 83 Ranges and midpoints for plate length and width descriptive code digits

A computer program has been written to estimate the outer shape perimeter of a component from the descriptive code number using the empirical formulae and the dimension range midpoints. It was tested using three structure groups of varying complexity from the SD14 data file, and for which assembly drawings were readily available.

These were:-

a) The fore end block (FE1 and FE2): a highly complex block with a high percentage of curved shell area

b) The engine room double bottom block (DBE): a fairly complex structure comprising of matrix type assemblies of individual tanks for oil, fuel, and water.

c) A typical double bottom block (DB2): comprising of open floor structures of low complexity.

The computer program and resulting list of estimated dimensions and shape perimeters for structure group DBE is shown in App.K.prog.1 A set of data cards corresponding to this list was also punched as output from the program run. The true shape perimeters of the plate components from these structure blocks were measured using the assembly drawings and punched onto the corresponding generated data cards. Using these cards, which contain both the estimated and actual component shape perimeters, a further listing has been generated of actual perimeter, estimated perimeter, estimate error (length), and percentage estimate error (% of actual length), this is shown in App.K.prog.2 Errors in individual component shape perimeter estimates occur for two reasons; the empirical formula is not applicable, or the dimensions (length and width) used are not the true dimensions of the component. Dimensional error is due to the use of dimension ranges in the code, the midpoint of the range is seldom the true dimensions of the component. However by studying the sums of a large number of estimated and actual perimeters for the same components the error observed is mainly caused by using unsuitable formulae. In this case the individual errors caused by using the range midpoints theoretically cancel each other. The tables in figure 84 show that total perimeter length errors for the structure groups are relatively small (0.9%, 0.2% 4.6% for FE, DB2, and DBE respectively), and for individual shapes they are also acceptable. The error of 4.6% for DBE is possibly due to the high frequency of the double bottom height which is near the boundary of two length ranges. An attempt has been made to compensate for this by adjusting the value from that range to be used in calculations, but the error was only slightly reduced.

Increments must be added to the overall shape perimeter for any holes and slots which are required in a plate component to give the resulting total cutting length. Estimating methods for these increments have been found by analysing the components involved.

Holes are cut in components for three reasons:-

a) to allow controlled flow of liquid (cargo, fuel oil, water) to prevent build-ups in rough seas which may make the vessel unstable.

b) to improve the weight/structural strength ratio of the component and thus lighten the complete ship.

c) to allow access, either by small hole for service facilities (pipes, cable lays) or larger hole or doorway for human access.

The most likely reason for a component to require a burned hole is for lightening purposes, with access the next most likely reason. It is therefore probable that the additional cutting length increment for burned holes is proportional to the size, and more particularly the length of the component. An exercise was carried out to plot the actual total hole cutting length per component against the length of the component (by descriptive code digit) for a complete structure group. Structure group DBE was chosen from those analysed previously (for shape perimeter) as this group contains a large number and variety of lightening and access holes. Components with burned holes (fourth descriptive code digit equals 3, 4 or 5) were listed and a data card pack punched. The actual cutting length required to produce the burned holes for these components was scaled from

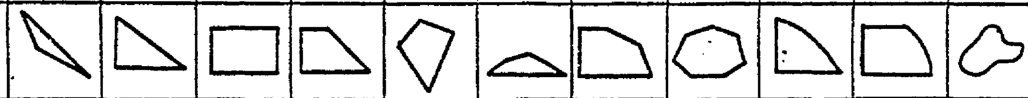
	FIRST TWO DIGITS OF SHAPE CODE	40	41	42	43	44	46	47	48	70	71	72	TOTALS
	PROBABLE SHAPE												
	ESTIMATE FORMULA	1.7L+ 1.55W	$\sqrt{L^2+W^2}$ +L+W	2L+2W	2L+ 1.65W	2L+ 1.3W	2L+W	2L+ 1.3W	2L+ 1.3W	2L+ 1.41W	2L+ 1.5W	L<1000 πL+2(L-W) L>1000 2L+1.5W	
(A)	NUMBER OF COMPONENTS	6	16	52	79	98	2	128	72	21	53	26	553
(A)	TOT. OF ACTUAL PART PERIMETERS	26.2	15.0	324.3	556.1	319.7	22.8	321.5	156.2	141.3	577.1	172.9	2,633.1
(A)	TOT. ESTIMATED PART PERIMETERS	25.0	16.2	328.1	537.0	305.2	21.5	314.5	168.5	151.3	563.1	177.7	2,608.1
(A)	'ERROR' = ACTUAL - ESTIMATE.	+ 1.2	- 1.2	- 3.8	+ 19.0	+ 14.5	+ 1.3	+ 7.0	- 12.3	- 10.0	+ 14.0	- 4.8	+ 25.0
(A)	'ERROR'/ACTUAL %	+ 4.6	- 8.0	- 1.2	+ 3.4	+ 4.5	+ 5.7	+ 2.2	- 7.9	- 7.1	+ 2.4	- 2.8	+ 0.95
(A)	ERROR TOT. CUTTING BLOCK LENGTH.	+ .045	- .045	- .145	+ .722	+ .551	+ .049	+ .256	- .467	- .380	+ .532	- .182	(0.936)
(B)	NUMBER OF COMPONENTS	0	16	154	4	0	0	0	0	77	12	0	263
(B)	TOT. OF ACTUAL PART PERIMETERS	0	12.3	2064.8	106.2	0	0	0	0	437.0	159.1	0	2779.4
(B)	TOT. ESTIMATED PART PERIMETERS	0	12.8	2071.4	108.4	0	0	0	0	422.0	157.1	0	2771.7
(B)	'ERROR' = ACTUAL - ESTIMATE	-	- 0.5	- 6.6	- 2.2	-	-	-	-	+ 15.0	+ 2.0	-	+ 7.7
(B)	ERROR/ACTUAL %	-	- 4.1	- 0.3	- 2.1	-	-	-	-	+ 3.4	+ 1.3	-	+ 0.28
(B)	ERROR TOT. CUTTING BLOCK LENGTH	-	- .02	- .24	- .08	-	-	-	-	+ .54	+ .07	-	(+0.28)
(C)	NUMBER OF COMPONENTS	0	0	175	20	0	3	0	0	20	55	0	273
(C)	TOT. OF ACTUAL PART PERIMETERS	0	0	1259.0	187.2	0	73.0	0	0	154.5	493.8	0	2167.5
(C)	TOT. ESTIMATED PART PERIMETERS	0	0	1169.9	191.0	0	70.4	0	0	152.3	483.7	0	2067.3
(C)	'ERROR' = ACTUAL - ESTIMATE	-	-	+ 89.1	- 3.8	-	+ 2.6	-	-	+ 2.2	+ 10.1	-	+ 100.2
(C)	ERROR/ACTUAL %	-	-	+ 7.1	- 2.0	-	+ 3.6	-	-	+ 1.4	+ 2.0	-	+ 4.6
(C)	ERROR TOT. CUTTING BLOCK LENGTH	-	-	+ 4.1	- .17	-	+ .12	-	-	+ .1	+ .47	-	(4.6)
(D)	NUMBER OF COMPONENTS	0	0	175	20	0	3	0	0	20	55	0	273
(D)	TOT. OF ACTUAL PART PERIMETERS	0	0	1259.0	187.2	0	73.0	0	0	154.5	493.8	0	2167.5
(D)	TOT. ESTIMATED PART PERIMETERS	0	0	1187.8	184.0	0	70.2	0	0	144.1	484.2	0	2070.3
(D)	'ERROR' = ACTUAL - ESTIMATE	-	-	+ 71.2	+ 3.2	-	+ 2.8	-	-	+ 10.4	+ 9.6	-	+ 97.2
(D)	ERROR/ACTUAL %	-	-	+ 5.7	+ 1.7	-	+ 3.8	-	-	+ 7.2	+ 1.9	-	+ 4.5
(D)	ERROR TOT. CUTTING BLOCK LENGTH.	-	-	+ 3.3	+ .15	-	+ .13	-	-	+ .48	+ .44	-	(4.5)

Figure 84 Analysis of estimated plate component outline perimeters for structure groups of SD14 cargo ship:- a)Fore-end (FE),b)Double bottom number 2 (DB2), c)Double bottom in engine room (DBE),d) DBE compensated for double bottom height.

assembly drawings and punched onto the respective data card as in the previous exercise for shape perimeter. The average hole perimeter for each length range of the descriptive code was then found and a graph of the two variables was plotted (figure 85) From the graph it can be seen that two straight lines are necessary to provide estimating formulae for cutting length. These are:-

$$\text{Hole length} = 510 \times \begin{pmatrix}\text{length code digit} \\ \text{value of component}\end{pmatrix} + 200$$

for length digit values less than 5

and

$$\text{Hole length} = 2068 \times \begin{pmatrix}\text{length code digit} \\ \text{value of component}\end{pmatrix} - 7750$$

for length digit value greater than 5

(When the length digit value is equal to 5 either formula may be used). When the length code digit is less than 5 the slope of the graph is caused by the increase in size of holes as there is only one hole per component (lightening hole in most cases). However, when the length code digit is greater than 5 then the number of holes in the component will probably increase with length. Thus the slope for longer components is caused by the number of holes in addition to the size of the holes. (see fig. 86). A method of incremental estimating has also been considered for hole perimeters, i.e. an increment is added to the estimated shape perimeter of each component corresponding to the length digit value of the component. Although this is possibly a more accurate estimating method (as the number of holes are incremental with length) it is thought cumbersome and not justifiable.

A program was written to compare the actual and estimated hole perimeter for structure group DBE. This is shown in App.K.prog.3 and gives the individual hole estimate error together with its relevance to the actual component shape perimeter length. Also included is the combined shape and hole estimate error for each individual component and the results of further investigation into these are shown in figure 87(a) a table and graph of percentage error in estimation against frequency of occurrence. It can be seen that 66% of the estimations are within 20% of the

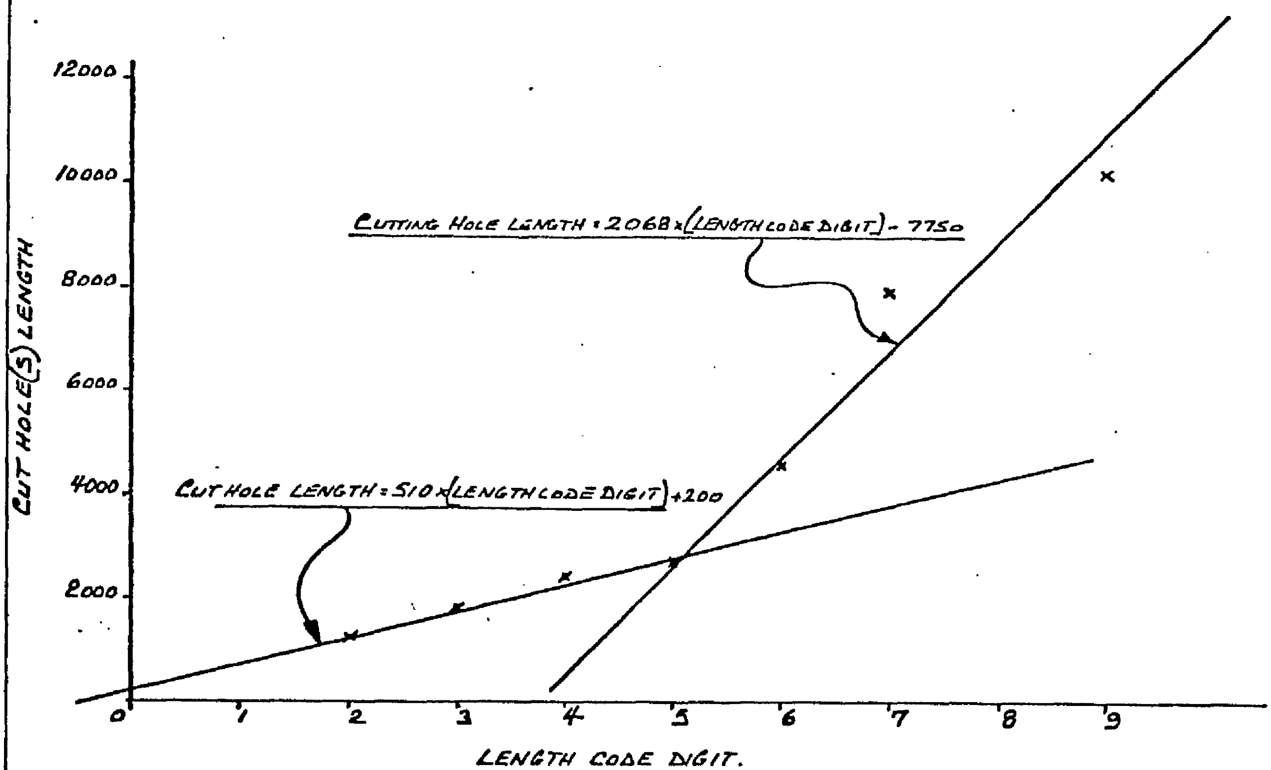


Figure 85 Graph of burned hole length against component length for plate components from structure group DB2.(SD14 cargo ship).

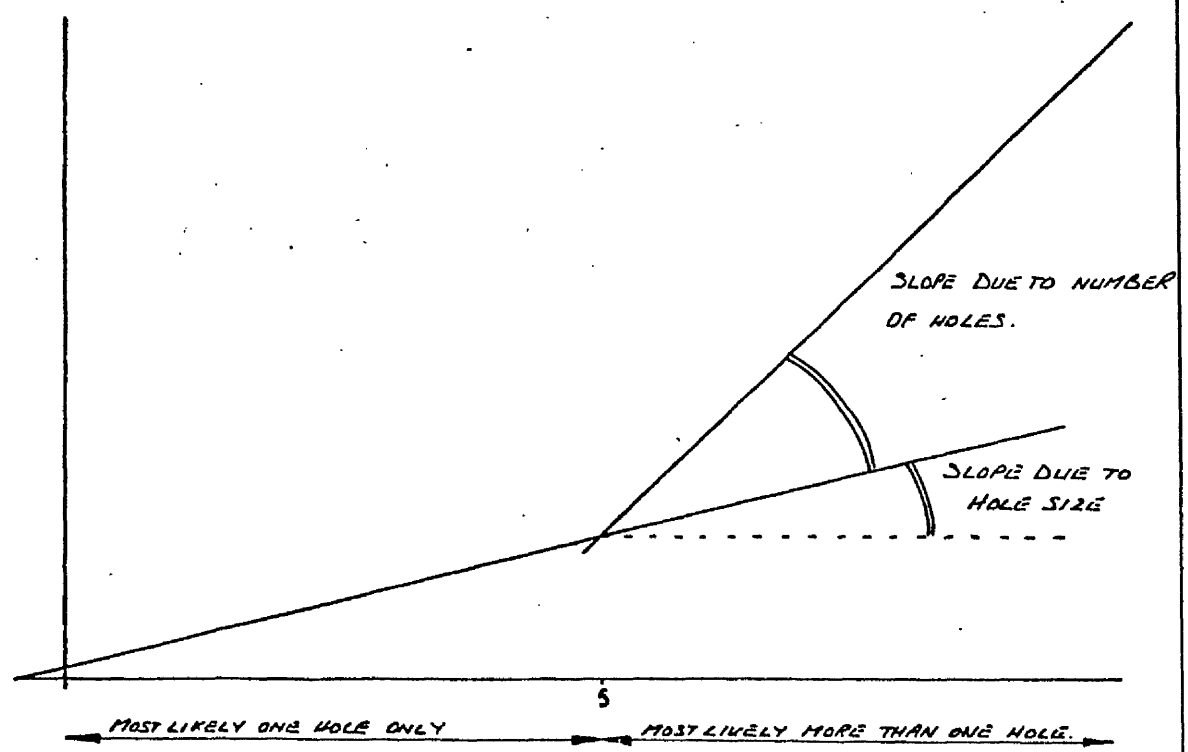
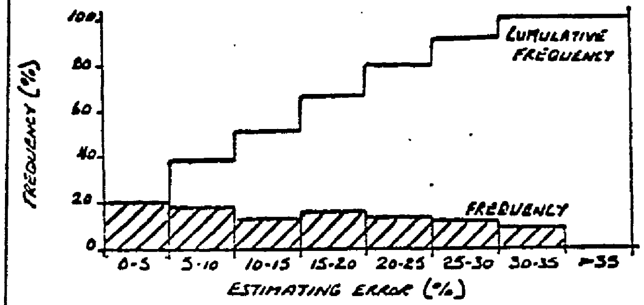
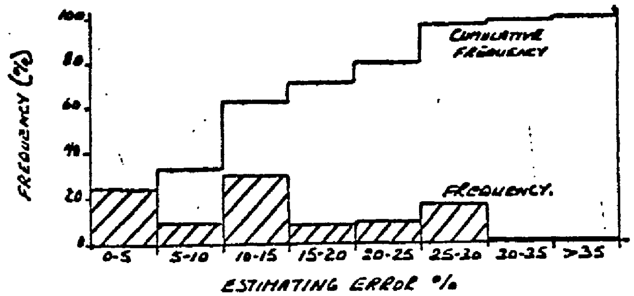


Figure 86 Relationship between burned hole length, number of holes, and plate component length.



ERROR % (RANGE)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
N° COMPONENTS	36	32	24	29	23	22	16	0
FREQUENCY %	20	18	13	16	13	12	9	0
CUM. FREQ. %	20	38	51	64	79	91	100	100

A.) STRUCTURE GROUP DBE



ERROR % (RANGE)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
N° COMPONENTS	16	6	20	5	6	11	1	1
FREQUENCY %	24	9	30	8	9	17	1.5	1.5
CUM. FREQ %	24	33	63	71	80	97	98.5	100

B.) STRUCTURE GROUPS FE

Figure 87 Histograms of frequency of percentage errors in plate component outline and hole perimeter estimations for:-
a) structure group DBE,
b) structure group FE
(SD14 cargo ship)

LENGTH CODE N°	TOT. N° COMP^TS. WITH CODE 2		SLOT LENGTH		SLOT LENGTH PER COMPONENT	
	DBE	FE1	DBE	FE1	DBE	FE1
0	0	0				
1	0	0				
2	0	1		800		800
3	0	1		800		800
4	4	2	2600	1600	650	800
5	0	0				
6	2	0	2600		1300	
7	0	1		2700		2700
8	0	0				
9	0	0				

A.) SLOT LENGTHS CUTOUT FOR COMPONENTS WITH FOURTH CODE DIGIT EQUAL TO 2 (SLOTS FOR CROSS MEMBERS)

LENGTH CODE N°	TOT. N° COMP^TS WITH CODE 5		N° WITH CODE 5 AND SLOTS		SLOT LENGTH		SLOT LENGTH PER COMP^T WITH CODE 5		SLOT LENGTH PER COMP^T WITH SLOTS	
	DBE	FE1	DBE	FE1	DBE	FE1	DBE	FE1	DBE	FE1
0	0	0	0	0						
1	0	0	0	0						
2	38	2	0	1		600		300		600
3	20	6	0	0						
4	82	8	25	0	16250		198		650	
5	10	9	2	7	1300	15000	130	1666	650	2164
6	16	6	12	6	6500	25700	406	4283	540	4283
7	5	3	0	3		13362		4440		4440
8	0	0	0	0						
9	3	0	0	0						

B) SLOT LENGTHS CUTOUT FOR COMPONENTS WITH FOURTH CODE DIGIT EQUAL TO 5 (BURNED HOLES PLUS SLOTS OR NIBBLED)

LENGTH CODE N°	TOT. N° COMP^TS. WITH SLOTS		SLOT LENGTH		SLOT LENGTH PER COMP^T.	
	DBE	FE1	DBE	FE1	DBE	FE1
0	0	0				
1	0	0				
2	0	2		1400		700
3	0	1		300		800
4	29	2	18850	1600	650	800
5	2	7	1300	15000	650	2144
6	14	6	9100	25700	650	4283
7	0	4		16062		4015
8	0	0				
9	0	0				

C) SLOT LENGTHS (CUT OUT) FOR COMPONENTS WITH SLOTS.

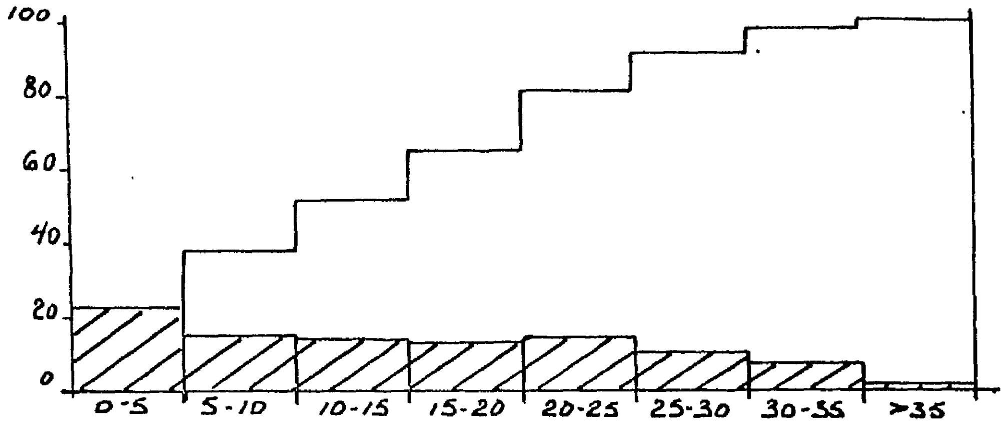
Figure 88 Analysis of slots and edge cutouts found in plate components from structure groups DBE and FE1.(SD14 cargo ship) actual cutting length with 30% within 10%. None of the estimates differed more than 35% from the actual cutting length. The exercise has also been carried out for components forming the fore-end block (FE) where the totals are found to be similar; 71% of estimations within 20% of actual and 33% within 10% (figure 87(b)) This indicates that the estimating procedure can be used for different types of structure group as DBE and FE differ significantly.

Slots are usually cut in plate components to allow frames or stiffeners to pass through a floor or bulkhead and be welded to it. Their positioning is consequently more important than for drainage nibbles and the work content because of this, in addition to their larger size, proportionally higher. The method of estimating additional increments for side slots and nibbles is further complicated by the combination of burned holes with edge features in the descriptive code. This limits the description of the slots and also fails to distinguish between carefully positioned slots or mere drainage nibbles when holes are also present. On investigating the slots in the plate components of structure group DBE it was found that the sample was small and no correlation between slot cutting length and component length could be made. It was also found that most slots occurred in a component which also had a burned hole, and yet an equivalent number of components had burned holes and nibbles, thus having the same code number. This highlighted a weakness in the coding system when used for work content estimation. Tables showing slot lengths for components from DBE and FE structure blocks are shown in figure 88. Although the sample is small it infers that the additional increment for components less than 2.5M long (lower limit of length code range 5) should be of the order 0.6 to 0.8 M. With components greater than 2.5M long the additional increment for slots increases dramatically, particularly for components forming the fore-end block. However, the fore-end is probably the least typical structure block in the ship and it is therefore hypothesised that

$$\text{Slot cutting} = 100 \times \begin{pmatrix}\text{length code digit} \\ \text{value of component}\end{pmatrix} + 400 \text{ mm}$$

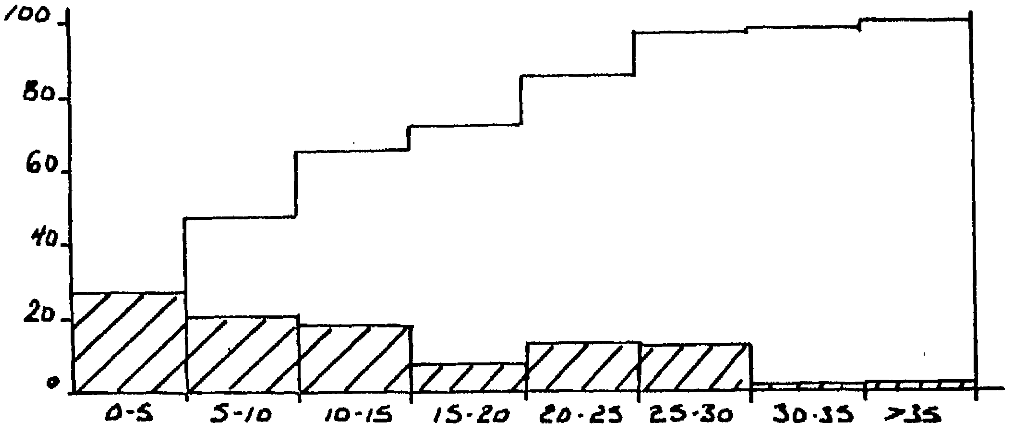
can be used to calculate the estimated slot cutting length increment until a more accurate estimating formula based on a larger sample can be found.

The routines for generating shape perimeter, hole perimeter, and slot length have been combined in a single program to give the total cutting length estimates of components. This is shown in App.K.prog.4. An exercise has since been carried out to investigate errors in the total cutting length estimations similar to that described earlier for estimation of shape perimeter plus burned holes. This includes components which have no holes or slots, many of which are smaller parts which may be guillotined. The results (figure 89) show that for the DBE structure group 65% of cutting lengths are estimated within 20% of the actual with 38% within 10%. Results for structure block FE are more favourable with 72% of estimated cutting lengths within 20% of actual and 47% within 10% This is probably because more components in structure group DBE have holes and slots and thus the errors due to all three are accumulated. In addition the double bottom height is at the extreme of a length range. This dimension occurs frequently and errors are increased as the midpoint of the respective range is used for calculation purposes. It is also noticeable that many of the components whose estimate errors are greater than 25% in structure block FE are in the length range '0' (less than 300 mm) and width range '0' (less than 300 mm). This accounts for thirty components or about 6% of the total number off. These components although having large individual percentage errors cause only slight discrepancies when the individual estimates are summed to give a 'work batch' cutting length. Histograms of error ranges above and below zero for structure groups FE and DBE are shown in figure 90, estimates which have no error have been evenly divided between -5% to 0 and 0 to +5%. The number of components which are overestimated is found to be 45.5% with underestimates accounting for 52.5%, the remaining 2% having no error. Again this slight underestimation may be due to the frequency of occurrence of the double bottom height which is near the upper extreme of one of the length ranges. Thus, by numbers, a slight underestimate results



ERROR % RANGE	0-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
N° COMPONENTS	63	40	37	35	44	28	18	7
FREQUENCY %	23	15	14	13	16	10	7	2
CUM. FREQ. %	23	38	52	65	81	91	98	100

A) STRUCTURE GROUP DBE



ERROR % RANGE	0-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
N° COMPONENTS	151	109	97	39	71	64	7	15
FREQUENCY %	27	20	18	7	13	12	1	2
CUM. FREQ. %	27	47	65	72	85	97	98	100

B) STRUCTURE GROUP FE

Figure 89 Histograms of frequency of percentage errors in total cutting length estimations for plate components from structure groups DBE and FE. (SD14 cargo ship)

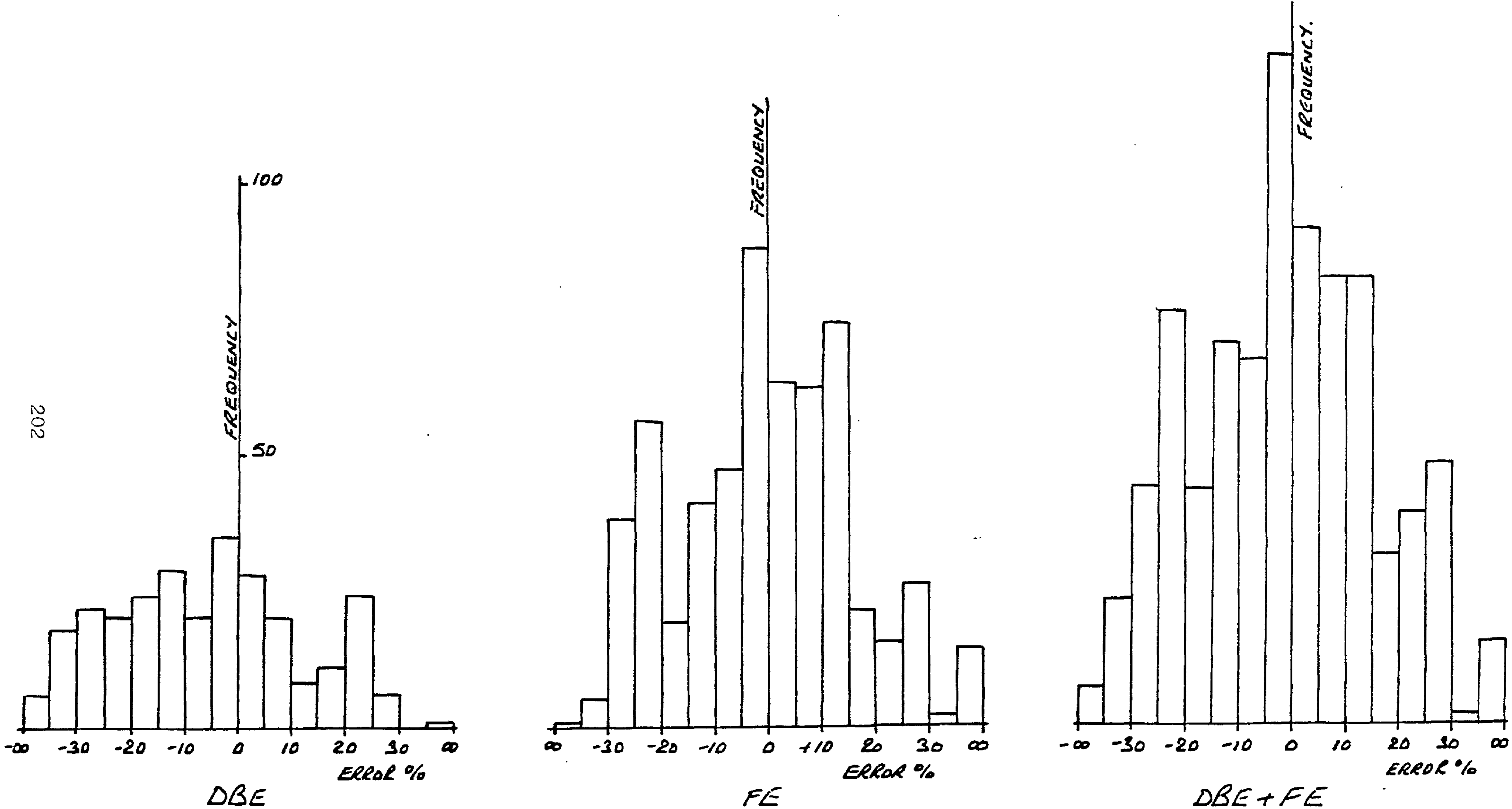


Figure 90 Distributions of cutting length estimation errors for structure groups DBE and FE.(SD14 cargo ship).

from the total sample taken.

These estimates are probably not accurate enough for payment systems based on individual components. However most steel component areas operate on a batch loading (by raw material) systems, and incentive schemes often relate to this. When summing individual component estimates to give the resulting batch cutting length these errors will be self cancelling. This has been simulated for batches of ten components using a cumulative frequency of error chart (figure 91) and a random number generator. It was assumed that components are of similar size (which is often the case in batching) and therefore over estimates and underestimates can be cancelled on a percentage basis. The results are shown in histogram form in figure 92 For five hundred simulated batches of ten components the mean error is found to be -1.4% (underestimate) with a spread of ± 15% and a standard deviation of 3% On increasing the batch size to twenty components the mean remains at -1.4% but the spread decreases to ± 9% and the standard deviation decreases to 2.5% Thus for batches of ten 95% of cutting lengths can be estimated within -4.4% and +1.6% (twice standard deviation) and for batches of twenty the corresponding limits are -3.9% and +1.1%.

For guillotine cutting operations the work content involved depends on handling time, time per operation (cut), and number of operations. The handling time is a factor of the size of the component similar to that for flame cut components, although a great deal of repositioning occurs between cuts. This repositioning time, however, is best treated as part of the operation time.

Cutting operations can be divided into four types:

1. Edge trimming of unnecessary material
2. Rough division of raw material into strips (usually on a larger guillotine) from which components can be more easily manufactured.
3. Final division of the strips into separate components
4. Corner 'snipping of the separate components to aid welding.

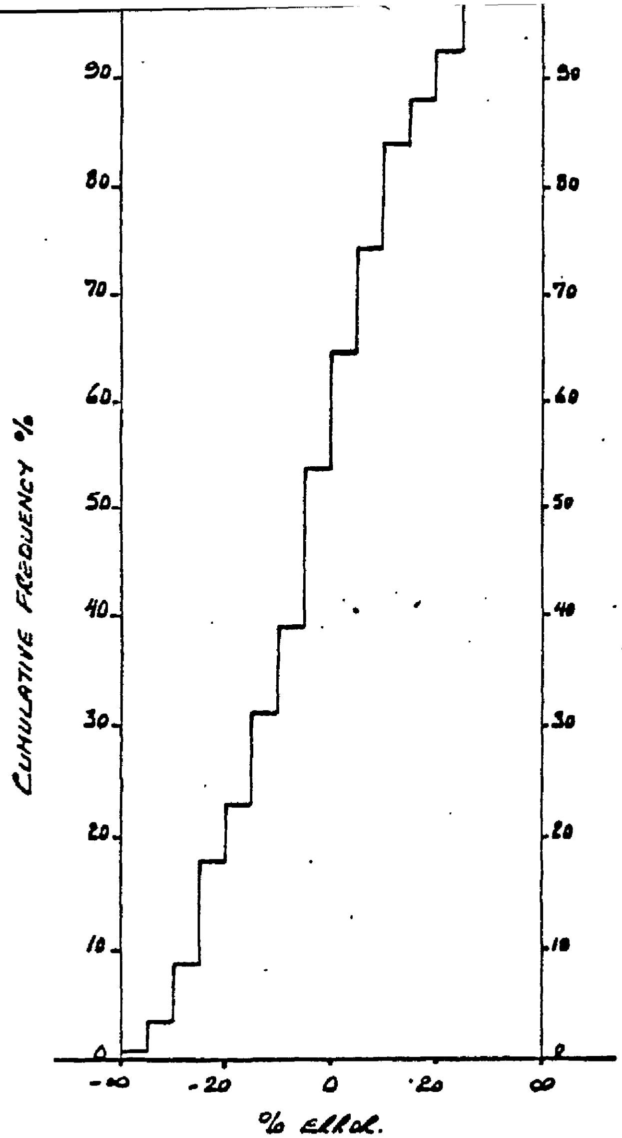


Figure 91 Cumulative frequency curve of plate cutting length estimation errors.

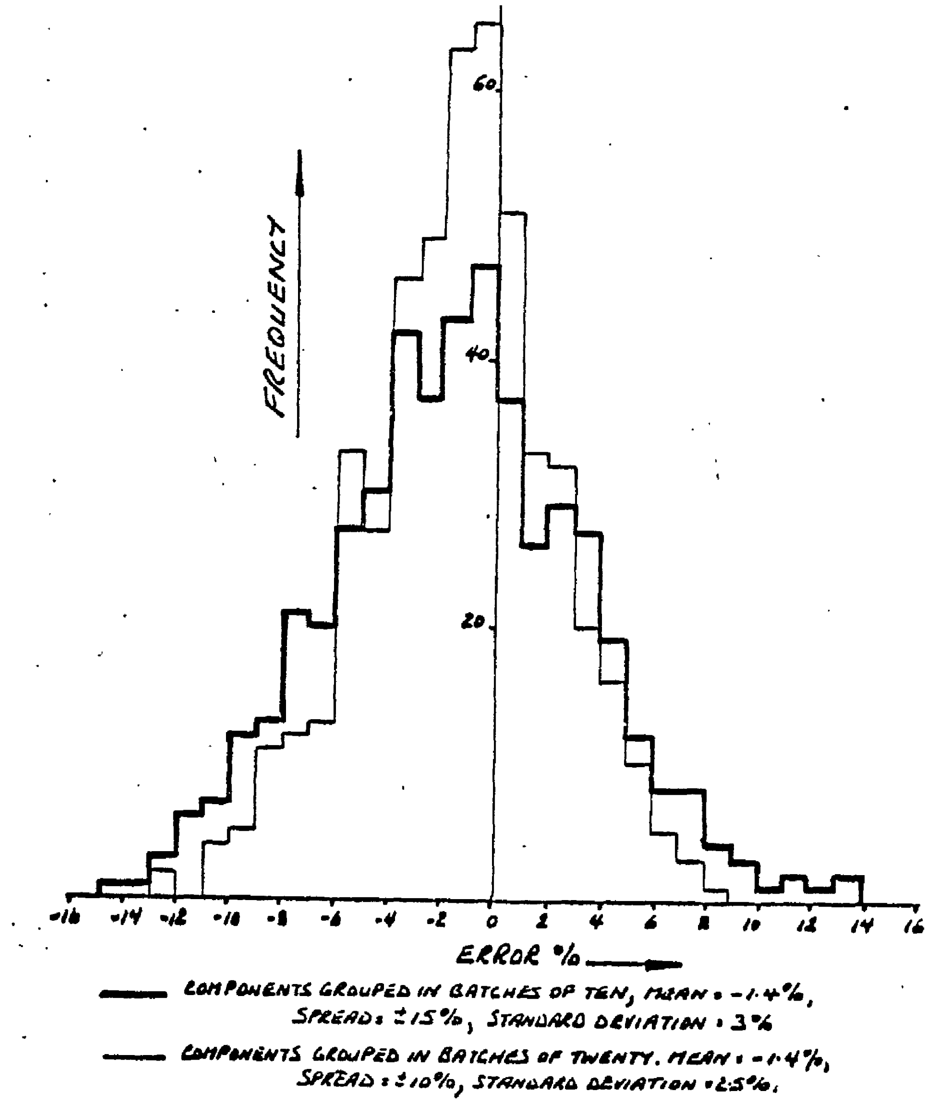


Figure 92 Simulated distributions of cutting length estimation errors for groups of ten and twenty plate components.

These 'divisions are shown schematically in figure 93. Edge trimming depends on the size and accuracy of raw material. If standard size raw material is used then two edges per raw material plate requires trimming. However, if raw material is specifically ordered for the components, and accurately cut at the steel mills, then the edges do not require trimming.

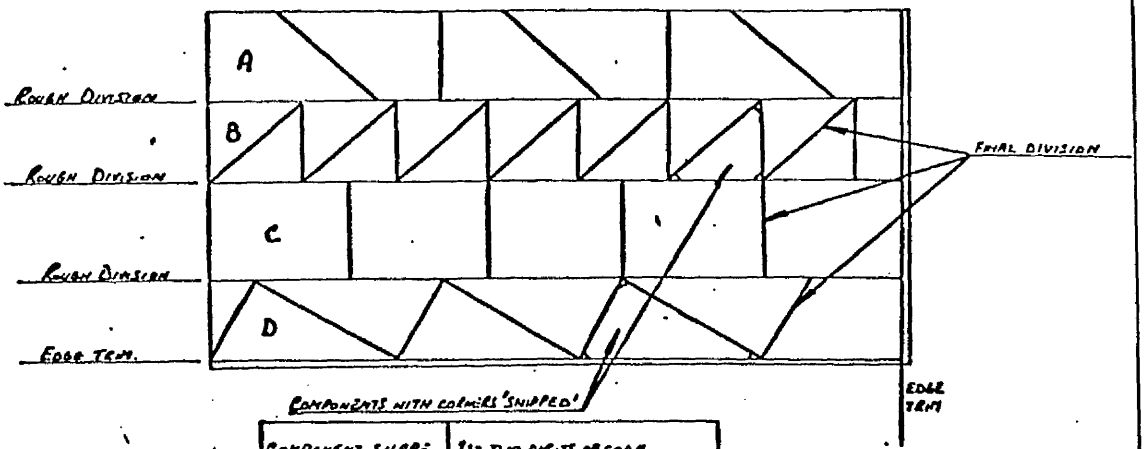
The number of rough divisions strips depends on the size of the component, generally two strips (one cut) are the minimum with four strips (three cuts) the maximum. The distribution of number of rough division strips for samples from side shell and fore end blocks are shown in figure 94. Although the number of strips is inversely proportional to the component width this property cannot be used to estimate the number from the descriptive code as the width measurement by range is too course. However for components whose width is less than 600 mm (code 1 upper limit) the average of 2.7 strips per raw material plate gives a fair estimate.

The <u>outline</u> shape (without corner snips) component distribution for FE guillotined parts is shown below.

First two digits of shape code	40	41	42	43	44	47	48
Number off	170	79	9	21	16	2	4

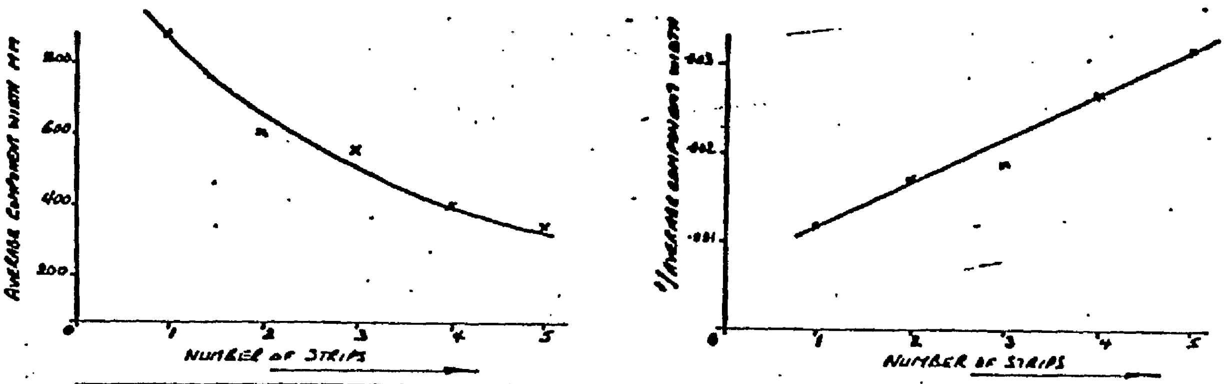
Most small guillotined parts in a ship are found to be connectors between decks and side shell, or bulkheads, or girders. Hence the vast majority of the 'three' sided components in the above table have their corners 'snipped to aid welding, and will become greater than four sided (code 47, 48) This is found to be the case with the components in the Fore-end block. However they may still be treated as three sided prior to the 'corner snipping' operation.

It is found that components whose <u>outline shape</u> descriptive code began 40, 41, 42 or 43 nests very easily into strips in every case, requiring only one operation to separate the final component from the strip (see figure 93) the only exception to this rule being components beginning 40 which require one 'starting' cut. These four plate outline shapes comprise 93% of the total.



COMPONENT SHAPE	1ST TWO DIGITS OF CODE
A	43
B	41
C	42
D	40

Figure 93 Typical nesting arrangement for guillotined plate components into a raw material piece.



NUMBER OF STRIPS	NUMBER OF CUTS	NUMBER OF RAW MATERIAL PLATES	AVERAGE COMPONENT WIDTH MM	COMPONENT WIDTH RANGE MM
1	0	2	875	725-1000
2	1	9	590	540-810
3	2	10	540	400-700
4	3	3	380	300-500
5	4	1	320	

Figure 94 Distribution of numbers of 'rough division' cuts for guillotined plate components from sample structure groups (Fore-end and side shell, SD14 cargo ship)

The remaining shapes (mainly 44..) can generally only be nested 'back to back' with another component, therefore if the number of sides of a part is n the number of cuts to produce the item is n-1 (two components sharing one side). Thus for four sided components the number of cutting operations is 3.5 and for more than four sides (less than 3% of the FE sample) the number of cuts is 4.5 (say)

<u>Therefore for components whose code number begins 40, 41, 42 or 43</u>

time for edge trimming

$$T_E = 2T1$$

where T_1 = time per cut for large plates

time for strip division

T_s = 0 (if component width 600mm)

T_s = 2.7T1 (if component width 600mm)

(Conditions from descriptive code)

Total operation time to divide raw material into strips

$$= 2T_1 + 2.7T_1$$

These are allocated by area to each component.

Total operation time per component

$$T_c = T_2 + \frac{(2T_1 + 2.7T_1)\ a}{A}$$

where a = estimated area component (see)

A = Average area of raw material plate

T_2 component cut time

<u>For components whose code number begins 47 or 48</u>

(3 sided with corners snipped)

$$T_c = T_2 + \frac{(2T_1 + 2.7T_1)a}{A} + 3T_3$$

where T_z = time to 'snip' corner of component

<u>For components whose code number begins 44</u>

$$T_c = 3.5T_z$$

10.1 Assembly component relationships

10.1.1 Assembly organisation

The use of flow assembly lines in shipyards to increase productivity (see chapter 3.3) also increases the cost of assembly hold-ups. Operations become interdependent and a production delay at one stage affects the entire manufacturing process. In order to organise flow assembly lines a breakdown of the ship into assembly stages and ultimately component parts is essential. The aims of such a breakdown are to design repetitive tasks and enable greater use of downhand welding (see figure 119) thereby allowing automated flow line work-stations to be designed. Thus the traditional practice of breaking down the ship into components directly from berth erection units is being superceded by intermediate divisions into flat panel, web, and bracket assemblies. Any breakdown, however, will never be completely hierarchial as loose components and minor assemblies will frequently be required at all stages of assembly because of fabrication constraints. The two systems of product breakdown are shown in figure 95.

Difficulties arise with more detailed product breakdowns in the use of numbering systems. Identical pieceparts and assemblies throughout the ship should receive the same part number so that some of the benefits of mass production can be achieved. It is also an advantage to encourage the use of standard designs for such items as lugs, collars, and tripping brackets. Thus two types of standard shipyard standards for highly repetitive parts will occur throughout the ships structure, and ship zone standards which apply to a specific area of a specific ship. The resulting hierarch of the ship product breakdown is shown in figure 96.

A product breakdown was defined for the SD14 vessel. This was fully documented and numbered, and sketches produced to demonstrate the order of assembly. Prior to the definition of the breakdown itself a simple system was devised for coding and numbering the type of assembly at

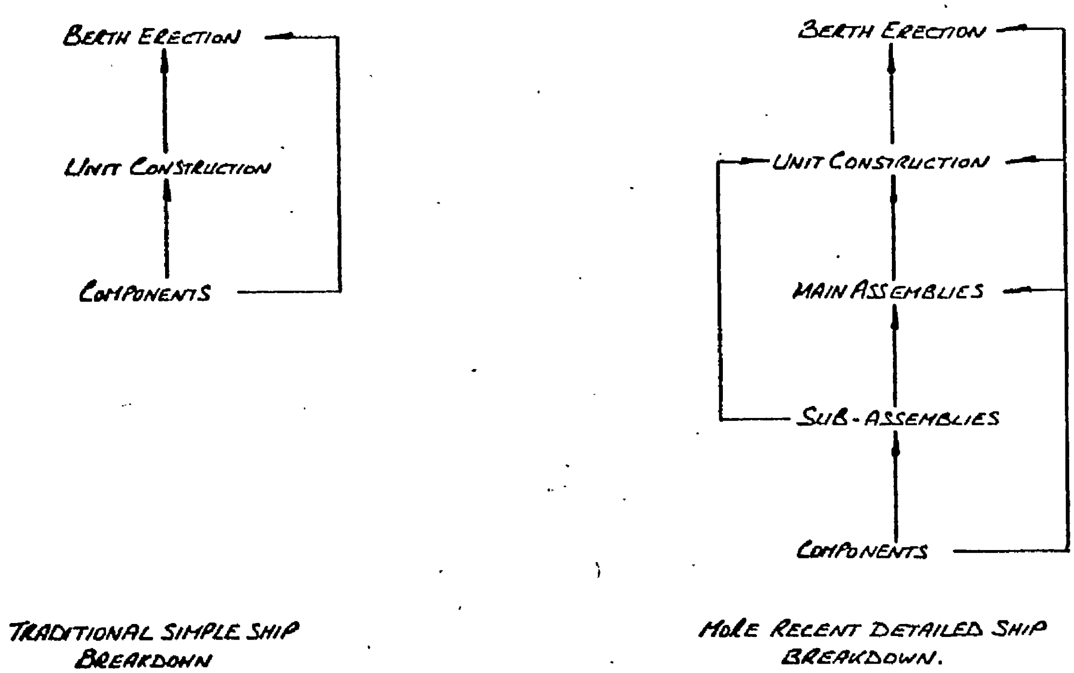


Figure 95 Ship product breakdown systems

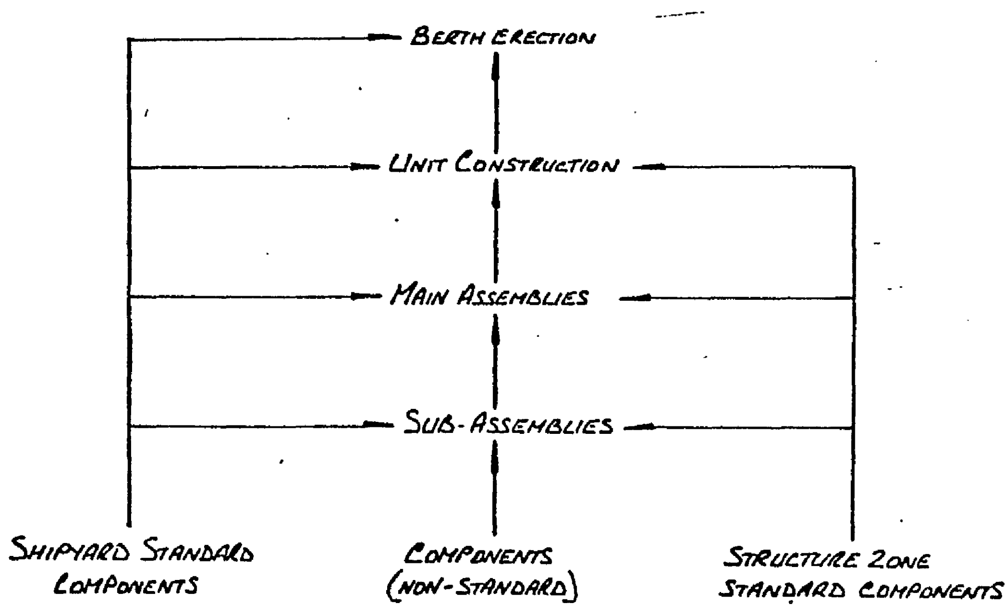


Figure 96 Proposed ship product breakdown and different component types.

each assembly stage, this is described in chapter 5.4. The exercise was subsequently repeated for the B26 bulk carrier and both sets of data were made available to the manufacturers (Austin and Pickersgill) and their consultants (A.P. Appledore) to aid in the design of production systems. However to fully exploit such detailed product breakdowns assembly work content is necessary to balance proposed assembly lines.

10.1.2 Group technology in assembly

The assembly data collected was used for reference by A. and P. Appledore in the design of new steelworking facilities for the Southwick shipyard of Austin and Pickersgill Data manipulation and retrieval was undertaken at Glasgow University and the consultants were initially given general information, and they later requested specific information when they recognised the potential of the data bank. The information was of two types; product breakdown information including the number of assemblies of a specific type in each structural control group, and statistical distributions of the numbers of components in each assembly type; and joint length incurred for each assembly type in each structural control group. The product breakdown gave an indication of the production control requirements, the material handling requirements, and the component work content involved. The joint lengths with the weld orientation implied by the assembly type gave an indication of the work content involved at each assembly workstation.

A. and P. Appledore personnel have described[47] features of the shipyard facilities which are under construction and have referred to the adoption of group technology principles in the design of assembly areas. The primary breakdown of the ship into fabrication units was used in the design of workshops, and the design of a mechanised manufacturing bay for the construction of double bottom units for cargo liners and bulk carriers is described. The bay consists of a main assembly line which is fed by three additional work areas, the flow chart for the bay is shown in figure 97 Both the main assembly and mechanised sub-assembly lines employ flow line principles and down-hand welding only.

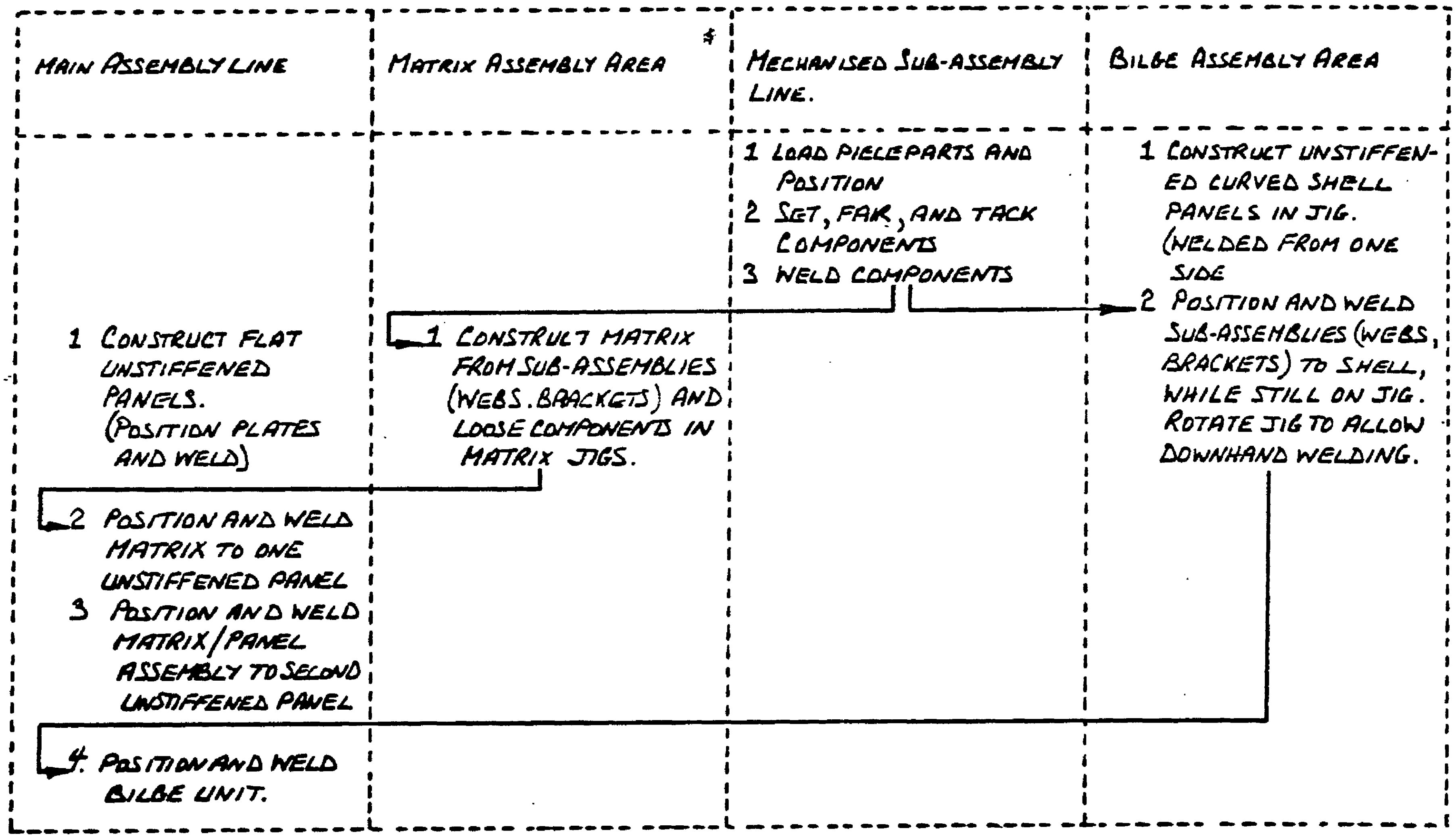


Figure 97 Double bottom assembly flowchart for new shipyard at Austin and Pickersgill, Southwick, Sunderland.

The matrix and bilge assembly areas make use of jigs which, although specialised, can hold different sizes of fabrication and allow flexibility when positioning sub-assemblies. In addition the bilge assembly jigs are capable of being rotated through 90^{0} to facilitate downhand welding. Although this layout cannot be accurately described as a traditional implementation it employs many group technology principles, for example the initial segregation into flat panel structures, complex curved shell structures, and matrix type structures. In addition flexible but sophisticated assembly jigs are used to exploit similarities in assembly types which are classified using a coding system which broadly follows group technology principles.

10.1.3 Component marshalling for assembly

Progressing and marshalling components for assembly has until now been simplified by the assembly techniques and work scheduling systems employed. Work packages have consisted of components comprising a complete fabrication unit. With the change from unit based work loading to larger work packages containing components from structure zones or groups (comprised of several fabrication units), the marshalling of parts for sub-assembly and then unit assembly will become more difficult. This difficulty will be compensated for by:-

a) the increase in the number of batches of components of similar characteristics which may be produced using mass or group technology principles.

b) the increase in use of flowlines for assemblies having similar characteristics.

c) the increase in number of components available for nesting operations (thus increasing nesting efficiency and reducing scrap percentages).

However, greater responsibility will be placed on the production controller or progress chaser to ensure that components are marshalled prior to assembly. The use of a descriptive code enables components to be easily located and identified by indicating the shape and size of the required part (see figure 98). Thus progress chasers searching for 'lost' components may be able to do so without needing to refer to manufacturing drawings, N.C. descriptions, or assembly drawings. A descriptive code number also gives a strong indication of the process route the component should follow. The quality and quantity of personnel required to carry out the progress and marshalling function can probably be correspondingly reduced. However, to enable these advantages of the classification and coding system to be fully exploited in marshalling and progress chasing a fully documented cross reference system must exist to cover the part number, the raw material mark number, and the descriptive code number.

10.1.4 Components in Assemblies

There will also exist a relationship between a specific unit or main assembly and the components which comprise the fabrication itself. Thus the type of unit, described by both function and configuration, will indicate the parts which will be used in its construction, and the production requirements to manufacture them. Alternatively the components forming a unit will give an indication of the type of unit involved and the difficulties which are encountered in its assembly. For example a group of components of which many are curve sided plates which are roll bent, or sections requiring cold frame bending will most probably comprise a curved shell unit; if many of the components have curved sides but are not rolled these will probably be transverse floors or longitudinal girders and the unit will probably be a double bottom unit in the curved shell area. Similarly groups of components consisting of a mixture of straight and curve-sided plates but with no forming and long straight section pieces will form a stiffened bulkhead or deck, while a group consisting of a mixture of straight and curve-sided plates with flanges but very few section pieces will be a corrugated bulkhead. Thus relationships exist between the type, shape, size and position of a unit within the ship and the components forming the unit, and these relationships will be reflected in the complexity and resulting work content required to produce both the components and the assemblies. These relationships can be exploited in the areas of part recognition and marshalling, estimation of unit complexity and assembly work content from component data banks, and estimation of steel component production requirements and work content values from a fabrication plan (unit breakdown) of known unit types.

10.2 Possible methods of estimating work content

The complexity and thence assembly work content of fabrication units can be estimated from comprising components, this can be attempted by two methods:-

a) by using direct correlation and regression techniques between the results of statistical analysis of the components forming the units, and historical work content values for the assembly of the units themselves. This involves the collection of accurate historical work content values of assembly at unit level from a real shipyard environment, and the results would probably only then be applicable to that specific or a very similar shipyard. The results would also have only limited application in a modern shipyard employing tree structure assembly techniques. To be fully applicable the historical work content values would have to be related to the product breakdown and this would dramatically increase the size of the required statistical analysis. The results of the correlation and regression analysis would be used to derive empirical relationships to estimate assembly work content from statistical analyses of the components involved. This would possibly involve the definition of statistical factors to be input into the empirical formulae, an outline of a possible estimating procedure is shown in figure 99. The method will be a 'top-down' technique in that lower level estimates are achieved using historical values from a higher assembly level.

b) by generating assembly welding work content values using the descriptive code numbers of individual components and empirical relationships to define the welding techniques which are employed, and the orientation of the weld or assembly (down-hand, vertical, overhead). The welding techniques will be defined from the shape and production detail digits of the descriptive code

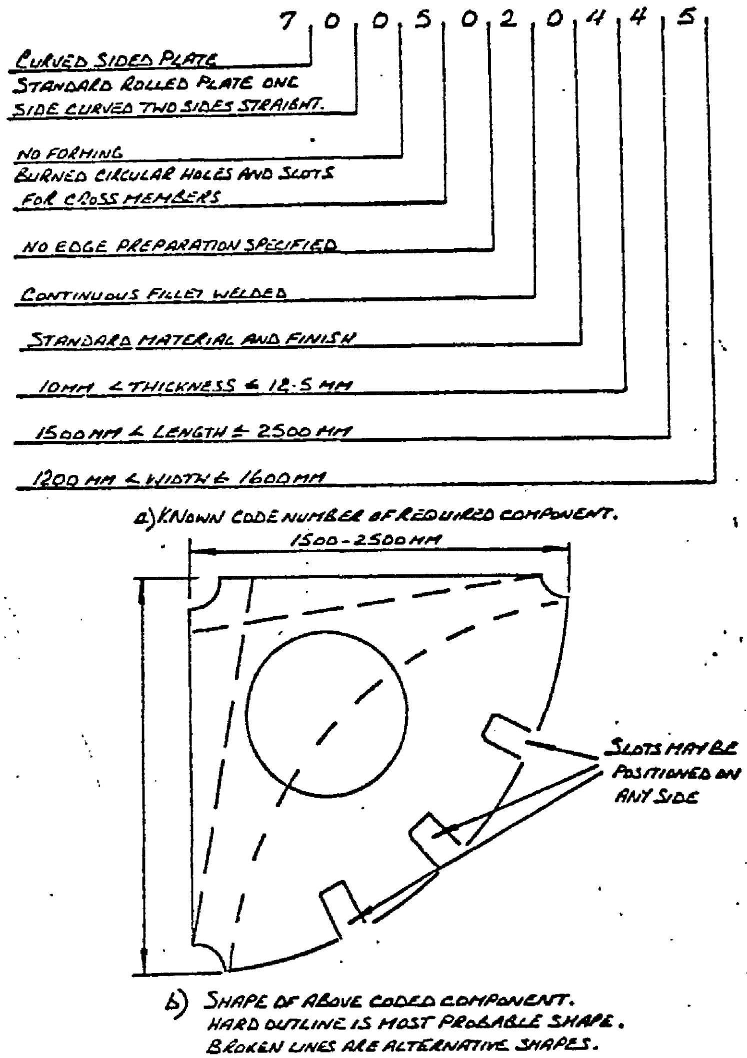


Figure 98 Example of component shape definition from a descriptive code number.

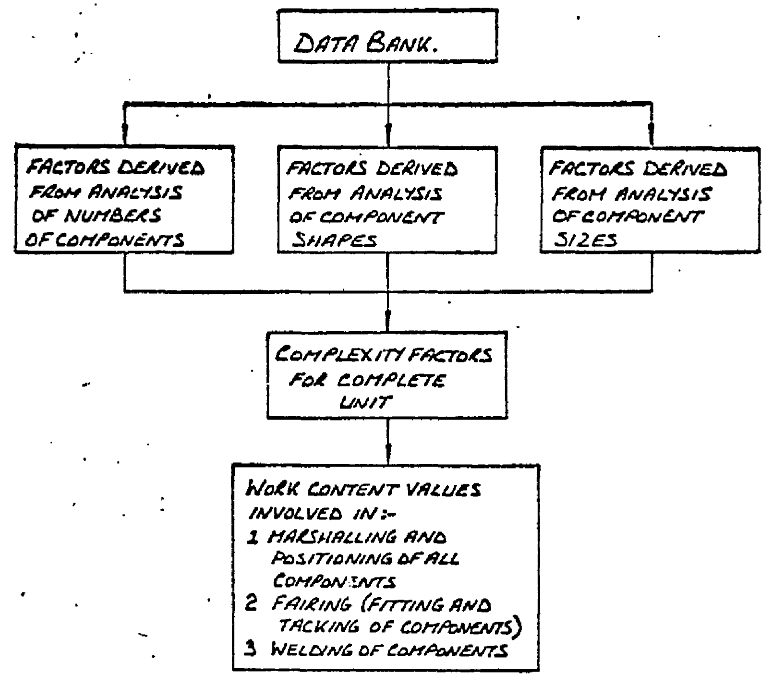


Figure 99 Outline of procedure to estimate assembly work content using historically based empirical relationships and component statistical analysas.

and the joint lengths involved will be derived from the dimension range digits. The outline of the proposed method is shown in figure 100 and an exercise attempting to develop this technique is described in the following sections. The technique will be 'bottom-up' in that estimates will be made at the lowest level (i.e. individual components) and will then be aggregated to achieve higher level values, these can be devised to include any stage of fabrication from minor bracket and web assemblies to final unit erection. An analogy may be drawn with well tried predetermined time study systems such as P.M.T.S. or W.O.F.A.C. which are employed in general engineering industries. These are accepted as being inherently more accurate than top-down techniques.

Work content values for the marshalling positioning and fairing of parts may be derived from a direct relationship with the manhours required for final welding. Alternatively they may be found from a statistical analysis of the numbers and sizes of the comprising components similar to that described in the first estimation method.

10.3 Estimating Procedure

An estimating system for the derivation of assembly work content values has been developed and demonstrated using a shipyard example. Difficulties were met in the collection of precise historical work content information at a low enough level to allow meaningful regression and correlation techniques to be employed. The shipyards who were collaborating in the project did not at that time have work content data in a form fine enough to be of great use, and other shipyards who had attempted to introduce various forms of work measurement, for example Doxford and Sunderland (now Sunderland Shipbuilders) and Govan Shipbuilders, did not at that time wish to collaborate in the project. In addition it was decided that a 'bottom-up' estimating system would be inherently more accurate and flexible than one devised using 'top-down' principles. The estimating system therefore uses the classification and coding system and the component data bank. It is designed to enable shape, size, and assembly relationships to be

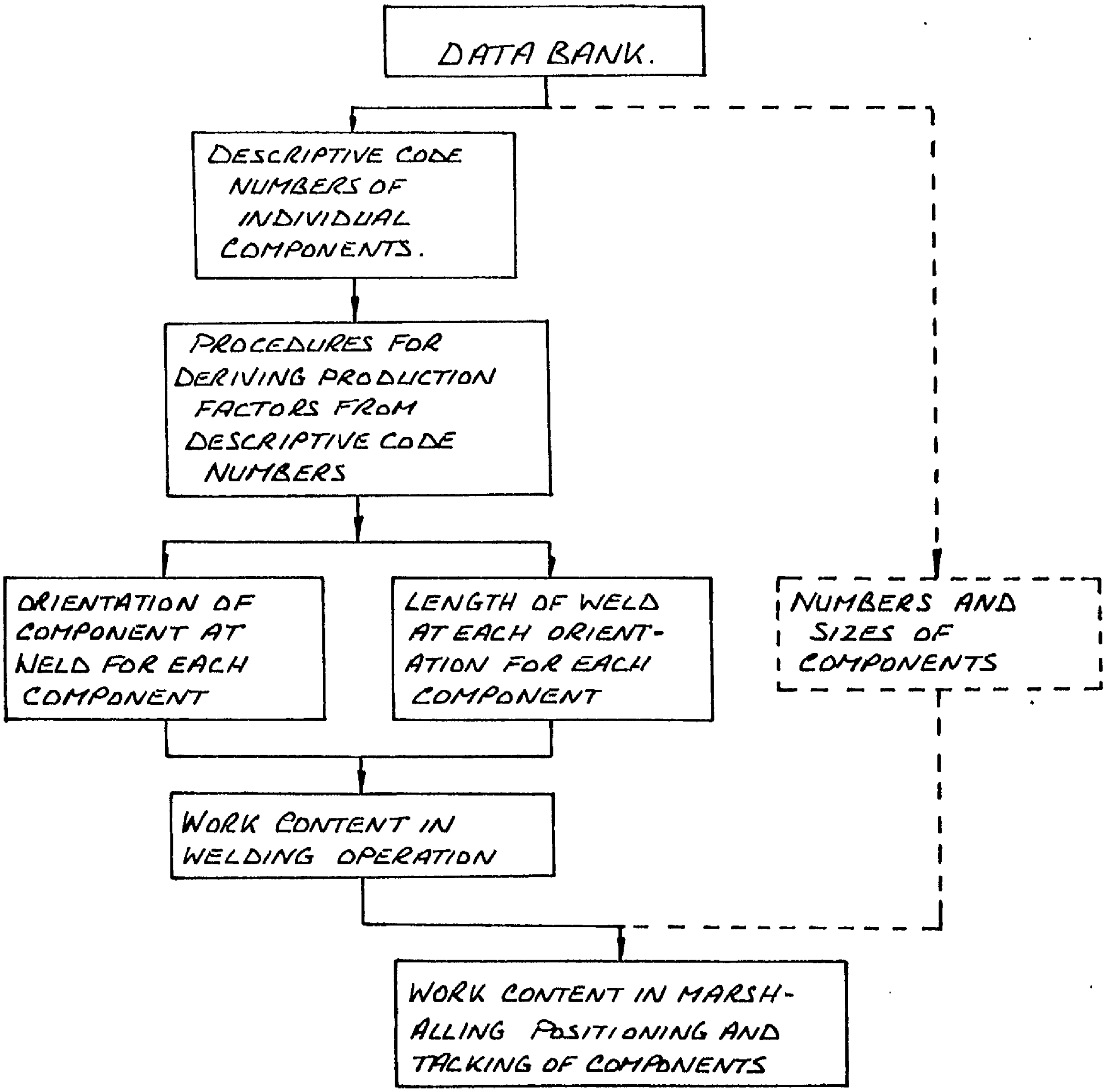


Figure 100 Outline of procedure to estimate assembly work content using descriptive code numbers to define welding technology. (Alternative is shown in joined lines).

exploited to define the most probable welding techniques employed on the component part and thence the assembly work content involved. The outline procedure is as follows:-

1 Determine the function of the component from its shape code and size.

2 Define the position of the component at assembly.

3 Determine the orientation of the component from the sizes of the sides and the work station at which each side of the component will be welded.

4 Estimate the joint length for each orientation of weld (downhand, vertical, and overhead).

5 Multiply the estimated joint length for each weld orientation by the work content required per unit of joint length in the determined orientation at the determined work station.

6 Group the estimated work content values (by structure or by work station as required) to arrive at aggregated work content values.

It is realised that the relationships between component shape and assembly details vary between different shipyards and different types of unit within a ship. It was therefore decided in the first instance to devise a model to describe the assembly techniques involved in the construction of one specific type of structure by one specific method. The type of structure chosen to demonstrate the procedure is that found in the double bottom of a ship; the structural details of this zone from several ships, and in particular the SD14 cargo vessel has been deeply analysed previously. Correspondingly a detailed knowledge of the assembly methods employed in the construction of the double bottom units of the SD14 at the manufacturing shipyards is known and this was used to develop the models required. Isometric sketches of the assembly stages are shown in figure 101 , and the assembly sequence is indicated.

The manufacturing procedure consists of the complete fabrication of the unit from components in unit workshops and on the erection berth. In the Southdock shipyard of Austin and Pickersgill curved bilge panels are added just

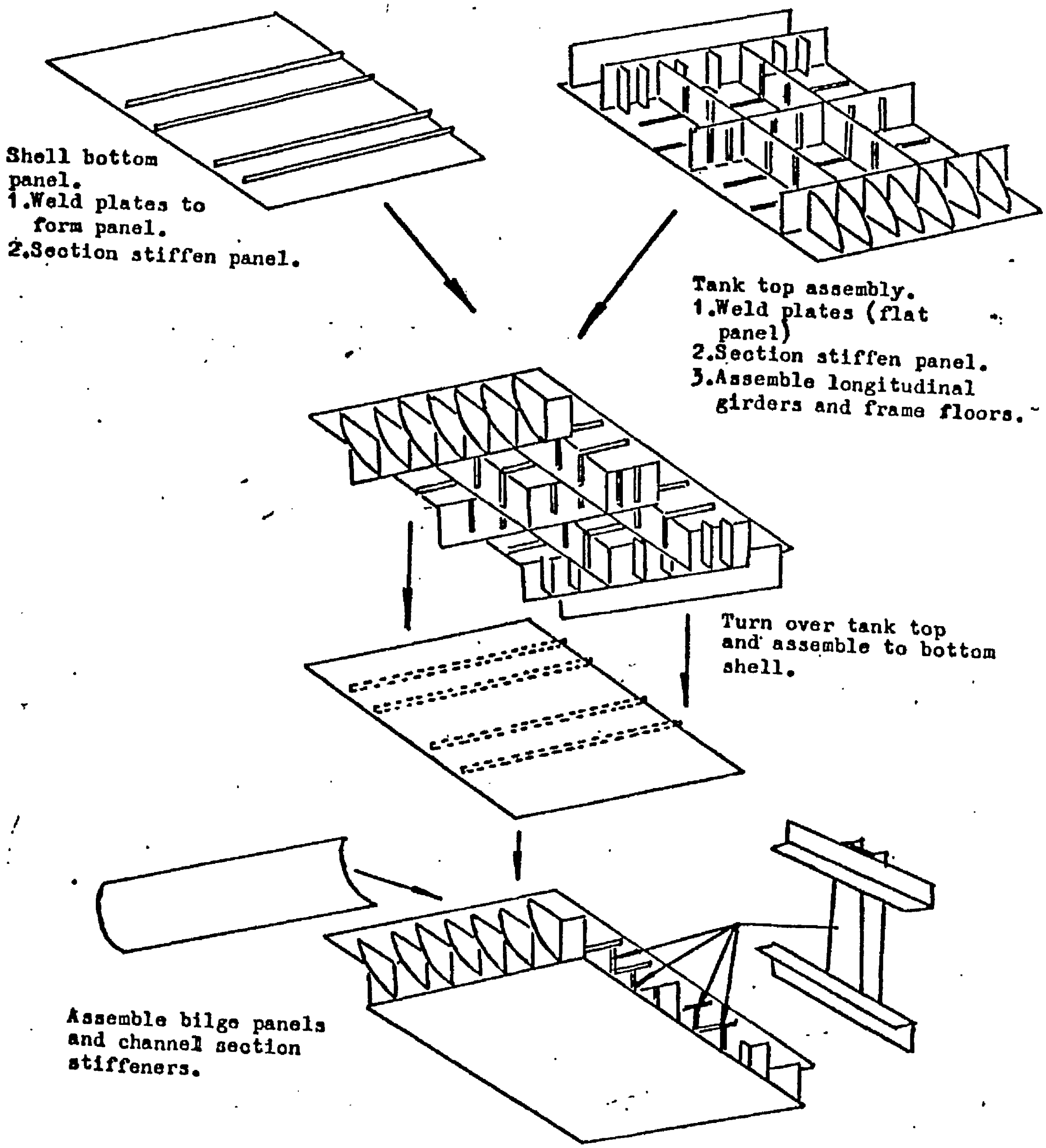


Figure 101 Double bottom construction sequence assumed in the development of assembly work content estimating systems.

prior to launch, this is to allow entry into the ships hull during berth erection at any point along its length. However the practice in the Southwick shipyard of the same company is to shell out the unit completely as soon as the tank top structure is welded onto the shell bottom. This has been incorporated into the assembly model. The introduction of sub-assembly stages to enable flow production principles to be applied as proposed previously will require a much more complex model to be developed. However, the present assembly procedure employed will be sufficient for the purposes of this example to demonstrate the development procedure. Any shipyard developing models for its own use will have to describe the assembly sequence employed for each type of structure to be incorporated into the estimating system. From this the orientation of weld for each edge of a component can be determined. For example in this case a component whose width is equal to the double bottom height is most probably a vertical placed double bottom component. Consideration of the straightness of the component edges determines whether the part constitutes an inner or outer floor. In addition for outer floor parts a forming operation indicates a flanged outer floor and the holes and slots digit determines whether it is watertight or webbed. For inner floor and girder parts lack of rectangularity is used to distinguish ends of floors or girders, and edge preparation is used to differentiate between floors and girders. Again holes and slot configuration are used to determine whether the part is watertight or not. Parts which are not floors or girders are segregated into small brackets and large shell and tank top plates, this is again achieved by checking whether the shortest component side is greater or less than the double bottom height. Small brackets are divided into those which are frame foot brackets, which are flanged, and others such as tripping brackets which do not need any forming operation. Rolled plates are immediately recognised as shell plates and large plate components with curved sides are generally found to be deck plates which are positioned at the intersection of the tank top and the shell. The edge preparation digit of the classification code immediately signifies whether large plate parts are welded from one side or two.

A decision flow chart was drawn to enable these indications to be employed with the descriptive code number to define the function of each part from its record in the data bank. Part of the flow chart covering section parts is shown in figure 102.

A fortran program has been written from the flow chart to investigate the classification code number and thus define the function of each part. During development input consisted of a record of forty digits corresponding to the first forty digits of a data bank record, this was manually typed into the system when requested by the program. It is intended to adapt the input specification of the program to accept information directly from the data bank. Output consisted at this stage of the function of the component and a listing of the original input information. Following debugging operations the program was tested using data describing various components from the double bottom of the SD14. The percentage of correct forecasts was about 90-95%, and remaining errors were found to be of minor importance. For example short girder pieces were forecast as floors, but the work content involved in assembling both these is about equal as the orientation and weld type employed is the same. In general it was found that floors and girders, tank top, shell, and small brackets were adequately differentiated between and defined using the program.

The program has been used as a basis for a more complex procedure resulting in work content estimate outputs. Following identification of the function of each component a series of subroutines are used to define the type of welding employed for each orientation of weld, the length of weld in each case, and thence the work content involved in manhour units derived from predetermined welding time data. The algorithms to define these factors, and of subprograms to employ them are described in the following sections.

10.4 Determination of component orientation

The position of the component in the fabrication unit is determined by its function and its shape. For example a component having curved sides intersects with the shell surface, while one having all straight sides forms part of

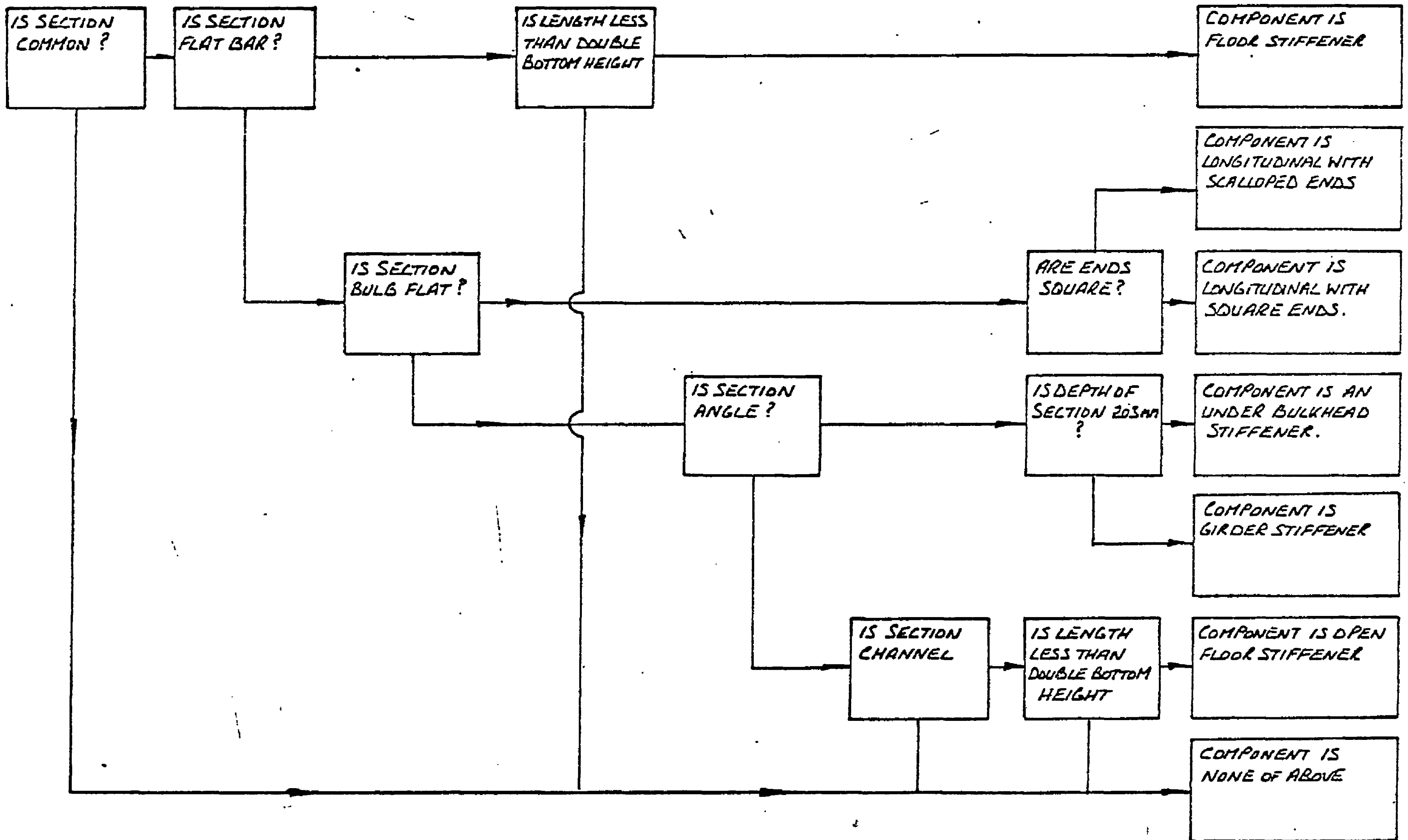


Figure 102 Assembly decision flow chart for section components

the matrix at the interior of the structure. (The curve also infers the orientation of the part in the structure.) Also a component having two or three straight sides with one side curved is, as stated previously, most probably an outer floor or tank top plate intersecting with the shell. The decision whether the part is outer floor or tank top plate is size dependent. The floor is as shown in figure 103, the orientation depends on the relationship between the double bottom height and the bilge radius; however in the SD14 the longest side of the part is found to lie along the line of tank top as shown.

The orientation of twenty one possible varieties of component function were investigated in this way and the position and orientation of each determined in relation to their length and width. The assembly sequence to define the orientation of parts on welding is shown in figure 100 and was discussed previously. It is assumed that all section parts (longitudinals to shell or tank top and stiffeners to girders and floors) are welded to their parent plate parts prior to matrix assembly. An investigation of shell plates has shown that the orientation on assembly is dependent on whether the part is formed. Shell plates with no forming are welded in a horizontal position, those with forming are welded with both long edges horizontal and the curved short edges changing from horizontal to vertical. Thus for shell parts an independent investigation of the form digit is required.

The full findings of the investigation of component position and orientation is shown in figure 104.

10.5 Determination of joint type and weld length

The welding schedule associated with the double bottom structure was investigated and used in conjunction with the previously devised orientation and function definition procedures to find the type of weld required. Weld types consist of fillet, butt, or section ends (see figure 105) with continuous or intermittent runs, and varying size of fillet leg. It was generally found that non-watertight girder and floor plates are welded using double sided chained intermittent fillet welds and girder and floor stiffeners are welded using double continuous fillet welds. The spacing

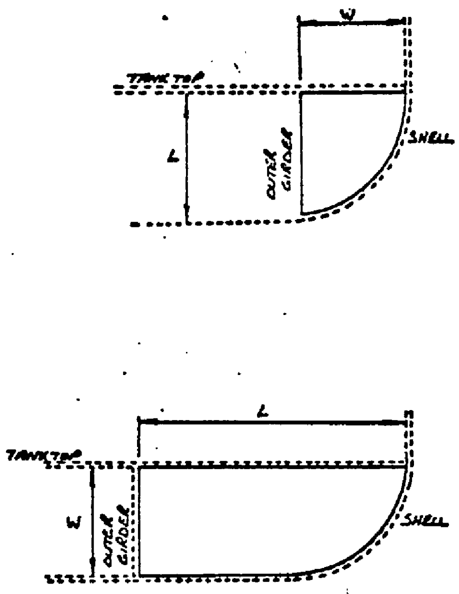


Figure 103 Orientation of outer floor in bilge area.

	COMPONENT FUNCTION	ORIENTATION AT WELD
1	STIFFENED OUTER FLOOR	VERTICAL (W VERT^L; L HORIZ^L)
2	OUTER WATERTIGHT FLOOR	VERTICAL (W VERT^L; L HORIZ^L)
3	NON.WATERTIGHT OUTER FLOOR	VERTICAL (W VERT^L; L HORIZ^L)
4	LONGITUDINAL GIRDER	VERTICAL (W VERT^L; L HORIZ^L)
5	NON.WATERTIGHT INNER FLOOR	VERTICAL (W VERT^L; L HORIZ^L)
6	WATERTIGHT INNER FLOOR	VERTICAL (W VERT^L; L HORIZ^L)
7	END OF GIRDER OR FLANGED STIFFENED FLOOR.	VERTICAL (W HORIZ^L; L VERT^L)
8	SHELL PLATE	HORIZONT^L (IF ROLLED - SPECIAL CASE)
9	TANK TOP PLATE AT SIDE WELDED FROM ONE SIDE	HORIZONTAL.
10	TANK TOP PLATE AT SIDE WELDED FROM TWO SIDES	HORIZONTAL
11	CENTRE TANK TOP PLATE WELDED FROM ONE SIDE.	HORIZONTAL
12	CENTRAL TANK TOP PLATE WELDED FROM TWO SIDES	HORIZONTAL
13	SMALL BRACKET.	VERTICAL (W HORIZ^L; L VERT^L)
14	FRAME FOOT BRACKET	VERTICAL (W HORIZ^L, L VERT^L)
15	FLOOR STIFFENER	HORIZONTAL
16	LONGITUDINAL WITH SCALLOPED ENDS	HORIZONTAL
17	LONGITUDINAL WITH SQUARE ENDS	HORIZONTAL
18	UNDER BULKHEAD STIFFENER	HORIZONTAL
19	GIRDER STIFFENER	HORIZONTAL
20	OPEN FLOOR STIFFENER	HORIZONTAL
21	UNSPECIFIED SECTION	SPECIAL. INVESTIGATE.

Figure 104 Relationships between component function and orientation at weld.

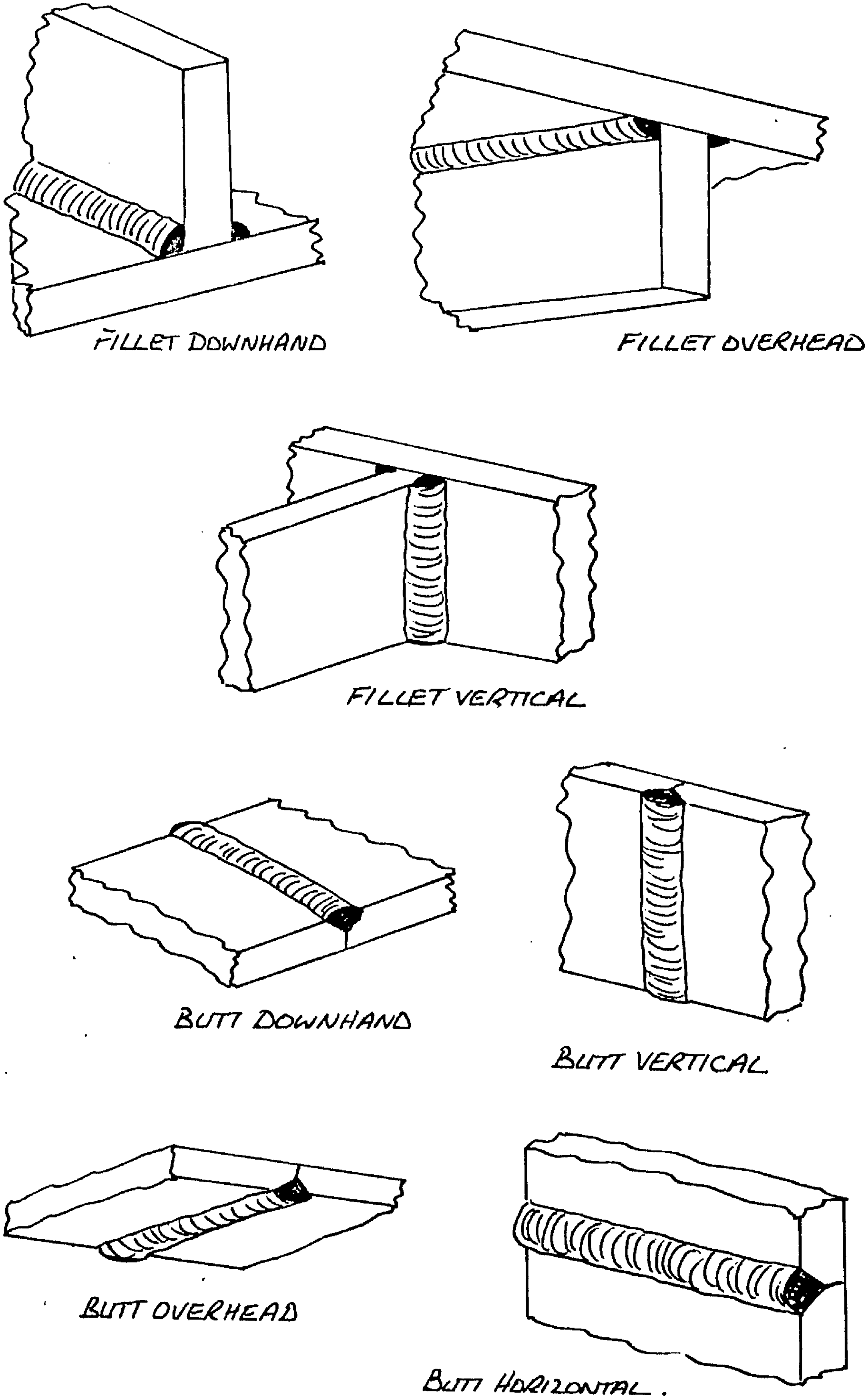


Figure 105   Possible weld orientations.

on intermittent welds is equal to the leg lengths with spaces on one side being bridged by runs on the other. Run lengths are equal to an integer number of welding rod usages, preferably a single run. However at stress points, particularly at the corners of components the weld strength is increased by employing double continuous welds. This factor is compensated for when estimating the length of welded component side. Watertight floors and girders are welded in position using double continuous fillet welds. Open floor supports (channel section) are welded at the ends only using fillet welds, for these components a standard assembly time can be found from time study. For each component function an individual investigation of the combination of weld factors was made. The results of this investigation are shown in tabular form in figure 106.

A weld length estimation associated with each component at each assembly stage was found using the previously defined shape and function of the part. The assembly production stages which were employed for this specific exercise are simplified and only unit assembly and berth erection are considered. For a further division of weld work content by workshop assembly area a more detailed analysis must be made of components using their individual function. The methods of assembly employed will vary between individual shipyards. However, the model which is employed here assumes that all floor, girder and flat panel stiffening is welded in a downhand position as occurs in a flow production system. Thus the simplified situation is still comparable with modern shipyard practice in that the total shed work and total berth work are correctly divided, and most orientations of weld are assumed correctly.

Each function of component was individually scrutinised to find the length of weld which is necessary to assemble it into the unit or to the ship on the berth. The length was measured as a factor of the length and width of the component. This factor is dependent on the continuity of the weld required, the type of weld, and the shape of the component. Three typical factors have been determined as follows:-

a) Consider an outer open floor bilge bracket (component function a) as shown in figure 107. The top of the component is welded to the tank top in a downhand position with a 3/16" leg double intermittent (equal spacing) fillet weld as specified previously. This is therefore allocated a fillet weld of length L (L ≐ longest side) in the downhand position in the unit assembly workshops. The flanged side does not require welding but the curved side is welded at the berth. The orientation of this weld changes gradually from vertical to horizontal with the bilge radius, it is therefore assumed that a weld length of 2/3 L downhand and 2/3 W vertical (W = component width) is an adequate estimate of the length involved.

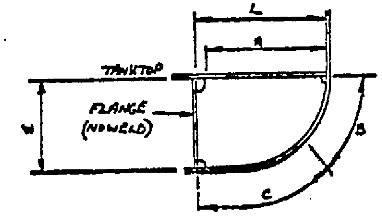
The value of 2/3 (L + W) for the curved side is extracted from a previous exercise to estimate the total component perimeter for flame cutting work content computation. This and other derivations for the estimation of side lengths of non-rectangular shapes are discussed in chapter 9, section 3.3, these were consulted throughout the exercise.

b) Consider the rectangular tank top plate shown in figure 107 (b) This component is butt welded on all four sides with a single weld run from one side (from single chamfer edge preparation). The total weld run around the perimeter is therefore 2(L + W), however the weld is 'shared' with the surrounding parts and the total perimeter is therefore halved. The resulting weld length for this type of component is therefore estimated as (L + W) in a horizontal downhand position in the unit assembly workshops.

c) Consider the frame foot bracket shown in figure 107 (c) It is assumed that the base is to be welded to the tank top in the unit assembly workshops after the tank top assembly (including girders and floors) has been turned over, this is before transport to berth and assembly to the bottom shell. The long side of the bracket is welded when the side shell unit is erected onto the bottom shell at berth. The weld leg length has been previously specified as 5/16" and the type of weld as

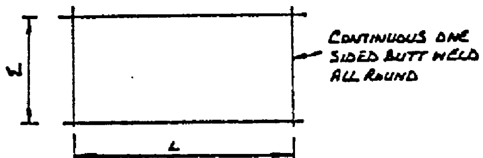
	Component Function	Weld Type Fillet or Butt	Continuity Continuous or Intermittent	Leg Length or Number of Sides Welded
1	Stiffened Outer Floor	Fillet	Intermittent	3/16"
2	Outer Watertight Floor	Fillet	Continuous	3/8"
3	Non-Watertight Outer Floor	Fillet	Intermittent	3/16"
4.	Longitudinal Girder	Fillet	Intermittent	1/4"
5	Non-Watertight Inner Floor.	Fillet	Intermittent	3/16"
6	Watertight Inner Floor.	Fillet	Continuous	3/8"
7	End of Girder or Flanged Stiffened Floor.	Fillet	Intermittent	1/4"
8	Shell Plate	Butt	Continuous	Two Sided
9	Tank Top Plate at Side Welded from One Side	Butt	Continuous	Two Sided
10	Tank Top Plate at Side Welded from Two Sides	Butt	Continuous	One Sided
11	Central Tank Top Plate Welded from One Side.	Butt	Continuous	One Sided
12	Central Tank Top Plate Welded from Two Sides.	Butt	Continuous	Two Sided
13	Small Bracket	Fillet	Continuous	3/16"
14	Frame Foot Bracket	Fillet	Continuous	5/16"
15	Floor Stiffener	Fillet	Continuous	3/16"
16	Longitudinal with Scalloped Ends	Fillet	Continuous	3/16"
17	Longitudinal with Square Ends	Fillet	Continuous	3/16"
18	Under Bulkhead Stiffener	Fillet	Continuous	3/16"
19	Girder Stiffener	Fillet	Continuous	3/16"
20	Open Floor Stiffener	Ends only - Fillet - Special Case.		
21	Unspecified Section	Fillet	Continuous	3/16"

Figure 106 Relationship between component function and welding factors.

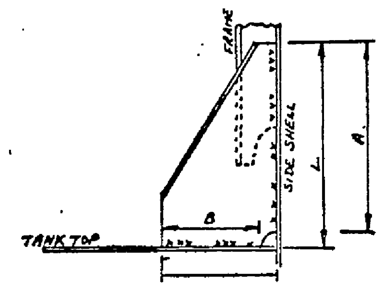


Weld Length Approximations:-
A. Approximated to L, workshop, downhand, fillet.
B. " " 1/3W, berth, vertical, fillet.
C " " 2/3W, " , horizontal, fillet.

a) Outer Open Floor Bilge Bracket.



Weld Length Approximated to (LxW) downhand butt
b) Rectangular Inner Tank Top Plate.



Weld Length Approximations:-
A Approximated to L, berth, vertical, fillet.
B " " W, workshop, downhand, fillet

c) Frame Foot Bracket

Figure 107 Examples of welding decisions for typical components.

double intermittent fillet. The weld associated with this type of component is therefore determined as consisting of W downhand fillet in the workshops and L vertical fillet at berth erection.

All twenty one varieties of component function were individually analysed in a manner similar to that demonstrated for these three.

Estimates of the lengths and widths of components to be used with the welding algorithms are arrived at by using the size ranges of the descriptive code number. The midpoints of the ranges have been employed previously to estimate component perimeters for flame cutting work content determination. The use of these midpoints and the probable resulting errors are discussed in detail in chapter 9.3.3.

10.6 Sources of work content values

Two possible sources of historical work content were investigated for use in the design of estimating systems. The first source was historical yard data from shipbuilding companies who were at the time collaborating in the project, or who it was thought might be interested in collaborating to develop an estimating system. It was known through personal contact that H.M. Maynard had previously been employed to carry out an exercise attempting to install a work measurement system at Sunderland Shipbuilders (then Doxford and Sunderland). However, no published literature was found on the exercise, and following a meeting with the technical director of the company Sunderland Shipbuilders stated that at that time they were not interested in collaborating or in allowing exploitation of the historical work measurement data for estimating systems. Another possible source of historical work content data was the Govan Shipbuilding company who were at the time developing work measurement procedures, however the exercise was at a very early stage and the use of it was not practically possible. The company promised full co-operation from its industrial engineering department which was developing the work measurement procedures.

The second possible source of historical work content data was the information accumulated by the Welding

Institute. The Welding Institute's Standard Data is a form of synthetic data, such as may be widely used to build up Standard Times by synthesis. It may also be used for other forms of estimation, such as the quantities of consummables required, or the weight of the completed weld. Examples of the use of butt weld standard data is shown in appendix L. The data concerning manual electric arc welding is presented in tabular form as a manual of edge preparations, run numbers, electrode size, current required, and operation times. Tables are presented for different orientations (downhand, horizontal, overhead) and type (butt, fillet) of weld. Each table consists of the time allowed per metre of weld for different size (parent metal thickness or leg length) of weld using different types and size of electrode. In addition the deslag and brush time are also tabulated for different leg lengths of weld; the slag deposited (and thus the content involved in removing it) is also proportional to the size of leg and the electrode used. Separate tables are presented for auxiliary elements involved at each change of electrode, these include change of stick, change of gloves, and fitting of mask.

It was decided that the Welding Institute Standard Data was adequate for the development of the assembly work content estimating system. However should any shipyard wish to employ the system it will be readily adapted to utilize any shipyard welding data which may be available. The basic elements of weld type, orientation, and joint length will be devised from modules of the proposed system. These can then be used in collaboration with individual shipyard data to result in an estimation of the time required to achieve a specified joint, and thus to weld a specified component into the required assembly.

The time involved in assembling a welded joint is divisible into three basic sections. These are the time associated with the start and finish of the joint, the time associated with changes of electrode, and the time associated with arc, deslag, and brush cleaning. Thus the total time to achieve the welded joint is given by:-

T_j = time for joint

T_j = Auxiliary elements per joint time

+ (Auxiliary elements per electrode time x number of electrodes required)

+ (Arc, Deslag, brush time per foot of joint) x (length of joint in feet)

The times associated with start and finish of the joint remain the same for all types and orientation of joint. They include times for fitting gloves, fitting welding helmet, and preparing to carry out the weld. The breakdown of weld elements for this section is as shown below:-

Obtain welding gloves and fit to hands	0.085
Pick-up carbon electrode and holder and fit carbon to holder	0.056
Pick-up face shield and position carbon to work	0.077
Aside face shield	0.025
Remove carbon stubb and aside holder	0.031
Remove welding gloves and place aside	0.062
	0.34

The times associated with change of electrode is the product of the number of electrodes and the time required per change. The time required per electrode change is given by the sum of the elements listed below.

Aside face shield	0.025
Remove carbon stud, pick-up new carbon and fit to holder	0.062
Pick up fact shield and position carbon to work	0.077
Total in standard minutes	0.164

The number of electrodes required for the joint is a function of the length of electrode, the length of electrode used per length of weld, and the length of the joint. The number of electrodes for a specified joint is given by:-

$$\frac{f^{l}/d + 1}{2} = \frac{fl + d}{2d}$$

where d = length of electrode

f = ft of electrode/ft of weld

l = length of joint

the total time for the joint is thus given by:-

$$T_j = 0.34 + 0.164 \left(\frac{fl + d}{2d} - 1 \right) + t_1 + t_2$$

For any specified type, orientation, and size of weld using a specified electrode d, f, t_1, t_2 is constant, thus the total time to achieve the weld can be shown graphically as shown in figure 108. The three divisions of the total joint length time can be superimposed as shown. An approximation can be made for each joint length by smoothing the step function of the line as shown in figure 108. The total weld time formula using this approximation is given by:-

$$T_j = (.34 - 0.82)\ l\ (.164\ f) + (t_1 + t_2)$$

$$\text{or } T_j = .258 + 1 \quad .164f \quad + \quad (t_1 + t_2)$$

This formula is used for all weld runs in the exercise with values of t_1 and t_2 extracted from WI Standard Data.

In the first instance it was decided to devise procedures to incorporate this algorithm into the main program for fillet welds. The mid-points of the descriptive code ranges are shown in figure 109, these have been transposed into imperial dimensions to be compatible with the W.I. Data. Using these values tables were defined of synthetic values for 3/16" leg, 1/4" leg, and 3/8" leg fillet weld for down-hand, vertical, and horizontal orientations. The tables, together with derivation formula are shown in appendix L.

Sub-routines were written for combinations of leg size and orientation (nine in total) and statements were added to the main Fortran program to call the relevant procedure when required. The different orientation, weld type, leg length, and workplace at which the welding operation takes place (workshop or both), have already been defined for each edge of the component in the main program. The sub-routines then investigate the size digits of the classification and coding system and allocate a time to each joint of the part.

10.7 Total system design and use

The program for estimation of assembly work content estimating is presented in appendix M , the flow diagram

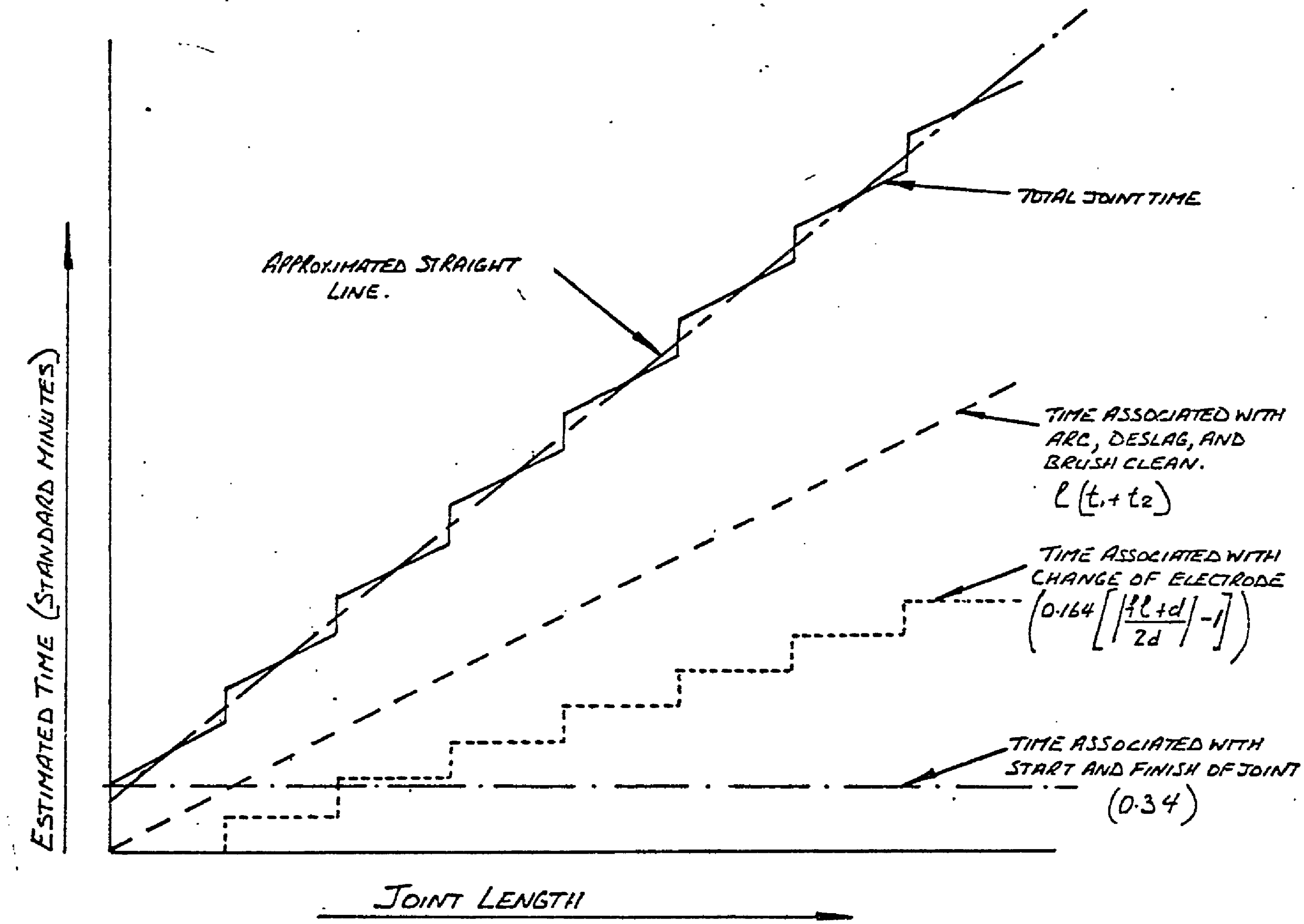


Figure 108 Approximated and actual weld time estimates for joint length

for the program is shown in figure 110. The program consists of two sections; the main program and a group of sub-routines.

The main program (pages 1 to 4, Appendix M) consists of an investigation of individual digits of the descriptive code number to determine its function, position in the unit, and the orientation at which each edge is welded in relation to its length and width. At this point the data record is reproduced and the estimated function of the part is printed for information purposes. With the knowledge of the component weld type and orientation at weld the main program then calls up the relevant sub-program to estimate the time required to complete the relevant welded joints. One or two possible orientation weld sub-programs from several alternatives may be called for each part. The alternatives are downhand, vertical, and overhead for fillet welding with the same orientations plus horizontal for butt welding. The orientations are shown in figure 105.

The sub-programs for butt welded joints have not yet been fully expanded. In this case the type of weld will vary drastically between different shipyards, possible variations including single or double sided welding and presence or absence of backgouging. For these reasons it is felt that potential users will be advised to develop sub-routines based on their own production methods for butt welding. However the sub-routines which will be devised will be very similar to those developed for fillet welds, and Welding Institute Standard Data may again be exploited.

The Welding Institute Standard Data which has been employed in the example program expresses time values in basic minutes, these are minutes of British Standard rate of working without any allowances of any sort. Thus allowance factors must be introduced for items such as difficulty of working conditions (confined spaces), fume extraction equipment handling, cover facilities (indoor or outdoor welding), crane waiting time, and rest contingencies. Exercises must be undertaken in the shipyard of any potential user to define the required factors.

Example output from the estimating system (not including butt weld estimations) is shown in figure 111.

CODE DIGIT. L	RANGE	MIDDLE RANGE (MM)	MIDDLE RANGE (FT)
0	≤300	250	0.82
1	>300 ≤ 600	450	1.47
2	>600 ≤ 1000	800	2.62
3	>1000 ≤ 1500	1250	4.10
4	>1500 ≤ 2500	2000	6.56
5	>2500 ≤ 4000	3250	10.65
6	>4000 ≤ 6000	5000	16.40
7	>6000 ≤ 7500	6750	22.10
8	>7500 ≤ 9000	8250	27.10
9	>9000	10,000	32.80

CODE DIGIT W	RANGE	MIDDLE RANGE (MM)	MIDDLE RANGE. (FT)
0	≤ 300	200	0.66
1	>300 ≤ 450	375	1.23
2	>450 ≤ 600	525	1.72
3	>600 ≤ 900	750	2.46
4	>900 ≤ 1200	1050	3.44
5	>1200 ≤ 1600	1400	4.59
6	>1600 ≤ 2000	1800	5.91
7	>2000 ≤ 2500	2250	7.38
8	>2500 ≤ 3000	2750	9.02
9	>3000	3500	11.49

Figure 109 Midpoints of descriptive code size ranges for use with assembly work content estimating systems.

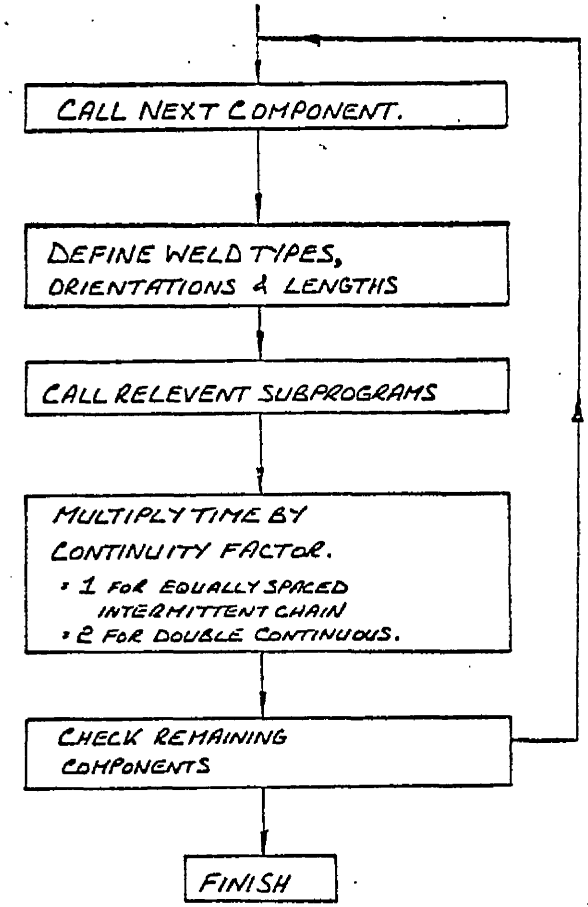


Figure 110 Program flowchart for double bottom assembly work content estimating system.

```
? 37D31CØ16   P13 *    71Ø5ØØ444 Ø1 ØØØ Ø1

OUT.FLR.37D31CØ16   P13 *    71Ø5ØØ444 Ø1 ØØØ Ø1
D/H.F.WELD.TIME(MIN)=13.ØØ
VERT.F.WELD.TIME(MIN)= 1Ø.9
INPUT:ØØØ3Ø
? 37D31CØ11   P15 *    71Ø5ØØ454 Ø1 ØØØ Ø1

OUT.FLR.37D31CØ11   P15 *    71Ø5ØØ454 Ø1 ØØØ Ø1
D/H.F.WELD.TIME(MIN)=2Ø.ØØ
VERT.F.WELD.TIME(MIN)= 1Ø.9
INPUT:ØØØ3Ø
? 37D31CØØ4   P12 *    71Ø5ØØ464 Ø1 ØØØ Ø1

OUT.FLR.37D31CØØ4   P12 *    71Ø5ØØ464 Ø1 ØØØ Ø1
D/H.F.WELD.TIME(MIN)=31.9Ø
VERT.F.WELD.TIME(MIN)= 1Ø.9
INPUT:ØØØ3Ø
? 37D31WØØ2   BOP      7237ØØ512 Ø1 ØØØ Ø1

SMALL BRACKET 37D31WØØ2   BOP      7237ØØ512 Ø1 ØØØ Ø1
D/H.F.WELD.TIME(MIN)= 4.65
VERT.F.WELD.TIME(MIN)=  6.4
```

Figure 111 Sample output from weld time estimating program.

When fully completed the results from the system will be of use in the simulation of alternative methods of assembly and shipyard design. In such simulations different manufacturing models may be devised and estimations of work content involved in workshop areas or modules of each model may be found. These work content values may then be used to balance work loads for each module in the model itself. Thus the different manufacturing models may be compared objectively, using computer simulation and data processing techniques. The results may alternatively be used for the preparation of work schedules for assembly areas. The individual component estimations will be aggregated to achieve grouped work content values for work packages compiled according to the manufacturing system employed in the shipyard. As previously described the assembly model which is used to devise the estimating system will vary between different shipyards and different structure group or unit type. Thus the model employed will vary from assembly of components directly into the unit or a full breakdown into panel, web, and bracket assemblies. In each case the tasks of identifying the component function, specifying the weld types to assemble it, defining the work station at which each joint is assembled and the orientation in which it is welded.

Implementation of the system will require careful monitoring of the variances between estimated values and the actual times taken, which may be caused by the two factors of volume and time. Volume variance occurs when more work has been undertaken than was estimated, and time variance occurs when the value of work has been estimated correctly but the estimated times are incorrect. By investigating these errors the estimating system itself may be refined and its accuracy eventually improved.

Chapter 11 Discussions and conclusions

11.1 The Aims of the work

The original objective of this work was to investigate the feasibility of applying the production analysis techniques of general manufacturing industry to the building of ships hulls.

The motivation for doing this was in part the belief that the declining role of British shipbuilding, relative to that of other nations, was mainly caused by a failure to develop new and better manufacturing systems.

However the British shipbuilding industry is not identical to its foreign competitors, otherwise much more could be achieved by merely copying their methods. In fact the situation in the U.K. is more complex because British yards aim to be flexible enough to make ships of many different types. Abroad there has been a tendency for shipyards to specialise by limiting the variety of ship types on offer. This has enabled foreign yards to reap the benefits of specialisation, notably by using special purpose equipment.

Whilst this pattern has been developing in the shipbuilding industry changes have been taking place in general manufacturing industry in the U.K. Here significant improvements in productivity have been achieved by the adoption of new production analysis techniques, usually computer based. In this work it was hoped to adapt these techniques to shipbuilding so that similar improvements could be derived.

In effect it was being assumed that a general purpose shipyard and a general purpose manufacturing unit had sufficient in common to enable management and control techniques to be transferable. Clearly it was necessary at the outset to test the validity of this assumption. Thus a start was made by looking at a number of shipyards to find our how they were operated.

It soon became clear that there were considerable differences which were sufficiently serious to require a reappraisal of objectives.

First there are fundamental organisational differences between the two types of industry. Indeed the organisational structure of the shipbuilding industry has more in common with that of the civil engineering industry than with that of the general manufacturing industry.

Second and more important it was discovered that the average shipyard does not record essential production data. Instead it leaves a great deal of production planning to the experience and skills of the workforce. (A somewhat similar situation existed in manufacturing industry at the turn of the century before the introduction of scientific management). Thus it is unusual in a shipyard to generate data about component process routes, assembly welding stages, component and assembly standard times, and standard costs.

In modern manufacturing industry such information forms the fundamental data base by which production control is exercised, and it is therefore an essential part of the system. Indeed the latest production analysis techniques are even more dependent on this information than previous methods ever were and, of course, the availability of computers makes the manipulation of such data a relatively simple task.

Thus the absence of such data in the shipbuilding industry made the initial objective of the work impossible to achieve. On the other hand it pointed the way to an even more useful project. This was to devise ways and means of filling the information gap so that, ultimately, control could be exercised through knowledge of the real situation. The original objective was therefore amended to that of developing methods of collecting, analysing and exploiting information, mainly design data, with the aim of establishing reliable production information. This entailed establishing computer data banks which described all the components, sub-assemblies, and assemblies for a complete ship's hull. To achieve this it was necessary to design a descriptive coding system which indicated, among other things, the manufacturing features of components and assemblies. In this way design data was exploited for the purposes of generating production data.

The details of what has been achieved are summarised in the next section but in simple terms it amounts to filling the information gap between design and production. This enables all the processes of raw material requisitioning, component process routing, work content estimation, and production-scheduling to be carried out with speed and reliability. From this base it should now be possible to evaluate the practicality of introducing modern production analysis techniques and the potential gains from any shopfloor reorganisation.

11.2 The techniques developed

The techniques which have been developed in this work enable potential users to:

- collect ship hull manufacturing information directly from a design data base in a consistent and all embracing manner.
- analyse raw material orders for ship hull manufacture, and estimate raw material requirements from ships drawings using a computer data bank.
- analyse ship hull components in four ways; total hull analysis, structure group analysis, shopfloor scheduling analysis, and group technology analysis.
- use a computer to derive component process routes from ship drawings by means of a descriptive coding system and component data bank.
- use a computer to derive component manufacture work content values from ship drawings by means of a descriptive coding system and component data bank.
- use a computer to derive fabricated assembly work content values from ship drawings by means of a descriptive coding system and component data bank.

Unique computer data banks have now been compiled to describe the shape, size and production features of ship hull components (see Chapter 5). They are of a fixed format, digitally significant type, and they employ coding systems which have been specifically designed for the purpose. The data format is a simple, quick, and efficient method of collecting raw material, component, and assembly information for ship hull steelwork. Each computer data bank describes components and assemblies which comprise a total ships hull. They can be analysed quickly and efficiently by using standard statistical analysis packages and computer programs. They therefore enable statistical analysis to be undertaken for bohh raw material and ship hull components. They also enable production information to be derived directly from a design data base, and thus allow quantitative investigation of ship hull production systems.

Studies of raw material usage can be undertaken using existing plate and bar orders. It is also possible to estimate raw material requirements where orders are not available. In both cases computer retrieval and analysis packages are used with the computer data bank to handle large amounts of information. Such analyses permit rationalisation exercises to be undertaken which result in savings in steel costs, stockholding costs, and handling costs.

Computer programs which calculate weight increases resulting from the specification of 'standard' plate widths and thicknesses have been written, and these show that the benefits of raw material rationalisation can be achieved with only a small increase in ship weight (see 7.2). These techniques are applicable wherever raw material lists are available (Appendix D).

Alternatively, raw material requirements have been analysed using estimates based on component data (see 7.3) These estimates have been used to calculate the paint and material handling equipment needed for section bars. These techniques can be used where raw material lists have not been compiled, and they have already been so employed in a shipyard development.

Analysis of ship hull components will be of value in three areas; in the manufacture of steel components, in the assembly of components to form the ship hull, and in determining material handling requirements in shipyards. Four types of component analysis have been undertaken. These were an investigation of total ship hulls, an investigation of work packages for material ordering and shop loading, a synthesis of the operation of a shipyard over a time period, and an analysis for group technology.

In each case the relationships between component shape and size, and the manufacturing methods employed has been considered. Component process routes are dependent on combination of different features which are indicated by digits of the descriptive code. Thus a set of standard statistical tables was devised to specify component sizes for each possible process route. Although these tables primarily specify the shape and size of components they are presented in such a way that a shipyard manager or designer may align them to the production methods employed in his shipyard, and where a manufacturing decision is shape and size dependent he is given the information necessary to make it.

Total ship hull analysis (8.2) allows quantitative comparisons to be made of different types of ship, or of similar ships manufactured in different shipyards. It has been found in general manufacturing industries that such an analysis results in a better knowledge of machine tool requirements. If exploited in shipbuilding this will be beneficial to machinery manufacturers in design, and to shipyard users in plant selection. Fabrication work package analyses and work schedules for a specific ship have been used to study component manufacture over a time period (8.4). Graphs of components in workshop production for one ship have been plotted, and the workload over a longer period has been synthesised by superimposing graphs of component numbers for several ships. Results show that this technique highlights workload imbalances, and if it is employed in production planning a 'smoother' building programme results.

The analysis of ship hull components will be of value in the rational design of steel preparation facilities, possibly based on group technology principles. It has been shown from an analysis of the products of one shipyard that component families can be established (8.5). The components in each family have similarities which can be exploited by manufacturing them in group technology work-cells, and processing plant has been specified for each cell. The balancing of workloads for the cells has been investigated using percentages of total production only, but future investigations will be able to exploit the work content information which can now be generated from component data banks. However, the implementation of group technology manufacturing cells is unlikely in small to medium sized shipyards for three reasons. First, there is a lack of workspace to accommodate workcells or for storage of component parts. Second, the number of existing machine tools is few and the cost of additional plant is high. Third, the existing practice of nesting components into raw material pieces can be practiced most economically if all components are available. Component manufacturing cells will therefore probably be first implemented in a 'green-field' shipyard design.

In present circumstances component analyses and work schedules can best be used to investigate workloads over the building cycle of a ship. Shipyard workloads over longer periods can then be simulated by superimposing work-loads for individual ships, and the effects of changes in schedule can be more accurately forecast.

In addition ship hull component statistics will be valuable to machine tool manufacturers as a source of data on machine size capacities required in the industry. The relationships between the shape and size of components and the methods to manufacture them has already been established (8.2). Further work is needed by machinery designers to ensure that the plant available at the moment is of the optimum size. The level of technology of the machines also requires investigation, principally by shipyard users who tend automatically to use high technology n.c. cutting equipment when straight line flame planners would suffice.

Comprehensive data analysis also provides accurate information about the material handling needs of a shipyard. Capital expenditure on material handling equipment can be higher than that on process plant, and it is therefore essential that the right equipment is selected. A good data bank permits a fast analysis of raw material, components, assemblies, and berth erection units, and their orientations at different stages of production. The data can then be used to specify and select handling equipment.

The derivation of production information directly from a design data bank using computer programs is a new concept in data base exploitation. Previously route sheets and job cards have been compiled manually by process planners, and on rare occasions job times have been estimated using simple work measurement techniques. In-depth applications of analytical work measurement methods (i.e. time study and synthetics) have not been successful in shipbuilding. This is because of the wide variety of work, and the historical opposition of shipyard workers to piecework payment systems. Present group bonus payment systems are invariably based on steel weight throughput. They are not very satisfactory because of differing complexity of ship structures. A need therefore exists for simple methods of estimating work requirements from other factors. The methods which are described here, although not accurate enough for individual piecework implementations, are suitable for use in production planning and group bonus systems. They involve the exploitation of component data banks to improve process planning and work content estimating (9.3 and 9.4).

Computer planning systems which define process routes and work content from component code numbers have been developed for a collaborating shipyard. They are faster in response and inherently more consistent than present manual planning methods. A comparison of computer planned process routes and routes defined by planning engineers showed 90% agreement. Although the shipyard for which the planning system was developed employs low technology, the technique can be used in more complex manufacturing systems to cover individual equipment, jigs, and fixtures.

A plate cutting length estimating system has also been developed. Estimated cutting lengths for work packages of ten components were found to be within 15% of actual values, and the standard deviation of the percentage error was 10%. Thus the cutting length estimating system is of value when work packages of normal size are considered.

The component data bank has also been exploited to improve assembly work content estimates. Particular attention has been paid to the breakdown of a ship hull into sub-assembly stages, and to the recognition of components from their code numbers (10.1 and 10.2). It has been shown (10.3) that there is a relationship between the code number of a component and its position in an assembly. This relationship has been exploited to estimate welded joint lengths (and thence assembly times) from component code numbers (see 10.4) for a specific type of fabrication. A general assembly procedure for the fabrication type must be defined by a potential user for his own shipyard facilities. However the function of the components will remain the same, and the joint length estimating and work content grouping methods which are described will be valid for all shipyards. The methods of deriving operation times is based on Welding Institute Standard Data, although other methods can be substituted if required. It is evident from assembly analysis that many common assembly features exist among the various types and size of ship studied, and that they can be exploited to improve plant layout.

A major aim of shipyard assembly area design is to maximise the use of downhand welding. This can be more easily automated than vertical or overhead welding, and it results in a faster rate of metal deposition. (Downhand welding times are about 60% of those for similar vertical joints). Given the type of data collected in the work described here it is possible to design assembly lines for a particular yard which maximises downhand welding.

11.3 Practical applications of the techniques

Following the work described here the value of computer data banks in production analysis and planning has become recognised within shipbuilding. Data banks are now computer-stored at many shipyards, although in most cases they are used principally for material ordering and control, and for component numbering and marshalling for assembly. They generally lack the degree of detail of the data banks compiled during this work, and they do not indicate production methods or work content. Three organisations have shown more active interest in the techniques described here; they are Austin and Pickersgill, A.P. Appledore, and the British Ship Research Association.

Austin and Pickersgill and A.P. Appledore were particularly interested in demonstrations which involved listing components by type from specific assemblies. A computer package capable of executing this task was found to be readily available to A.P. Appledore, and following costing exercises a copy of the data files describing ships manufactured by Austin and Pickersgill was transferred to their facilities. The techniques have proved to be of value in the calculation of material handling requirements for a shipyard development.

Computer production information systems are now being developed in a number of shipyards for material ordering, component manufacture, and marshalling for assembly. However, these systems are based on production data which is manually specified. They require greater effort and specialised skills from production departments than those described here. The data manipulation and retrieval techniques can, however, be applied to any data storage system which employs a standard fixed format.

Further work on the compilation and exploitation of data banks is being undertaken by A.P. Appledore and the British Ship Research Association (B.S.R.A.). A.P. Appledore are employing an amended and abbreviated version of the coding system described in the thesis to compile ship hull data banks. B.S.R.A. are using the coding system with only slight amendments to compile data banks for several ships as part of an Advanced Technology in Shipbuilding (A.T.S.) project. They are then investigating possible alternative work content parameters using the coding system and the data banks. They are also using the data banks to investigate plant and equipment requirements for ship hull production. It has already been shown (Chapter 8) that the data bank indicates production methods, and these relationships have been used as a basis for the design of standard statistical tables (8.2). However plant and equipment requirements were not fully investigated, it is intended to do this as part of the A.T.S. project. Information presented in the thesis was supplied to, and used by B.S.R.A. to part justify the A.T.S. project.

B.S.R.A. also plan to exploit the coding system to output production information from the Ship Structural Design System (S.S.D.S.). This is a computer aided design system for ship hull steelwork which is currently under development. It encompasses the entire design function from preliminary ship specification to the definition of n.c. information for production purposes. It involves the definition and development of a design data base, and it is envisaged that components may be coded directly from this design information.

Selected examples of the techniques described here were outlined in a paper (48) presented to a working party on group technology in shipbuilding at Newcastle University. A wide variety of interests were represented in subsequent discussions, ranging from shipyards (eleven companies), research and consultant establishments (two), universities (two) and a draughtsman's union. Other papers presented at the working party covered assembly, and many of the establishments concerned had contributed in developing the techniques.

11.4 General recommendations

World shipbuilding is at present passing through a phase of deep recession and vast overcapacity. The latter has been caused by new shipyards which were built to meet the sudden demand of the mid-sixties, combined with a subsequent recession in world shipping since then (see Chapter 2).

Many companies are accepting contracts which result in financial losses, but they can only do this if they have enough capital or financial backing to survive. This is particularly so with Japanese shipbuilders. Financial backing usually comes from government sources (U.K.), or from large multi-industry combines of which the shipbuilding company is one part (I.H.I., Mitsubishi). It has led to a rift between Western Europe and Japan, and finally to tenuous agreements for a planned cutback in capacity on both sides.

The British shipbuilding industry is in a strong position to survive the recession for three reasons. Firstly, the government has been willing to back shipbuilders with shipyard redevelopment grants. These are being used to improve facilities at various shipyards, many of which are now capable of coming into full production (Cammel Laird, Austin and Pickersgill, Sunderland Shipbuilders, Govan). Secondly, since nationalisation the government has been more willing to subsidise contracts from overseas with low or interest-free foreign-aid grants. Nationalisation has also led to a centralised marketing policy, and closer collaboration between previous competitors against overseas shipbuilders. The third and most important reason is that Britain has the design experience and the best type of shipyards to meet present and future world shipping needs. Most of the new overseas shipyards which were built during the mid-sixties were designed to build supertankers. Since the collapse of the tanker market these shipyards have been forced to accept orders for much smaller ships which they cannot build economically. British shipbuilders, with the exception of a few shipyards, are geared to build smaller and technically more complex ships (cargo liners, product tankers). This is particularly true of the new shipyard developments listed earlier. However to take advantage of its relatively strong position, British shipbuilding must improve its management techniques. The most important areas for improvement are the design-production interface, production planning and control, and industrial relations.

At present ship design and ship production are conceived of and practiced as two distinct and separate functions. A ship is designed, and only then does the information to manufacture it start to be generated. These two functions should be fully integrated then manufacturing information can be generated as the early stages of a design evolve, and manufacturing information can be fed back into the design at the same time. Ship designers should be familiar with good current engineering practice, and they should incorporate this at the preliminary, as well as at the detail design stage. This is particularly important to fully benefit from the techniques of modular construction, standardisation, and variety reduction during manufacture. Ships should be designed to use, where possible, plates and section bars selected from shipyard standards. Each structure zone should be designed so as to be made up of a number of similar units, which should be of a length equal to a pre-determined shipyard standard plate-length. In addition standard codes of procedure should be devised which will introduce consistent design-for-production principles into the practice of steelwork detailing. These may be incorporated into the many computer aided design systems which are being developed throughout the shipbuilding industry.

Until now detailed investigations of the planning and control function in ship production have not been possible because of the lack of good standard work content data. Consequently improvements have been only slight, and production systems still basically consist of releasing material and marshalling parts for assembly of large structural units. The inherent skill of the workforce is relied upon to process steelwork between these stages. This often leads to imbalances in planned workloads which are compensated by excess work in progress (see 8.4). This must result in a less than optimum manufacturing situation. In this work it was not possible to investigate production planning and control in shipyards as fully as was desired. However future researchers will have available the data banks, process planning, and work content estimating systems which have been developed. Detailed quantitative investigations can now be made of production planning and control in shipyards. The most fruitful area of investigation is likely to be a study of specialised flow lines for the manufacture of similar components or small welded assemblies. Work has already been done on components (see 8.5), but at that time detailed work content data was not available. Flow lines will take full advantage of repetitive tasks, down-hand welding, and conveyor material handling systems. It will now be possible to balance and control such flow lines using the work content estimating systems which have been developed.

Industrial relations are generally poor in shipyards. Some of the worst disputes have been caused by pay differentials between various trades. These differentials were originally based on the skills of trades which have since changed considerably. One example is the highly skilled plater-boilermaker who has been replaced by the lesser skilled welder, however pay differentials still exist in his favour. This has led to inter-union and demarcation disputes, and a 'leap-frog' effect on wages. Industrial relations seem to have improved recently by a process of attrition, particularly since nationalisation and the introduction by the government of national limits to pay increases. Lines of demarcation have been cut to allow better use to be made of the available labour force. However the practice of threatening to switch contracts to other nationalised companies unless a no-strike guarantee is given by the workforce of a particular yard can only damage industrial relations. (e.g. Polish order for Swan-Hunter 1977). While solving problems in the short term it will lead to deeper resentment of management, who it will seem are using the present economic climate and nationalisation to suppress disputes. Efforts must be made to improve industrial relations on an industry-wide front before the shipbuilding market improves, otherwise traditional problems will recur.

British shipbuilding has a reputation for poor productivity and late deliveries which although deserved to some extent, has been exaggerated by the national press. However, there have already been noticeable improvements in production facilities, shipyard management, marketing techniques, and industrial relations. It must use public relations techniques to promote these improvements through the media must as in the past its shortcomings have been publicised. Only than can it re-establish the reputation of British shipbuilders for good design and delivery to contract.

REFERENCES

1 Booze, Allen, and Hamilton International BV. 'British Shipbuilding 1972'. (Issued by) the Department of Trade and Industry, London. (1973).

2 Barkowski J.V., 'Lash v containership slot construction cost', Fairplay International Shipping Weekly. pp.7-10 (11 Dec. 1975).

3 Lloyd's register of shipping. Rules and regulations for the construction and classification of steel ships. (published yearly).

4 Lloyd's register of shipping. 'N.A.S.T.R.A.N.' computer service.

5 Trading tradition for innovation. Surveyor. (August 1972).

6 Shama M, Miller N.S., 'A design study of a numerically controlled frame bending machine.' Paper No. 6, R.I.N.A., London. (March 25, 1965).

7 Venus J., 'The viability and economics of covered-in building'. Motor Ship Special Survey p. 49. (June 1971).

8 'Veni' First of a series of large oil tankers from Gotaverkens Arrendell shipyard. Shipping world and shipbuilder. p.1695 (Dec. 1965).

9 Cammel Laird development.

10 A covered shipyard at Pallion gives British shipbuilding a new look. The Naval Architect pp.78-79 (1976).

11 Kimber, D., Hargroves, M., Creating a production facility for standard ships. The Naval Architect No. 1 (transaction), (Jan. 1977).

12 Hirschberg H., Krahl A., Mechanised 2-sided welding of flat plates without a turning operation. Welding and Metal Fabrication 40 (1972) p.72 (March).

13 Palmer T.J., Panel flow line at Scottish shipyard. Welding and Metal Fabrication 39. (1971) p.350 (Oct.)

14 £3m steel panel facility serves 5 Tyne yards. Shipbuilding and Shipping World. 118 (1971) p.19 (31 Dec.)

15 Takezawa I., Development of the automated shipyard. Royal Society, London (Paper presented at discussion meeting on ship technology in the 1980's Jan. 1972).

16 Varvarin N.N., Lushkov N.L., A group method of hull structure fabrication for one-off and short series ship construction. Sudostroenie, No.8 (1974) p.36 (Aug.).

17 Maeda K., Approach to a new shipbuilding system. Japan Shipbuilding and Marine Engineering 6 (1971) p.17 (No.3)

18 Advanced Technology in Shipbuilding Definition studies (part 1) (British Ship Research Association Report N543T) 1975.

19 Limbert W.J., Work measurement of welding operations in a shipbuilding environment. Work study and management services, pp.400-405, June 1973.

20 Advanced Technology in Shipbuilding -Definition studies (Part IV) (British Ship Research Association Report N543T) 1975.

21 Harry A.N.T., Holliday R.E., A parts numbering system for steelwork (TM344), British Ship Research Association, 1968.

22 Gombinski J., Fundamental Aspects of Component Classification. Annals of C.I.R.P., 17, 923 (1969).

23 Opitz H., A Classification system to describe workpieces. Pergamon Press, Oxford. (1970).

24 Homann H.W., Guhring H., and Brankamp K., Ein Klassifiizerungs-system fur Stshlbaueinzelteile-Entwicklung und Beschreibung des Systems. Industrie Anzeiger, 92, 91 (1970).

25 Banerjee S.K., Southern G., Gallagher C.C., A classification system for ship hull components. Dept. of Management Studies, Glasgow University, Glasgow.

26 Bahruden H.A., Analysis of classification and coding system for shipbuilding industry. Dissertation as part requirement for the degree of M.Sc., Strathclyde University, Glasgow. (1973).

27 Belda J.A., Foran, International Conference on Computer Aided Ship Design (I.C.C.A.S.) Athens. Section I4 (1973).

28 Hitachi Zozen's Computer for Shipbuilding. Motor Ship. pp.90, June 1975.

29 Magnussen L., Viking, International Conference on Computer Aided Ship Design (I.C.C.A.S.)Athens, Section I3, (1973).

30 Southern G., Design for production, SSDS Memorandum No. 8, British Ship Research Association. March 1976.

31 P.E.R.A. (Production Engineering Research Association) Survey of the machining requirements of industry (1969).

32 Connolly R., Middle G.H., Thornley R.H., Organising the manufacturing facilities in order to obtain a short and reliable manufacturing time. Proc. of 11th International M.T.D.R. Conference, University of Birmingham, pp. 509-529, (Sept. 1970).

33 Ransom G.M., Toms B.H., Group technology atSerch Audco. Group Technology - Proc. of an international seminar held at the International Centre for Advanced Technology and Vocational Training (237-262, Sept. 1969. (Edited by J.L. Burbidge).

34 Nicolson D.L., Cranes in works and shipyards. Transactions of the Institute of Engineers and Shipbuilders in Scotland, Vol. 101 (1957-58) (p.224-250).

35 Honeywell Information Systems, T.S.P.S. Store & Manipulate (S.A.M.) reference manual (ref.DA04) (April 1971).

36 Comshare Inc., Composit '77 Introductory Guide, (serial No. 9419), (April 1971).

37 Nie N.H., Hadlai Hull C., Jenkins J.G., Steinbeuner K., Bent D.M., Statistical Package for the Social Sciences (S.P.S.S.), McGraw Hill, (second ed. 1977).

38 British Steel, Heavy steel plate. Price list No. 7.

39 Dalton I., Crook J, Williams E.A., Steel plate ordering technique (S.P.O.T) Mark 5, British Ship Research Association (1972).

40 Sim R.A.B., Britships - computerising from stem to stern, The Naval Architect No. 4, pp 133-135 (Oct. 1974).

41 Mack J.F., Autocon '76 Research and Engineering for Automation and Productivity in Shipbuilding (R.E.A.P.S.), Technical Symposium 1977, p 253 (Illinois Institute of Technology, 1977).

42 Compusize Inc., New Jersey, U.S.A. (see also B.S.R.A. internal committee papers 492/PB (April 1972) and 596/BTP (Nov. 1972).

43 Southern G., Banerjee S.K., Gallagher C.C., The component statistics of a ship hull structure. Proc. 3rd International Product Design and Manufacturing Technology Conference, Strathclyde University, Glasgow, Sept. 1973.

44 Gallagher C.C., Southern G., Banerjee S.K., The use of statistical data in Shipbuilding, The Naval Architect No.1 p.15 (Jan. 1977).

45 Southern G., Component statistical analysis: an aid to shipyard design, The Naval Architect No. 2, (April 1975).

46 Buffa E.S., Modern Production Management, pp.181-182, John Wiley & Sons, New York and London (1969).

47 Forbes S., Unit and ship assembly, Paper 3, Proceedings of a joint one day working party on Group Technology in Shipbuilding, Dept. Management Studies, Glasgow University and Dept. of Naval Architecture and Shipbuilding, Newcastle University (Newcastle, May 1976).

48 Southern G., Ship Component Production, Paper 4, Proceedings of a joint one day working party on Group Technology in Shipbuilding, Dept. Management Studies, Glasgow University, and Dept. of Naval Architecture and Shipbuilding, Newcastle University (Newcastle, May 1976).

APPENDIX A

Industrial Collaboration

Industrial Collaboration

In order to ensure that this thesis has practical value efforts were made to contact shipyards who might wish to collaborate in the associated research. A comprehensive list was compiled of all major shipbuilding and shiprepairing companies which were geographically accessible. Individual members of large shipbuilding groups were omitted in favour of a direct approach to the managing director of the respective group. This resulted in nineteen feasible shipyards who were asked if they wished to collaborate. In addition three 'remote' shipyards were approached to find out if they were working in associated areas, although their collaboration was not sought. The shipyards who were approached, together with their responses are listed in figure A(1)

The initial response from shipyards to letters requesting collaboration was disappointing. Of nineteen shipyards approached, only four expressed interest in active collaboration, although a further five said that the time was inopportune but future work might be possible. Ten shipyards did not wish to collaborate or did not reply. It appeared that of the yards which showed interest, the smaller companies were more likely to exploit proposals put to them. The larger yards appeared to be less likely to adopt suggestions until they had been proved in smaller organisations. The four shipyards who wished to participate, with details of collaborative efforts are as follows:-

Ailsa Shipbuilding and Engineering, Troon, Ayrshire

This is a small shipbuilding company of 400 to 500 employees who build ships up to about 5000 tons. Ships were at that time erected on two slipways and there was also a small drydock for ship repair and servicing. A ten day familiarisation period was spent in the Ailsa shipyard in October 1972, and a short report on the findings and plan for future action was presented to the company.

SHIPYARD CONTACTED	REACTION								Yard visited	Initial two week period spent in yard
		UNFAVOURABLE								
	Favourable (invited to work in yard)	New company or large reorganisation	New Management	Labour problems or new agreements	Poor order book	Security problems	Leave open possibility of future collaboration	No reply		
Ailsa Shipbuilding (Troon)	*								*	*
J.Lewis & Sons (Aberdeen)			*				*			
Hall Russel & Co (Aberdeen)					*		*			
Yarrow Shipbuilders (G/gow)			*	*		*			*	
Robb Calledon (Dundee)			*				*			
Marathon Manufng. (Glasgow)		*								
Govan Shipbuilders (G/gow)		*					*			
J.Lamont & Co.Ltd.(Greenock)					*					
Scott Lithgow (Greenock)	*								*	*
Vickers Ltd. (Barrow)						*			*	
Austin & Pickersgill (S/land)	*								*	*
Brooke Marine (Lowestoft)								*		
Doxford & Sunderland (S/land)			* (phone)					*		
Ryton Marine (Newcastle)	*								*	*
Swan Hunter (Newcastle)				*					*	
New Holland (Barrow on Humber)								*		
Newport Shipbuilders (N/port)								*		
Richards (Lowestoft)								*		
Camel Laird (Birkenhead)		*					*		*	

FIGURE A1

A further period was spent with the company in early 1973 to collect data describing the ship's hull steelwork of a 5000 ton sand dredger. All of the basic systems of data collection and analysis were developed and refined during these periods and the considerable help of the yard management at this early stage contributed greatly to long-term progress.

Ryton Marine, Wallsend, Tyne and Wear

Ryton Marine was a newly established shipbuilding company. The workforce at that time was 200 strong but there were plans for expansion and the aim was to increase this to 450. Ships, consisting of small coastal ferries, tugs and fishing vessels, were built on two totally covered shipways and new steelworking facilities were planned. While the shipbuilding facilities were being developed the yard management was continued on a "day-to-day" basis with the shipyard manager seemingly in sole charge and control of shipbuilding operations. During short periods in the shipyard data describing the double bottom structure block of a 3000 ton coastal ferry was obtained. Before further work was possible the company was put into liquidation, thus ending the possibility of further collaboration.

Scott Lithgow, Greenock, Renfrewshire

Scott Lithgow are a large lower Clyde based shipbuilding company with several shipyards producing ships up to 250,000 tons. An initial period of data collection was spent in the Kingston shipyard and a short initial report of findings presented to the company. No further collaboration was proposed by the management.

Austin and Pickersgill, Sunderland, Tyne and Wear

This company specialises in the SD14 vessel, a series "shelter deck" cargo ship of 14000 tons which is built in two shipyards, each employing two shipbuilding berths. Following an initial familiarisation period and first report, data describing the hull of the SD14 was collected and analysed. Two further reports were subsequently presented to the company. Orders were subsequently received by Austin and Pickersgill to build five 26,000 ton bulk carriers (B26's) and a comprehensive shipyard redevelopment project is now nearing completion. This involves the erection of a totally enclosed shipbuilding factory with allied steelworking facilities to replace the two existing shipyards. A revised building method for the SD14 and B26 has been devised by A. and P. Appledore (Shipbuilding Consultants) in an attempt to significantly reduce berth cycle times by pre-assembly techniques. Data banks describing the two ships' hulls (SD14 and B26) were prepared and used by both companies in the design of the new shipbuilding facilities.

Following collaborative work with the above companies three further companies have shown interest in the compilation of a data bank to describe the ships, or type of ship which they are producing. These are:-

Camel Laird, Birkenhead, Cheshire

Camel Laird are nearing completion of a large redevelopment project and are producing a series of 55,000 ton product tankers (STAT.55) This is the first type of a series of ships of similar design but differing size. A data bank describing the hull of the STAT.55 has been compiled from steelwork assembly drawings, direct from the ship drawing office.

Swan Hunters, Wallsend, Tyne and Wear

Swan Hunter have supplied drawings and material lists for a 130,000 ton crude oil tanker (very large crude carrier - VLCC) and work has been started to convert these also into a computerised data bank for analysis and production purposes. Due to delays in receiving drawings and difficulties in employing labour for data collection, work on the preparation of the data bank for Swan Hunter has been slower than expected and is about one third completed.

Harland and Woolf, Belfast

Harland and Woolf have supplied drawings for a 250,000 ton oil tanker (V.L.C.C.) for preparation of a data bank. However, due to limitations of time and piecepart coding facilities this work has not been started. The ship itself also differs slightly from thos presently in production, although the ship's hull statistical analysis would not be significantly different.

In addition to liaison with shipbuilding companies active collaboration has been maintained with the British Ship Research Association, and with A. and P. Appledore (Consultants).

The British Ship Research Association is the central research organisation of the British shipbuilding industry. It is funded jointly by the industry and the Government, and is organised in four main divisions - Naval Architecture Production, Computer, and Marine Systems. Close liaison with the Production Division of B.S.R.A. has been maintained throughout the research period and various ships' hull statistics were supplied to them. These were used as part justification for an Advanced Technology in Shipbuilding (A.T.S.) project, part of which is the generation of a statistical data bank describing various ships. This data bank, it is understood, will use aspects of the descriptive coding system devised and described in the thesis, and be similar in content to that generated in Glasgow. B.S.R.A. were also supplied with a complete set of punched cards describing the components forming the hull of the SD14 which they have used for a pilot study. The library facilities of the B.S.R.A. were made available to the author and found of great benefit during the literature search.

A. and P. Appledore are independent consultants who have connections with Austin and Pickersgill and Appledore Shipbuilders. They have interests in shipbuilding developments world-wide and with the redevelopments at Cammel Laird, Austin and Pickersgill, and Sunderland Shipbuilders in the United Kingdom. Workpiece statistics and assembly information describing the hulls of the SD14 and B26 have been supplied to them to aid design of facilities at Austin and Pickersgill. This has also been of use for overseas contracts (A.P.A. have licenced the construction of the SD14 in countries all over the world). A.P.A. intend to continue work on the compilation of a statistical data bank, probably describing a number of the ships in which they have an interest.

APPENDIX B

Cost breakdown - Ailsa Shipbuilding time sharing computer system

COST BREAKDOWN OF TIME SHARING COMPUTER SYSTEM

A Fixed Costs

1. GPO Datel – 200 modem		
	Rental	£ 100/year
	Installation	Nil
2. Teletype – Printer from the Computer Service		
	Rental	£ 400/year
NB. outright purchase of the equipment approximately £1000		
3. GPO telephone line (optional)		
	Rental	£ 30/year
Total fixed cost		£ 530/year
	or approximately	£45/month

B Variable or Running Cost

1. Terminal use per hour		£ 5.60
2. Computer unit time cost for (1) average		£ 6.00
	Total	£ 11.00/hour
If average use is say 5 hours /month	= £55/month	
3. Overnight storing of data and other storage costs say		£ 15/month
4. Telephone charges (approximately £2.00/hour from Troon to Glasgow)		£ 10/month
Total Variable cost		£ 80.00/month
Total cost of the time sharing computer service (A&B) =		£ 125.00/month

C Data Preparation Cost

1. Card Punching	
2. Sorting	
3. Mag Tape	
4. Listing	£30/1000 cards
Say 7000 cards/year	£210/year

D Data Information Sheet Preparation Cost

Assumptions: i) Coding of components to be done by draughtsman.

ii) Coding speed after initial training of 2-5 days is 150 cards per day.

Considering 7000 cards/year.

Total time required to prepare data for 7000 cards = 48 days

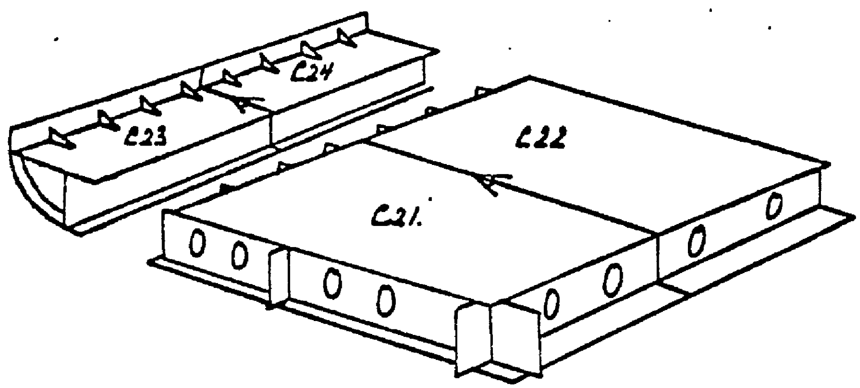
≃ 9 working weeks

Wages: £40/week	
Total cost =	£ 360/year
Other Incidentals (Administration, stationary etc.)	£ 230/year
Total	£ 490/year
Total of (C) and (D)	£ 700/year
or total average cost per month =	£ 60.00
Grand Total of (A), (B), (C), (D) =	£ 185.00 per month

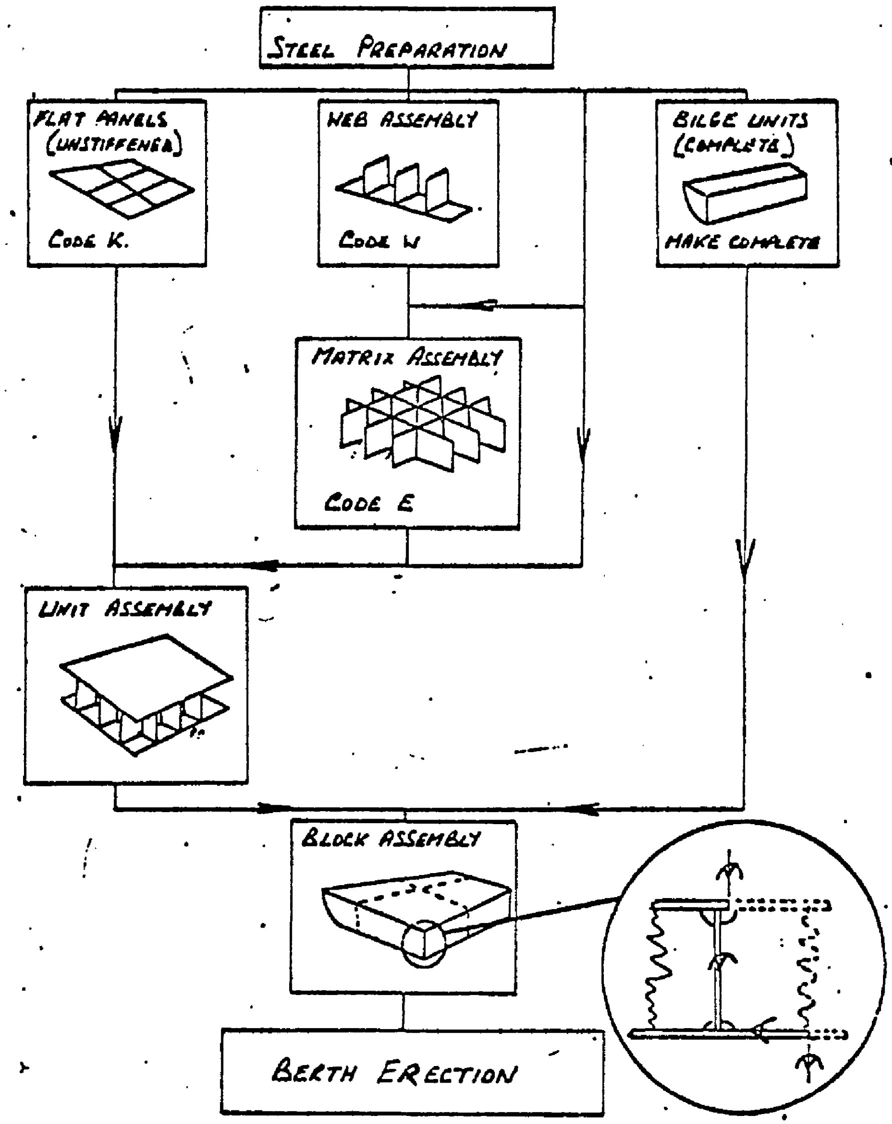
APPENDIX C

Example structural unit breakdown and sub-assembly listings. (Double bottom - S.D.14 cargo vessel).

TYPICAL 'C' BLOCK (DOUBLE BOTTOM)



ASSEMBLY SEQUENCE - 'C' UNITS (DOUBLE BOTTOM)



'C' BLOCKS (Double Bottom Units)

Unit	Main Assembly	Sub-Assembly	Comment or Description
C13P C13S C14P C14S			)) Bilge units - make complete))
C11P			DB unit includes keel and centre girder
	E01		Port matrix
		W02	Centre girder
		W01	12 ft girder
		W41	4 off)
		W44	1 off) floors
		W45	1 off)
		W46	2 off)
	L01		Tank top panel
		K01	Unstiffened panel
	L03		Bottom shell panel
C11S			DB unit without keel or centre girder
	E02		Starboard matrix
		W01	12 ft girder
		W41	4 off)
		W44	1 off) floors
		W45	1 off)
		W46	4 off)
	L02		Tank top panel
		K02	Unstiffened panel
	L04		Bottom shell panel
C12P			DB unit includes keel and centre girder
	E03		Port matrix
		W03	Centre girder
		W04	12 ft girder
		W41	3 off)
		W42	2 off) floors
		W47	4 off)
	L05		Tank top panel
		K03	Unstiffened panel
	L07		Bottom shell panel

Table 2. Increase in steel weight for standard widths (Thickness=6.5 mm)

Width Range mm	New Standard mm	Number of Plates	Original Weight tonnes	Weight of Standardised Plates tonnes	Weight Increase tonnes
0–1100	1100	14	2.65	2.91	0.35
1100–1400	1400	8	2.57	2.94	0.27
1400–1780	1780	11	4.13	4.38	0.25
1780–1920	1920	23	11.50	11.62	0.12
1920–2200	2200	20	9.98	10.26	0.36
2200–2310	2310	59	39.51	39.67	0.15
2310–2450	2450	19	11.41	11.56	0.14
2450–2605	2605	12	7.22	7.32	0.10
2605–3000	3000	2	1.35	1.48	0.14
TOTALS		168	90.14	92.04	1.88

Total weight increase = 2%

FIGURE 3

READY
313 B1=2310 LOWER WIDTH STANDARD
020 B2=2450 UPPER WIDTH STANDARD
RUNNI

PLATE No	No OFF	THICK MM	LNGTH MM	WDTH MM	ORIG WEIGHT	WEIGHT INCREASE
DH1P49	1	6.5	4620	2450	0.5636	0.0117
MH1P22	1	6.5	7210	2360	0.8649	0.0330
AE2P60	1	6.5	2460	2425	0.3832	0.0331
DH5P06	1	6.5	5690	2450	0.7986	0.0002
DH5P07	2	6.5	4020	2450	1.1507	0.0003
DH1P46	1	6.5	6700	2450	0.8247	0.0172
DH1P43	1	6.5	6120	2450	0.7466	0.0156
DH5P04	1	6.5	5200	2450	0.6550	0.0000
TB1P33	1	6.5	3350	2450	0.3721	0.0076
AE2P35	1	6.5	3230	2425	0.3981	0.0041
FE2P19	2	6.5	3630	2450	0.9614	0.0000
FE2P20	1	6.5	5440	2450	0.6775	0.0000
FE2P17	1	6.5	5920	2450	0.7372	0.0000
FE2P18	1	6.5	6120	2365	0.7357	0.0254
MH1P21	1	6.5	5370	2360	0.6442	0.0246
DH5P05	2	6.5	4290	2450	1.0685	0.0000

ORIG.WT= 11.41 TONNE
NEW.WT= 11.56 TONNE
WT.INCREASE= 0.14 TONNE

RUNNING TIME: 11.4 SECS I/O TIME : 2.5 SECS

APPENDIX E

S.D.14 Section Bar Analysis

(Prepared from existing material lists).

Thickness mm.	Width mm.	Depth mm.	Total Lengthh
FLAT BAR			
6.4	51	51	3690
6.4	76	76	10980
6.4	102	102	40250
6.4	127	127	30850
7.5	76	76	3430
8.0	51	51	18280
8.0	102	102	19460
8.0	152	152	20700
8.0	305	305	18900
9.0	229	229	14020
9.5	38	38	19450
9.5	64	64	129930
9.5	76	76	325140
9.5	89	89	6710
9.5	102	102	10980
9.5	152	152	36100
9.5	203	203	88450
9.5	229	229	8260
9.5	254	254	9240
9.5	305	305	4570
10.0	76	76	57900
10.0	89	89	32940
10.0	102	102	36270
10.0	127	127	29420
10.0	152	152	133640
10.0	229	229	52280
10.0	254	254	14650
10.2	152	152	113880
10.2	229	229	10980
11.5	64	64	44160
11.5	152	152	279480
11.5	229	229	4930
11.5	305	305	5440
12.5	178	178	3735
12.5	203	203	5670
12.5	280	280	3250

Thickness mm.	Width mm.	Depth mm.	Total Length
12.7	51	51	23160
12.7	76	76	8280
12.7	89	89	18090
12.7	102	102	97508
12.7	114	114	56260
12.7	115	115	9760
12.7	127	127	84260
12.7	152	152	208550
12.7	178	178	25440
12.7	229	229	8410
12.7	240	240	6090
12.7	254	254	4730
12.7	305	305	174890
13.0	127	127	6100
13.0	152	152	12800
13.0	254	254	8790
13.0	305	305	25920
15.8	51	51	38340
15.8	152	152	18300
15.9	51	51	48000
15.9	114	114	10980
15.9	152	152	9070
15.9	203	203	27440
15.9	305	305	25840
19.0	76	76	12200
19.0	102	102	12200
19.0	178	178	48800
20.0	152	152	10460
24.0	229	229	36100
25.0	89	89	13720
25.0	229	229	29080
25.0	305	305	10720
30.5	305	305	15630
31.9	305	305	12200
38.0	51	51	19508
51.0	305	305	18040

Thickness mm.	Width mm.	Depth mm.	Total Length
ANGLE BAR			
6.3	64	64	15250
6.5	76	64	60060
7.5	76	64	74930
7.5	76	76	112860
7.5	102	76	258770
7.5	127	76	60150
8.0	76	64	15540
8.0	102	76	7010
8.0	127	76	180420
8.0	176	176	5870
8.5	76	76	83400
8.5	127	76	109940
8.5	152	76	6450
8.9	203	203	11040
9.0	76	38	119920
9.0	76	76	16520
9.0	102	76	377100
9.0	102	89	6120
9.0	102	102	4370
9.0	127	76	293250
9.0	152	76	450440
9.0	152	89	158850
9.0	152	152	4120
9.0	178	89	267230
9.1	102	76	80000
9.5	76	51	36860
9.5	76	76	6100
9.5	178	89	192570
10.0	102	76	23540
10.0	102	102	21970
10.0	152	76	6480
10.0	178	89	128490
10.0	203	102	901710
10.1	178	89	11340
10.2	152	152	37020
10.5	178	89	145574
10.5	229	229	5050

Thickness mm.	Width mm.	Depth mm.	Total Length
11.0	127	76	9140
11.0	152	89	691130
11.0	152	102	12500
11.0	178	89	87040
11.0	203	102	396560
11.2	152	89	7620
11.5	203	102	818160
11.7	203	102	62020
12.0	178	89	65013
12.2	178	102	21640
12.5	102	102	4724
12.5	203	102	4800
12.7	152	76	23320
12.7	152	102	9220
13.0	76	76	50250
13.0	102	76	33130
13.0	102	89	151230
13.0	102	102	29420
13.0	127	76	107410
13.0	127	127	41400
13.0	152	76	7020
13.0	152	89	12820
13.0	152	102	795620
13.0	152	152	4950
13.0	203	102	8080
13.0	254	102	5360
13.0	343	343	12900
13.5	102	102	9240
13.5	203	102	6430
13.5	203	203	21470
14.5	254	102	8050
15.0	203	203	24860
16.0	152	102	10260
25.4	102	102	4340
57.0	254	785	10260

Thickness mm.	Width mm.	Depth mm.	Total Length
BULB FLAT BAR			
7.5	127	127	1047510
7.5	152	152	29970
7.6	102	102	22860
8.9	203	203	468600
10.0	152	152	81600
10.0	254	254	10980
10.2	203	203	26780
10.2	254	254	843242
10.5	152	152	15240
10.5	229	229	9220
10.7	203	203	62560
11.0	152	152	13100
11.0	203	203	152970
11.7	305	305	258520
12.7	254	254	46560
12.7	305	305	48600
12.7	343	343	1633200
13.0	254	254	167470
13.0	343	343	3050
13.2	305	305	163360
13.5	305	305	3050
13.5	381	381	611540
13.7	343	343	69480
13.7	381	381	53360
14.7	381	381	81200
14.7	432	432	122690
15.2	432	432	11760
17.0	432	432	45920
17.5	432	432	12200
19.7	432	432	14420
19.8	432	432	10740

Thickness mm.	Width mm.	Depth mm.	Total Length
R.S.J. SECTION.			
	102	64	7160
	152	127	14410
	305	165	19500
CHANNEL			
	152	76	39870
	203	76	13530
	381	102	19110
U.B. SECTION			
	610	229	40260
	610	305	145222
OTHER SECTIONS			
9.1	254	89	29120
9.5	102	76	38710
	254	89	6860
10.2	254	89	41470
11.2	203	76	202800

APPENDIX F

Proposed plating arrangement definition method

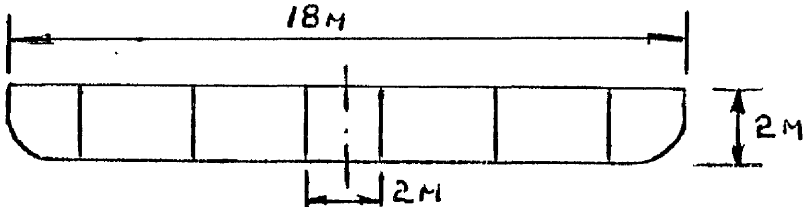
Example - cargo vessel double bottom

Plating Arrangement Definition Example

Cargo Ship Double Bottom

Assumptions

Outline



1 Overlap of shell above tank top to be determined during double bottom plating arrangement definition

2 Duct keel shell plate to overlap duct keel apexes and to be of thicker material

3 No seam to occur in way of duct keel in tank top
(Note: From assumptions 2 and 3 an odd number of Plates are required for shell and tank top)

4 Double bottom may be transversely divided into two or three sections, but duct keel must be made complete for outfitting purposes

5 Standard size plate widths are 3M, 2.75M, 2.5M, and 2.25M. Half width plates may be used if absolutely necessary

Method

Complete panel widths (apex to apex) are given by:-
Tank top = 18M (exactly)
Shell panel greater than 16+2+3.142 (=21.142M)

From these, and using standard plate widths, alternative plating arrangements are automatically developed and presented. Examples are shown in Table 1

For the tank top options 1 and 4 do not result in an odd number of plates, and B does not present the odd width plate required to cover the duct weel. Therefore option C will be utilised and checked.

TANK-TOP ALTERNATIVE ARRANGEMENTS

OBTION NUMBER	PRIMARY PLATE WIDTH (M)	NUMBER OF WIDTHS REQUIRED	SECONDARY PLATE WIDTH (M)	NUMBER OF WIDTHS REQUIRED	NUMBER OF RESULTING SEAMS	SCRAP WIDTH. (M)
1	3	6	NONE	–	5	0
2	2·75	6	1·5 (3/2)	1	6	0
3	2·5	6	3	1	6	0
4	2·5	8	NONE	–	7	0

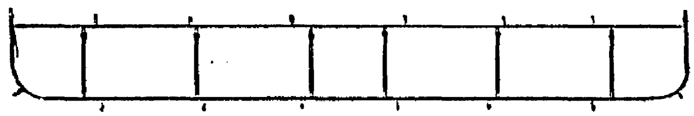
SHELL ALTERNATIVE ARRANGEMENTS

OBTION NUMBER	PRIMARY PLATE WIDTH (M)	NUMBER OF WIDTHS REQUIRED	SECONDARY PLATE WIDTH (M)	NUMBER OF WIDTHS REQUIRED	NUMBER OF RESULTING SEAMS	OVERLAP EACH SIDE (M)
1	3	6	2·25	3	8	0·804
2	3	8	NONE	–	7	1·458
3	2·75	8	NONE	–	7	0·429
4	2·75	7	3	1	7	0·55
5	2·5	9	NONE	–	8	0·679
6	2·5	8	3	1	8	0·929
7	2·25	10	NONE	–	9	0·679

TABLE 1 TABLE OF EXAMPLE PLATING ARRANGEMENTS

For the shell options 2,3, and 4 do not result in an odd number of plates. Option 7 results in the greatest number of welded seams. Option 1 incurs material price extras. The choice between 5 and 6 is borderline but the width of the duct keel is reduced by using option 5 thus reducing ship weight. Therefore option 5 will be utilised and checked.

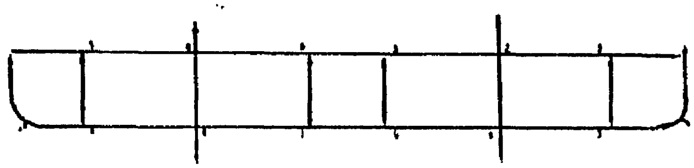
The plating arrangements chosen are displayed on the outline below



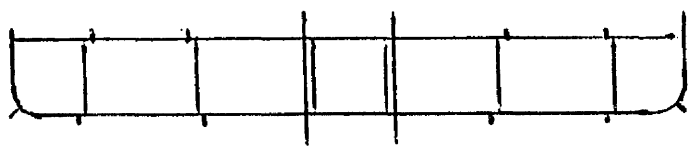
If the plating arrangement is not found to be suitable an alternative may be substituted.

The transverse section is then divided into units, several alternatives are possible of which three are shown below

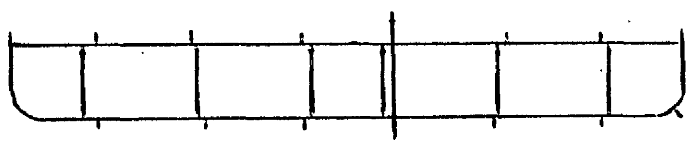
1



2



3



If no suitable unit breakdown is found alternative plating arrangements may be tried.

One of these is selected and the weight per unit found (with preoutfitting) The maximum length of unit within the shipyard constraints is then found and the next standard plate length below this then selected as the unit length. If unit option 1 (above) is chosen then the resulting longitudinal division might be as shown in Figure 1

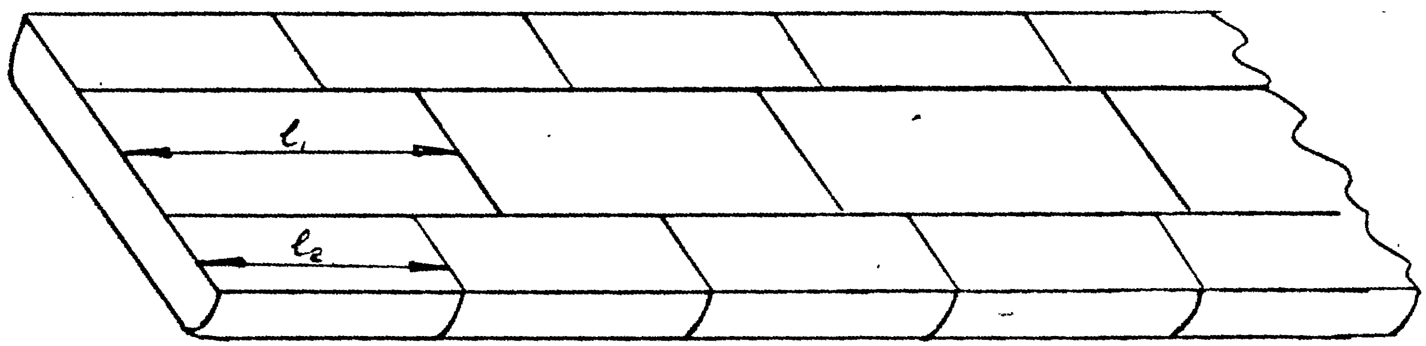


FIGURE 1. POSSIBLE LONGITUDINAL BREAKDOWN
(ℓ_1, ℓ_2 - STANDARD LENGTHS)

APPENDIX G

Standard statistical tables

(S.D.14 and B.26)

CONTENTS

Table 3: Numbers of components of various lengths and depths for flat bar material
14,000 ton vessel
26,000 ton vessel

Histogram of Table 3

Table 4: Numbers of components of various lengths and depths for bulb flat bar material
14,000 ton vessel
26,000 ton vessel

Histogram of Table 4

Table 5: Numbers of components of various lengths and depths for angle bar material
14,000 ton vessel
26,000 ton vessel

Histogram of Table 5

Table 6: Numbers of components of various lengths and depths for channel bar material
14,000 ton vessel
26,000 ton vessel

Histogram of Table 6

Table 7: Numbers of components having vaious "holes and slots" from section material
14,000 ton vessel
26,000 ton vessel

Table 8: Numbers of components having various forming operations for section material
14,000 ton vessel
26,000 ton vessel

Table 9: Numbers of components from plate having various orthogonal shapes
14,000 ton vessel
26,000 ton vessel

Histogram of Table 9

Table 10: Numbers of components having various lengths and widths for flame planed or guillotined plate
14,000 ton vessel
26,000 ton vessel

Histogram of Table 10

Table 11: Numbers of components having various lengths and widths for flame planed and hand burned or profile cut plate
14,000 ton vessel
26,000 ton vessel

Histogram of Table 11

Table 12: Numbers of components having various lengths and widths for profile cut plate
14,000 ton vessel
26,000 ton vessel

Histogram of Table 12

Table 13: Numbers of plate components having various types of edge preparation
14,000 ton vessel
26,000 ton vessel

Table 14: Numbers of plate components of various lengths and widths having flanging operations
14,000 ton vessel
26,000 ton vessel

Histogram of Table 14

Table 15: Numbers of plate components of various lengths and widths having swedging operations
14,000 ton vessel
26,000 ton vessel

Histogram of Table 15

Table 16: Numbers of plate components of various lengths and widths having roll bending operations
14,000 ton vessel
26,000 ton vessel

Histogram of Table 16

Descriptive code size ranges for section and plate components

1. A general description of the coding system, data-bank, and ship component statistics

1.1 Introduction

The shipbuilding industry is at present passing through a phase of substantial change and modernisation, in both its production processes and in organisation. The industry is historically a one off or small batch manufacturer which involves the production and assembly of a wide variety of items, many of which at the same time have a number of features in common. Although many now produce 'standard' series ships, the building cycle time involved is relatively long (six months to one year) and, as the areas of a ship differ significantly, shipbuilding is still a small batch manufacturing situation.

Shipbuilding uses the materials and tools of the heavy engineering industry but is controlled using a building plan similar to that used in civil engineering. It is not surprising therefore that some of the techniques developed in these industries have been found to be of value in the general design and management of shipyards. Group technology is a technique which has evolved largely in the engineering industry. The use of production oriented classification and coding systems, and the related analysis of component statistics, are aspects of this technique which can be used fruitfully in the shipbuilding industry. The ship hull classification and coding system and related component statistics described here, which have been devised at Glasgow University, allow a statistical analysis of ship steelwork components to be carried out, as an aid to manufacture and assembly.

Following such statistical analyses a standard set of data tables have been devised and are detailed here which allows a comparative analysis to be made of different ship hulls. By using these sets of tables a comparative measure of the differences in work content required to produce different hulls may be arrived at. The differences in the shipbuilding facilities needed and the individual loading which may occur on these facilities to produce a vessel may also be quantitatively compared.

The data will be of use to prospective builders of ships which are of similar design and size to those already coded, both in the design of shipbuilding facilities to produce the ships and in the estimation of time and cost figures for tendering and planning purposes. In addition they will be of value to machine-tool and equipment manufacturers, as they give information about the needs of the shipbuilding industry both in terms of the size and production characteristics of components and assemblies, and of relative demand.

Standard statistical tables are presented here describing the components forming the hulls of two ships which have been coded and analysed. These are a 14,000 ton cargo vessel and a 26,000 ton bulk carrier.

The production of a ship-hull has changed considerably in recent years, from the days of total outdoor assembly and erection to the modern practice of large unit assembly under cover, with only the final assembly of the units taking place in the building dock (although this may also be covered). Ship-hulls are constructed from two basic raw materials; standard rolled steel sections, and steel plate. Each is prepared and transformed into components separately, ready for assembly. Hull construction follows three basic stages: -

(a) Steel preparation. Basic steel plates and sections are painted then cut, bent, flanged, edge-prepared, etc. into individual components.

(b) Prefabrication and unit assembly. The prepared components are assembled into sub-assemblies, or units, which vary in size depending upon the ship design and production facilities. In recent years the trend has been towards increasing the size of such units, and up to 800 tons in weight is not uncommon today. The trend is due mainly to a desire for the maximum amount of work to be carried out under cover and with the availability of all of the facilities of a production shop. This reduces the amount of work needed on the berth where adverse weather conditions, and the difficulty of using capital equipment, inevitably interferes with production.

(c) Erection. The units are finally transported to the berth for assembly, fairing and welding.

It appears that many of the techniques recently developed in the group technology field to deal specifically with the problems of small batch and high variety manufacture can be used to considerable advantage in the shipbuilding industry. Two important areas in which it is considered that a group technology approach is particularly relevant, are in the cutting, preparation and assembly of the steelwork, and in the use of a descriptive coding system for components and sub-assemblies as an aid to production organisation.

A coding and classification system for ship-hull components has now been devised(1) to allow some of the advantages of group technology to be applied to shipbuilding. One of the advantages derived from this coding system is that an in-depth analysis can now be made of the steelwork components which form the hull of a particular ship. This is useful to the shipyard which is producing that ship both to improve manufacturing decisions and to improve the design of production facilities. Components can also be analysed with this code in detail by structure group and the results then used together with the building cycle programme to aid work loading, and smooth production flow at shopfloor level. Previous publications(2,3) have already described some statistical analyses of individual ships in a way which can be useful to the shipyards concerned.

A further advantage arising from the use of the coding system is that it enables a comparative analysis to be made of the steelwork components forming the hulls of different types of ship. This is of value in the pre-production planning stage and in the design stage of steelwork production facilities in any shipyard which produces a 'mix' of ships or intends to produce a ship similar in type and size to one which has been analysed.

A standard set of tables have therefore been prepared and are presented here which describe the steelwork components of the two hulls which have have been coded. The tables have been designed as an aid to the design of ship hull steelwork production facilities, and are therefore closely linked with production processes, such as the type of cutting or bending required, the size of the particular components involved, and the numbers required.

1.2 The development of the coding system

Considerable work has previously been carried out on the design of classification systems for general engineering purposes, and the basic construction of two systems were studied prior to the development of a system for ship-hull components. The first was one for structural steel components and assemblies developed jointly by the Aachen Technical University and the Demag Organisation.(4) The method of approach to the problem of this system was found to be of value during the development of the ship-hull code.

The second system studied was a general shipyard classification system developed by the British Ship Research Association.(5) This code was developed primarily as an aid to assembly, and its principal feature is that components which have similar numbers are used in the same part of the ship and have similar functions (shell-plates, webs, floors, etc.). While the importance of this approach is recognised, the system is not suitable for an in-depth study of the 'component statistics' of ships. A shape based coding system, similar to the Demag development but more applicable to shipbuilding was therefore developed.(1)

Initial studies were carried out in four shipyards to gather basic information about the processes used and the types of component produced. Data was collected both from manufacturing sheds and from drawings. (As component drawings do not often exist, the parameters of each component had to be interpreted from the assembly drawing). From this work a nine digit draft system was developed which was 'tested' on similar structure groups from three different vessels which were produced in three different shipyards. In addition, at this stage an independent analysis of the proposed coding system was carried out and a report(6) of anomalies produced. The draft system was then refined and developed into its present form, in which it has been comprehensively explained and documented.[1] The classification and coding system is ten digits long, and is of the fixed digital significance type as is the Opitz (Aachen) machined component code. Indeed the format of the system follows that of Opitz closely. The first five digits describe the geometric shape of the component in such a way that will provide useful information to the industry. For example, a major segregation is made in the first digit between sections and plates, in order to follow manufacturing practice. The general allocation of digits is as follows: -

Digit 1 General Classification
The sub-division into sections and plates, and major variations within these groups

Digit 2 Shape before forming
Defines the geometric profile of the cut component

Digit 3 Forming
Defines the forming to be carried out - bends, corrugations, flanges

Digit 4 Holes and Slots
Types required in terms of machining or burning

Digit 5 Edge preparation
The variety and types required for welding

Digit 6 Welding detail
The type of welding used to join the component into the following sub-assembly

Digit 7 Material and finish
Defines raw material type and final finished condition

The final three digits are concerned with the dimensions of the component.

Digit 8 Thickness

Defines component material thickness in mm.

Digit 9 Length

Defines component length in mm.

Digit 10 Width

Defines component width in mm.

1.3 Coding procedure

Ambiguities were found to exist in the draft form of the system which were open to the discretion of the individual coder. During the development and later use of the draft prior to publication of the final system attempts were made to remove as many of these ambiguities as possible. The system is now fully detailed and explained. However because all numbering systems are inevitably a compromise between the desire for brevity and at the same time maximum information storage, some ambiguities will always exist. An organisation using the system should therefore have a single internal authority to establish in-house definitions for this small number of cases. It should keep records of these definitions and where an interchange of data with any other organisation takes place, should pass them on.

To obtain the full benefits of a data bank, coding should be carried out when drawings and parts lists are prepared by the ship drawing office or at an additional stage subsequent to detail design but prior to production. When carried out by the ship drawing office, a major advantage is that parts are coded as they are numbered, thus saving the time needed for cross-reference at a later stage. If carried out at a subsequent stage then personnel more knowledgeable of shipyard production methods, such as production planners, may be employed. In both cases the coding personnel should have a sound understanding of shipyard drawings and parts lists, which themselves should be well documented and systematic. The coding operation itself is simple, and the learning curve involved is fairly short. As an example, the case of an engineering student with no previous experience of shipyard drawings can be quoted, where it was found to be two weeks. In this case the greatest difficulty found was in the referencing and location of components on drawings, thus endorsing the need for systematic part numbering. There is no doubt that, as has already been mentioned, the most effective answer is to carry out component coding at the same time that part-numbering is carried out in the ship drawing office.

The code is presented in a 'flick over' book form in which, after making the initial decision (plate or section) the respective page is opened for the subsequent decision to be made. This process is continued for the full ten digits resulting in a ten digit number which describes the component. Examples of components with their respective code numbers are given in figures 1(a) and 1(b).

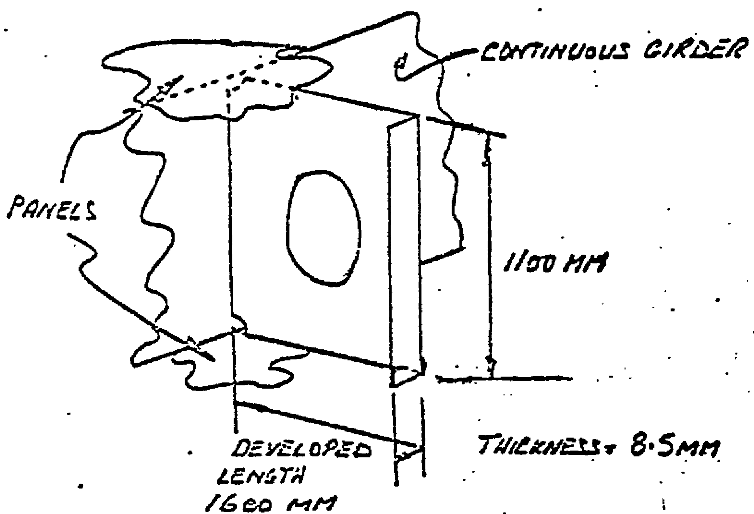
The time involved in coding varies with the area of the ship involved. For many structure group areas such as the double bottom, midship and side-shell, a large number of repeat components are found. In other areas such as the fore and aft ends, a wider variety of parts exist, thus increasing the coding work load. In general it was found that components could be coded at an average rate of twenty per hour by a person with experience of ship drawings. This included the collection of ancillary data (see Section 2.3) and results in a total time of about sixteen man weeks for compiling a data bank describing a vessel of 10,000 components (say a 14,000 ton cargo vessel). The operation is inevitably somewhat monotonous which increases the likelihood of errors, which is an additional argument in favour of combining the coding and part numbering operations at the detail design stage, as described earlier.

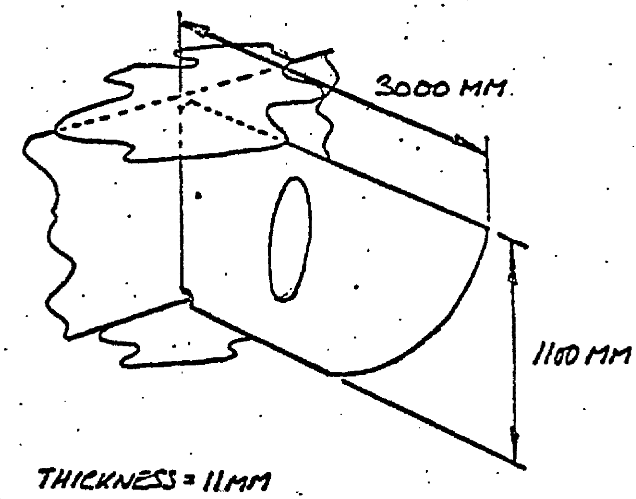
1.3 The contents of the data bank

In compiling the initial data bank, the following information was noted in each component file record: -

i) The shipyard component number
ii) The presence of other identical parts
iii) The number of raw material pieces required (for raw material analysis)

FIGURE 1(a)





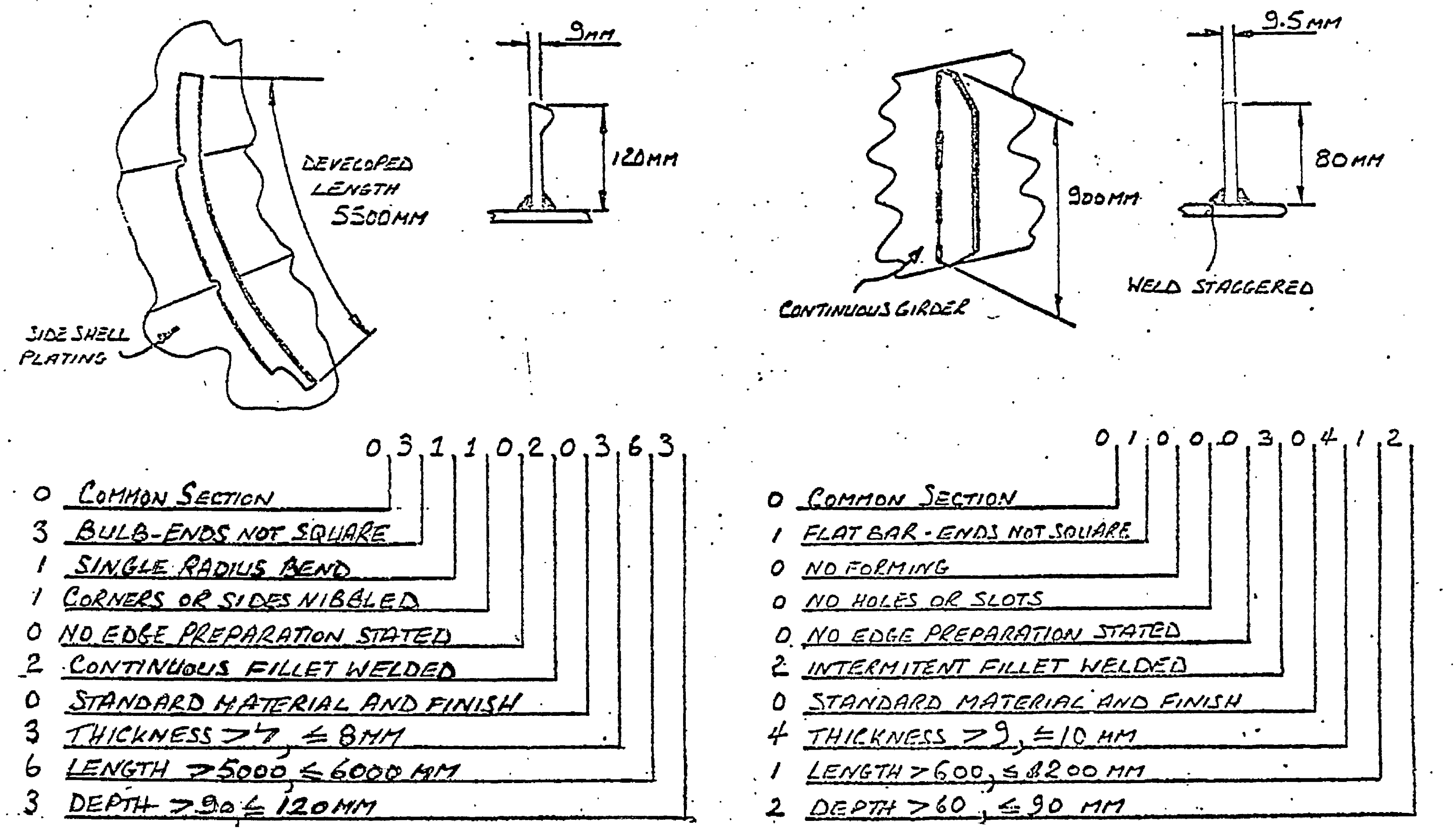
4 2 1 5 0 2 0 2 4 4

4 STANDARD PLATE ALL SIDES STRAIGHT
2 RECTANGLE
1 SINGLE FLANGE
5 BURNED HOLE AND NIBBLES
0 NO EDGE PREPARATION STATED
2 CONTINUOUS FILLET WELD
0 STANDARD MATERIAL AND FINISH
2 THICKNESS $> 8, \leq 9$ MM
4 LENGTH $> 1500, \leq 2500$ MM
4 WIDTH $> 900 \leq 1200$ MM

7 1 0 5 0 2 0 4 5 4

7 CURVED SIDED PLATE
1 ONE CURVE > 2 STRAIGHT
0 NO FORMING
5 BURNED HOLES AND NIBBLES
0 NO EDGE PREPARATION STATED
2 CONTINUOUS FILLET WELD
0 STANDARD MATERIAL AND FINISH
4 THICKNESS $> 10, \leq 12.5$ MM
5 LENGTH $> 2500, \leq 4000$ MM
4 WIDTH $> 900, \leq 1200$ MM

FIGURE 1(b)


DEVELOPED LENGTH 5500MM
SIDE SHELL PLATING
9MM
120MM
CONTINUOUS GIRDER
900MM
9.5MM
80MM
WELD STAGGERED
0 3 1 1 0 2 0 3 6 3
0 COMMON SECTION
3 BULB-ENDS NOT SQUARE
1 SINGLE RADIUS BEND
1 CORNERS OR SIDES NIBBLED
0 NO EDGE PREPARATION STATED
2 CONTINUOUS FILLET WELDED
0 STANDARD MATERIAL AND FINISH
3 THICKNESS >7, ≤8MM
6 LENGTH >5000, ≤6000 MM
3 DEPTH >90, ≤120MM
0 1 0 0 0 3 0 4 1 2
0 COMMON SECTION
1 FLAT BAR - ENDS NOT SQUARE
0 NO FORMING
0 NO HOLES OR SLOTS
0 NO EDGE PREPARATION STATED
2 INTERMITENT FILLET WELDED
0 STANDARD MATERIAL AND FINISH
4 THICKNESS >9, ≤10 MM
1 LENGTH >600, ≤1200 MM
2 DEPTH >60, ≤90 MM

iv) The descriptive code number

v) The number of components required

vi) The component sizes as defined by the descriptive code number

vii) The raw material sizes

viii) A brief verbal description of the component

For later data bank compilations the components and raw material sizes (vi and vii) were omitted and replaced with information describing the assembly of the components into the ship. This included the sequence of assembly into the ship (first sub-assembly numbers, second sub-assembly number, unit number, etc.) and the weld length involved at each of the assembly stages in millimeters. Thus later data banks contain full and comprehensive information on both the ship-hull components and the assembly procedures involved in manufacturing the completed ship's hull. However, for a statistical analysis of ship-hull components, only the descriptive code number is neccssary.

2. Component Analysis

2.1 Introduction

Analyses have been completed on both 'macro' and 'micro' scales. The first will be of interest mainly to the shipbuilding industry, the second to builders of specific ships, and both of general interest to the machine tool industry. The micro-scale analysis involves the description of individual structure groups or assemblies within a specific ship. The prospective builder of that or a similar type of ship can use this data to investigate the workload fluctuations of the various manufacturing centres which take place during manufacture. In such an exercise plotting component production over the building cycle of a ship, it was noted that the workload on the various machines or processes varied widely from week to week. If such anomalies can be highlighted before construction starts then plans can be modified to ensure an optimum use of machinery and manpower.

The macro-scale analysis which is presented here involves the description of a complete ship's hull. This enables a comparison to be made of the work content of various ships for the measurement of shipyard efficiency and for the development of cost estimating and control systems. The most widely accepted shipyard measure of work content and efficiency is steel throughput. However ships vary widely in their complexity and therefore steel weight, even when an empirical complexity weighting factor is employed, is not always a good measure of work content. A data bank which records the number and complexity of parts required can be used to present a more accurate assessment of the workload on the steel preparation shops. It will also give a better indication of the assembly shop workload that is directly influenced by the number and complexity of the pieceparts forming the assemblies. Having obtained a better measure of workload, the efficiencies of individual shipyards may be compared and more accurate overall cost estimating systems developed. The publication of a standard set of tabulated statistics describing the hulls of a variety of ships also allows a shipyard to compare a proposed ship with a vessel previously built in that yard. This can also enable a more accurate assessment to be made of the time and cost it will take to build the proposed ship.

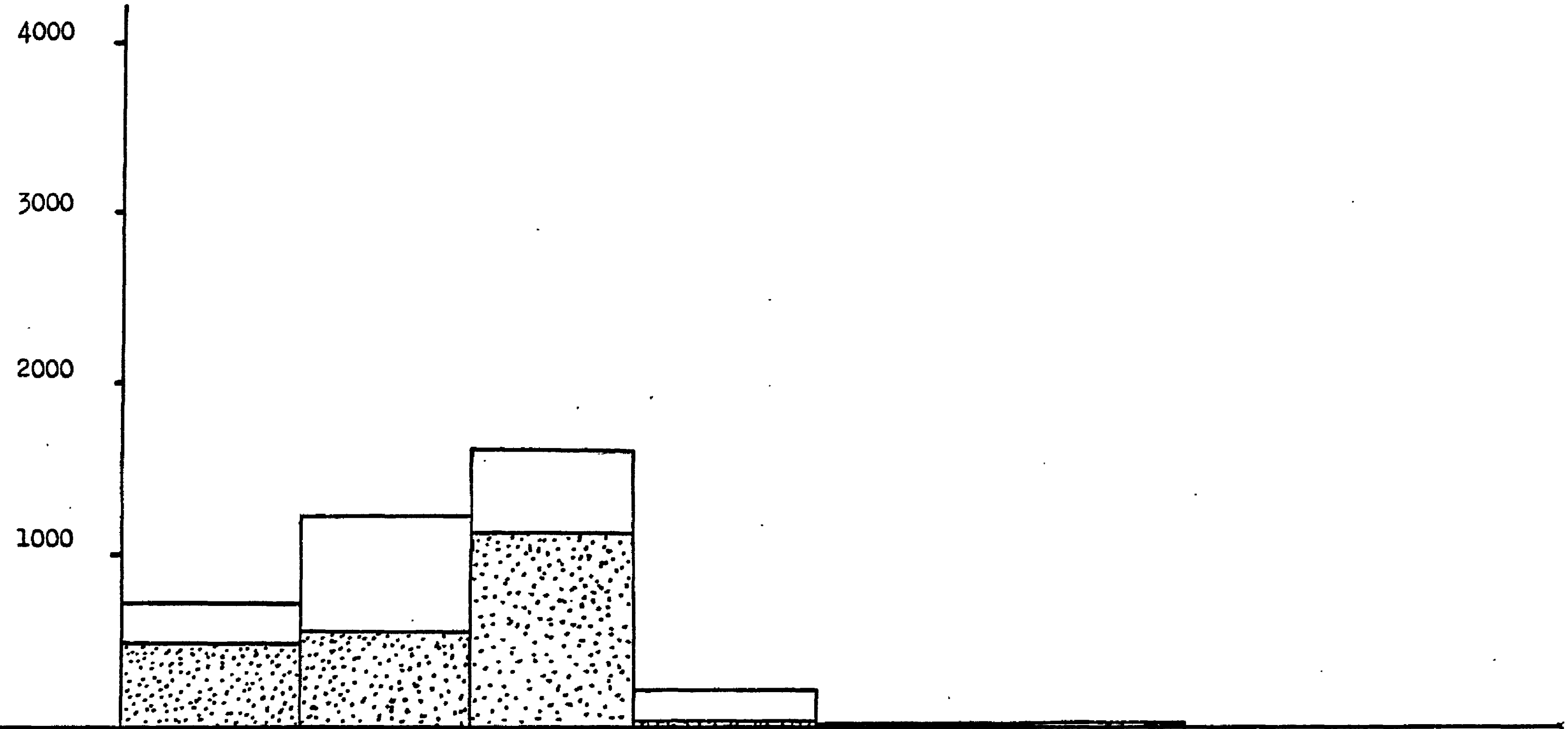
2.2 Methods of component analysis

Four data analysis methods were used to investigate the component statistics of the two vessels described here. They ranged from simple punched card sorting to the use of specialised computer packages and tailored programs. Card sorting was primarily used for micro-analysis work. Component information was collected on data sheets and then transferred to punched cards, which were initially grouped into their respective structure groups and assembly units. Plates and sections were completely segregated by sorting on the first digit of the code. The part was then further defined, and then the size ranges (length and width or depth) were tabulated for specific shapes. These results were presented at a conference in Glasgow in September 1973.[2]

The second approach to the problem made use of the Honeywell Store and Manipulate (S.A.M.) package. Punched cards were used to transfer data records to a computer file where it was readily manipulated from a remote terminal. This method was used mainly to supply information for a plant layout and material handling system under design as part of a redevelopment project at a collaborating shipyard. At a later stage the shipyard was supplied with a copy of the data file for their own use. This was transferred into computer storage on the 'Comshare' time sharing system to which they had access also through a remote terminal.

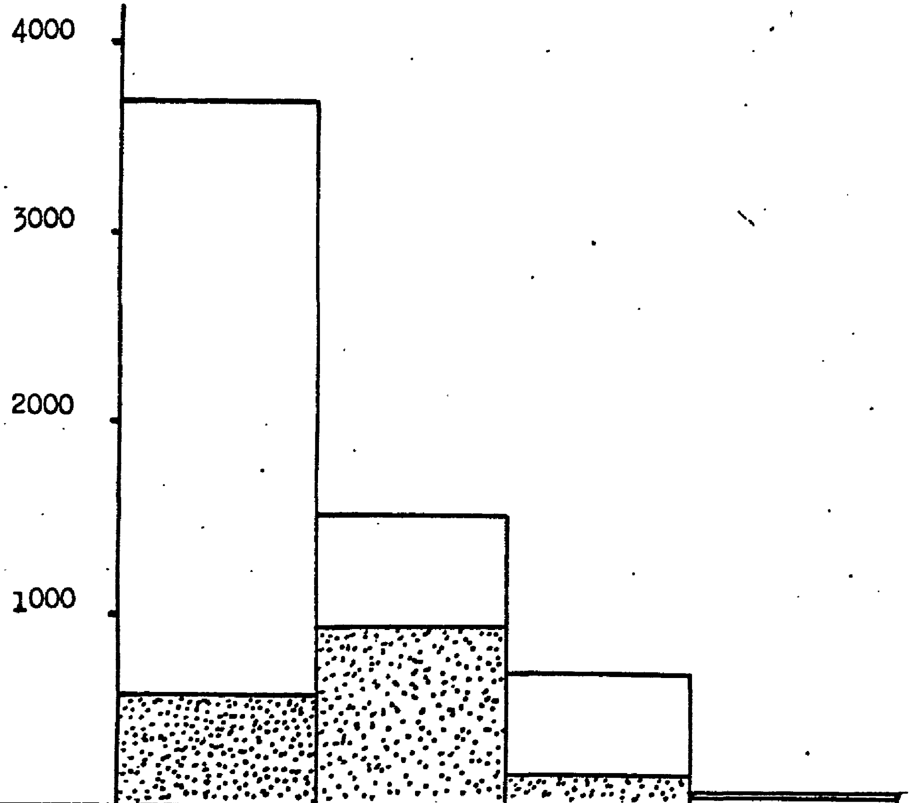
The third approach made use of a very powerful analysis package which is well known to social scientists, but is frequently unfamiliar to technologists. The 'Statistical Package for the Social Sciences'[7] (S.P.S.S.) is a computer program designed for detailed statistical survey analysis. It enables a wide range of statistical techniques to be used on data files, and the results presented in a concise form which can usually be interpreted by even the layman. It enables various statistical indices to be computed and tables of numbers and percentages of components having specified characteristics to be printed. The major advantage of this method of analysis was that a 'weighting' factor could be used to count the number of components required rather than the number of data records. Thus a weakness of the previous methods

wedging and roll bending) again on a length/width size range matrix.
full list of tables is detailed in the contents of each data set.



Section Type	Flat bar	Bulb flat bar	Angle bar	Channel	T Section	I Section	Hollow round bar	Hollow square bar
Components with square ends	232	684	499	232	0	8	0	0
Components with shaped ends	475	552	1131	17	10	1	0	0
Total number off	707	1236	1630	249	10	9	0	0
% of total number components (for ship)	8.0	13.9	18.3	2.8	0.1	0.1	0	0

Table 1: Numbers of components required of various types of section bar material. 14,000 Ton Vessel



Section Type	Flat bar	Bulb flat bar	Angle bar	Channel	T Section	I Section	Hollow round bar	Hollow square bar
Components with square ends	3116	599	537	13	1	6	0	0
Components with shaped ends	551	907	151	13	0	0	0	0
Total number off	3667	1506	688	26	1	6	0	0
% of total number components (for ship)	28.5	11.7	5.3	0.2	0	0	0	0

Table 1: Numbers of components required of various types of section bar material. 26,000 Ton Vessel

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	139	0	10	0	0	1	0	0	0	0	150
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	3	1	130	3	11	0	0	0	148
3	0	0	1	0	43	4	11	0	0	0	59
4	0	0	0	0	48	44	37	0	0	0	129
5	0	0	4	0	38	23	64	0	0	0	129
6	0	0	21	0	14	2	2	0	3	0	42
7	0	0	0	0	0	8	5	0	0	0	13
8	0	0	8	0	19	1	2	2	3	2	37
9	0	0	0	0	0	0	0	0	0	0	0
TOTAL	139	0	47	1	292	86	132	2	6	2	707

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	1.56	0.00	0.11	0.00	0.00	0.01	0.00	0.00	0.00	0.00	1.69
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.03	0.01	1.46	0.03	0.12	0.00	0.00	0.00	1.66
3	0.00	0.00	0.01	0.00	0.48	0.04	0.12	0.00	0.00	0.00	0.66
4	0.00	0.00	0.00	0.00	0.54	0.49	0.42	0.00	0.00	0.00	1.45
5	0.00	0.00	0.04	0.00	0.43	0.26	0.72	0.00	0.00	0.00	1.45
6	0.00	0.00	0.24	0.00	0.16	0.02	0.02	0.00	0.03	0.00	0.47
7	0.00	0.00	0.00	0.00	0.00	0.09	0.06	0.00	0.00	0.00	0.15
8	0.00	0.00	0.09	0.00	0.21	0.01	0.02	0.02	0.03	0.02	0.42
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	1.56	0.00	0.53	0.01	3.28	0.97	1.48	0.02	0.07	0.02	8.00

TABLE 2:Depth (rows) v thickness (columns) for flat bar components (00...,01...).

26,000 Ton Vessel

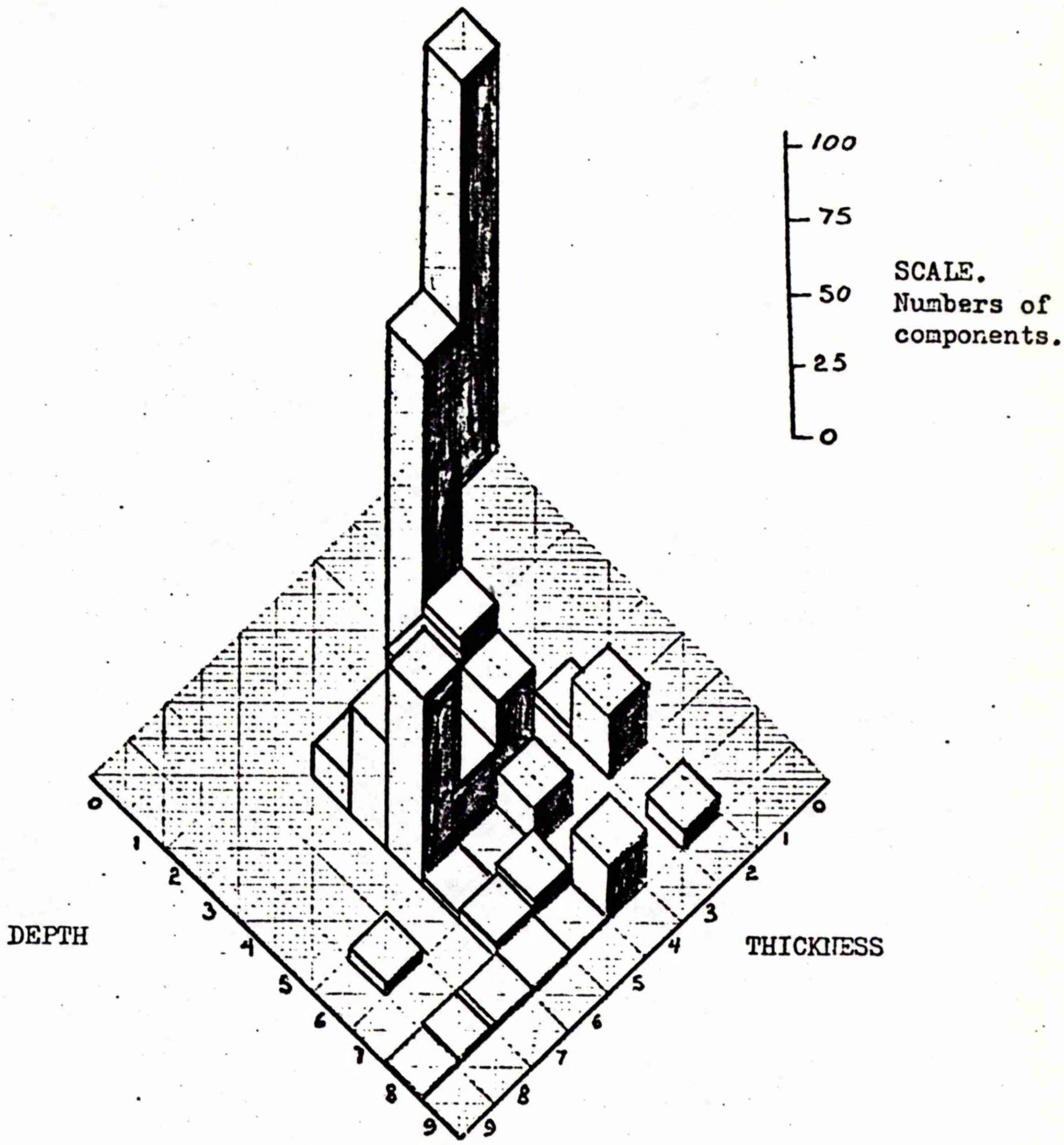
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	8	0	0	0	5	2	0	0	0	0	15
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	40	4	0	0	0	0	44
3	0	0	0	0	356	1983	0	0	0	0	2339
4	0	0	0	0	787	169	2	14	0	0	972
5	0	0	0	2	42	39	35	4	0	0	122
6	0	0	0	0	4	5	0	0	0	0	9
7	0	0	0	0	0	4	6	0	138	0	148
8	~~0~~	0	0	0	0	0	0	0	18	0	18
9	0	0	0	0	0	0	0	0	0	0	0
TOTAL	8	0	0	2	1234	2206	43	18	156	0	3667

% OF TOTAL NUMBER OFF (FOR SHIP).

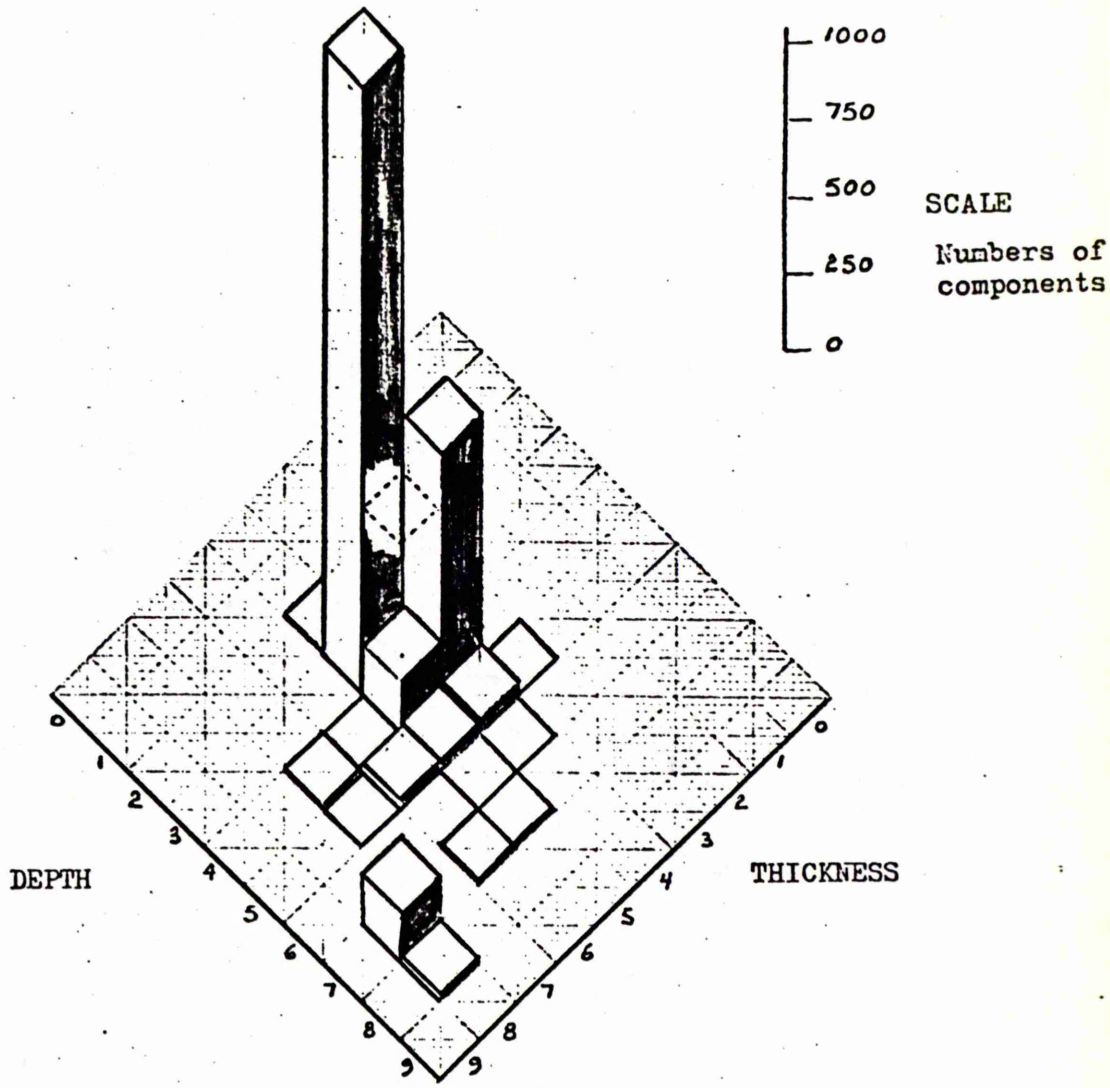
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.06	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.31	0.03	0.00	0.00	0.00	0.00	0.34
3	0.00	0.00	0.00	0.00	2.77	15.40	0.00	0.00	0.00	0.00	18.17
4	0.00	0.00	0.00	0.00	6.11	1.31	0.02	0.11	0.00	0.00	7.55
5	0.00	0.00	0.00	0.02	0.33	0.30	0.27	0.03	0.00	0.00	0.95
6	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.00	0.07
7	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.00	1.07	0.00	1.15
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.14
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.06	0.00	0.00	0.02	9.59	17.14	0.33	0.14	1.21	0.00	28.5

TABLE 2: Depth (rows) v thickness (columns) for flat bar components (00...,01...).



Histogram of numbers of components v depth and thickness of flat bar components (table 2).

26,000 Ton Vessel



Histogram of numbers of components v depth and thickness of flat bar components (table 2).

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	140	0	44	3	16	4	8	0	0	0	215
1	0	0	65	34	95	66	25	12	24	0	321
2	0	0	34	11	12	20	2	0	3	0	82
3	0	0	1	5	6	11	3	0	3	0	29
4	10	0	2	5	0	6	2	0	2	0	27
5	0	0	0	0	0	5	0	0	0	0	5
6	0	0	0	0	0	8	2	1	1	0	12
7	0	0	2	0	0	9	0	0	2	0	13
8	0	0	0	0	0	0	0	0	2	0	2
9	0	0	0	1	0	0	0	0	0	0	1
TOTAL	150	0	148	59	129	129	42	13	37	0	707

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	1.57	0.00	0.49	0.03	0.18	0.04	0.09	0.00	0.00	0.00	2.42
1	0.00	0.00	0.73	0.38	1.07	0.74	0.28	0.13	0.27	0.00	3.61
2	0.00	0.00	0.38	0.12	0.13	0.22	0.02	0.00	0.03	0.00	0.92
3	0.00	0.00	0.01	0.06	0.07	0.12	0.03	0.00	0.03	0.00	0.33
4	0.11	0.00	0.02	0.06	0.00	0.07	0.02	0.00	0.02	0.00	0.30
5	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.06
6	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.01	0.01	0.00	0.13
7	0.00	0.00	0.02	0.00	0.00	0.10	0.00	0.00	0.02	0.00	0.15
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
9	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TOTAL	1.69	0.00	1.66	0.66	1.45	1.45	0.47	0.15	0.42	0.00	8.00

TABLE 3: Length (rows) v depth (columns) for flat bar components (00...,01...).

26,000 Ton Vessel

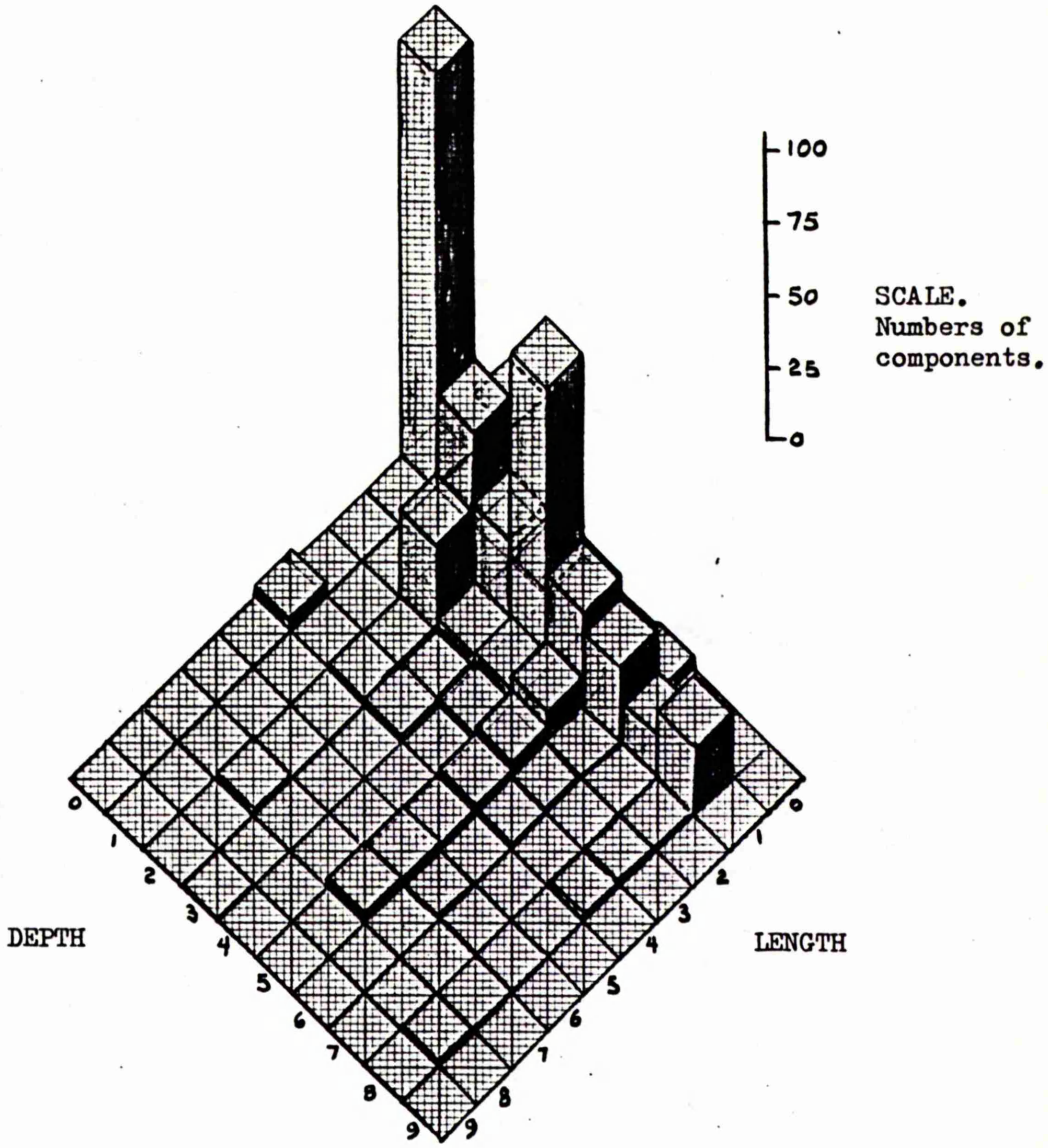
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	6	0	8	296	461	54	1	0	0	0	826
1	8	0	28	900	218	50	7	0	0	0	1211
2	1	0	0	1089	57	9	1	12	0	0	1169
3	0	0	0	35	171	1	0	0	0	0	207
4	0	0	0	14	45	6	0	10	0	0	75
5	0	0	8	2	7	0	0	0	0	0	17
6	0	0	0	3	11	2	0	0	0	0	16
7	0	0	0	0	2	0	0	0	0	0	2
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	126	18	0	144
TOTAL	15	0	44	2339	972	122	9	148	18	0	3227

% OF TOTAL NUMBER OFF (FOR SHIP).

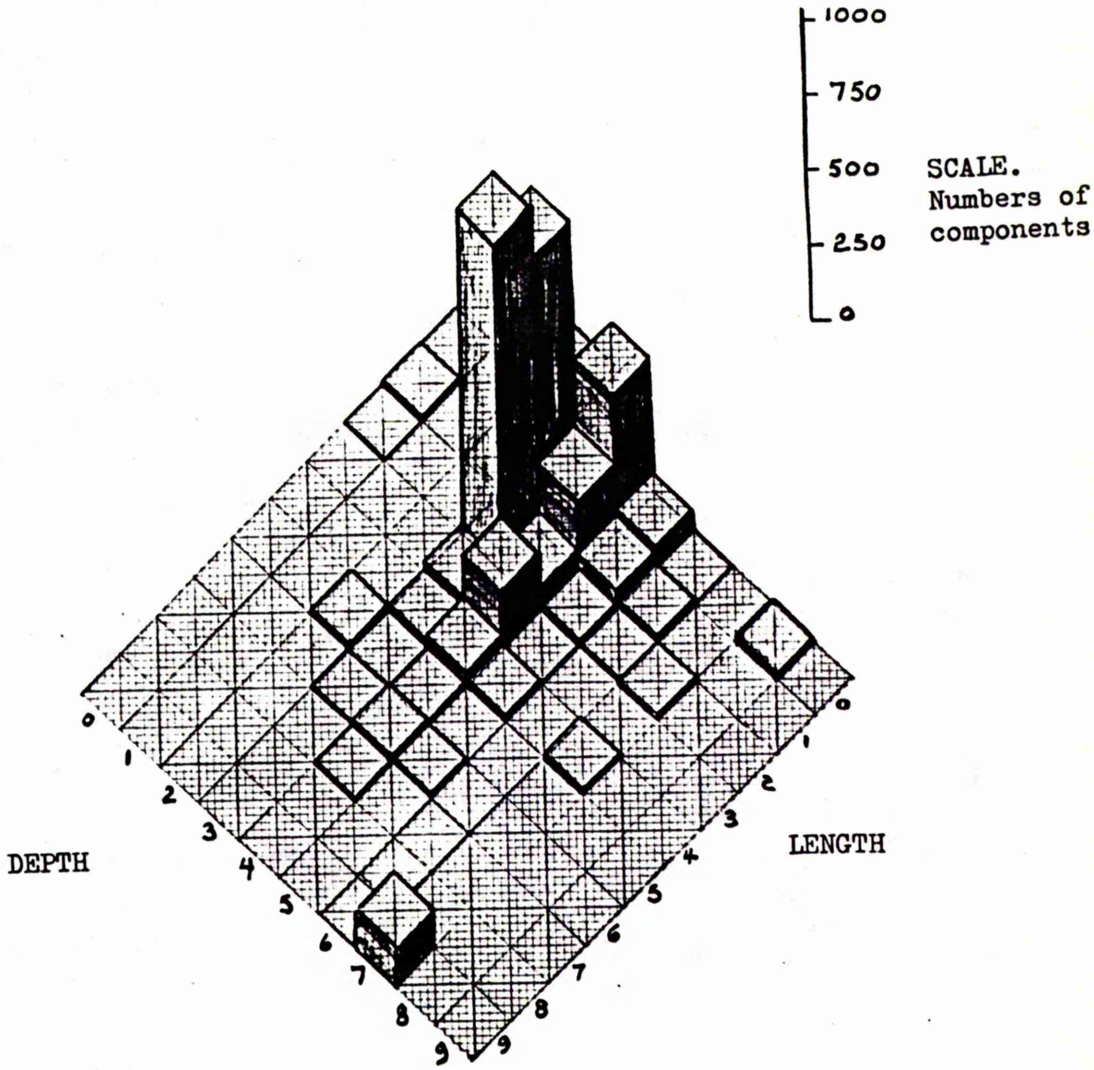
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.05	0.00	0.06	2.30	3.58	0.42	0.01	0.00	0.00	0.00	6.42
1	0.06	0.00	0.22	6.99	1.69	0.39	0.05	0.00	0.00	0.00	9.41
2	0.01	0.00	0.00	8.46	0.44	0.07	0.01	0.09	0.00	0.00	9.08
3	0.00	0.00	0.00	0.27	1.33	0.01	0.00	0.00	0.00	0.00	1.61
4	0.00	0.00	0.00	0.11	0.35	0.05	0.00	0.08	0.00	0.00	0.58
5	0.00	0.00	0.06	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.13
6	0.00	0.00	0.00	0.02	0.09	0.02	0.00	0.00	0.00	0.00	0.12
7	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.14	0.00	1.12
TOTAL	0.12	0.00	0.34	18.17	7.55	0.95	0.07	1.15	0.14	0.00	28.2

TABLE 3: Length (rows) v depth (columns) for flat bar components (00...,01...).



Histogram of numbers of components v length and depth of flat bar components (table 3).

26,000 Ton Vessel



Histogram of numbers of components v length and depth of flat bar components (table 3).

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	2	210	0	0	212
1	0	0	0	0	0	0	12	2	2	0	16
2	0	0	0	0	0	0	16	26	8	8	50
3	0	0	0	0	0	8	66	37	63	0	174
4	0	0	0	18	0	2	197	36	28	0	281
5	0	0	0	0	0	0	26	53	53	2	134
6	0	0	0	0	0	0	6	37	26	13	82
7	0	0	0	0	0	0	4	17	2	5	28
8	2	0	0	0	0	0	0	0	169	2	173
9	0	0	0	0	0	0	5	0	81	0	86
TOTAL	2	0	0	18	0	10	334	418	432	22	1236

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.36	0.00	0.00	2.38
1	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.02	0.02	0.00	0.18
2	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.29	0.09	0.00	0.56
3	0.00	0.00	0.00	0.00	0.00	0.09	0.74	0.42	0.71	0.00	1.96
4	0.00	0.00	0.00	0.02	0.00	0.02	2.22	0.40	0.31	0.00	3.16
5	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.60	0.60	0.02	1.51
6	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.42	0.29	0.15	0.92
7	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.19	0.02	0.06	0.31
8	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.02	1.95
9	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.91	0.00	0.97
TOTAL	0.02	0.00	0.00	0.20	0.00	0.11	3.76	4.70	4.86	0.25	13.9

TABLE 4: Length (rows) v depth (columns) for bulb flat bar components (02...,03...).

26,000 Ton Vessel

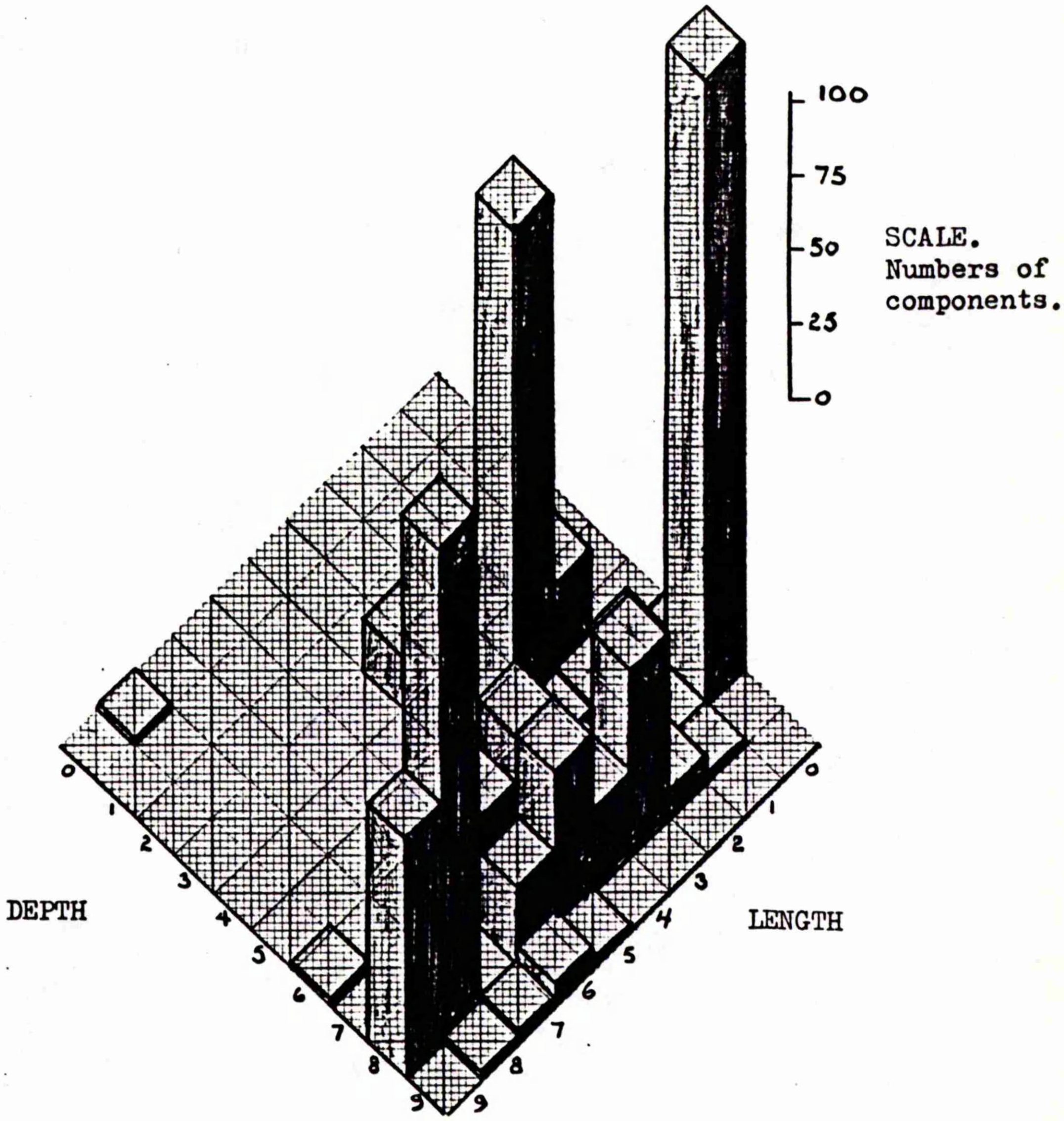
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	8	2	0	16	0	0	0	26
1	0	0	0	0	12	1	41	11	6	0	71
2	0	0	3	0	20	13	47	8	7	0	98
3	0	0	0	0	8	27	60	41	13	0	149
4	0	0	0	0	0	29	173	63	25	0	290
5	0	0	0	0	0	0	67	57	16	2	142
6	0	0	0	0	0	0	40	47	25	4	116
7	0	0	0	0	0	0	22	28	3	0	53
8	~~0~~	0	0	0	0	0	8	16	262	60	346
9	0	0	0	0	0	2	14	115	76	8	215
TOTAL	0	0	3	8	42	72	488	386	433	74	1506

% OF TOTAL NUMBER OFF (FOR SHIP).

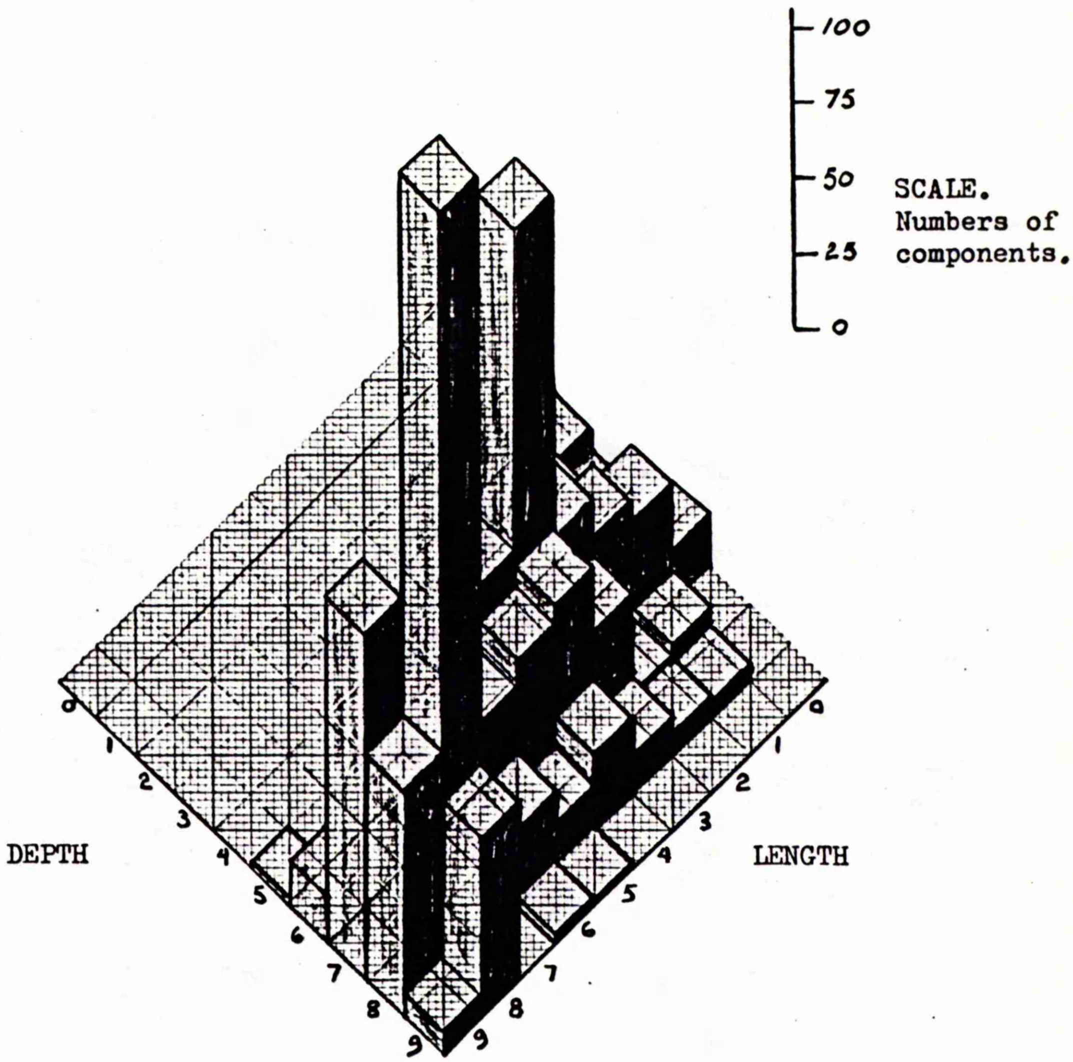
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.06	0.02	0.00	0.12	0.00	0.00	0.00	0.20
1	0.00	0.00	0.00	0.00	0.09	0.01	0.32	0.09	0.05	0.00	0.55
2	0.00	0.00	0.02	0.00	0.16	0.10	0.37	0.06	0.05	0.00	0.76
3	0.00	0.00	0.00	0.00	0.06	0.21	0.47	0.32	0.10	0.00	1.16
4	0.00	0.00	0.00	0.00	0.00	0.23	1.34	0.49	0.19	0.00	2.25
5	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.44	0.12	0.02	1.10
6	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.37	0.19	0.03	0.90
7	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.22	0.02	0.00	0.41
8	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.12	2.04	0.47	2.69
9	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.89	0.59	0.06	1.67
TOTAL	0.00	0.00	0.02	0.06	0.33	0.56	3.79	3.00	3.36	0.57	11.7

TABLE 4: Length (rows) v depth (columns) for bulb flat bar components (02...,03...).



Histogram of numbers of components v length and depth of bulb flat bar components (table 4)

26,000 Ton Vessel



Histogram of numbers of components v length and depth of bulb flat bar components (table 4)

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	18	37	0	0	0	0	55
1	0	0	1	27	311	64	62	0	0	0	465
2	0	0	5	11	70	98	1	0	0	0	185
3	0	0	17	20	28	128	7	0	0	0	200
4	0	0	0	9	18	62	23	0	0	0	112
5	0	0	0	3	0	29	0	1	0	0	33
6	0	0	0	19	46	15	16	0	1	0	97
7	0	0	2	0	22	86	14	0	0	0	124
8	0	0	0	0	4	43	2	0	0	0	49
9	0	0	0	0	8	301	1	0	0	0	310
TOTAL	0	0	25	89	525	863	126	1	1	0	1630

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.20	0.42	0.00	0.00	0.00	0.00	0.62
1	0.00	0.00	0.01	0.30	3.50	0.72	0.70	0.00	0.00	0.00	5.23
2	0.00	0.00	0.06	0.12	0.79	1.10	0.01	0.00	0.00	0.00	2.08
3	0.00	0.00	0.19	0.22	0.31	1.44	0.08	0.00	0.00	0.00	2.25
4	0.00	0.00	0.00	0.10	0.20	0.70	0.26	0.00	0.00	0.00	1.26
5	0.00	0.00	0.00	0.03	0.00	0.33	0.00	0.01	0.00	0.00	0.37
6	0.00	0.00	0.00	0.21	0.52	0.17	0.18	0.00	0.01	0.00	1.09
7	0.00	0.00	0.02	0.00	0.25	0.97	0.16	0.00	0.00	0.00	1.39
8	0.00	0.00	0.00	0.00	0.04	0.48	0.02	0.00	0.00	0.00	0.55
9	0.00	0.00	0.00	0.00	0.09	3.38	0.01	0.00	0.00	0.00	3.49
TOTAL	0.00	0.00	0.28	1.00	5.90	9.70	1.42	0.01	0.01	0.00	18.3

TABLE 5: Length (rows) v depth (columns) for angle bar components (40...,05...).

26,000 Ton Vessel

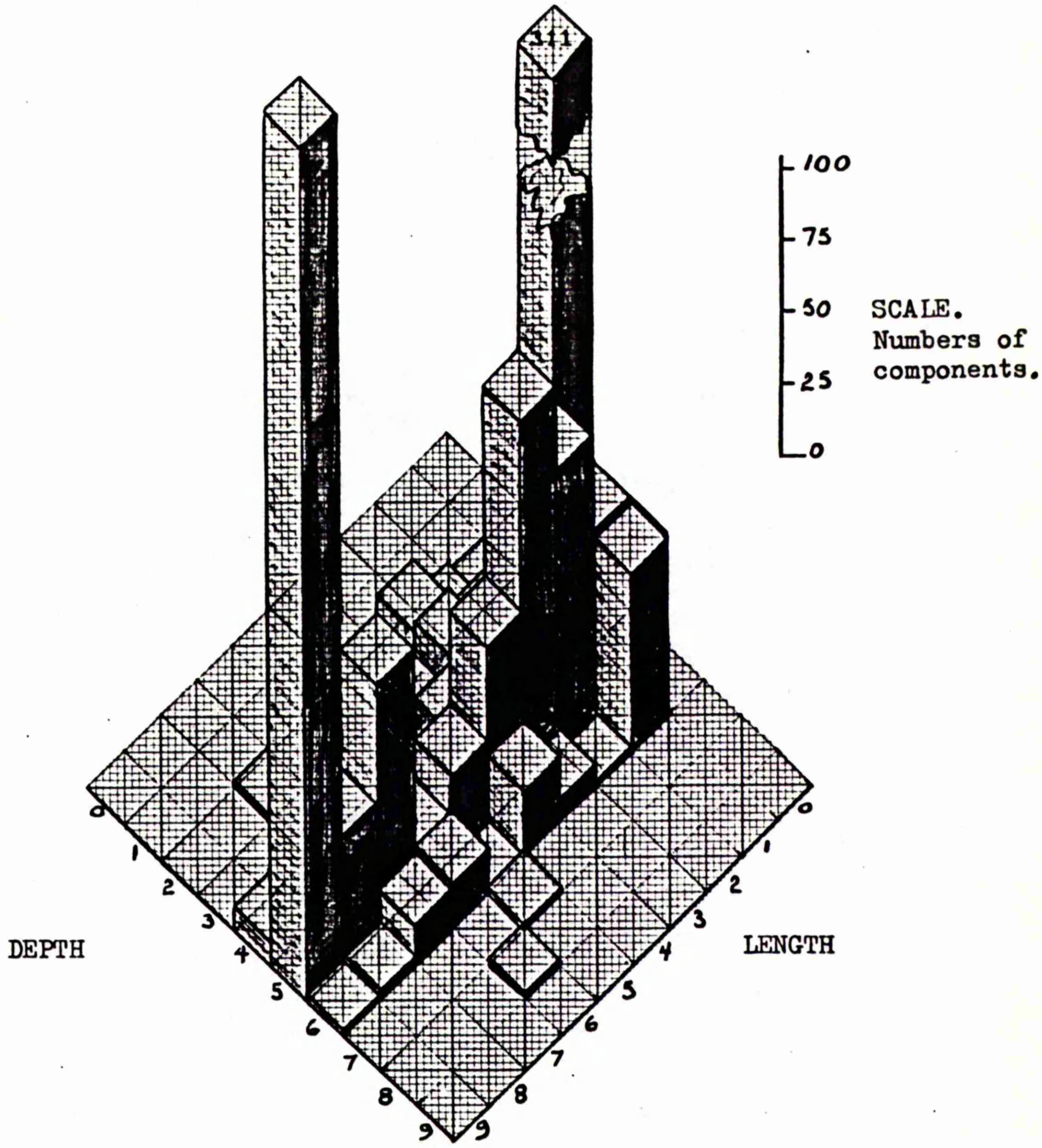
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	4	0	0	2	28	0	0	0	0	0	34
1	0	0	0	148	27	0	0	0	0	0	175
2	0	0	0	282	27	0	0	0	0	0	309
3	0	0	0	90	58	0	0	0	0	0	148
4	0	0	0	0	2	0	0	0	0	0	2
5	0	0	0	3	2	0	0	0	0	0	5
6	0	0	0	5	8	0	0	0	0	0	13
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	2	0	0	0	0	0	0	2
TOTAL	4	0	0	532	152	0	0	0	0	0	688

% OF TOTAL NUMBER OFF (FOR SHIP).

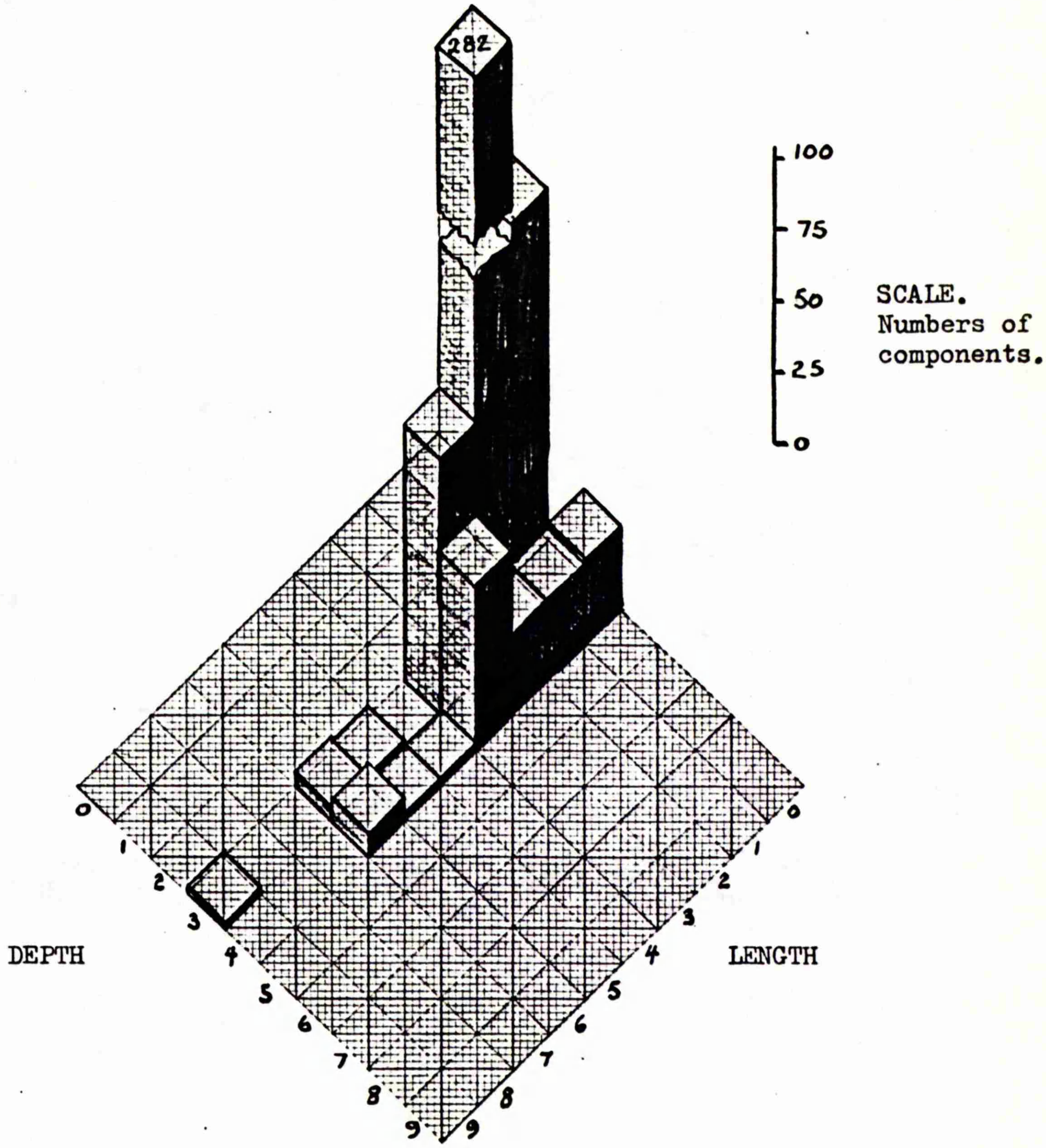
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.03	0.00	0.00	0.02	0.22	0.00	0.00	0.00	0.00	0.00	0.26
1	0.00	0.00	0.00	1.15	0.21	0.00	0.00	0.00	0.00	0.00	1.36
2	0.00	0.00	0.00	2.19	0.21	0.00	0.00	0.00	0.00	0.00	2.40
3	0.00	0.00	0.00	0.70	0.45	0.00	0.00	0.00	0.00	0.00	1.15
4	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
5	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.04
6	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00	0.00	0.10
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02
TOTAL	0.03	0.00	0.00	4.13	1.18	0.00	0.00	0.00	0.00	0.00	5.3

TABLE 5: Length (rows) v depth (columns) for angle bar components (04...,05...).



Histogram of numbers of components v length and depth of angle bar components (table 5).

26,000 Ton Vessel



Histogram of numbers of components v length and depth of angle bar components (table 5).

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	2	0	223	0	0	0	225
2	0	0	0	0	0	0	1	0	0	0	1
3	0	0	0	0	0	0	0	3	0	0	3
4	0	0	0	0	0	1	0	6	0	0	7
5	0	0	0	0	0	0	0	2	4	0	6
6	0	0	0	0	0	0	0	3	0	0	3
7	0	0	0	0	0	0	0	2	0	0	2
8	0	0	0	0	0	0	0	1	0	0	1
9	0	0	0	0	0	0	0	0	1	0	1
TOTAL	0	0	0	0	2	1	224	17	5	0	249

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.02	0.00	2.51	0.00	0.00	0.00	2.53
2	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
4	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.07	0.00	0.00	0.08
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.07
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
TOTAL	0.00	0.00	0.00	0.00	0.02	0.01	2.52	0.19	0.06	0.00	2.8

TABLE 6: Length (rows) v depth (columns) for channel components (06...,07...).

NUMBERS OFF (FOR SHIP).

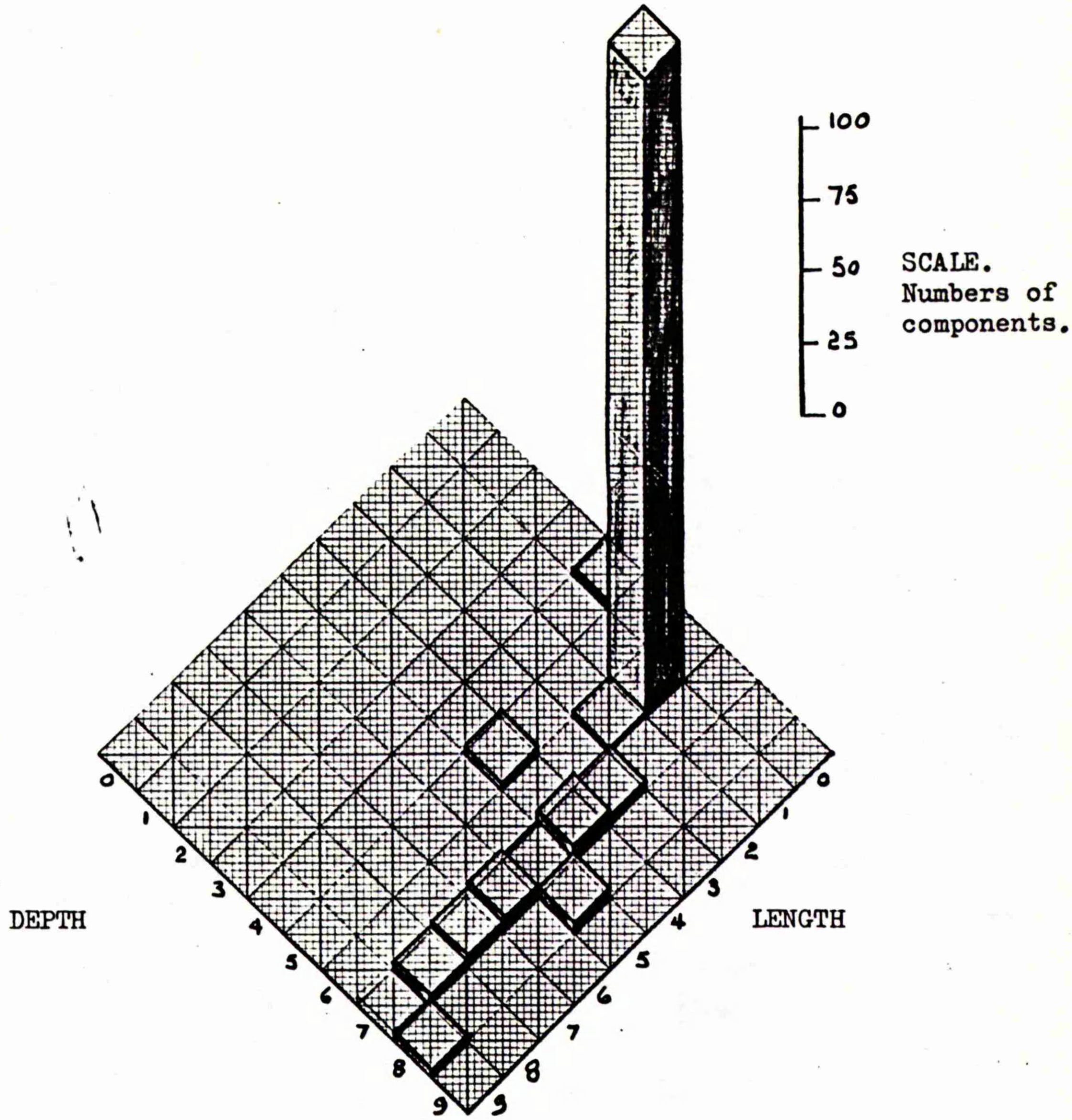
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	2	0	2
4	0	0	0	0	0	0	0	0	2	0	2
5	0	0	0	0	0	0	0	0	5	0	5
6	0	0	0	0	0	0	0	0	5	0	5
7	0	0	0	0	0	0	0	0	3	0	3
8	0	0	0	0	0	0	0	0	3	0	3
9	0	0	0	0	0	0	0	0	3	0	3
TOTAL	0	0	0	0	0	0	0	0	23	0	23

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
TOTAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.2

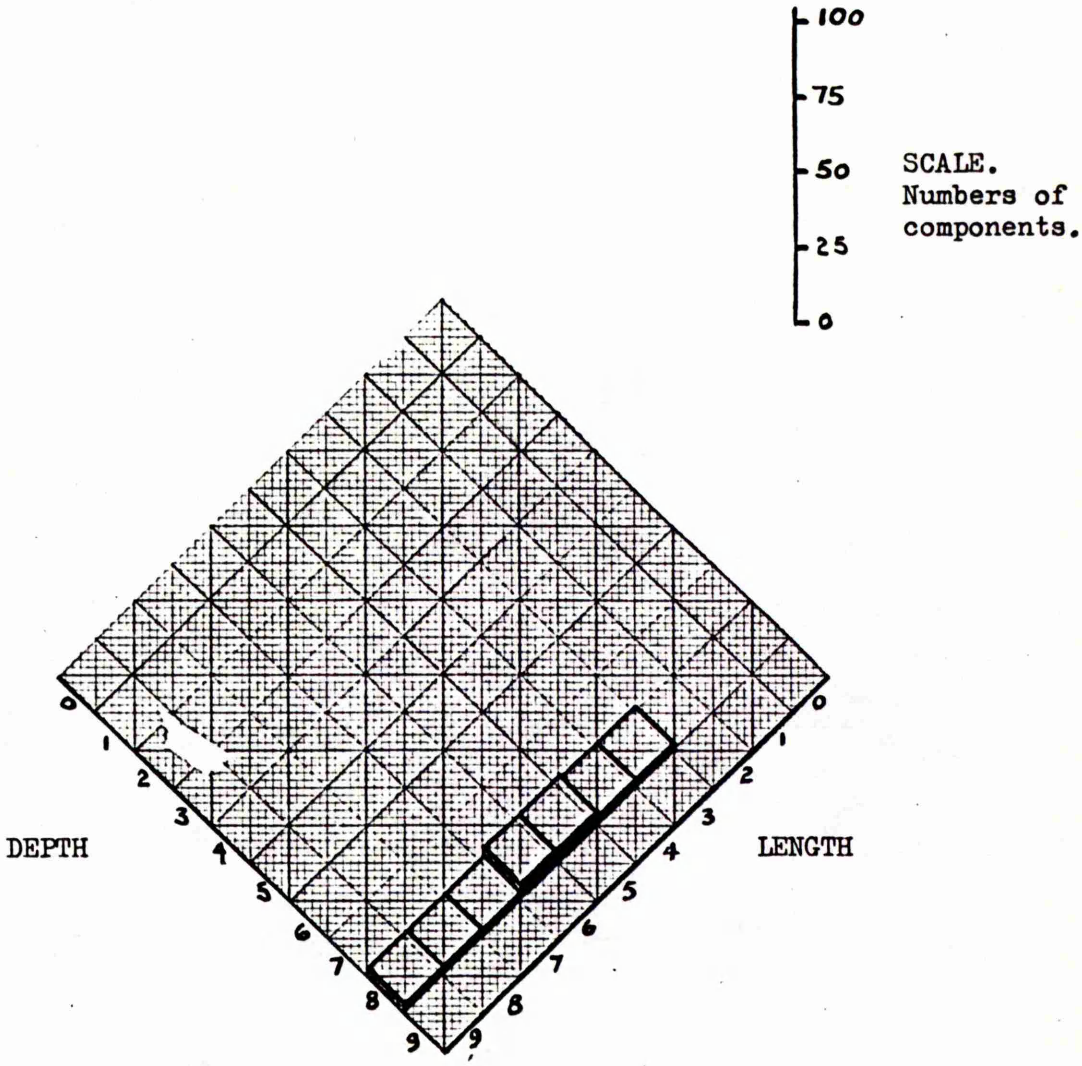
TABLE 6: Length (rows) v depth (columns) for channel components (06...,07...).

14,000 Ton Vessel



Histogram of numbers of components v length and depth of channel section components (table 6).

26,000 Ton Vessel



Histogram of numbers of components v length and depth of channel section components (table 6).

14,000 Ton Vessel

	Component feature	No holes or slots	Corners and/or sides nibbled	Slots for cross members	Non-circular burned holes	Drilled holes (pattern)	Drilled holes (no pattern)	Drille and bu holes
FLAT BAR	Numbers of components having feature.	628	60	3	0	16	0	0
	% of total number of components	7.1	0.7	0.0	0.0	0.2	0.0	0.0
BULB FLAT BAR	Numbers of components having feature.	401	349	64	0	45	0	377
	% of total number of components.	4.5	3.9	0.7	0.0	0.5	0.0	4.2
ANGLE BAR	Numbers of components having feature.	914	693	0	12	0	11	0
	% of total number of components.	10.3	7.8	0.0	0.1	0.0	0.1	0.0
CHANNEL	Numbers of components having feature.	249	0	0	0	0	0	0
	% of total number of components.	2.8	0.0	0.0	0.0	0.0	0.0	0.0

Table 7: Numbers of components having various 'hole and slots' from section material

26,000 Ton Vessel

	Component feature	No holes or slots	Corners and/ or sides nibbled	Slots for cross members	Non-circular burned holes	Drilled holes (pattern)	Drilled holes (no pattern)	Drill and bu hole
FLAT BAR	Numbers of components having feature.	3637	30	0	0	0	0	0
	% of total number of components	28.2	0.2	0.0	0.0	0.0	0.0	0.0
BULB FLAT BAR	Numbers of components having feature.	1269	233	4	0	0	0	0
	% of total number of components.	9.9	1.8	0.0	0.0	0.0	0.0	0.0
ANGLE BAR	Numbers of components having feature.	660	18	0	0	0	0	0
	% of total number of components.	5.1	0.1	0.0	0.0	0.0	0.0	0.0
CHANNEL	Numbers of components having feature.	0	0	0	0	0	0	0
	% of total number of components.	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7: Numbers of components having various 'hole and slots' from section material

14,000 Ton Vessel

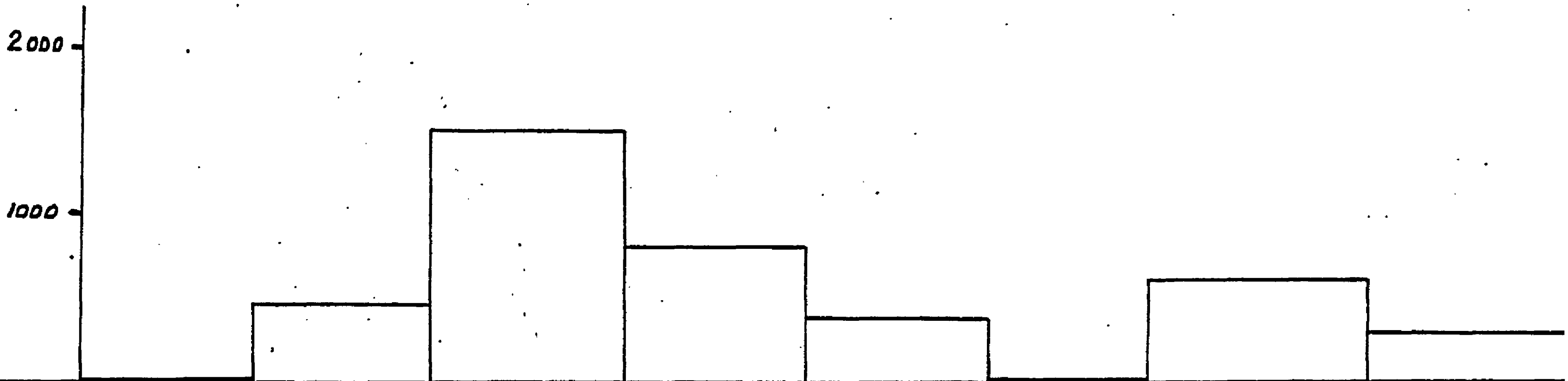
	Component feature	No Forming	Single Radius bend	Multi-Radius Bend	Single Flange	Multiple Flange
FLAT BAR	Numbers of components having feature.	649	11	0	0	0
FLAT BAR	% of total number of components.	7.1	0.1	0.0	0.0	0.0
BULB FLAT BAR	Numbers of components having feature.	779	446	17	0	0
BULB FLAT BAR	% of total number of components.	8.8	4.9	0.2	0.0	0.0
ANGLE BAR	Numbers of components having feature.	1570	50	10	0	0
ANGLE BAR	% of total number of components.	17.6	0.6	0.1	0.0	0.0
CHANNEL	Numbers of components having feature.	230	0	0	0	0
CHANNEL	% of total number of components.	2.6	0.0	0.0	0.0	0.0

Table 8 Numbers of components having various forming operations for section material parts.

26,000 Ton Vessel

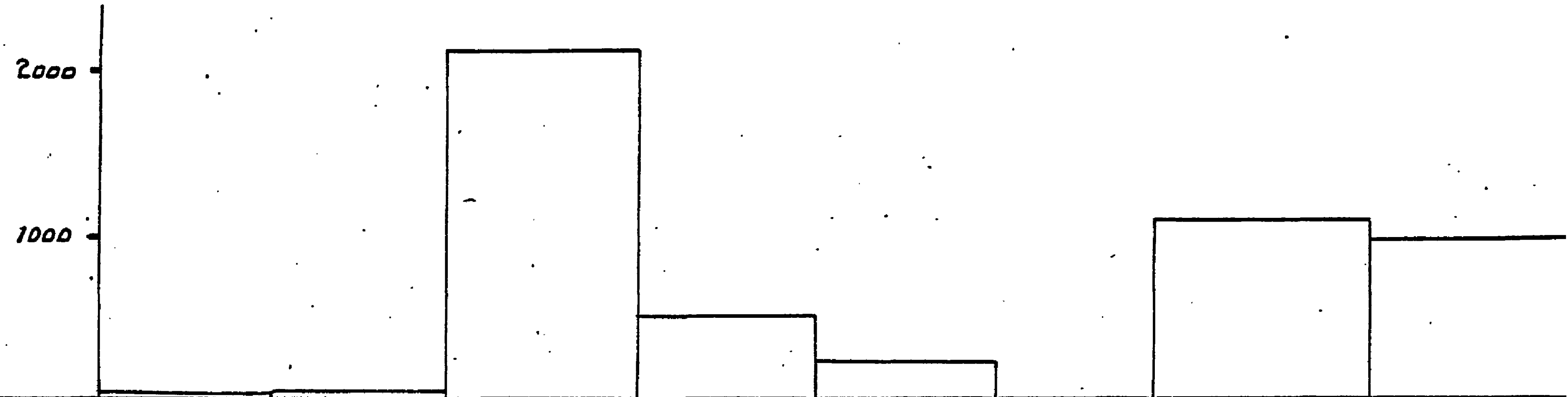
	Component feature	No Forming	Single Radius bend	Multi-Radius Bend	Single Flange	Multiple Flange
FLAT BAR	Numbers of components having feature.	3620	43	4	0	0
	% of total number of components.	28.1	0.3	0.0	0.0	0.0
BULB FLAT BAR	Numbers of components having feature.	1161	343	2	0	0
	% of total number of components.	9.0	2.7	0.0	0.0	0.0
ANGLE BAR	Numbers of components having feature.	688	0	0	0	0
	% of total number of components.	5.3	0.0	0.0	0.0	0.0
CHANNEL	Numbers of components having feature.	23	0	0	0	0
	% of total number of components.	0.2	0.0	0.0	0.0	0.0

Table 8 Numbers of components having various forming operations for section material parts.



Component Shape.	3-Sided with no square corner.	3-Sided with one square corner.	Rectangular.	4-Sided with one or more square corners.	4-Sided with no square corners.	Many sided with one long side.	Many sided with at least one square corner.	Many sided with no square corner.
Number of components required.	10	452	1530	805	392	9	619	338
% of total number of components required.	0.1	5.1	17.2	9.0	4.4	0.1	7.0	3.8

TABLE 9: Numbers of components from plate having various orthogonal shapes.



Component Shape.	3-Sided with no square corner.	3-Sided with one square corner.	Rectangular.	4-Sided with one or more square corners.	4-Sided with no square corners.	Many sided with one long side.	Many sided with at least one square corner.	Many sided with no square corner.
Number of components required.	35	42	2177	518	224	0	1131	1002
% of total number of components required.	0.3	0.4	16.9	4.0	1.7	0.0	8.8	7.8

TABLE 9: Numbers of components from plate having various orthogonal shapes.

26,000 Ton Vessel

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	502	0	1	0	0	0	0	0	0	0	503
1	223	470	198	0	0	0	0	0	0	0	891
2	221	462	159	130	16	0	0	0	0	0	988
3	0	19	24	61	28	0	0	0	0	0	132
4	0	11	15	24	68	13	11	1	1	0	144
5	5	14	9	29	18	12	66	23	6	0	182
6	5	38	4	42	6	18	46	25	27	0	211
7	4	6	3	22	17	11	18	50	36	0	167
8	0	5	9	15	3	5	2	25	20	2	86
9	2	5	0	6	7	10	4	35	125	14	208
TOTAL	962	1030	422	329	163	69	147	159	215	16	3512

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	5.64	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.66
1	2.51	5.29	2.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.02
2	2.49	5.20	1.79	1.46	0.18	0.00	0.00	0.00	0.00	0.00	11.11
3	0.00	0.21	0.27	0.69	0.31	0.00	0.00	0.00	0.00	0.00	1.48
4	0.00	0.12	0.17	0.27	0.76	0.15	0.12	0.01	0.01	0.00	1.62
5	0.06	0.16	0.10	0.33	0.20	0.13	0.74	0.26	0.07	0.00	2.05
6	0.06	0.43	0.04	0.47	0.07	0.20	0.52	0.28	0.30	0.00	2.37
7	0.04	0.07	0.03	0.25	0.19	0.12	0.20	0.56	0.40	0.00	1.88
8	0.00	0.06	0.10	0.17	0.03	0.06	0.02	0.28	0.22	0.02	0.97
9	0.02	0.06	0.00	0.07	0.08	0.11	0.04	0.39	1.41	0.16	2.34
TOTAL	10.82	11.58	4.75	3.70	1.83	0.78	1.65	1.79	2.42	0.18	39.5

TABLE 10: Length (rows) v width (columns) for flame planed or guillotined plate components, i.e. orthogonal with no holes and slots (4...0..), or orthogonal with "nibbles" only (4..1..), or orthogonal and drilled (4..7..,4..8..).

26,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

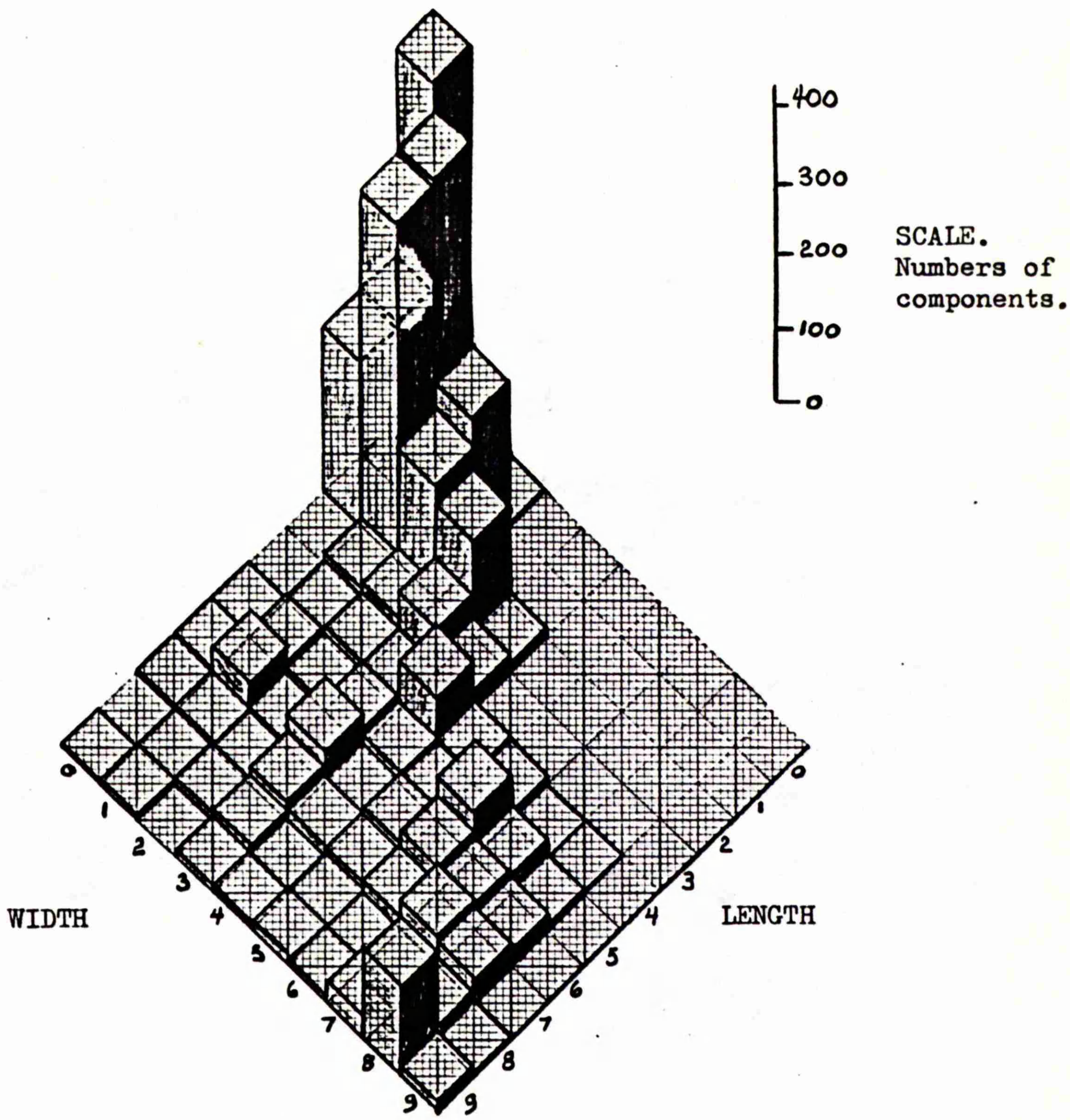
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	508	5	0	0	0	0	0	0	0	0	513
1	205	361	124	0	0	0	0	0	0	0	690
2	17	106	187	107	0	0	0	0	0	0	417
3	2	17	48	453	22	5	4	0	0	0	551
4	5	9	30	104	168	32	6	6	0	0	360
5	3	4	19	96	9	11	17	10	5	1	175
6	0	1	9	26	8	21	12	43	29	0	149
7	2	0	4	4	6	22	26	29	56	48	197
8	~~0~~	2	0	2	0	6	1	4	4	0	19
9	0	0	0	23	6	64	24	8	167	0	292
TOTAL	742	505	421	815	219	161	90	100	261	49	3325

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	3.95	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.99
1	1.59	2.80	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.36
2	0.13	0.82	1.45	0.83	0.00	0.00	0.00	0.00	0.00	0.00	3.24
3	0.02	0.13	0.37	3.52	0.17	0.04	0.03	0.00	0.00	0.00	4.28
4	0.04	0.07	0.23	0.81	1.31	0.25	0.05	0.05	0.00	0.00	2.80
5	0.02	0.03	0.15	0.75	0.07	0.09	0.13	0.08	0.04	0.01	1.36
6	0.00	0.01	0.07	0.20	0.06	0.16	0.09	0.33	0.23	0.00	1.16
7	0.02	0.00	0.03	0.03	0.05	0.17	0.20	0.23	0.44	0.37	1.53
8	0.00	0.02	0.00	0.02	0.00	0.05	0.01	0.03	0.03	0.00	0.15
9	0.00	0.00	0.00	0.18	0.05	0.50	0.19	0.06	1.30	0.00	2.27
TOTAL	5.76	3.92	3.27	6.33	1.70	1.25	0.70	0.78	2.03	0.38	26.1

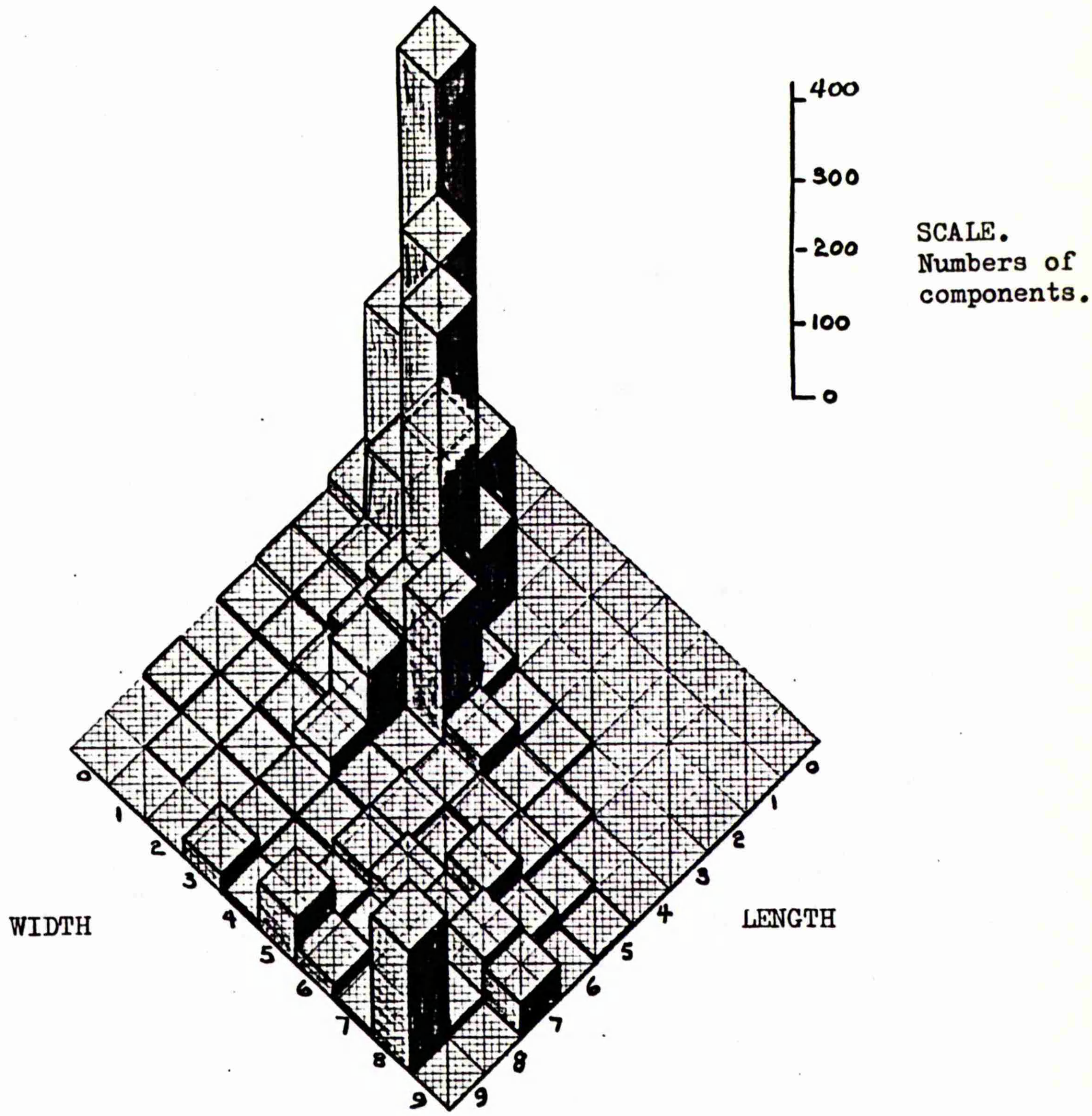
TABLE 10: Length (rows) v width (columns) for flame planed or guillotined plate components, i.e. orthogonal with no holes and slots (4..0..), or orthogonal with "nibbles" only (4..1..), or orthogonal and drilled (4..7.., 4..8..).

14,000 Ton Vessel



Histogram of numbers of components v length and width for flame planed or guillotined plate components (table 10).

26,000 Ton Vessel



Histogram of numbers of components v length and width for flame planed or guillotined plate components (table 10).

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	2	6	0	0	0	0	0	0	0	0	8
2	0	4	26	32	10	0	0	0	0	0	72
3	0	0	0	40	106	3	0	0	0	0	149
4	0	0	0	52	14	27	2	0	0	0	95
5	0	6	4	5	55	3	17	14	19	0	123
6	0	0	20	14	36	6	7	6	7	0	96
7	0	0	10	9	1	8	4	7	3	0	42
8	0	0	3	0	2	0	0	2	0	0	7
9	0	0	0	2	18	3	6	11	1	10	51
TOTAL	2	16	63	154	242	50	36	40	30	10	643

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
2	0.00	0.04	0.29	0.36	0.11	0.00	0.00	0.00	0.00	0.00	0.81
3	0.00	0.00	0.00	0.45	1.19	0.03	0.00	0.00	0.00	0.00	1.68
4	0.00	0.00	0.00	0.58	0.16	0.30	0.03	0.00	0.00	0.00	1.07
5	0.00	0.07	0.04	0.06	0.62	0.03	0.19	0.16	0.21	0.00	1.38
6	0.00	0.00	0.22	0.16	0.40	0.07	0.08	0.07	0.08	0.00	1.08
7	0.00	0.00	0.11	0.10	0.01	0.09	0.04	0.08	0.03	0.00	0.47
8	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.08
9	0.00	0.00	0.00	0.02	0.20	0.03	0.07	0.12	0.01	0.11	0.57
TOTAL	0.02	0.18	0.71	1.73	2.72	0.56	0.40	0.45	0.34	0.11	7.2

TABLE 11: Length (rows) v width (columns) for plate components which are flame planed and hand burned, or profile cut. i.e. orthogonal, with intricate cutouts (4..2..,4..3..,4..4..,4..5..,4..9..).

26,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

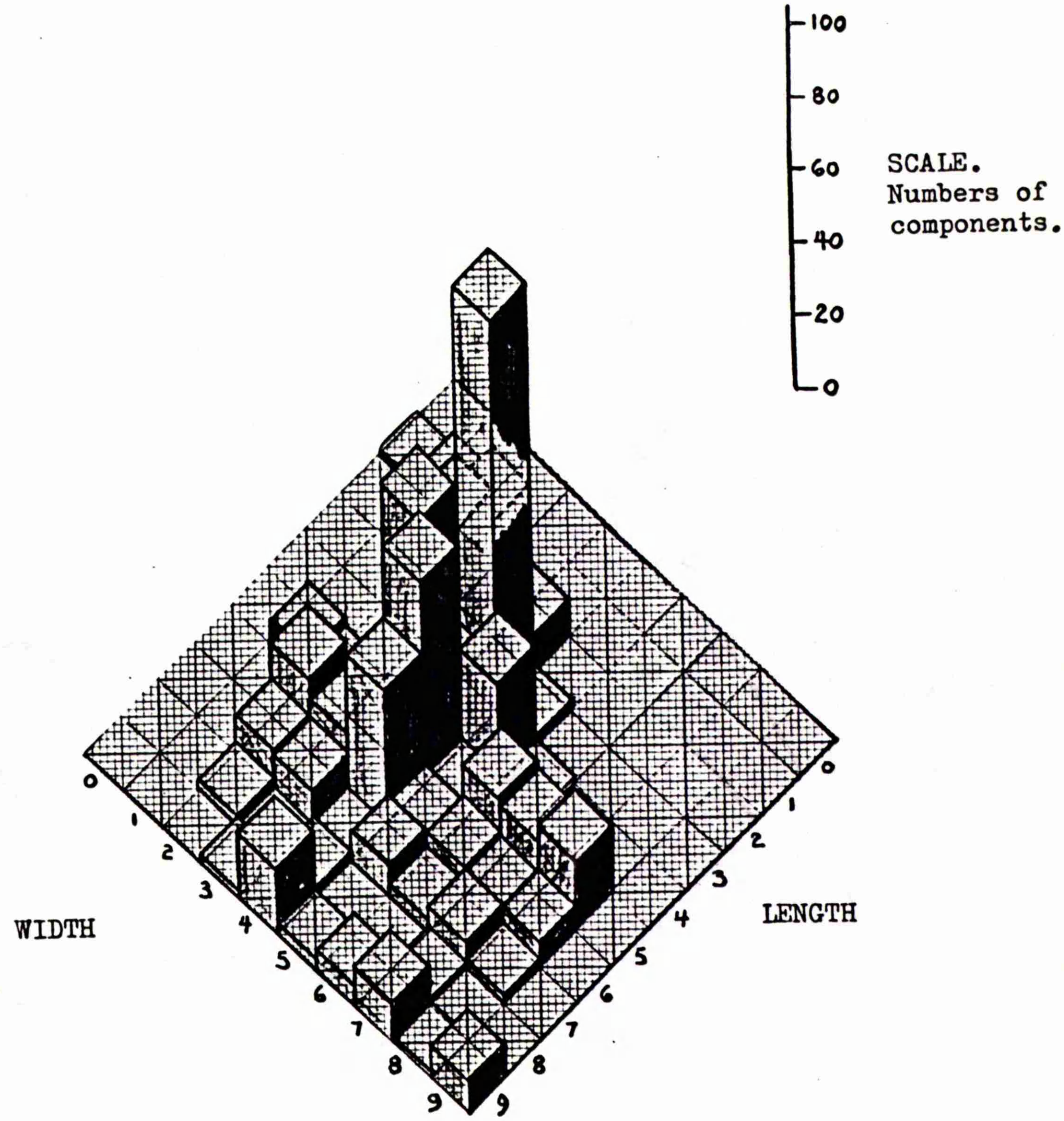
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	6	0	0	0	0	0	0	0	0	0	6
1	0	0	0	0	0	0	0	0	0	0	0
2	0	1	10	50	0	0	0	0	0	0	61
3	0	0	24	1017	52	2	2	0	0	0	1097
4	0	2	20	45	10	11	6	48	1	0	143
5	0	0	10	34	7	13	14	6	2	3	89
6	2	4	8	78	4	1	9	13	15	6	140
7	1	2	3	0	0	2	12	7	4	0	31
8	0	0	0	0	0	8	0	5	7	0	20
9	0	0	0	0	0	149	1	0	36	0	186
TOTAL	9	9	75	1224	73	186	44	79	65	9	1773

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.01	0.08	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.47
3	0.00	0.00	0.19	7.90	0.40	0.02	0.02	0.00	0.00	0.00	8.52
4	0.00	0.02	0.16	0.35	0.08	0.09	0.05	0.37	0.01	0.00	1.11
5	0.00	0.00	0.08	0.26	0.05	0.10	0.11	0.05	0.02	0.02	0.69
6	0.02	0.03	0.06	0.61	0.03	0.01	0.07	0.10	0.12	0.05	1.09
7	0.01	0.02	0.02	0.00	0.00	0.02	0.09	0.05	0.03	0.00	0.24
8	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.04	0.05	0.00	0.16
9	0.00	0.00	0.00	0.00	0.00	1.16	0.01	0.00	0.28	0.00	1.44
TOTAL	0.07	0.07	0.58	9.51	0.57	1.44	0.34	0.61	0.50	0.07	13.7

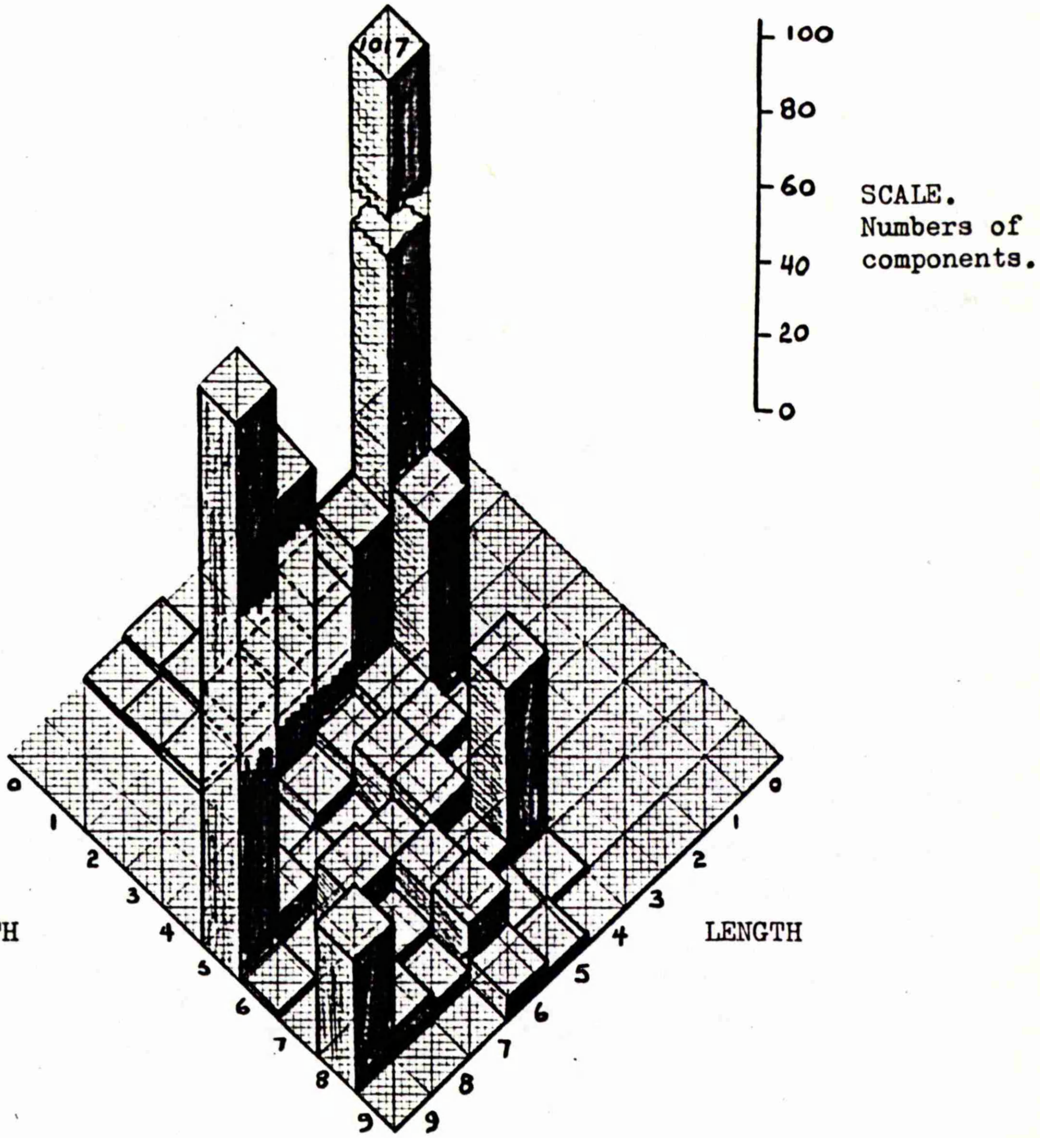
TABLE 11: Length (rows) v width (columns) for plate components which are flame planed and hand burned, or profile cut, i.e. orthogonal with intricate cutouts (4..2..,4..3..,4..4..,4..5..,4..9..).

14,000 Ton Vessel



Histogram of numbers of components v length and width of plate components which are flame planed and hand burned,or profile cut.(table 11).

26,000 Ton Vessel



Histogram of numbers of components v length and width of plate components which are flame planed and hand burned, or profile cut. (table 11).

26,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	20	0	0	0	0	0	0	0	0	0	20
1	102	6	0	0	0	0	0	0	0	0	108
2	0	361	58	209	0	0	0	0	0	0	628
3	0	1	11	91	39	38	0	0	0	0	180
4	0	1	22	51	53	70	31	2	0	0	230
5	0	0	4	5	22	16	42	159	0	2	250
6	0	0	0	8	111	56	27	10	12	0	224
7	0	0	0	6	1	9	22	11	6	0	55
8	~~0~~	0	0	0	0	5	0	10	2	0	17
9	0	0	2	0	0	16	0	18	97	0	133
TOTAL	122	369	97	370	226	210	122	210	117	5	1846

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
1	0.79	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84
2	0.00	2.80	0.45	1.62	0.00	0.00	0.00	0.00	0.00	0.00	4.88
3	0.00	0.01	0.09	0.71	0.30	0.30	0.00	0.00	0.00	0.00	1.40
4	0.00	0.01	0.17	0.40	0.41	0.54	0.24	0.02	0.00	0.00	1.79
5	0.00	0.00	0.03	0.04	0.17	0.12	0.33	1.24	0.00	0.02	1.94
6	0.00	0.00	0.00	0.06	0.86	0.44	0.21	0.08	0.09	0.00	1.74
7	0.00	0.00	0.00	0.05	0.01	0.07	0.17	0.09	0.05	0.00	0.43
8	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.08	0.02	0.00	0.13
9	0.00	0.00	0.02	0.00	0.00	0.12	0.00	0.14	0.75	0.00	1.03
TOTAL	0.95	2.87	0.75	2.87	1.76	1.63	0.95	1.63	0.91	0.02	14.3

TABLE 12: Length (rows) v width (columns) for profile cut plate components i.e.non-orthogonal (47...).

14,000 Ton Vessel

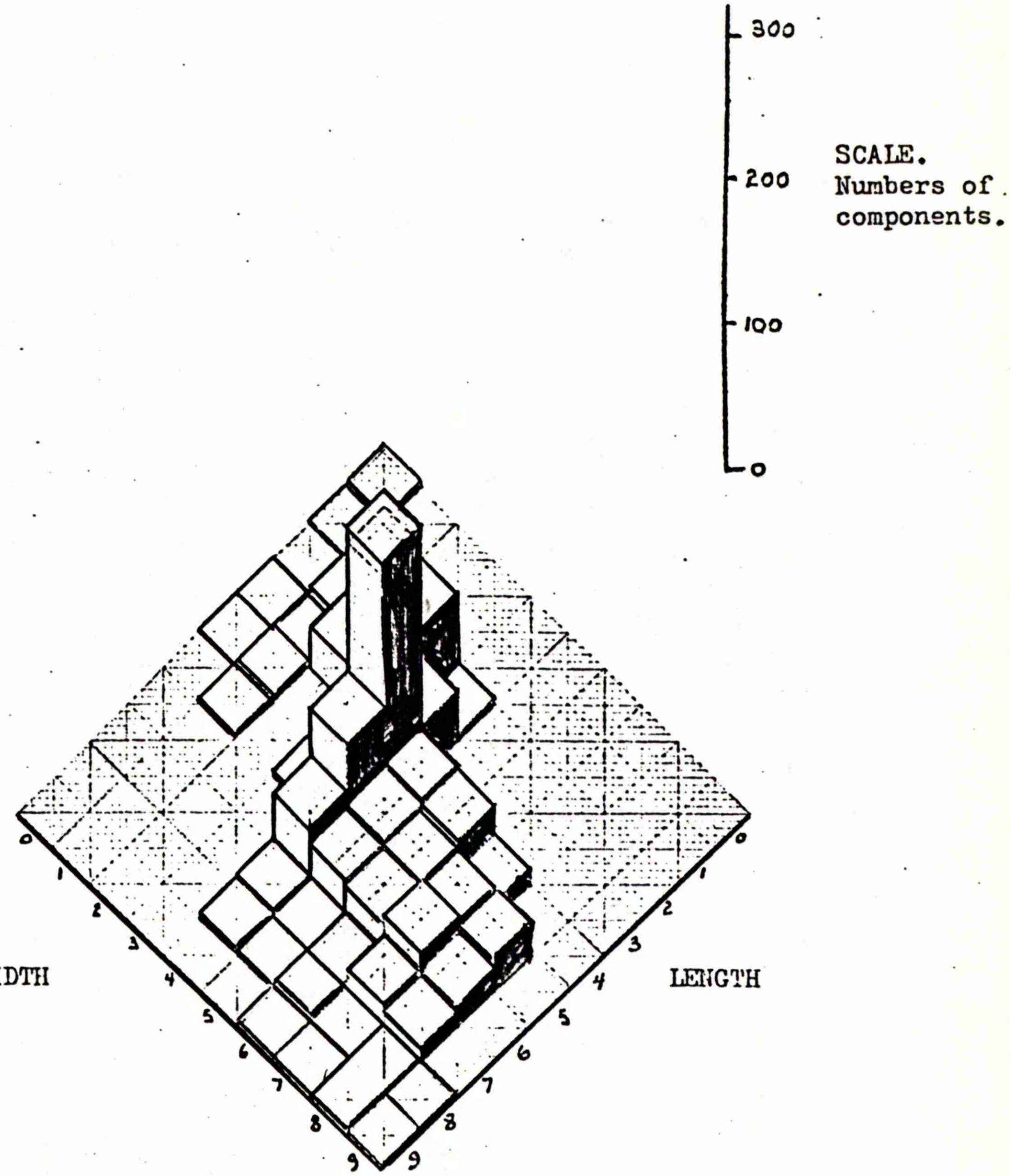
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	6	0	0	0	0	0	0	0	0	0	6
1	2	8	4	0	0	0	0	0	0	0	14
2	0	6	26	51	2	0	0	0	0	0	85
3	1	0	28	115	34	0	0	0	0	0	178
4	0	4	0	4	171	30	29	13	0	0	258
5	0	1	0	2	71	28	23	22	18	0	165
6	0	0	0	0	37	26	22	28	16	0	129
7	0	0	0	0	4	2	6	15	12	0	39
8	0	0	0	0	3	2	6	2	4	2	19
9	0	0	0	0	0	0	2	2	4	2	10
TOTAL	9	19	58	172	322	88	88	82	54	4	897

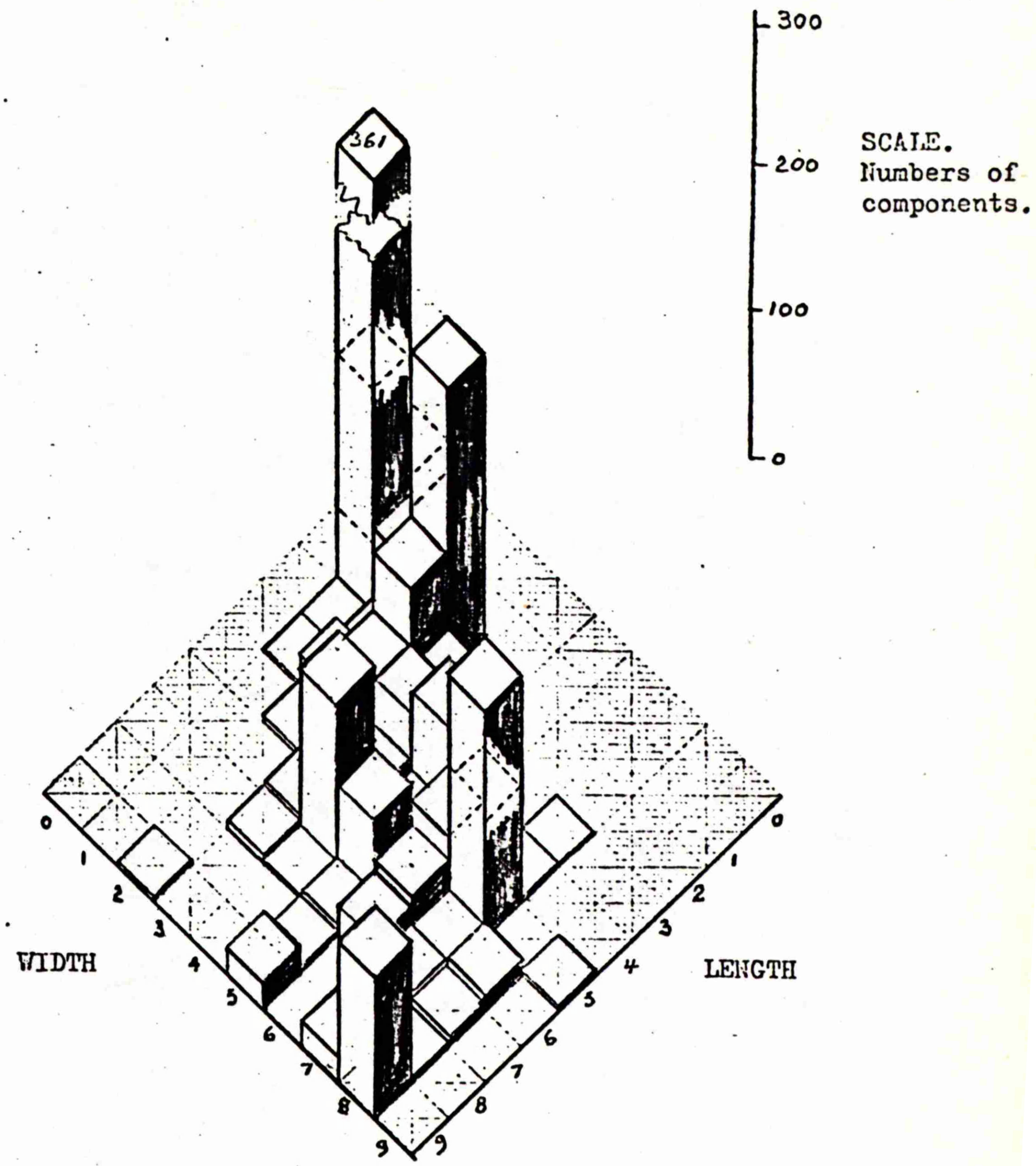
% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
1	0.02	0.09	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
2	0.00	0.07	0.29	0.57	0.02	0.00	0.00	0.00	0.00	0.00	0.96
3	0.01	0.00	0.31	1.29	0.38	0.00	0.00	0.00	0.00	0.00	2.00
4	0.00	0.04	0.00	0.04	1.92	0.34	0.33	0.15	0.00	0.00	2.82
5	0.00	0.01	0.00	0.02	0.80	0.31	0.26	0.25	0.20	0.00	1.86
6	0.00	0.00	0.00	0.00	0.42	0.29	0.25	0.31	0.18	0.00	1.45
7	0.00	0.00	0.00	0.00	0.04	0.02	0.07	0.17	0.13	0.00	0.44
8	0.00	0.00	0.00	0.00	0.03	0.02	0.07	0.02	0.04	0.02	0.21
9	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.04	0.02	0.11
TOTAL	0.10	0.21	0.65	1.93	3.62	0.99	0.99	0.92	0.61	0.04	10.2

TABLE 12: Length (rows) v width (columns) for profile cut plate components, i.e. non orthogonal (47...).



Histogram of numbers of components v length and width of profile cut plate components (table 12).



Histogram of numbers of components v length and width of profile cut plate components (table 12).

14,000 Ton Vessel

Edge preparation required.	COMPONENT SHAPE					
	ORTHOGONAL		NON-ORTHOGONAL		TOTALS	
	Number required	% of total	Number required	% of total	Number required	% of total
A) Non-stated	3529	39.7	721	8.1	4520	47.8
B) Specifically square.	4	0.0	0	0.0	4	0.0
C) One side chamfer.	531	6.0	164	1.8	695	7.8
D) Two side chamfer.	60	0.7	12	0.1	72	0.8
E) B and C (different edges).	25	0.3	0	0.0	25	0.3
F) C and D (different edges).	6	0.1	0	0.0	6	0.1
TOTALS.	4155	46.7	897	10.1	5052	56.8

Note: Only 3.5% of components require edge preparation subsequent to cutting, i.e. non-orthogonal shapes.

TABLE 13: Details of edge preparation for plate components.

26,000 Ton Vessel

Edge preparation required.	COMPONENT SHAPE					
	ORTHOGONAL		NON-ORTHOGONAL		TOTALS	
	Number required	% of total	Number required	% of total	Number required	% of total
A) Non-stated	4508	35.0	1726	13.4	6234	48.4
B) Specifically square.	88	0.7	20	0.2	108	0.8
C) One side chamfer.	467	3.6	78	0.6	545	4.2
D) Two side chamfer.	30	0.2	2	0.0	32	0.2
E) B and C (different edges).	36	0.3	20	0.2	56	0.4
F) C and D (different edges).	0	0.0	0	0.0	0	0.0
TOTALS.	5129	39.8	1846	14.3	6975	54.1

Note: Only 1.5% of components require edge preparation subsequent to cutting,i.e. non-orthogonal shapes.

TABLE 13: Details of edge preparation for plate components.

14,000 Ton Vessel.

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	2	0	0	0	0	0	0	0	0	0	2
1	3	55	94	0	0	0	0	0	0	0	152
2	6	160	105	96	0	0	0	0	0	0	367
3	0	0	26	80	56	0	0	0	0	0	162
4	1	0	4	10	18	5	3	2	0	0	43
5	1	0	12	10	9	2	56	19	20	0	129
6	1	0	11	22	8	7	24	7	2	0	82
7	0	0	7	10	18	1	0	15	2	0	53
8	0	2	5	4	0	0	4	15	2	0	32
9	0	0	0	2	0	0	0	0	0	0	2
TOTAL	14	217	264	234	109	15	87	58	26	0	1024

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
1	0.03	0.62	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71
2	0.07	1.80	1.18	1.08	0.00	0.00	0.00	0.00	0.00	0.00	4.13
3	0.00	0.00	0.29	0.90	0.63	0.00	0.00	0.00	0.00	0.00	1.82
4	0.01	0.00	0.04	0.11	0.20	0.06	0.03	0.02	0.00	0.00	0.48
5	0.01	0.00	0.13	0.11	0.10	0.02	0.63	0.21	0.22	0.00	1.45
6	0.01	0.00	0.12	0.25	0.09	0.08	0.27	0.08	0.02	0.00	0.92
7	0.00	0.00	0.08	0.11	0.20	0.01	0.00	0.17	0.02	0.00	0.60
8	0.00	0.02	0.06	0.04	0.00	0.00	0.04	0.17	0.02	0.00	0.36
9	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02
TOTAL	0.16	2.44	2.97	2.63	1.23	0.17	0.98	0.65	0.29	0.00	11.5

TABLE 14: Length (rows) v width (columns) for flanged plate components (single and multiple flange).

26,000 Ton Vessel

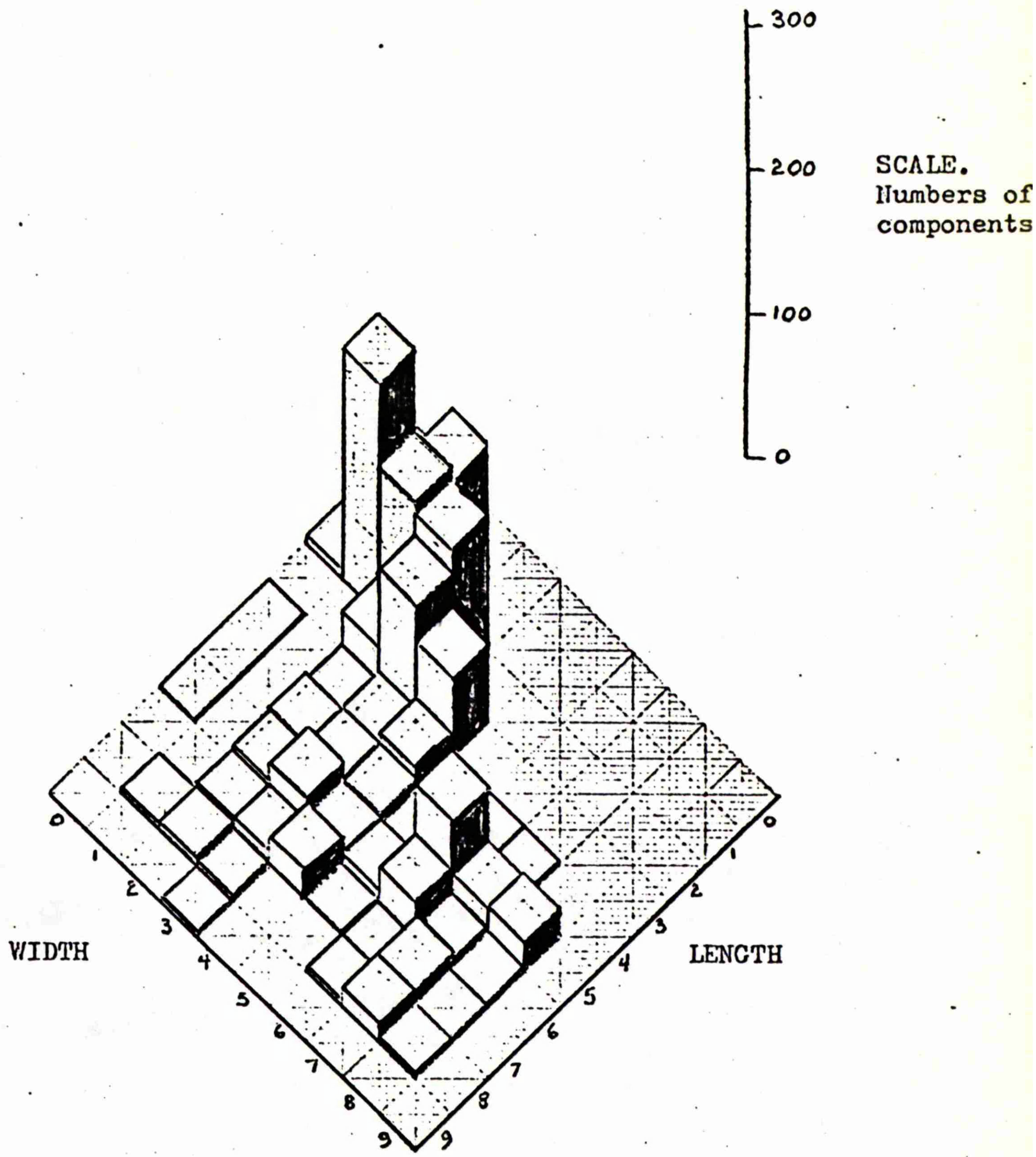
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	4	0	0	0	0	0	0	0	0	0	4
1	2	8	21	0	0	0	0	0	0	0	31
2	1	11	48	279	0	0	0	0	0	0	339
3	0	3	27	284	17	0	0	0	0	0	331
4	0	5	34	85	160	23	5	9	1	0	322
5	2	2	19	82	10	1	4	8	2	4	134
6	2	4	2	10	8	0	2	3	18	3	52
7	0	2	3	0	0	0	1	1	47	48	102
8	0	0	0	0	0	0	0	6	2	0	8
9	0	0	0	0	0	0	8	2	12	0	22
TOTAL	11	35	154	740	195	24	20	29	82	55	1340

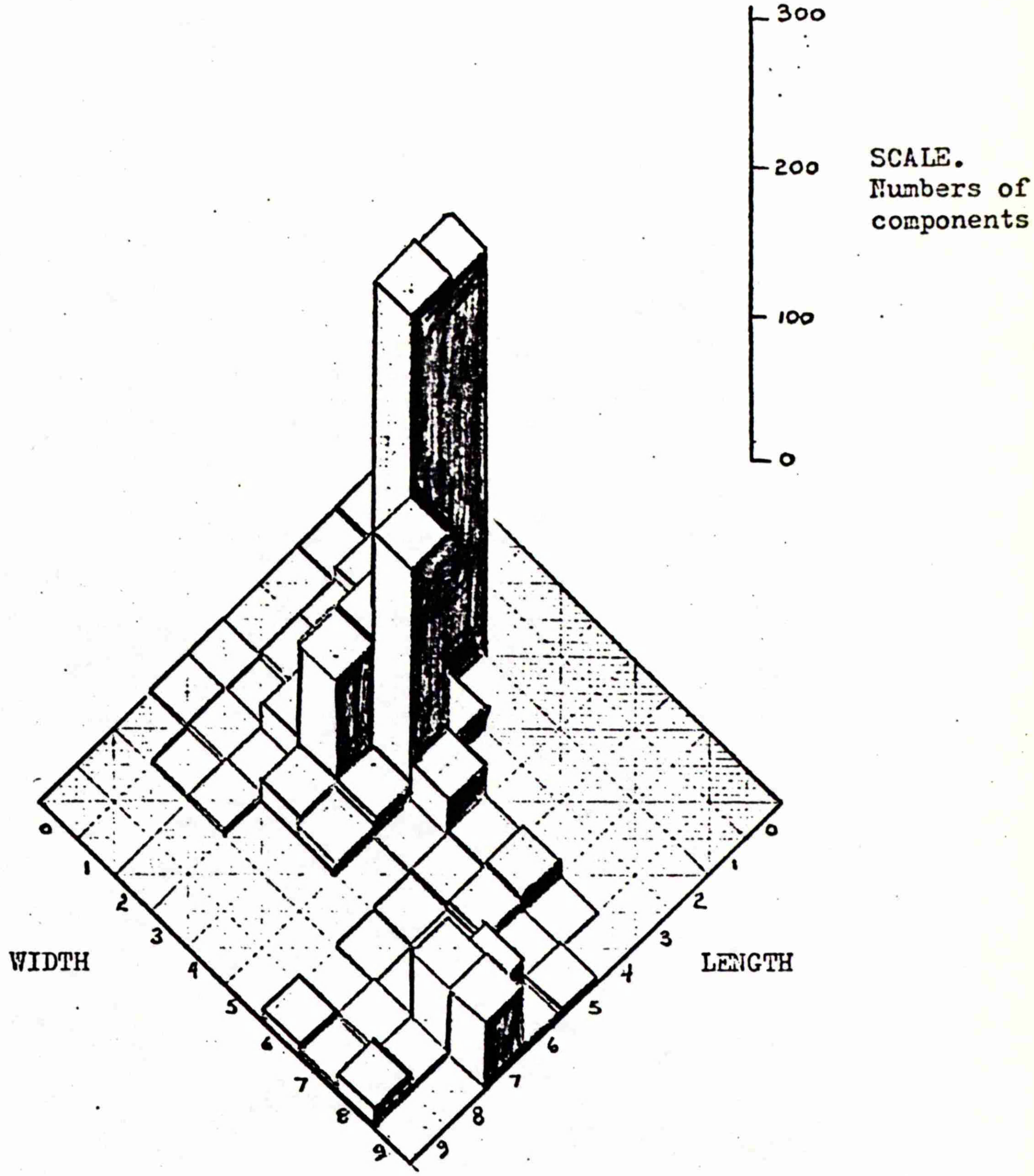
% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
1	0.02	0.06	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24
2	0.01	0.09	0.37	2.17	0.00	0.00	0.00	0.00	0.00	0.00	2.63
3	0.00	0.02	0.21	2.21	0.13	0.00	0.00	0.00	0.00	0.00	2.57
4	0.00	0.04	0.26	0.66	1.24	0.18	0.04	0.07	0.01	0.00	2.50
5	0.02	0.02	0.15	0.64	0.08	0.01	0.03	0.06	0.02	0.03	1.04
6	0.02	0.03	0.02	0.08	0.06	0.00	0.02	0.02	0.14	0.02	0.40
7	0.00	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.37	0.37	0.79
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.06
9	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.09	0.00	0.17
TOTAL	0.09	0.27	1.20	5.75	1.51	0.19	0.16	0.23	0.64	0.43	10.4

TABLE 14: Length (rows) v width (columns) for flanged plate components, (single and multiple flange).



Histogram of numbers of components v length and width of flanged plate components (table 14).



Histogram of numbers of components v length and width of flanged plate components (table 14).

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	4	5	0	0	0	9
5	0	0	0	0	6	4	15	14	6	0	45
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	6	8	20	14	6	0	54

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.10
5	0.00	0.00	0.00	0.00	0.07	0.04	0.17	0.16	0.07	0.00	0.51
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.00	0.00	0.00	0.07	0.09	0.22	0.16	0.07	0.00	0.6

TABLE 15: Length (rows) v width (columns) for swedged plate components.

26,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

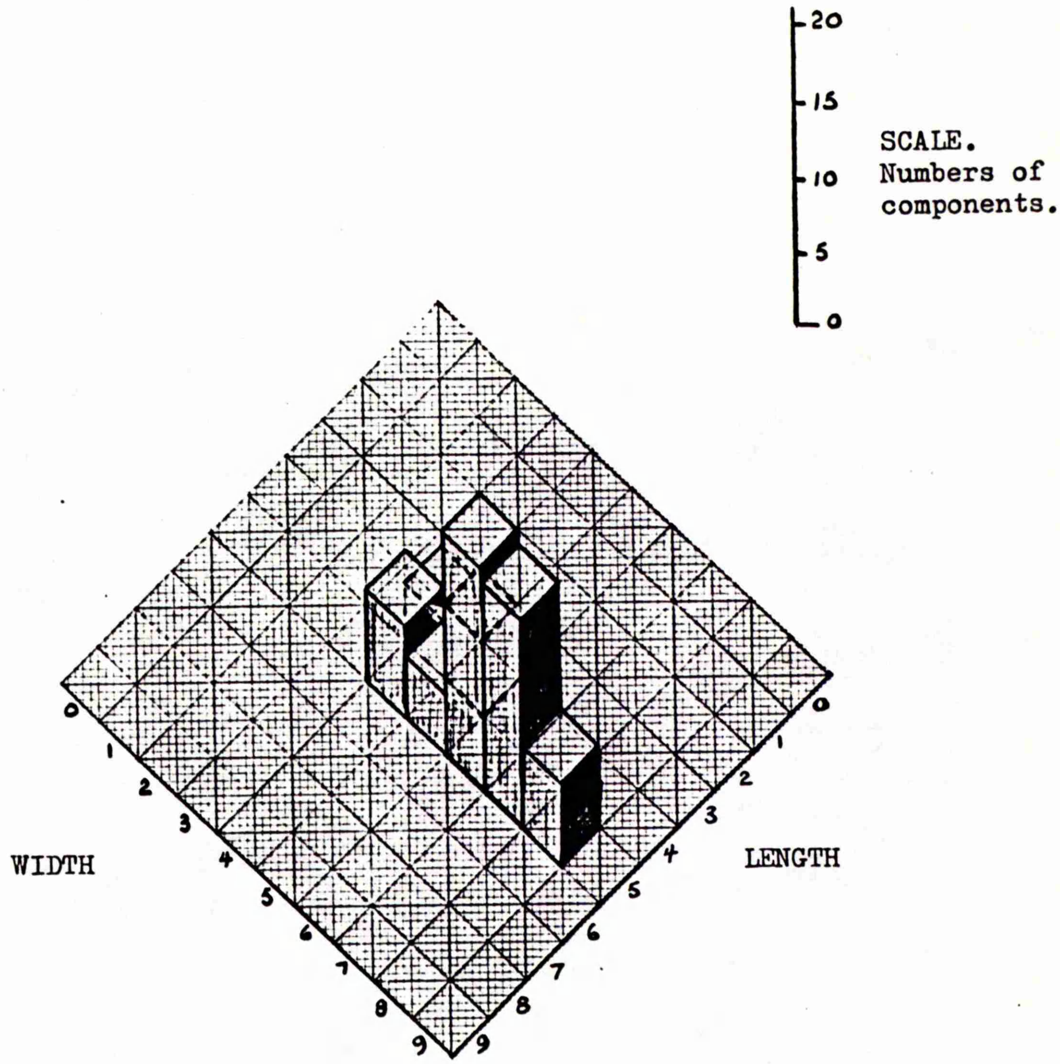
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	2	4	0	0	7
5	0	0	0	0	2	9	31	5	2	0	49
6	0	0	0	0	0	1	12	10	2	0	25
7	2	0	0	0	1	0	9	1	0	0	13
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
TOTAL	2	0	0	0	3	11	54	20	4	0	90

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.00	0.00	0.05
5	0.00	0.00	0.00	0.00	0.02	0.07	0.24	0.04	0.02	0.00	0.38
6	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.08	0.02	0.00	0.19
7	0.02	0.00	0.00	0.00	0.01	0.00	0.07	0.01	0.00	0.00	0.10
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.02	0.00	0.00	0.00	0.02	0.09	0.42	0.16	0.03	0.00	0.7

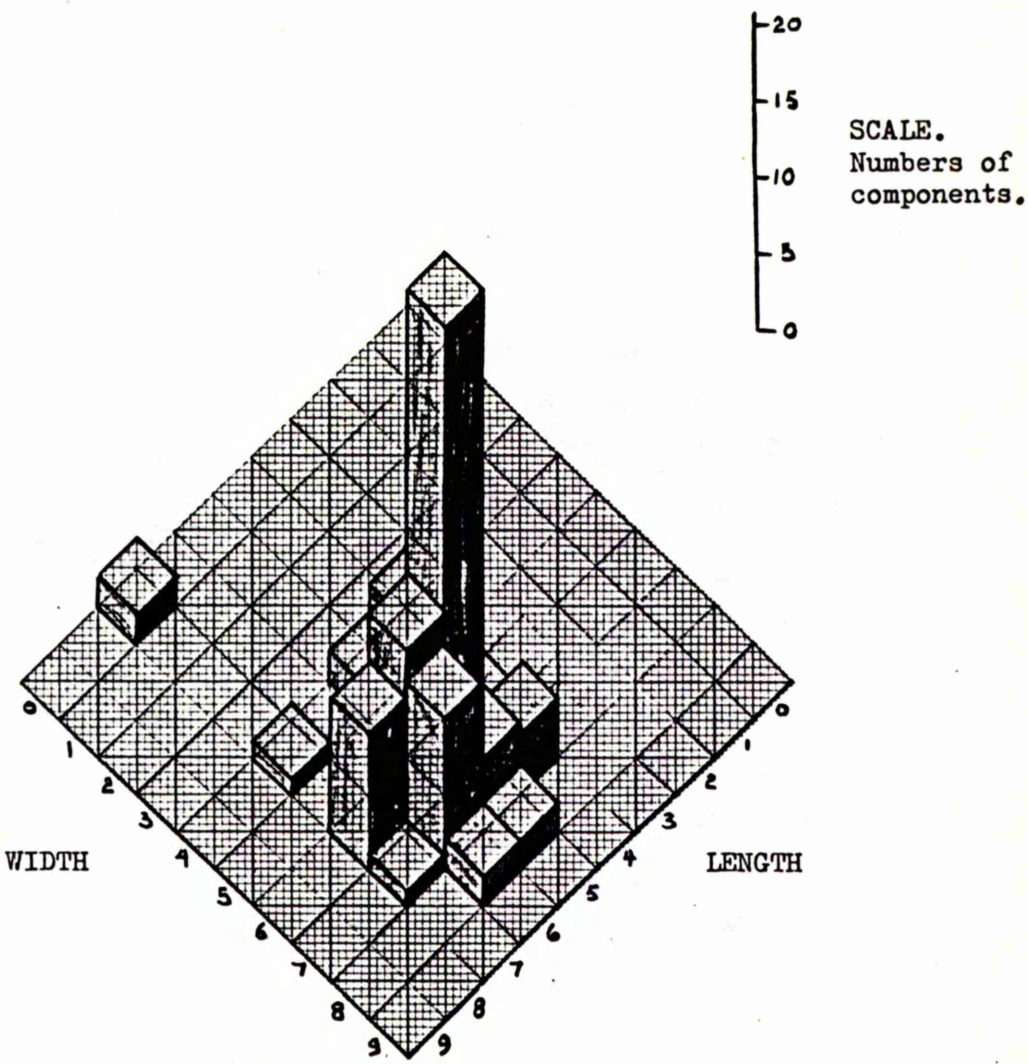
TABLE 15: Length (rows) v width (columns) for swedged plate components.

14,000 Ton Vessel



Histogram of numbers of components v length and width of swedged plate components (table 15).

26,000 Ton Vessel



Histogram of numbers of components v length and width of swedged plate components (table 15).

14,000 Ton Vessel

NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	2	1	3	4	0	1	0	11
5	0	1	0	1	0	7	9	4	3	0	25
6	0	0	0	0	2	5	10	6	4	0	27
7	0	0	0	2	0	5	9	19	24	0	59
8	0	0	0	2	0	0	0	4	8	2	16
9	0	0	0	0	0	0	2	10	46	4	62
TOTAL	0	1	0	7	3	20	34	43	86	6	200

% OF TOTAL NUMBER OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.02	0.01	0.03	0.04	0.00	0.01	0.00	0.12
5	0.00	0.01	0.00	0.01	0.00	0.08	0.10	0.04	0.03	0.00	0.28
6	0.00	0.00	0.00	0.00	0.02	0.06	0.11	0.07	0.04	0.00	0.30
7	0.00	0.00	0.00	0.02	0.00	0.06	0.10	0.21	0.27	0.00	0.66
8	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.04	0.09	0.02	0.18
9	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.52	0.04	0.70
TOTAL	0.00	0.01	0.00	0.08	0.03	0.22	0.38	0.48	0.97	0.07	2.2

TABLE 16: Length (rows) v width (columns) for roll bent plate components, (single and multiple roll, not crossing).

26,000 Ton Vessel

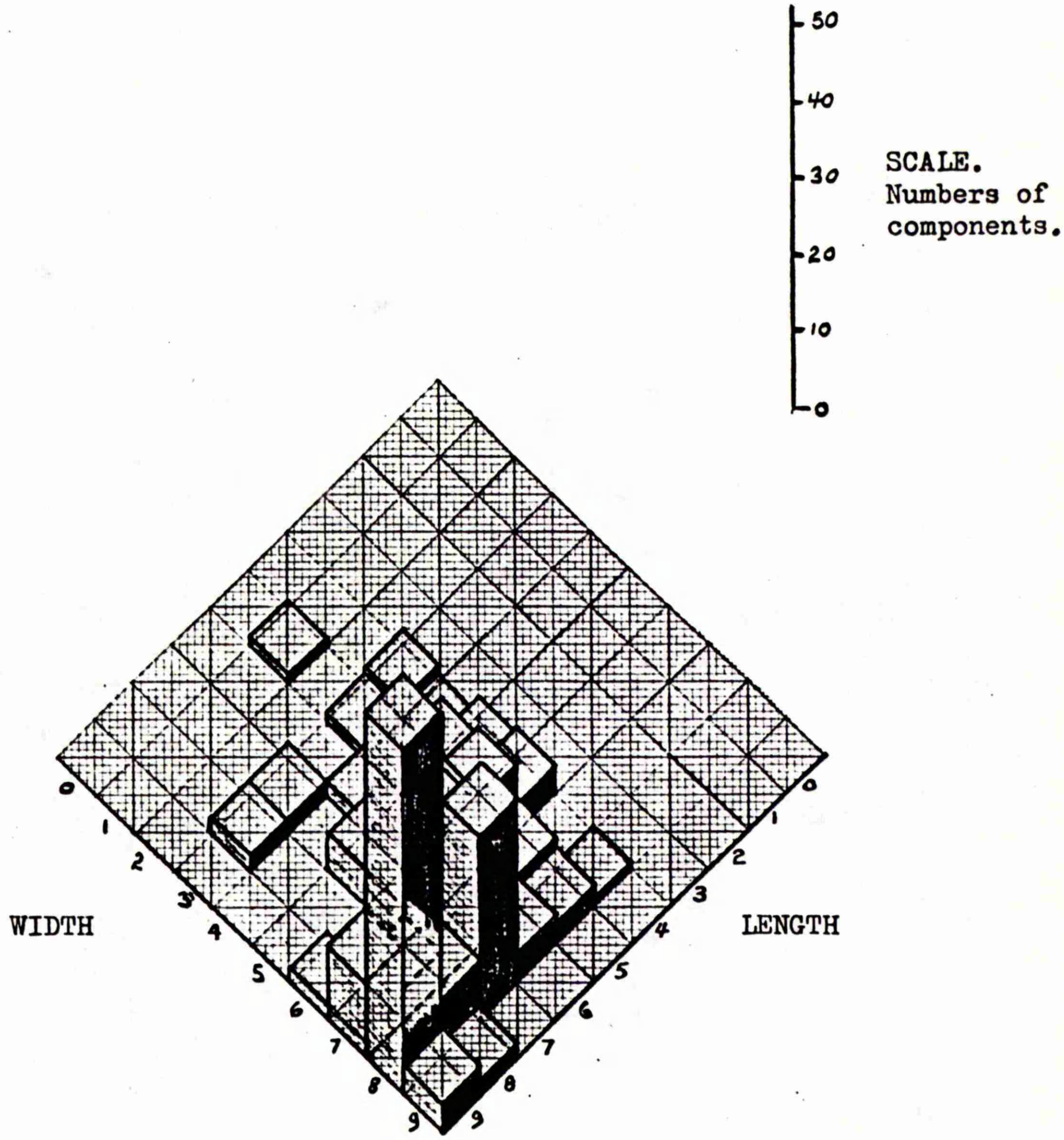
NUMBERS OFF (FOR SHIP).

CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	2	0	0	0	0	0	0	2
4	4	0	4	2	0	0	0	0	0	0	10
5	0	0	4	8	1	2	0	0	0	0	15
6	0	0	0	6	2	13	16	8	3	0	48
7	0	0	0	0	2	12	22	24	6	0	66
8	0	0	0	0	0	2	0	2	0	0	4
9	0	0	2	2	0	10	4	14	37	0	69
TOTAL	4	0	10	20	5	39	42	48	46	0	214

% OF TOTAL NUMBER OFF (FOR SHIP).

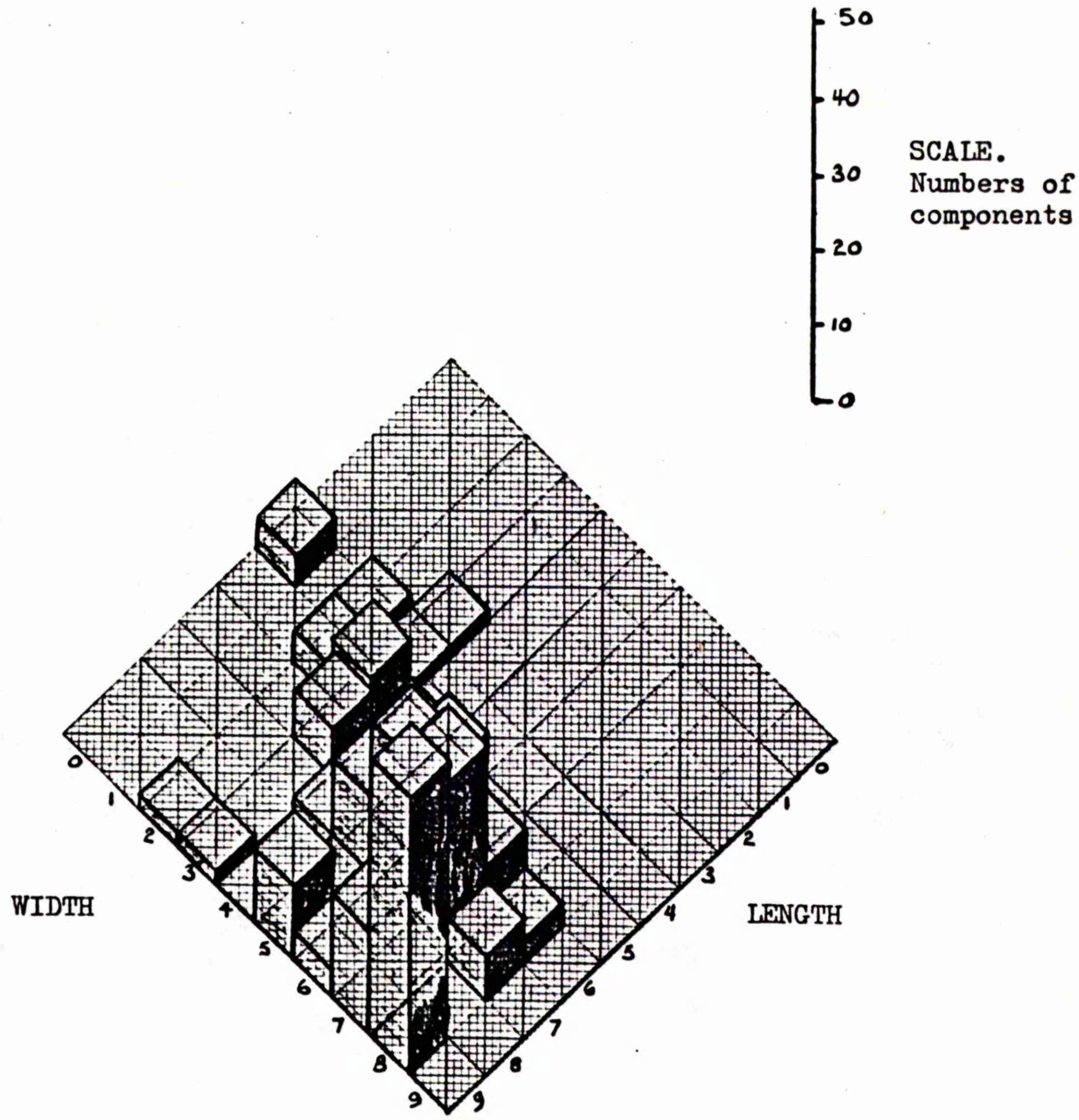
CODE	0	1	2	3	4	5	6	7	8	9	TOTAL
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02
4	0.03	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	
5	0.00	0.00	0.03	0.06	0.01	0.02	0.00	0.00	0.00	0.00	0.12
6	0.00	0.00	0.00	0.05	0.02	0.10	0.12	0.06	0.02	0.00	0.37
7	0.00	0.00	0.00	0.00	0.02	0.09	0.17	0.19	0.05	0.00	0.51
8	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.03
9	0.00	0.00	0.02	0.02	0.00	0.08	0.03	0.11	0.29	0.00	0.54
TOTAL	0.03	0.00	0.08	0.16	0.04	0.30	0.33	0.37	0.36	0.00	1.7

TABLE 16: Length (rows) v width (columns) for roll bent plate components, (single and multiple roll, not crossing).



Histogram of numbers of components v length and width of roll bent plate components (table 16).

26,000 Ton Vessel

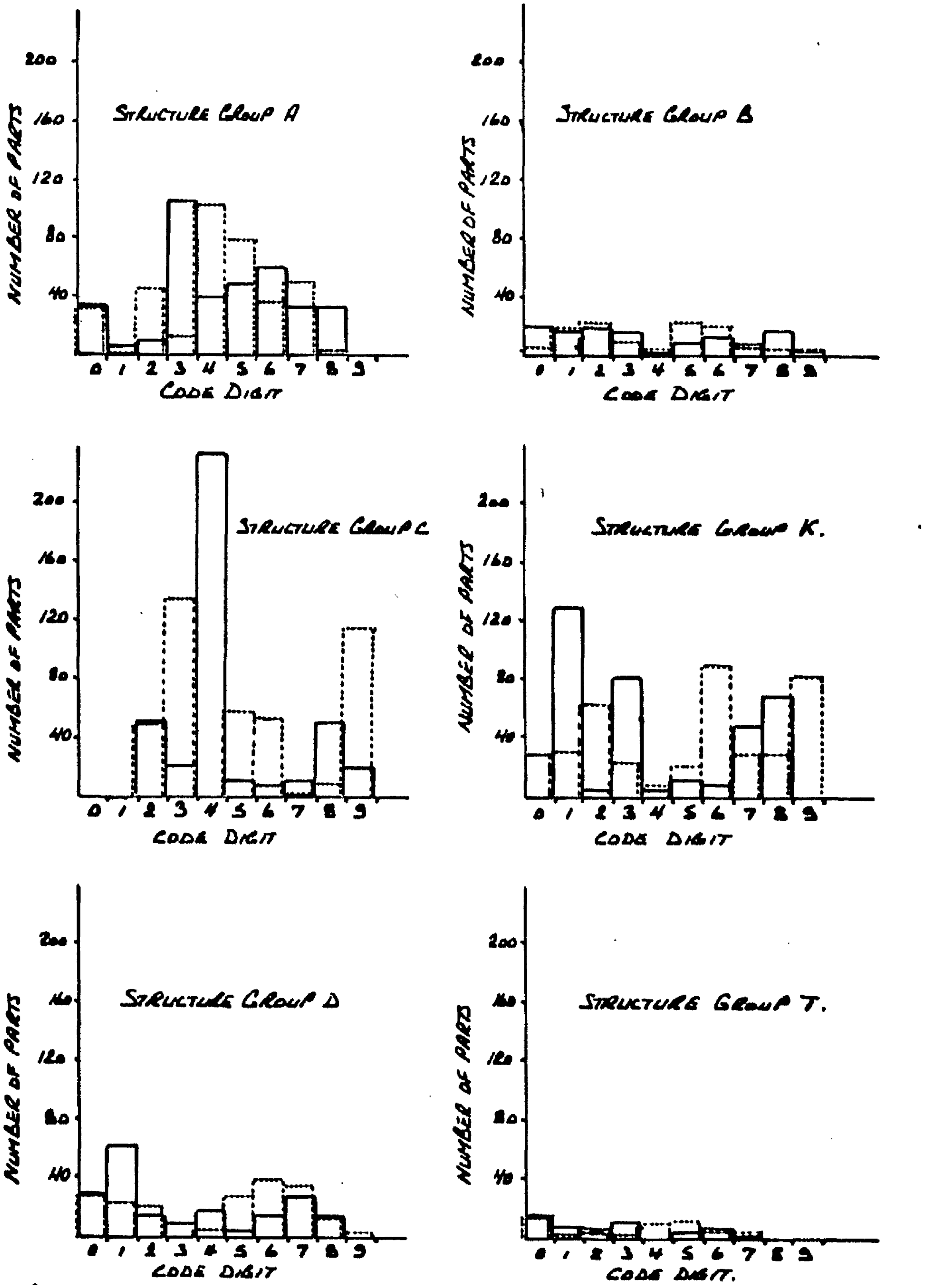


Histogram of numbers of components v length and width of roll bent plate components (table 16).

APPENDIX H

Detailed analysis of components comprising structure groups in proposed fabrication breakdown of S.D.14 cargo vessel.

Figure	Type of component	Description
1	Rectangular plate parts	Histograms of numbers of components for both length and width ranges (superimposed).
2	Straight sided parts with at least one square corner	ditto.
3	Straight sided plate parts with no square corners.	ditto.
4	Plate parts with one curved side	ditto.
5	Plate parts with more than one curved side.	ditto.
6	Angle bar	Histograms of numbers of components within length ranges - with square ends and total (superimposed)
7	Bulb flat bar	ditto.
8	Flat bar	ditto.
9	Angle bar	Histograms of numbers of components within depth ranges - with square ends and total (superimposed).
10	Bulb flat bar	ditto.
11	Flat bar	ditto.
12	Angle bar	Histograms of numbers of components having various forming operations for bars - with square ends and total (superimposed).
13	Bulb flat bar	ditto.
14	Flat bar	ditto.
15	Angle bar	Histograms of numbers of components having auxiliary features (holes and slots) - with square ends and total (superimposed).
16	Bulb flat bar	ditto.
17	Flat bar	ditto.

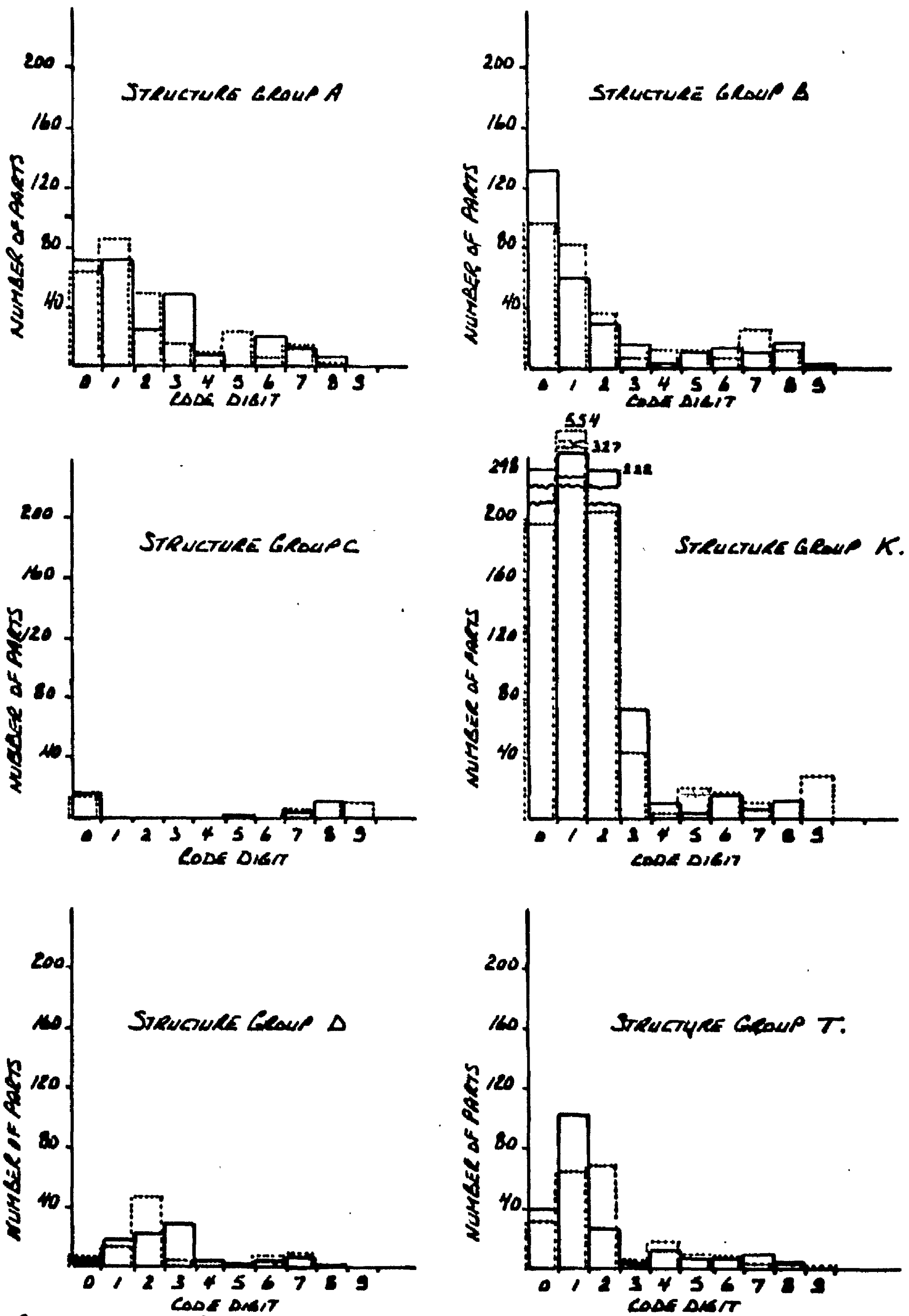


CODE DIGIT VALUES:-

WIDTH: (0) ≤300 (1) >300 ≤450 (2) >450 ≤600 (3) >600 ≤900 (4) >900 ≤1200 (5) >1200 ≤1600 (6) >1600 ≤2000 (7) >2000 ≤2500 (8) >2500 ≤3000 (9) >3000

LENGTH (0) ≤3000 (1) >300 ≤600 (2) >600 ≤1000 (3) >1000 ≤1500 (4) >1500 ≤2500 (5) >2500 ≤4000 (6) >4000 ≤6000 (7) >6000 ≤7500 (8) >7500 ≤9000 (9) >9000

FIGURE 1 : SIZE ANALYSIS FOR RECTANGULAR PLATE PARTS (14,000 T DWT CARGO VESSEL)



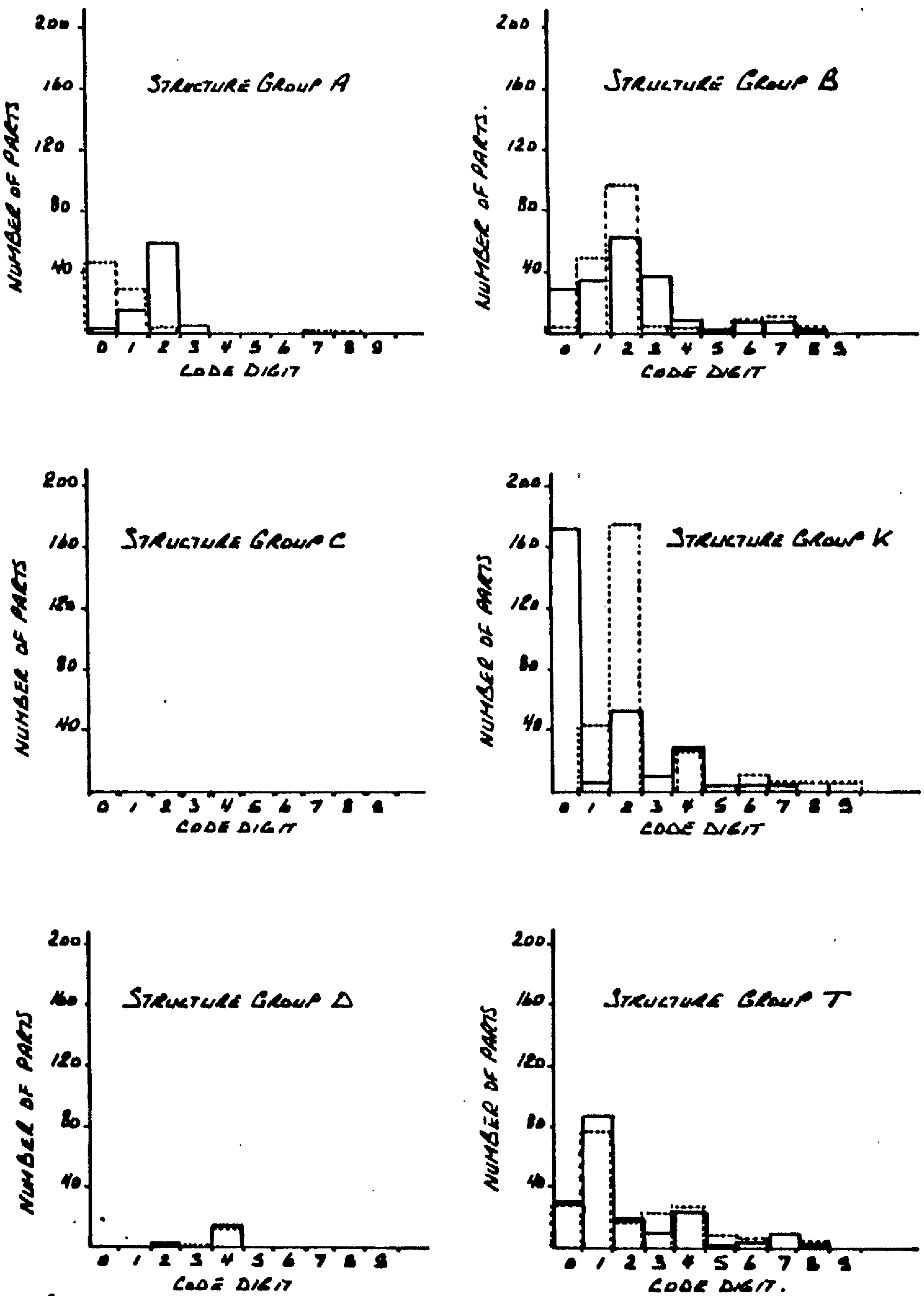
CODE DIGIT VALUES:-

WIDTH: (0) ≤ 300, (1) > 300 ≤ 450, (2) > 450 ≤ 600, (3) > 600 ≤ 900, (4) > 900 ≤ 1200, (5) > 1200 ≤ 1600, (6) > 1600 ≤ 2000 (7) > 2000 ≤ 2500, (8) > 2500 ≤ 3000, (9) > 3000. MM

LENGTH: (0) ≤ 3000, (1) > 300 ≤ 600 (2) > 600 ≤ 1000 (3) > 1000 ≤ 1500 (4) > 1500 ≤ 2500 (5) > 2500 ≤ 4000 (6) > 4000 ≤ 6000 (7) > 6000 ≤ 7500 (8) > 7500 ≤ 9000 (9) > 9000

FIGURE 2: SIZE ANALYSIS FOR PLATE PARTS WITH STRAIGHT SIDES AND AT LEAST ONE SQUARE CORNER (OTHER THAN RECTANGLES) BY STRUCTURE GROUP.

(14,000 T DWT CARGO VESSEL)

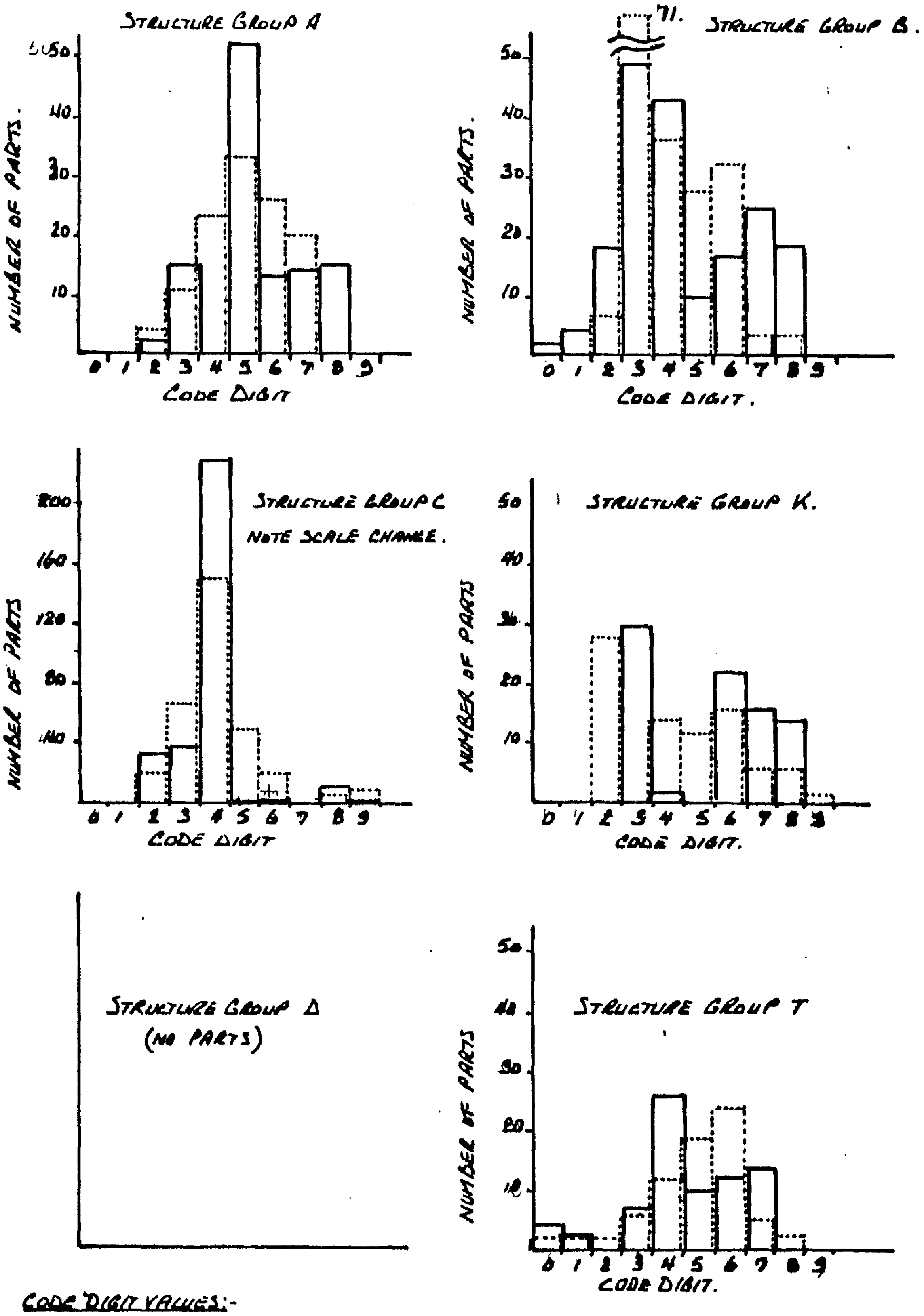


CODE DIGIT VALUES:-

WIDTH: (0) ≤300 (1) >300 ≤450 (2) >450 ≤600 (3) >600 ≤900 (4) >900 ≤1200 (5) >1200 ≤1600 (6) >1600 ≤2000 (7) >2000 ≤2500 (8) >2500 ≤3000 (9) >3000

LENGTH (0) ≤3000 (1) >300 ≤600 (2) >600 ≤1000 (3) >1000 ≤1500 (4) >1500 ≤2500 (5) >2500 ≤4000 (6) >4000 ≤6000 (7) >6000 ≤7500 (8) >7500 ≤9000 (9) >9000

FIGURE 3: SIZE ANALYSIS FOR PLATE PARTS WITH STRAIGHT SIDES AND NO SQUARE CORNERS (14,000 T DWT CARGO VESSEL)

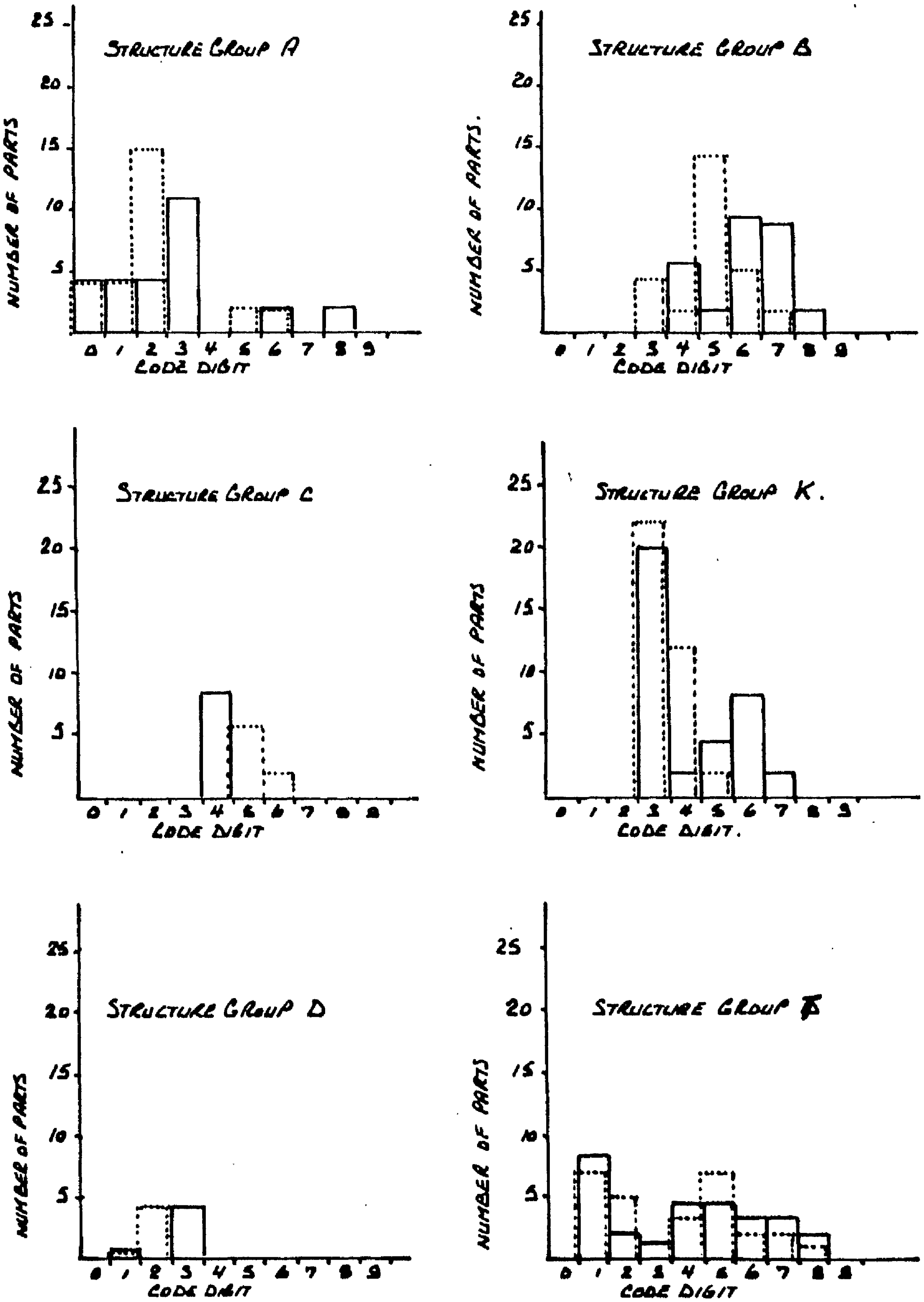


CODE DIGIT VALUES:-

WIDTH: (0) ≤ 300 (1) > 300 ≤ 450 (2) > 450 ≤ 600 (3) > 600 ≤ 900 (4) > 900 ≤ 1200 (5) > 1200 ≤ 1600 (6) > 1600 ≤ 2000 (7) > 2000 ≤ 2500 (8) > 2500 ≤ 3000 (9) > 3000

LENGTH: (0) ≤ 3000 (1) > 300 ≤ 600 (2) > 600 ≤ 1000 (3) > 1000 ≤ 1500 (4) > 1500 ≤ 2500 (5) > 2500 ≤ 4000 (6) > 4000 ≤ 6000 (7) > 6000 ≤ 7500 (8) > 7500 ≤ 9000 (9) > 9000

FIGURE 4: SIZE ANALYSIS FOR PLATE PARTS WITH ONE CURVED SIDE BY STRUCTURE GROUP (14,000 T DWT CARGO VESSEL)

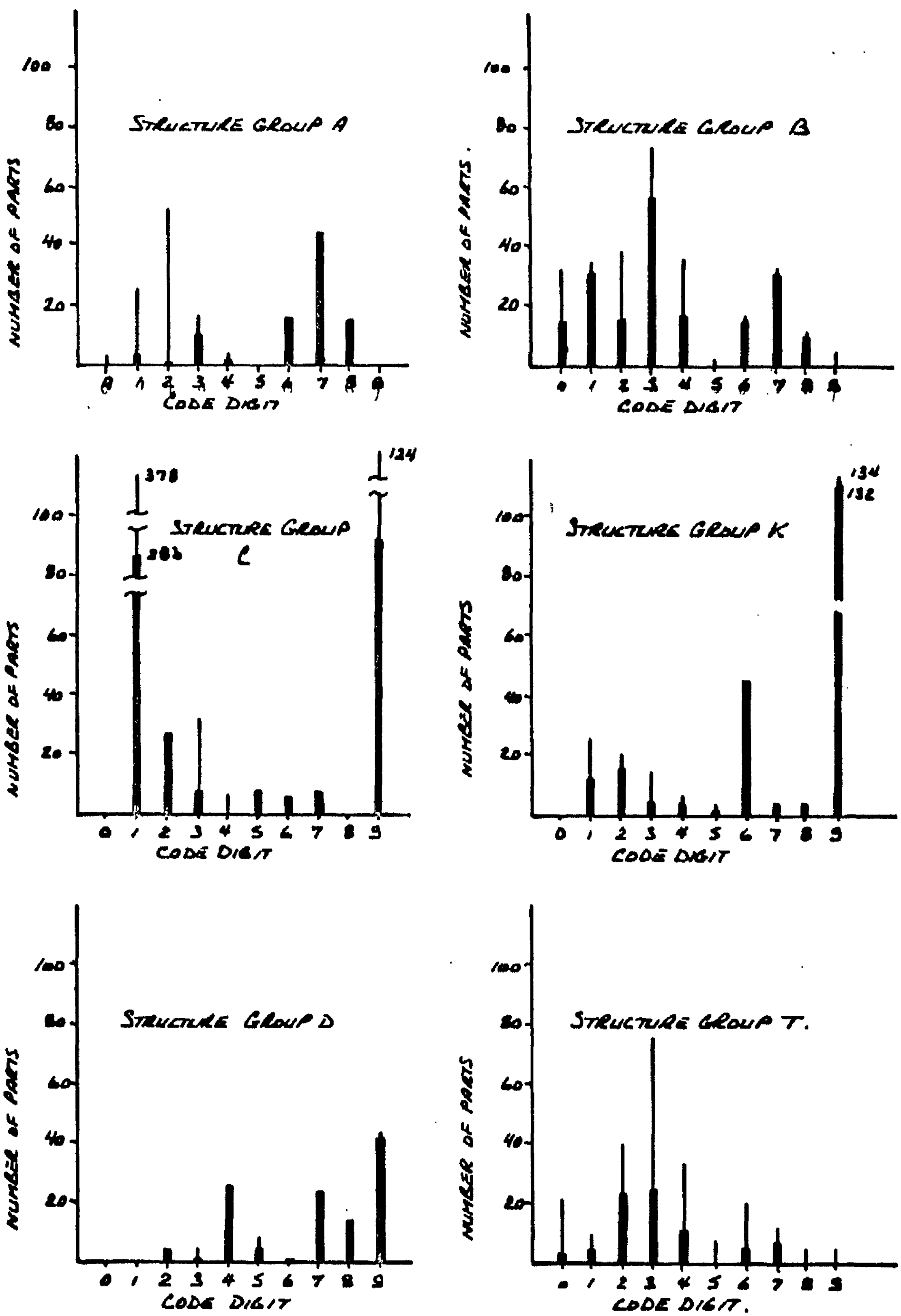


CODE DIGIT VALUES:-

WIDTH: 0 ≤300 1 >300≤450 2 >450≤600 3 >600≤900 4 >900≤1200 5 >1200≤1600 6 >1600≤2000 7 >2000≤2500 8 >2500≤3000 9 >3000 MM

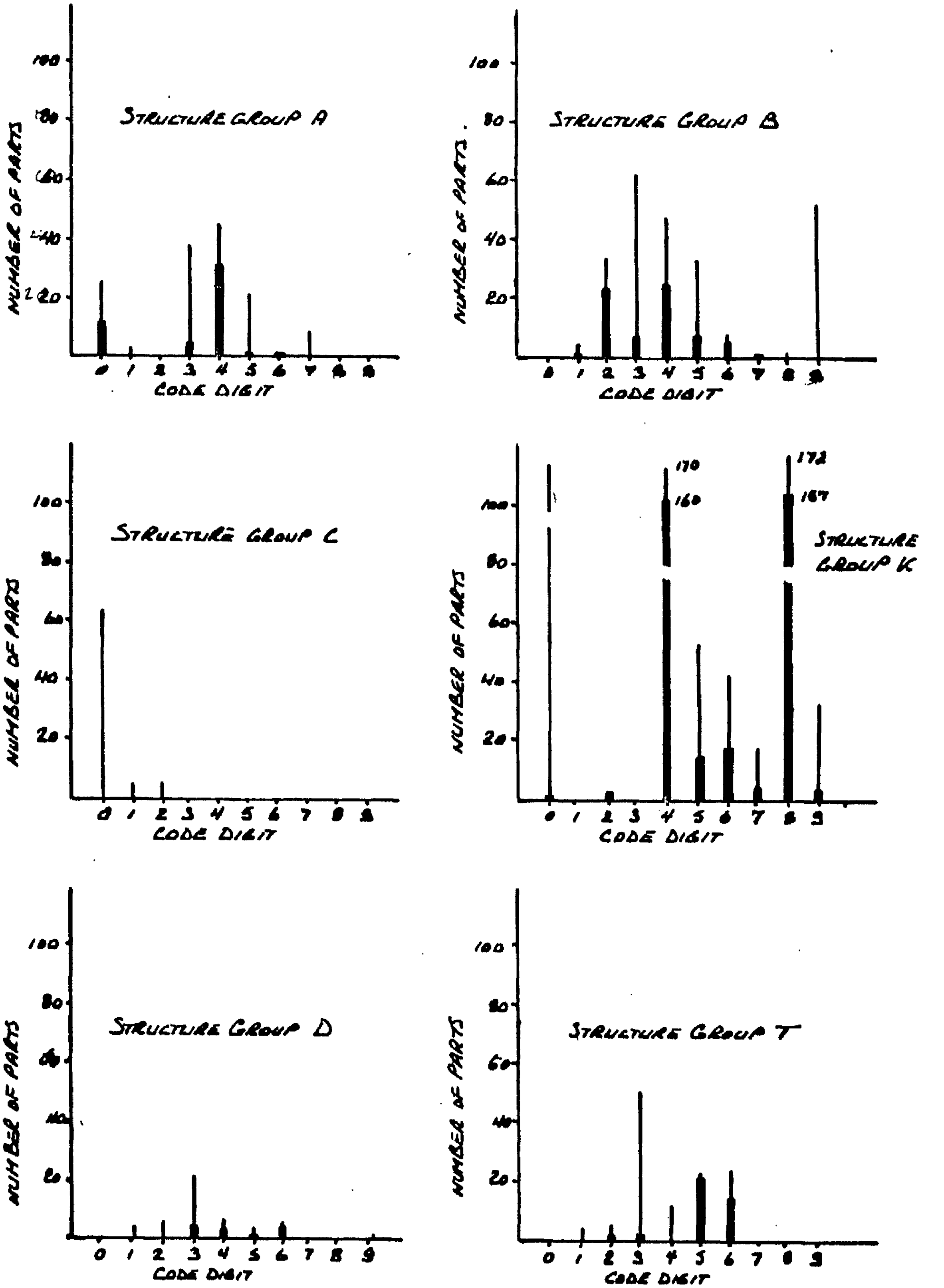
LENGTH: (0) ≤300 (1) >300 ≤600 (2) >600 ≤1000 (3) >1000 ≤1500 (4) >1500 ≤2500 (5) >2500 ≤4000 (6) >4000 ≤6000 (7) >6000 ≤7500 (8) >7500 ≤9000 (9) >9000

FIGURE 5: SIZE ANALYSIS FOR PLATE PARTS WITH MANY CURVED SIDES BY STRUCTURE GROUP (14,000 T DWT CARGO VESSEL)



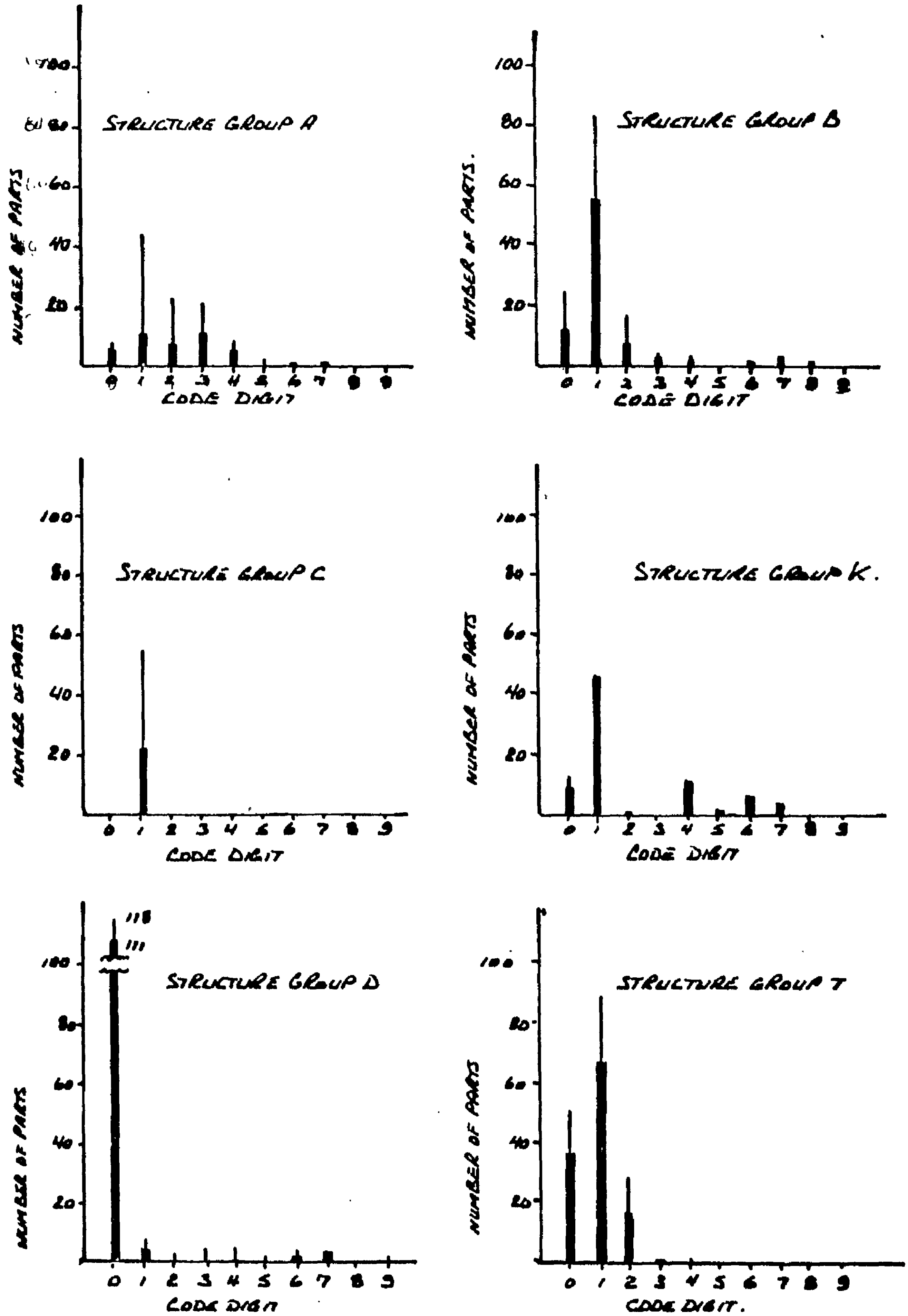
CODE DIGIT VALUES: (0) <600 (1) >600 ≤ 1200 (2) >1200 ≤ 2000 (3) >2000 ≤ 3000 (4) >3000 ≤ 4000 (5) >4000 ≤ 5000 (6) >5000 ≤ 6000 (7) >6000 ≤ 7000 (8) >7000 ≤ 8000 (9) >9000
DIMENSIONS MM

FIGURE 6: ANGLE BAR LENGTH ANALYSIS BY STRUCTURE GROUP
(14000 T. D.WT. CARGO VESSEL)



CODE DIGIT VALUES: (0) < 600 (1) > 600 ≤ 1200 (2) > 1200 ≤ 2000 (3) > 2000 ≤ 3000 (4) > 3000 ≤ 4000 (5) > 4000 ≤ 5000 (6) > 5000 ≤ 6000 (7) > 6000 ≤ 7000 (8) > 7000 ≤ 8000 (9) > 8000
DIMENSIONS MM

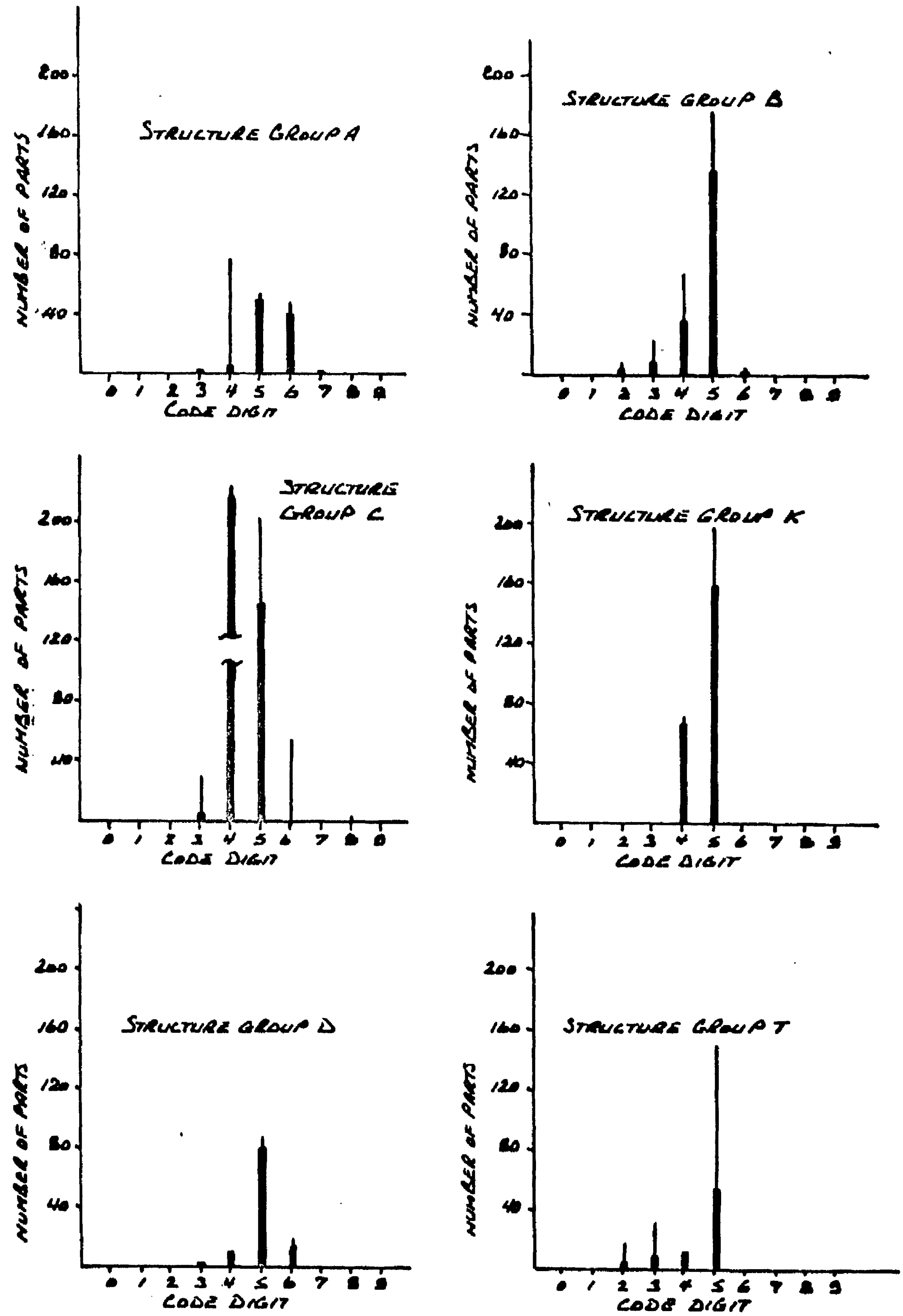
FIGURE 7: BULB FLAT BAR LENGTH ANALYSIS BY STRUCTURE GROUP.
(14.000 T. CARGO VESSEL)



CODE DIGIT VALUES: (0) ≤ 600 (1) > 600 & 1200 (2) > 1200 & 2000 (3) > 2000 & 3000 (4) > 3000 & 4000 (5) > 4000 & 5000 (6) > 5000 & 6000 (7) > 6000 & 7000 (8) > 7000 & 8000 (9) > 8000
DIMENSIONS MM.

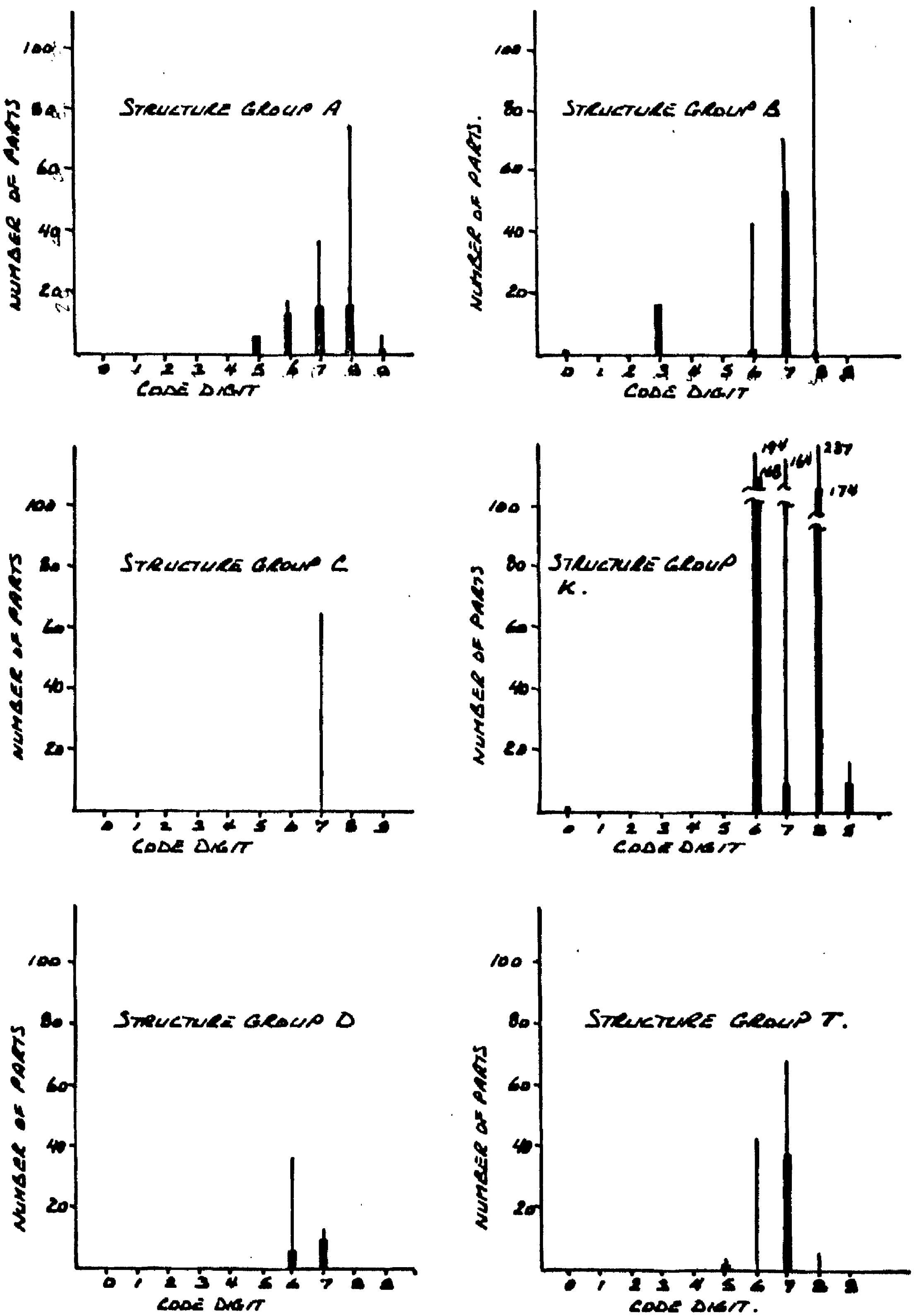
FIGURE 8: FLAT BAR LENGTH ANALYSIS BY STRUCTURE GROUP

(14,000 T DWT CARGO VESSEL)



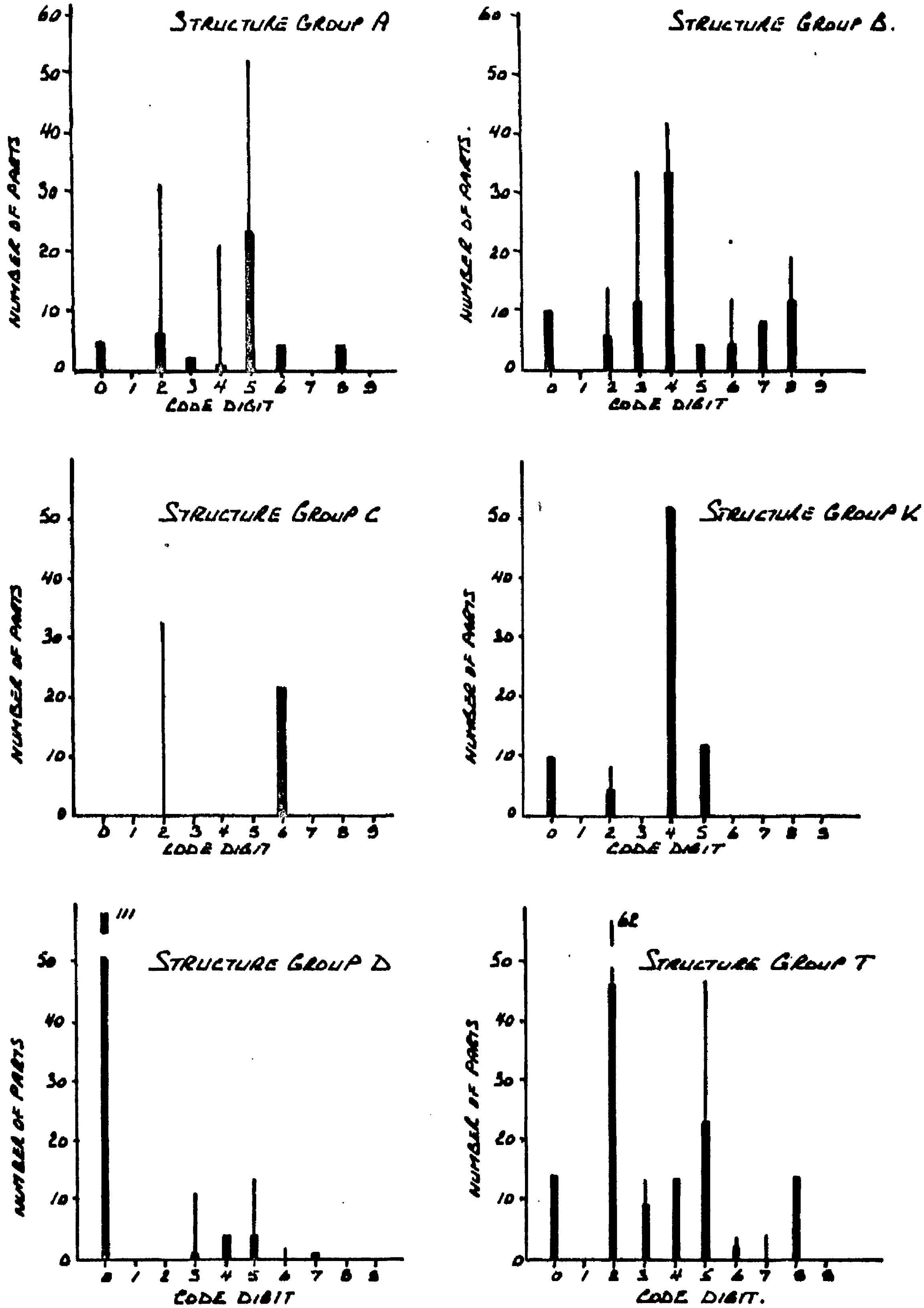
CODE DIGIT VALUES: (0) ≤40 (1) >40 & 60 (2) >60 & 80 (3) >80 & 120 (4) >120 & 150 (5) >150 & 200 (6) >200 & 250 (7) >250 & 300 (8) >300 & 425 (9) >425
DIMENSIONS - MM

FIGURE 9: ANGLE BAR DEPTH ANALYSIS BY STRUCTURE GROUP (14.000 TDWT CARGO VESSEL)



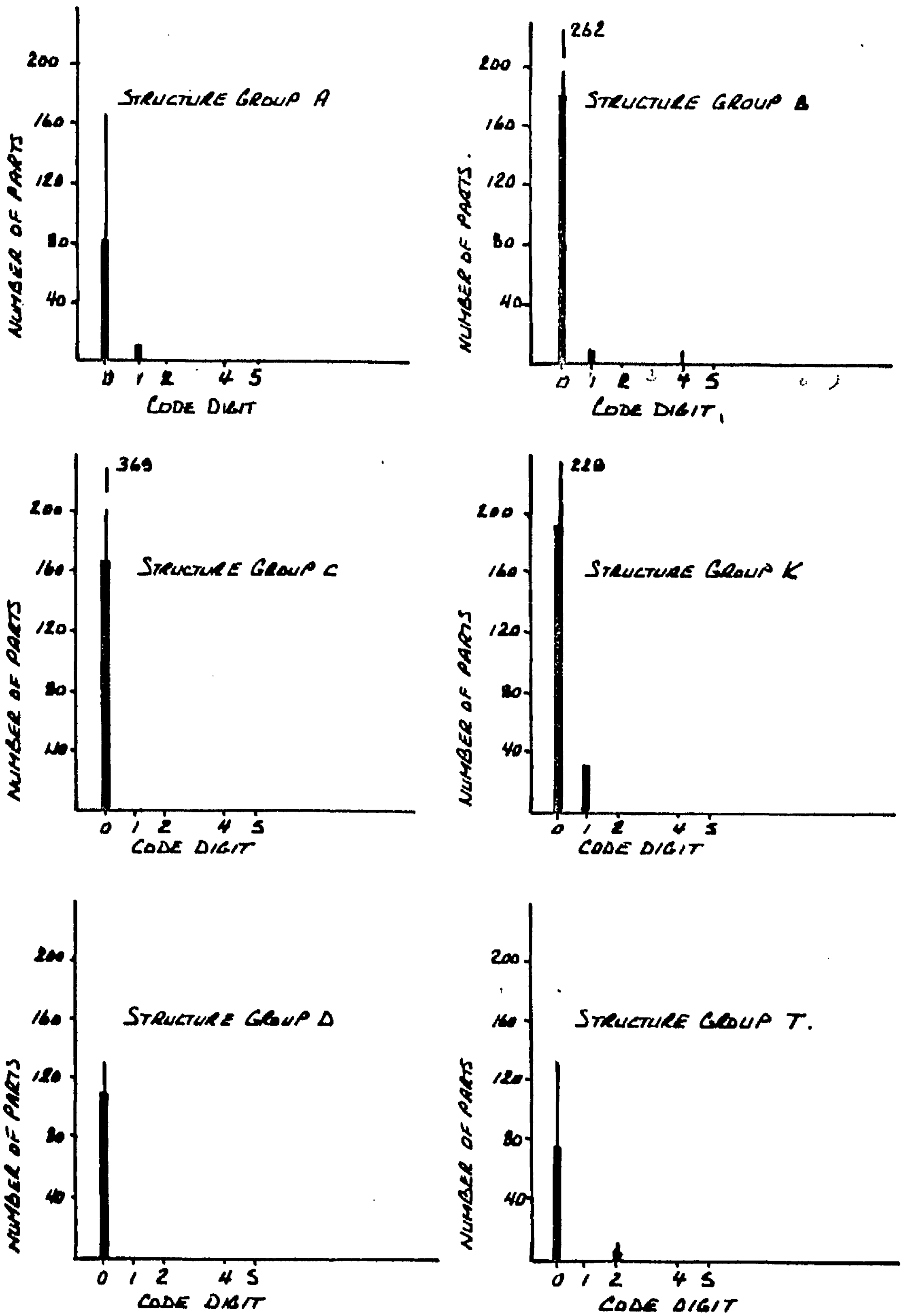
CODE DIGIT VALUES: (0) ≤ 40 (1) > 40 ≤ 60 (2) > 60 ≤ 90 (3) > 90 ≤ 120 (4) > 120 ≤ 150
(5) > 150 ≤ 200 (6) > 200 ≤ 250 (7) > 250 ≤ 300 (8) > 300 ≤ 425 (9) > 425
DIMENSIONS MM

FIGURE 10: BULB FLAT BAR DEPTH ANALYSIS BY STRUCTURE GROUP.
(14.000 T. DWT CARGO VESSEL)



CODE DIGIT VALUES: (0) ≤ 40 (1) > 40 ≤ 60 (2) > 60 ≤ 90 (3) > 90 ≤ 120 (4) > 120 ≤ 150
(5) > 150 ≤ 200 (6) > 200 ≤ 250 (7) > 250 ≤ 300 (8) > 300 ≤ 425 (9) > 425
DIMENSIONS - MM

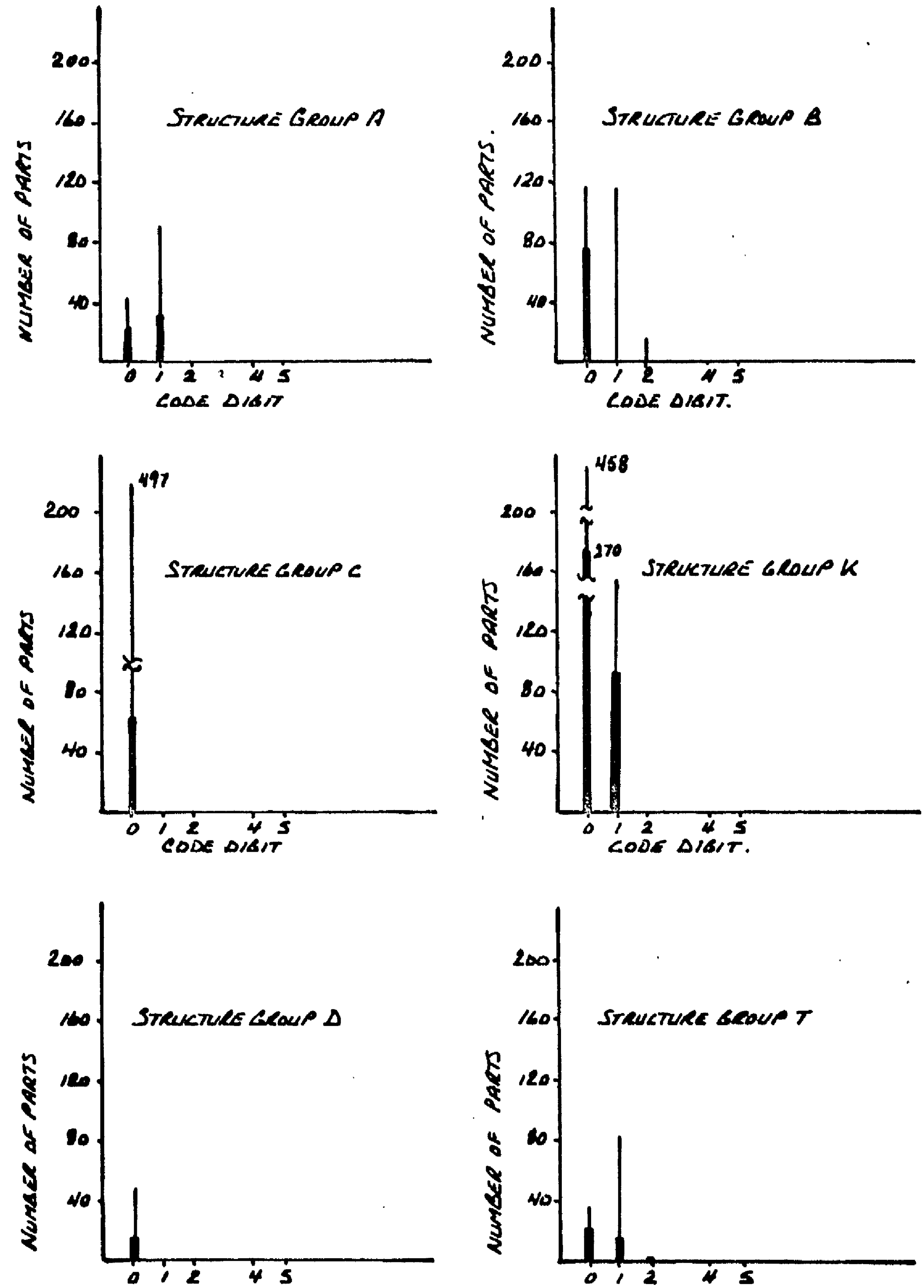
FIGURE 11 : FLAT BAR DEPTH ANALYSIS BY STRUCTURE GROUP.
(14.000 T DWT CARGO VESSEL)



CODE DIGIT VALUES: (0) NO FORMING (1) SINGLE RADIUS BEND (2) MORE THAN ONE RADIUS BEND (4) SINGLE FLANGE (5) MULTIPLE FLANGE

FIGURE 12: FORMING ANALYSIS FOR ANGLE BAR BY STRUCTURE GROUP.

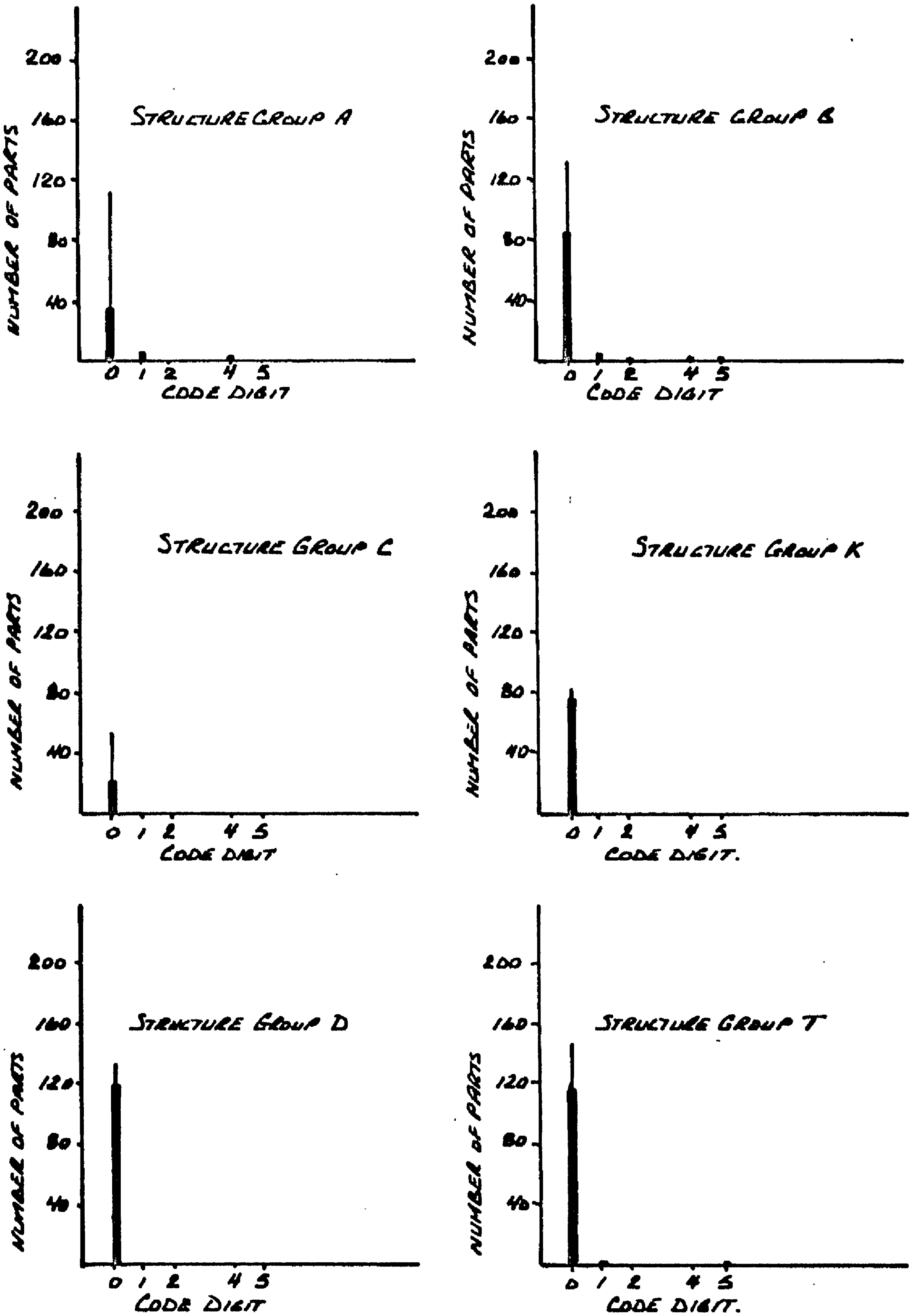
(14,000 T DWT CARGO VESSEL)



CODE DIGIT VALUES: (0) NO FORMING (1) SINGLE RADIUS BEND (2) MORE THAN ONE RADIUS BEND (4) SINGLE FLANGE (5) MULTIPLE FLANGE

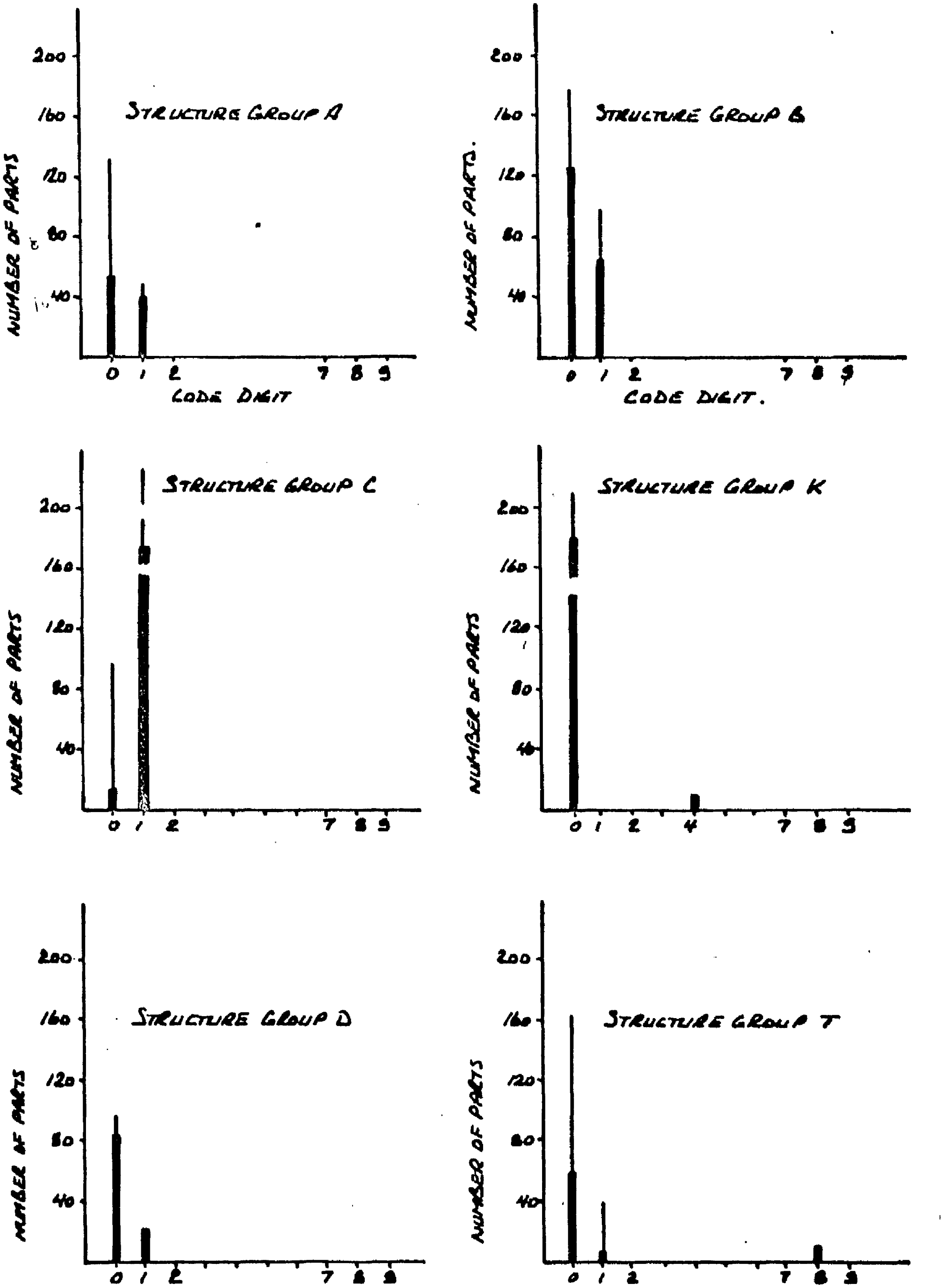
FIGURE 13: FORMING ANALYSIS FOR BULB FLAT BAR BY STRUCTURE GROUP.

(14,000 T DWT CARGO VESSEL)



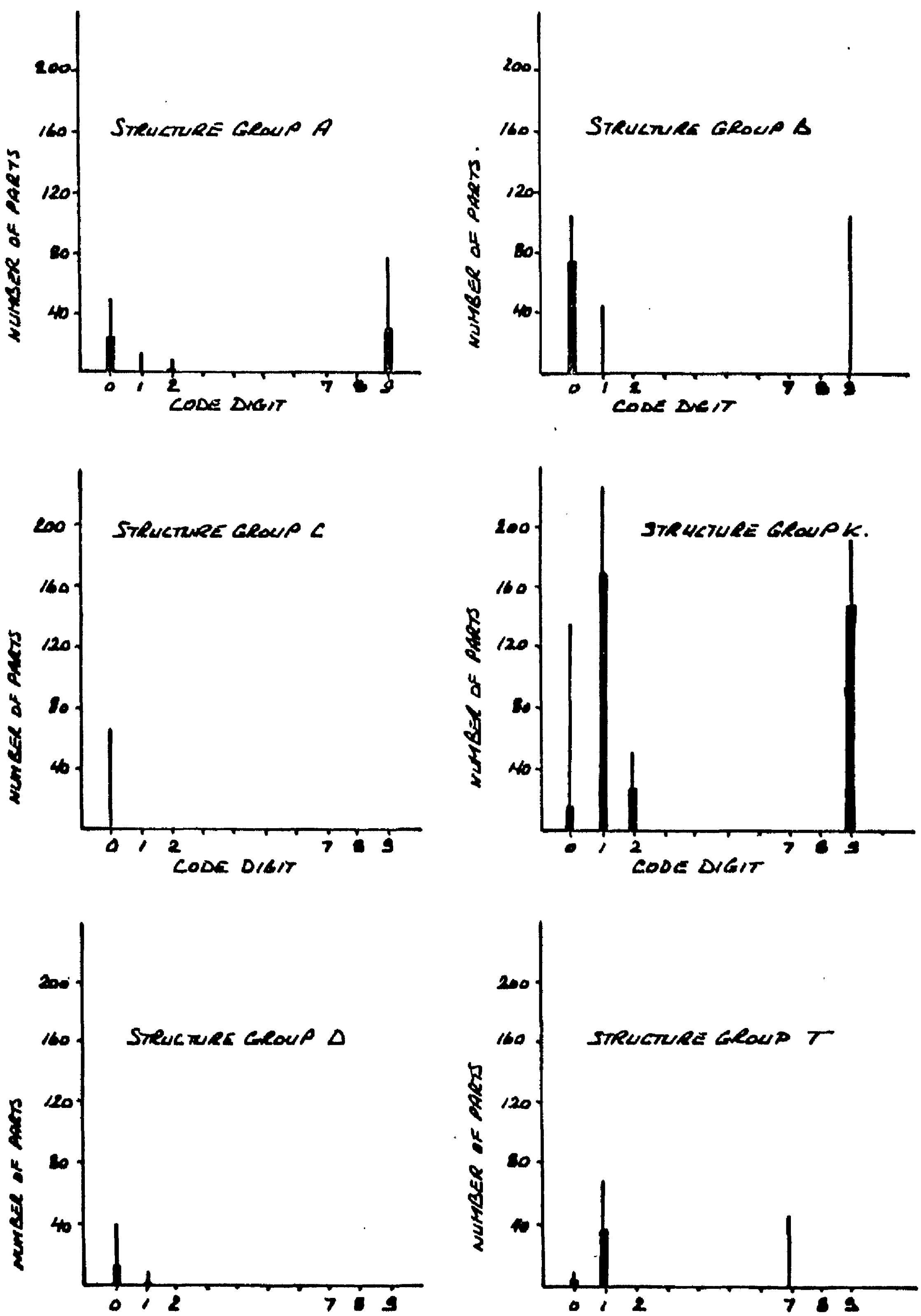
CODE DIGIT VALUES: (0) NO FORMING (1) SINGLE RADIUS BEND (2) MORE THAN ONE RADIUS BEND (4) SINGLE FLANGE (5) MULTIPLE FLANGE.

FIGURE 14: FORMING ANALYSIS FOR FLAT BAR BY STRUCTURE GROUP (14,000 T. DWT. CARGO VESSEL)



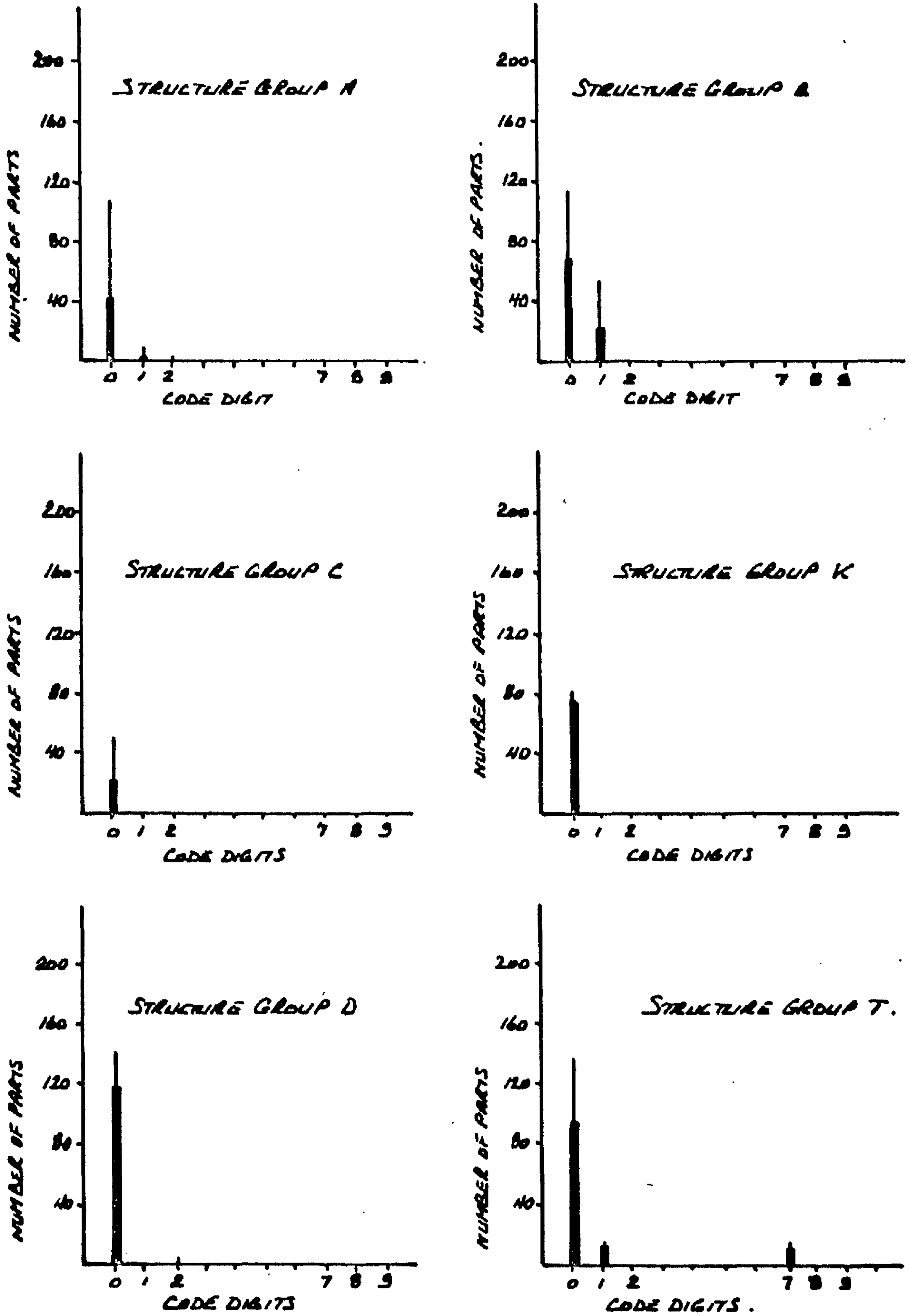
CODE DIGIT VALUES: (0) NO HOLES, SLOTS, OR DRILLING (1) NIBBLED (2) SLOTS FOR CROSS MEMBERS (4) BURNED HOLES (7) DRILLED HOLES - PATTERN (8) DRILLED HOLES - NO PATTERN (9) DRILLED HOLES AND EDGE CUTOUTS

FIGURE 15: AUXILIARY FEATURE ANALYSIS FOR ANGLE BAR BY STRUCTURE GROUP (14,000 T. DWT. CARGO VESSEL)



CODE DIGIT VALUES: (0) NO HOLES, SLOTS, OR DRILLING (1) NIBBLED (2) SLOTS FOR CROSS MEMBERS (7) DRILLED HOLES - PATTERN (8) DRILLED HOLES - NO PATTERN (9) DRILLED HOLES AND EDGE CUTOUTS

FIGURE 16: AUXILIARY FEATURE ANALYSIS FOR BULB FLAT BAR BY STRUCTURE GROUP. (14,000 T DWT CARGO VESSEL)



CODE DIGIT VALUES : (0) NO HOLES SLOTS OR DRILLING (1) NIBBLED (2) SLOTS FOR CROSS MEMBERS (7) DRILLED HOLES - PATTERN (8) DRILLED HOLES NO PATTERN (9) DRILLED HOLES AND EDGE CUTOUTS

FIGURE 17 : AUXILIARY FEATURE ANALYSIS FOR FLAT BAR BY STRUCTURE GROUP (14,000 T. DWT. CARGO VESSEL)

APPENDIX I

Program to define process routes
from descriptive code number.

```
      INTEGER B
      DIMENSION A(18),B(10),C(12)
   10 READ(5,20,END=900)A,B,NOFF,THK,C
  020 FORMAT(18A1,10I1,1X,3I1,1X,F4.1,32X,12A1)
      WRITE(6,400)
  400 FORMAT(40H========================================)
      WRITE(6,30)A,B,NOFF,THK
   30 FORMAT(18A1,1X,10I1,1X,3I1,1X,F4.1)
      WRITE(6,400)
C     CONTINUE IF NOT PLATE
      IF(B(1).GT.3)GO TO 500
      WRITE(6,410)
  410 FORMAT(21H COMPONENT IS SECTION)
C     CONTINUE IF NOT COMMON SECTION
      IF(B(1).EQ.0)GO TO 100
      WRITE(6,411)
  411 FORMAT(29H NOT COMMON=PLAN INDIVIDUALLY)
      GO TO 10
C     SPECIFY TYPE OF SECTION
  100 IF(B(2).GT.1)GO TO 110
      WRITE(6,412)
  412 FORMAT(10H FLAT BAR.)
      GO TO 140
  110 IF(B(2).GT.3)GO TO 120
      WRITE(6,413)
  413 FORMAT(14H BULB FLAT BAR)
      GO TO 140
  120 IF(B(2).GT.5)GO TO 130
      WRITE(6,414)
  414 FORMAT(10H ANGLE BAR)
      GO TO 140
  130 WRITE(6,415)
  415 FORMAT(8H CHANNEL)
C     PRINT PRIMARY OPERATIONS
  140 WRITE(6,401)
  401 FORMAT(18H          SHOTBLAST)
      WRITE(6,402)
  402 FORMAT(14H          PAINT)
C     FLAT BAR ?
      IF(B(2).GT.1)GO TO 180
C     CONTINUE IF THERE IS NO FORMING
      IF(B(3).GT.0)GO TO 160
      WRITE(6,403)
  403 FORMAT(17H          MARK OUT)
      WRITE(6,404)
  404 FORMAT(17H          CUT ENDS)
      GO TO 200
C     CONTINUE IF NOT BENT
  160 IF(B(3).GT.2)GO TO 170
      WRITE(6,403)
      WRITE(6,416)
  416 FORMAT(19H          ROLL BEND )
      WRITE(6,404)
      GO TO 200
C     MUST BE FLANGED
  170 WRITE(6,403)
```

READ AND PRINT OUT DATA RECORD.

(FOR IDENTIFICATION)

IS COMPONENT PLATE OR SECTION

DEFINES TYPE OF SECTION

PRINTS PRIMARY OPERATIONS

FLAT BAR SECTIONS (MARK-OUT, CUT, FORM.)

COMPONENTS FROM SECTION.

```
0049              WRITE(6,404)
0050              WRITE(6,417)
0051          417 FORMAT(16H          FLANGE )
0052              GO TO 200
            C     MUST BE BULB FLAT,ANGLE,OR CHANNEL
            C     CONTINUE IF THERE IS NO FORMING
0053          180 IF(B(3).GT.0)GO TO 190
0054              WRITE(6,403)
0055              WRITE(6,404)
0056              GO TO 200
            C     MUST BE'FRAME'BENT
0057          190 WRITE(6,418)
0058          418 FORMAT(20H          FRAME BEND)
0059              WRITE(6,403)
0060              WRITE(6,404)
            C     INVESTIGATE HOLES AND SLOTS
            C     CONTINUE IF NO HOLES OR SLOTS
0061          200 IF(B(4).EQ.0)GO TO 10
            C     CONTINUE IF CUTTING ONLY
0062              IF(B(4).GT.6)GO TO 210
0063              WRITE(6,406)
0064          406 FORMAT(26H          CUT HOLES & SLOTS)
0065              GO TO 10
            C     CONTINUE IF DRILLING ONLY
0066          210 IF(B(4).GT.8)GO TO 220
0067              WRITE(6,405)
0068          405 FORMAT(14H          DRILL)
0069              GO TO 10
            C     MUST BE CUT & DRILLED
0070          220 WRITE(6,406)
0071              WRITE(6,405)
0072              GO TO 10
            C     PLATES
0073          500 WRITE(6,810)
0074          810 FORMAT(19H COMPONENT IS PLATE)
            C     CONTINUE IF NON-STD MATL/FINISH
0075              IF(B(7).EQ.0)GO TO 505
0076              WRITE(6,811)
0077          811 FORMAT(37H NON-STANDARD MATL/FINISH-INVESTIGATE)
0078              GO TO 10
            C     PRIMARY OPERATIONS (S/B & PAINT)
0079          505 WRITE(6,800)
0080          800 FORMAT(18H   003   SHOTBLAST)
0081              WRITE(6,801)
0082          801 FORMAT(14H          PAINT)
            C     CONTINUE IF NOT PROFILE CUT ONLY
0083              IF(B(1).EQ.7)GO TO 530
0084              IF(B(4).GT.0)GO TO 530
            C     CONTINUE IF NOT FLAME PLANE ONLY
0085              IF(B(5).GT.0)GO TO 520
            C     CONTINUE IF NOT FLAME PLANED OR PROFILE CUT
0086              IF(B(8).GT.3)GO TO 510
0087              IF(B(9).GT.2)GO TO 510
0088              IF(B(13).GT.4)GO TO 510
            C     MUST BE GUILLOTINED
0089              WRITE(6,812)
```

OTHER SECTIONS (MARK-OUT, CUT, FORM)

ALL SECTIONS (ADDITIONAL HOLES, SLOTS, DRILLING)

INVESTIGATES MATERIAL AND FINISH

PRINTS PRIMARY OPERATIONS

```
  812 FORMAT(25H   010    MARK OUT(BY HAND)
      WRITE(6,813)
  813 FORMAT(19H   030    GUILLOTINE)
      GO TO 540
  510 WRITE(6,802)
  802 FORMAT(17H   010    MARK OUT)
      WRITE(6,803)
  803 FORMAT(20H   020    FLAME PLANE)
      WRITE(6,814)
  814 FORMAT(23H          OR PROFILE CUT)
      GO TO 540
  520 WRITE(6,802)
      WRITE(6,803)
      GO TO 540
  530 WRITE(6,815)
  815 FORMAT(20H   022    PROFILE CUT)
C     CHECK IF ANY EXTRA EDGES CHAMFERED
      IF(B(5).LT.2)GO TO 540
      WRITE(6,803)
      WRITE(6,816)
  816 FORMAT(21H          CHAMFER EDGE)
C     IF THERE IS DRILLING CONTINUE
  540 IF(B(4).LT.7)GO TO 550
      WRITE(6,817)
  817 FORMAT(14H          DRILL)
C     CONTINUE IF NOT SWEDGED & FLANGED
  550 IF(B(3).EQ.5)GO TO 600
C     CONTINUE IF NOT SWEDGED ONLY
      IF(B(3).EQ.4)GO TO 590
C     CONTINUE IF NOT FLANGED
      IF(B(3).EQ.2)GO TO 580
      IF(B(3).EQ.1)GO TO 580
C     CONTINUE IF NOT SINGLE BEND
      IF(B(3).EQ.6)GO TO 570
      IF(B(3).EQ.7)GO TO 570
C     CONTINUE IF NO CROSS BENDING
      IF(B(3).EQ.8)GO TO 560
C     MUST BE NO FORMING,GO TO NEXT RECORD
      GO TO 10
  560 WRITE(6,818)
  818 FORMAT(23H          HEAT LINE BEND)
      GO TO 10
  570 WRITE(6,819)
  819 FORMAT(18H   040    ROLL BEND)
      GO TO 10
  580 WRITE(6,804)
  804 FORMAT(16H   032    KNUCKLE)
      GO TO 10
  590 WRITE(6,805)
  805 FORMAT(15H   034    SWEDGE)
      GO TO 10
  600 WRITE(6,805)
      WRITE(6,804)
      GO TO 10
  900 STOP
      END
```

MARK-OUT AND CUTTING.

DRILLING.

FORMING.

COMPONENTS FROM PLATE.

```
#======================================
 TEST CARD  1      4700020321 00
#======================================
COMPONENT IS PLATE
  003   SHOTBLAST
        PAINT
  010   MARK OUT(BY HAND
  030   GUILLOTINE
#======================================
 TEST CARD  2      4410020344 00
#======================================
COMPONENT IS PLATE
  003   SHOTBLAST
        PAINT
  010   MARK OUT
  020   FLAME PLANE
        OR PROFILE CUT
  032   KNUCKLE
#======================================
 TEST CARD  3      4400020321 00
#======================================
COMPONENT IS PLATE
  003   SHOTBLAST
        PAINT
  010   MARK OUT(BY HAND
  030   GUILLOTINE
#======================================
 TEST CARD  4      7015020354 00
#======================================
COMPONENT IS PLATE
  003   SHOTBLAST
        PAINT
  022   PROFILE CUT
  032   KNUCKLE
#======================================
 TEST CARD  5      0500020365 00
#======================================
COMPONENT IS SECTION
ANGLE BAR
        SHOTBLAST
        PAINT
        MARK OUT
        CUT ENDS
#======================================
 TEST CARD  6      0700020447 00
#======================================
COMPONENT IS SECTION
CHANNEL
        SHOTBLAST
        PAINT
        MARK OUT
        CUT ENDS
#======================================
 TEST CARD  7      4715020333 00
#======================================
COMPONENT IS PLATE
  003   SHOTBLAST
        PAINT
  022   PROFILE CUT
  032   KNUCKLE
```

SAMPLE OUPUT FROM PROCESS ROUTE GENERATION PROGRAM

APPENDIX J

Derivation of empirical formulae for plate component perimeters and areas.

Empirical Formulae for Plate Component Perimeters and Areas

The estimation of shape perimeter lengths (ignoring holes and cutouts) is of major importance in the generation of metal cutting work content data. Shapes occuring frequently in the SD14 and B26 vessels have been fairly closely investigated but in many cases only rough estimating formulae have been derived for less frequent shapes. The estimation of area of components is of lesser importance as this will chiefly be used to allocate relatively minor collective work content (i.e. raw material plate handling and painting) to individual components. However if accuracy of area estimation is possible then weight estimating systems may be evolved.

The dimension of perimeter is length and the dimension of area is length multiplied by length, where length is estimated in both cases. Therefore perimeter estimate accuracy will automatically be greater than area estimate accuracy by a factor of four.

Components may be classified by descriptive shape code into three categories of perimeter shape and hence area:-

a) Absolutely defined shapes
b) Other shapes which occur frequently
c) Other shapes which occur infrequently

a) Absolutely defined shapes

1 Right angled triangle (code 4 1---)

(9% SD14, 0.6% B26)

Probable Shape

$L \geqq W$

W

L

Perimeter

$$P = W + L + \sqrt{W^2 + L^2}$$

Area

$$A = W\,L/2$$

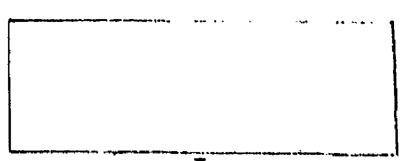
2 Rectangle (code 42---)

(30.3% SD14, 31.2% B26)

Probable shape

$L \geqq W$

W



L

Perimeter

$$P = 2(L + W)$$

Area

$$A = W \cdot L$$

b) Other shapes which occur frequently

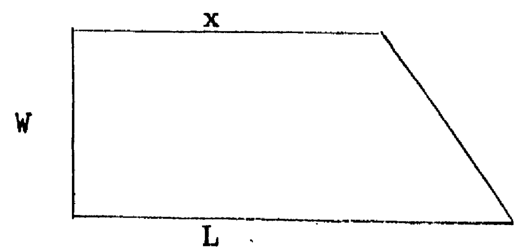
3 Four sided within rectangle (code 43---)

(16.0% SD14, 7.4% B26)

Probable shape

L = W

x (0<x<L) is not specified

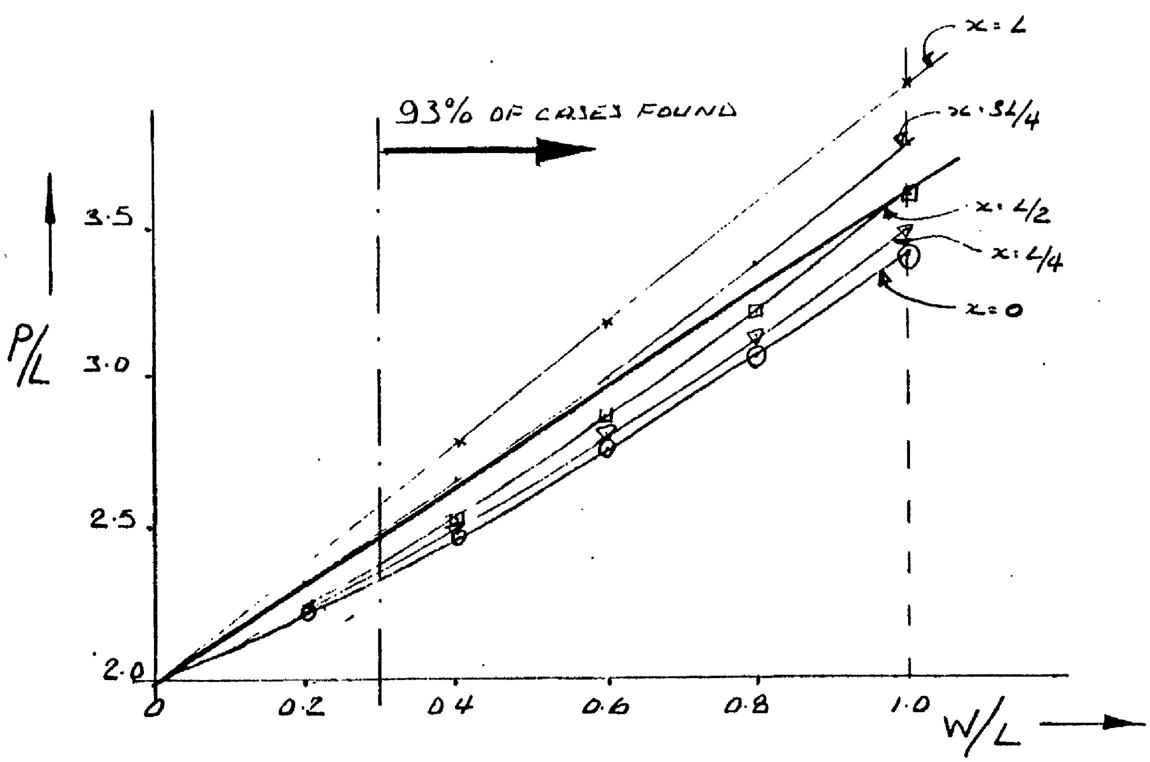


Perimeter

$$P = W + L + x + \sqrt{W^2 + (L - x)^2}$$

or $$P/_L = W/_L + 1 + x/_L + \sqrt{\left(\frac{W}{L}\right)^2 + 1/_{L^2}\,(L - x)^2}$$

Graphs of P/L against W/L were drawn for x = 0, L/4, L/2, 3L/4, and L, and are shown below



A suitable line to fit these curves is P = 2L + 1.65W. From the graph the highest estimating errors resulting from this formula will occur when W = L and x tends to zero (a triangle) and when W = L and x tends to L (a rectangle). These errors are found to be 16.7% and 8.7% respectively. Various other cases were considered and the results are tabulated overleaf:-

W	x	% error (of actual)
0.25L	0.25L	5.3
0.25L	0.5L	2.4
0.5L	0.25L	6.4
0.5L	0.5L	4.4
0.5L	0.75L	1.3
L	0.5L	0.8

Area

$$A = Wx + \frac{W}{2} \times (L - x)$$

Let $W = nL$, then

$$A = nLx + \frac{nL}{2}(L - x)$$

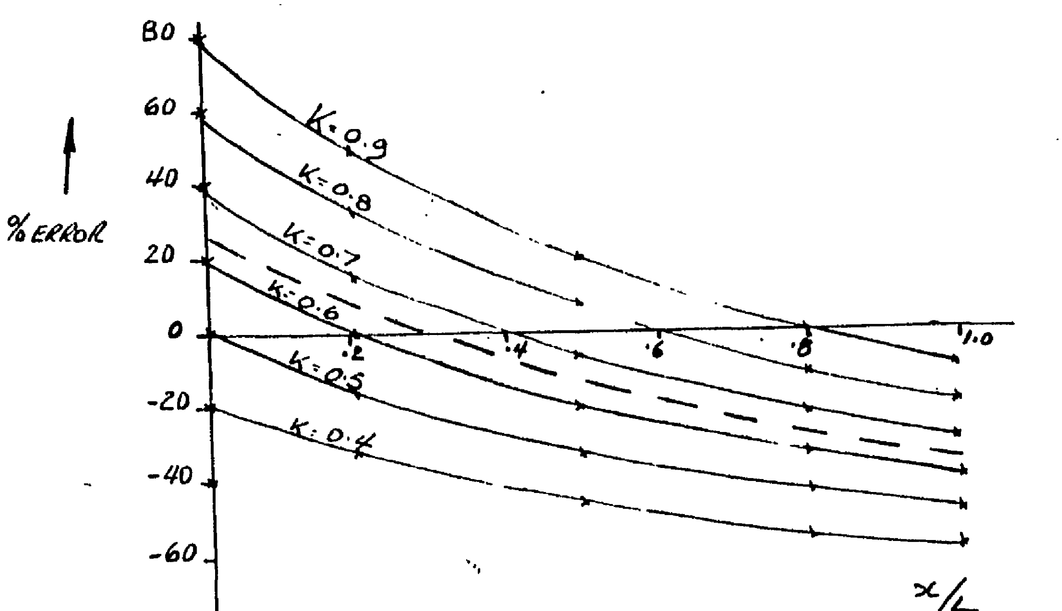
at boundary conditions ($x = 0$, $x = L$) the area is given by $A = WL/2$ and WL respectively. Therefore a formula $A = KWL$ ($0.5 < K < 1$) will give an estimated area. Then the relative

$$\text{error} = \frac{\text{estimate} - \text{actual}}{\text{actual}} = \frac{KnL^2 - nLx - nL^2/2 + nLx/2}{nLx + nL^2/2 - nLx/2}$$

$$= \frac{L(2K - 1) - x}{L + x}$$

Graphs were plotted (below) of error against x for values of K. The best value of K was found to be K = 0.65 which gives maximum errors of + 30% and -35% when x = 0 and x = L respectively.

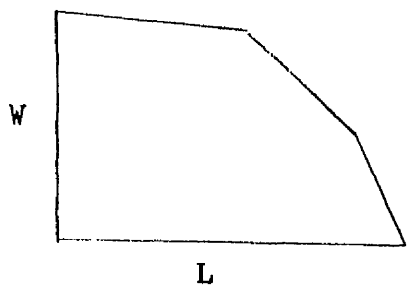
∴ A = 0.65 WL will give the best estimate



4 More than four sides with one square corner (code 47---)

(12.2% SD14, 16.2% B26)

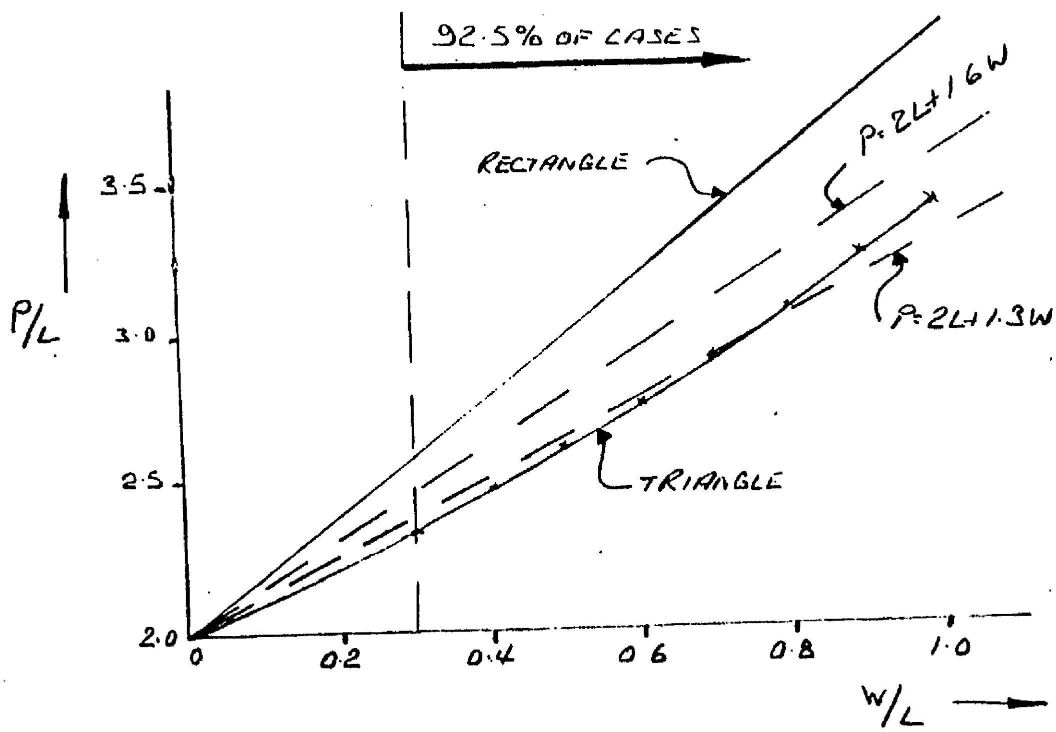
Probable shape
L ≏ W



This shape is less easily defineable using the descriptive code.

Perimeter

From an analysis of the SD14 vessel 92.5% of components having this shape have an L/W ratio between 0.3 and 1, therefore these were accepted as the boundary conditions. The boundary conditions of the shape will be a triangle and a rectangle, as for the previous shape category. A graph of P/L against W/L for these boundary conditions was drawn and is shown below.



From the graph a suitable straight line to fit these curves is P = 2L + 1.65 W. However on testing this formula for a sample of 12B components (Fore-end, SD14) it was found that P = 2L + 1.3W gave a more accurage result. This implies that the majority of these components were nearer triangular than rectangular in shape.

Area

The estimate of area will be less than that for components whose shape code is 43--- (0.65WL) but greater than that for a triangle (0.5WL) The formula A = 0.6WL will therefore result in a reasonable estimate.

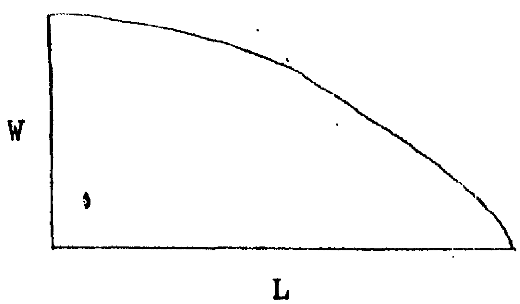
5 One side curved - two sides straight (code 70---)

(10.9% SD14, 2.7% B26)

Probable shape

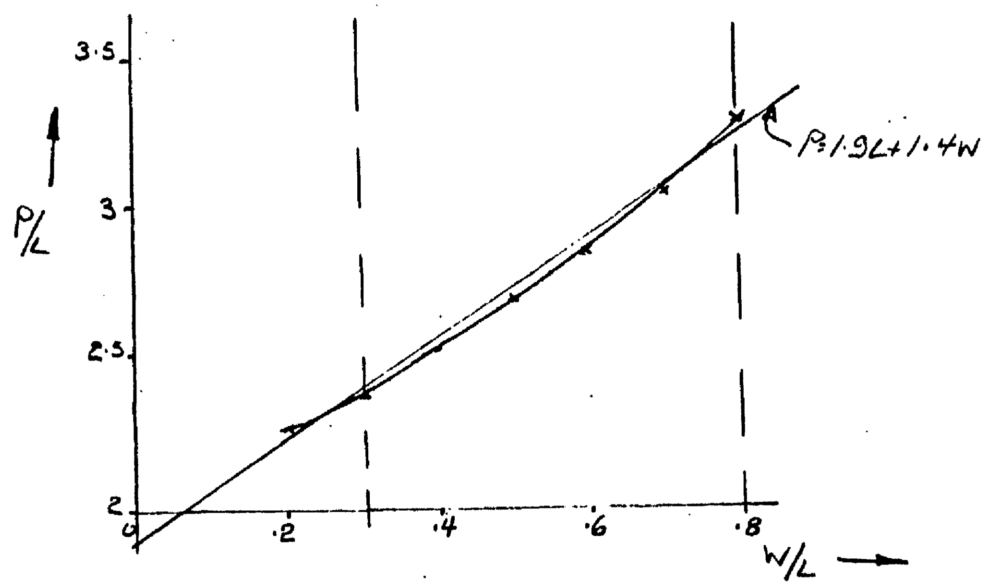
L ⇌ x

The majority of components having this shape will be found perpendicular to the shell of the ship, particularly in the bilge region.



Perimeter

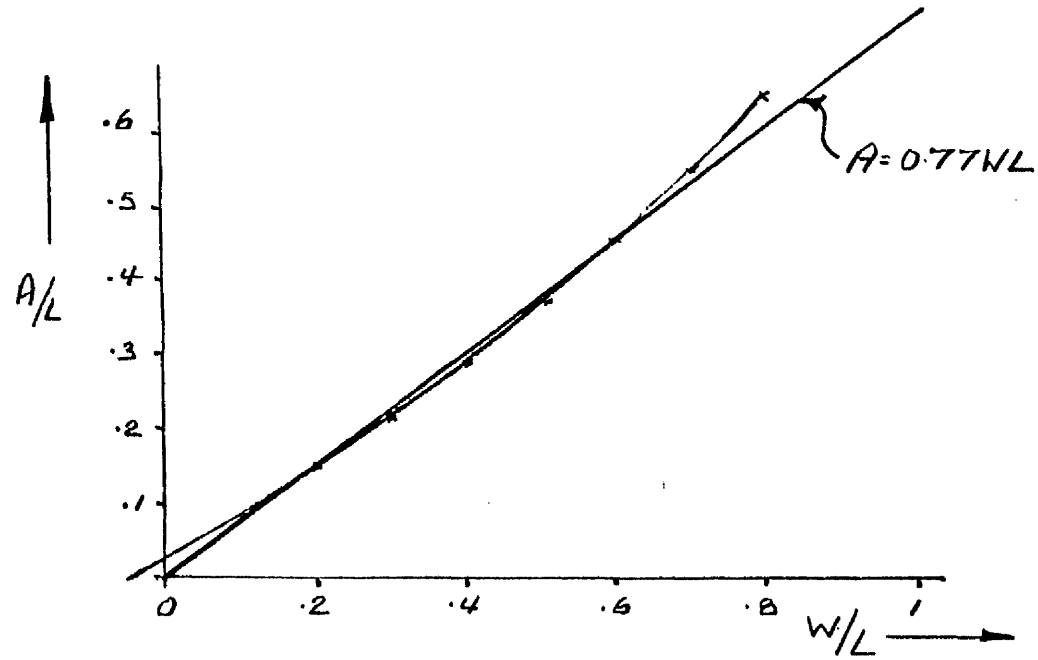
From a sample of 219 plates (SD14 total) the L/W matrix for this shape is shown in figure 1. In 96.5% of the sample the L/W ratio was between 0.3 and 0.8, typical outlines were constructed for these and intermediate values and the perimeters measured. A graph of P/L against W/L is as shown:-



A suitable straight line for this curve is P = 1.9L + 1.4W and from the graph the maximum error will occur when W/L = 0.5 and is found to be 3.7%. Other errors in the derivation will occur from the construction of the shapes (figure 2)

Area

The areas of the typical outlines (figure 2) were measured and a graph of A/L against W/L is as follows:-



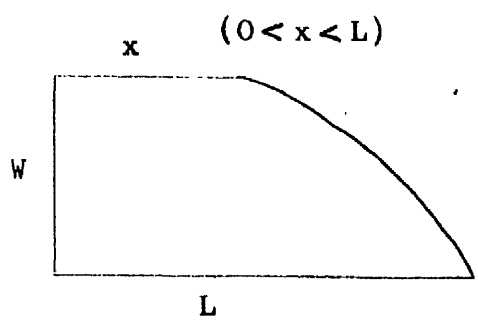
A suitable straight line to describe this curve is A = 0.77 WL which gives an error of + 10% at W = 0.4L and -5% at W = 0.8L.

6 One side curved - greater than two straight (code 71---)
(4.3% SD14, 21.2% B26)

Probable Shape

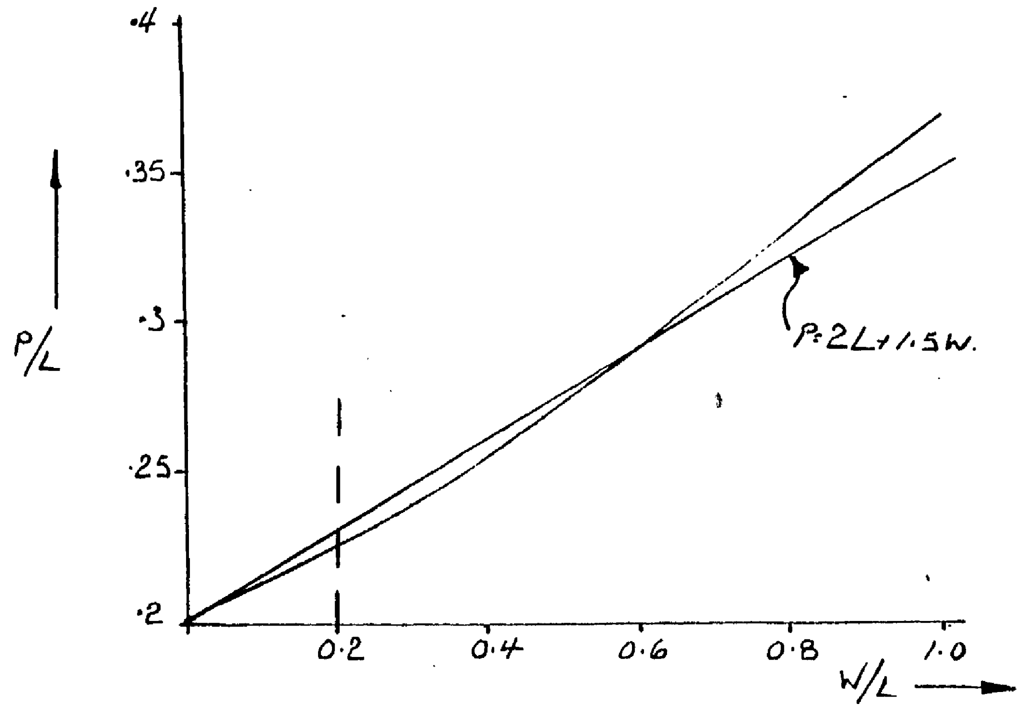
L ≥ W

The majority of components having this shape will be found perpendicular to the ship, particularly in the bilge and fore mid aft end region



Perimeter

From a sample of 539 plates (total SD14) the L/W matrix is as shown in figure 3. Typical outlines were constructed for x = L/2 with increasing values of W/fig 4). The outlines were measured and a graph of P/L against W/L is shown below.

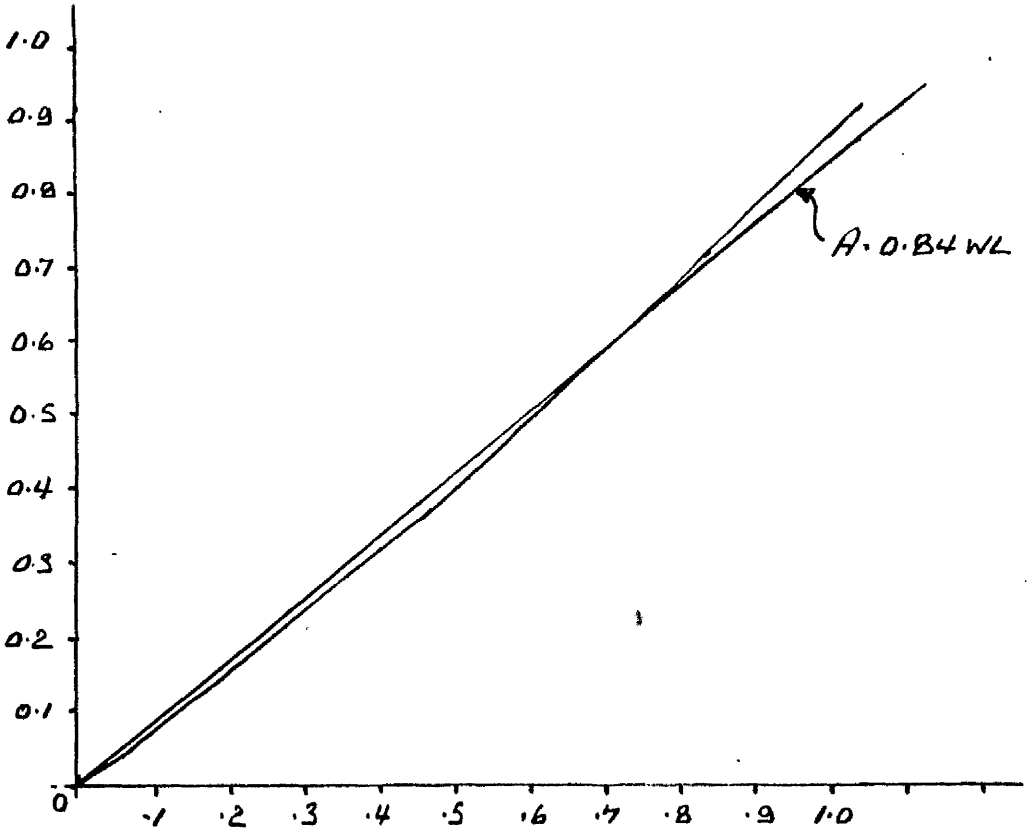


A suitable straight line to describe the curve is P = 2L + 1.5W with the maximum errors being 1.5% and 5% at W/L = 0.4 and 1 respectively. Additional errors will occur due to the construction of the curves and variation of x. An indication of the latter error was found by letting W = L/2 and varying x. The curves were drawn and measured as before and the errors were as follows:-

x	0	0.25L	0.5L	0.75L	L
Error	3%	2.2%	0.7%	0%	8.3%

Area

The areas of typical outlines were measured and a graph of A/L against W/L for x = 2 is shown overleaf.



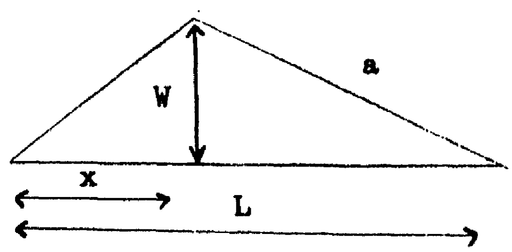
A suitable straight line to describe this curve is given by A = 0.84 WL which gives an error of 0.6% and 6% at W = 0.5L and L respectively. The boundary errors for the plate shape (at x = 0 and x = L) with W = L/2 were found to be 22% and 12% respectively.

c) Other shapes which occur infrequently

7 Three sided with no square corner (code 40---)
(0.2% SD14, 0.5% B26)

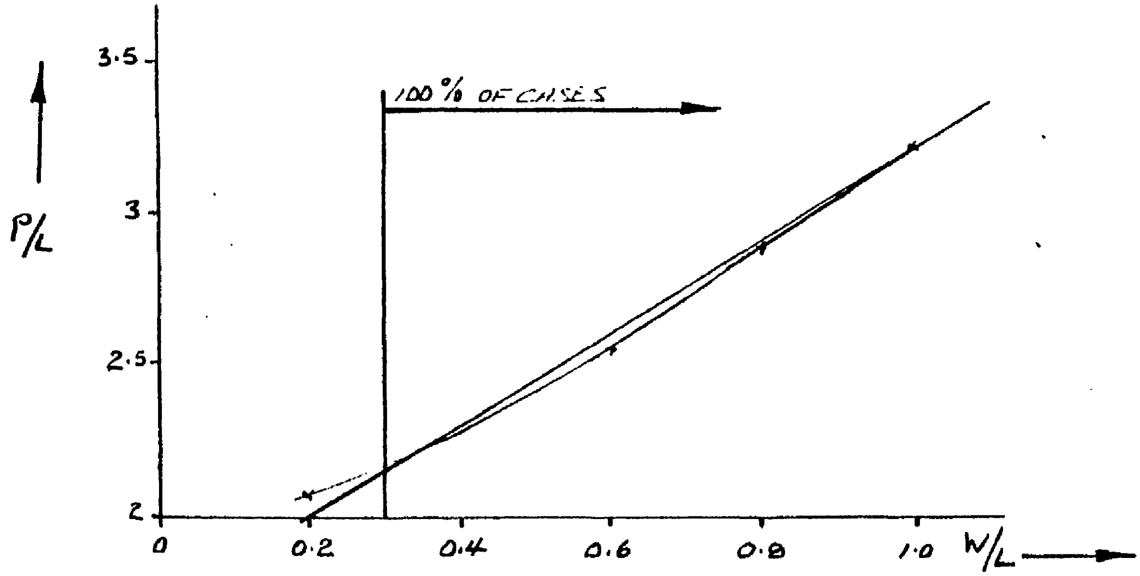
Probable shape

The boundary conditions occur when A = L (if a > L then L is not the largest size)



Perimeter

The graph below shows P/L against W/L for x = L/2
A suitable formula from the graph is P = 1.7 L + 1.55



Errors at boundary conditions (a = L) for varying values of W were found.

W	L/4	L/E	3L/4	L 3/4
a	L	L	L	L
Error	16%	5.3%	3.8%	1.3%

In all nine cases found in the SD14 W/L was greater than 0.3

Area

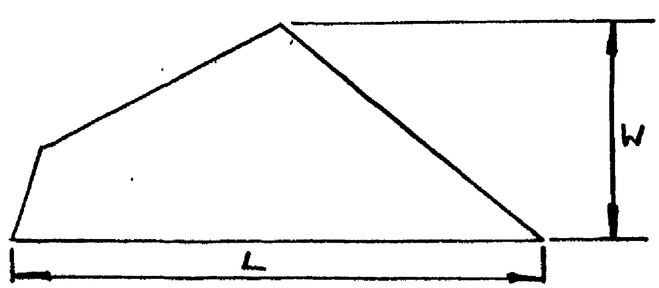
The area of the shape is given by A = WL/Z. This is an absolute (not empirical) formula.

8 Four sides and no square corner (code 44---)

(7.7% SD14, 3.2% B26)

Probable shape

L ≑ W



Perimeter

A formula P = 2L + 1.3W based on that for four sided within a rectangle (code 43---) was tried on a sample of 98 components (fore-end SD14) It was found to give an over-estimate of 4.5% on components having this shape resulting in a 0.5% overestimate for the whole structure block.

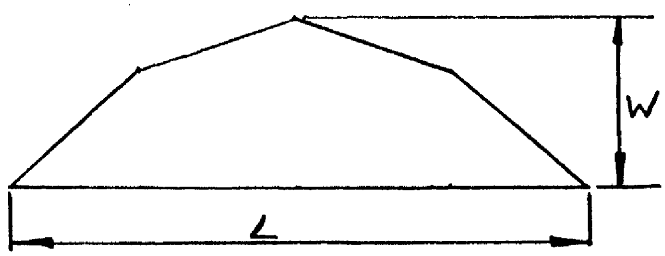
Area

The areas at the boundary conditions are A = 0.5WL (triangle) and A = 0.65WL (four sided within rectangle). A formula A ≐ 0.58 WL will therefore give a rough estimate of the area.

9 Four sides with one long side (code 46---)

(0.2% SD14, 0% B26)

Probable shape



Perimeter

A formula of P = 2L + W results in a 5% underestimate for the five components having this shape found in the FE and DBE structure groups of the SD14.

Area

The areas at the boundary conditions are A = 0.5WL (triangle) and A = WL (rectangle). By definition, however, this shape will resemble a triangle more than a rectangle and therefore A = 0.6WL will give a reasonable estimate.

10 More than four sides - no square corner (code 48---)

Perimeter

Similar to four sided with no square corner (code 44---) a formula P = 2L + 1.3W results in an underestimate of 0.5% on the total component perimeter of the SD14 fore-end.

Area

An estimate of A = 0.8LW will result in a reasonable overestimate as nesting of these parts is more difficult and material will be 'wasted'

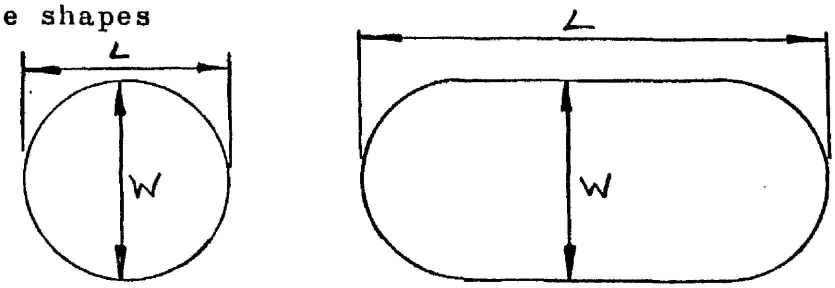
11 Many sides curved (code 72---)

(2.6% SD14, 2.6% B26)

Components having this shape fall into two categories, small covers and larger bulkheads.

a) Small covers will be round or 'eliptical'

Probable shapes



<u>Perimeter</u>

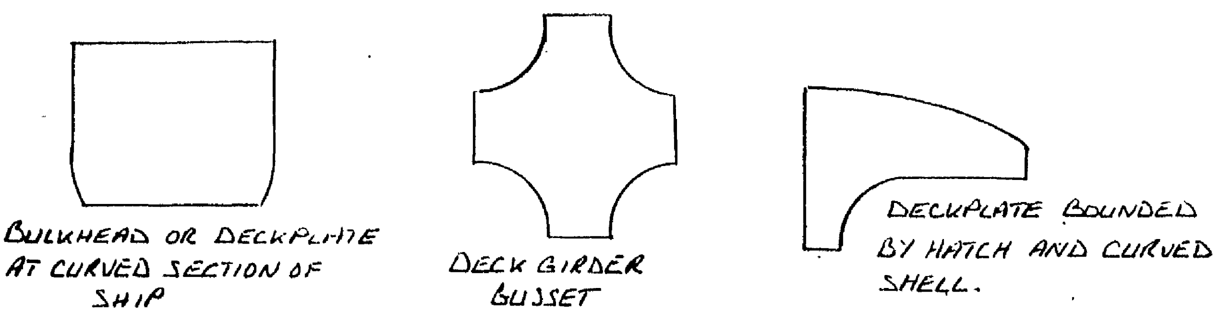
For the circle $P = \overline{11}W$ and for the 'elipse' $P = 11W + 2(L - W)$

However $P = 11W + 2(L - W)$ is applicable to both cases ($L = W$ for circle)

<u>Area</u>

For the circle $A = 11W^2/4$ and for the 'elipse' $A = 11W^2/4 + W(L-W)$
Again $A = 11W^2/4 + W(L-W)$ is applicable to both

b) Larger components are less easily defineable. The probable shape will vary with structure group but typical outlines are shown below.



<u>Perimeter</u>

A formula $P = 2L + 1.5W$ gives an underestimate of 2.8% on the perimeters of 26 components having this shape found in the fore-end of the SD14.

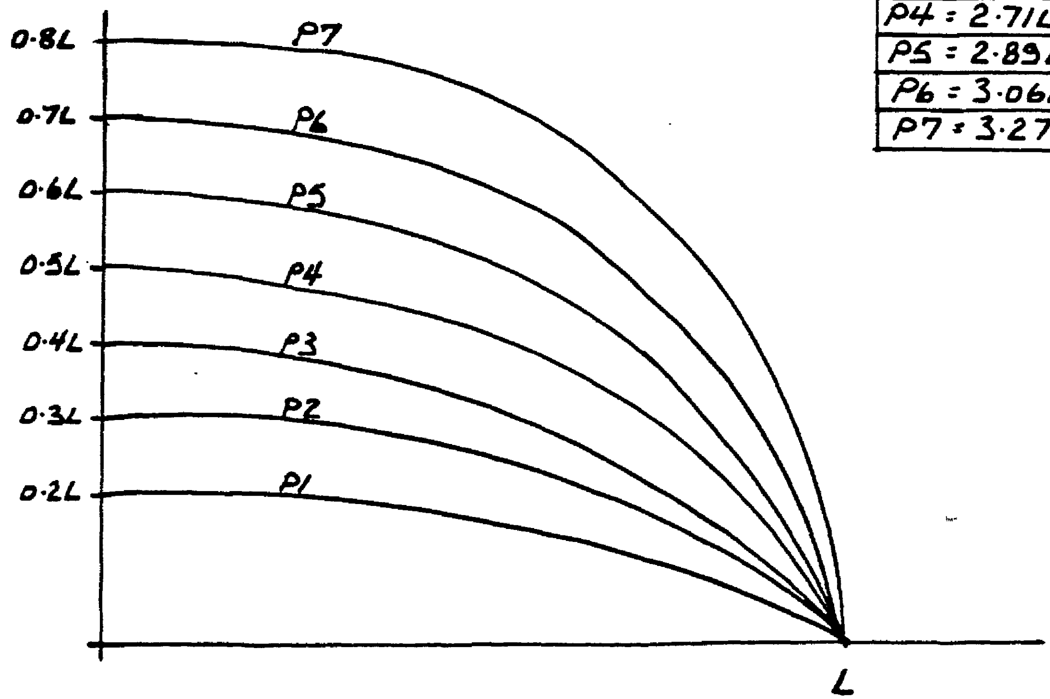
<u>Area</u>

A formula of $A = 0.85WL$ will in most cases result in an over-estimate but again frequency is small and nesting is difficult. Therefore an overestimation of area is justified.

LENGTH \ WIDTH	0 L.T. 300 MM	1 300 -450 MM	2 450 -600 MM	3 600 -900 MM	4 900 -1200 MM	5 1200 -1600 MM	6 1600 -2000 MM	7 2000 -2500 MM	8 2500 -3000 MM	9 G.T. 3000 MM	TOTALS
0 L.T. 300 MM											
1 300-600 MM											
2 600-1000 MM											
3 1000-1500 MM				2	6						8
4 1500-2500 MM				2	145	8					155
5 2500-4000 MM					23	14					37
6 4000-6000 MM					2	1	2	2	2		9
7 6000-7500 MM								2	2		4
8 7500-9000 MM									4	2	6
9 G.T. 9000 MM											
TOTALS				4	176	23	2	4	8	2	219

CODE:
- (double line) MIDPOINT RATIO G.T. 0·3 (216 COMP'S = 98·8%)
- (heavy line) MIDPOINT RATIO G.T. 0·2 (219 COMP'S = 100 %)
- (dashed line) MIDPOINT RATIO L.T. 0·8 (G.T·3 L.T·8 = 211 COMP'S = 96·5%)

FIGURE 1: LENGTH/WIDTH MATRIX FOR COMPONENTS HAVING ONE CURVED AND TWO STRAIGHT SIDES.



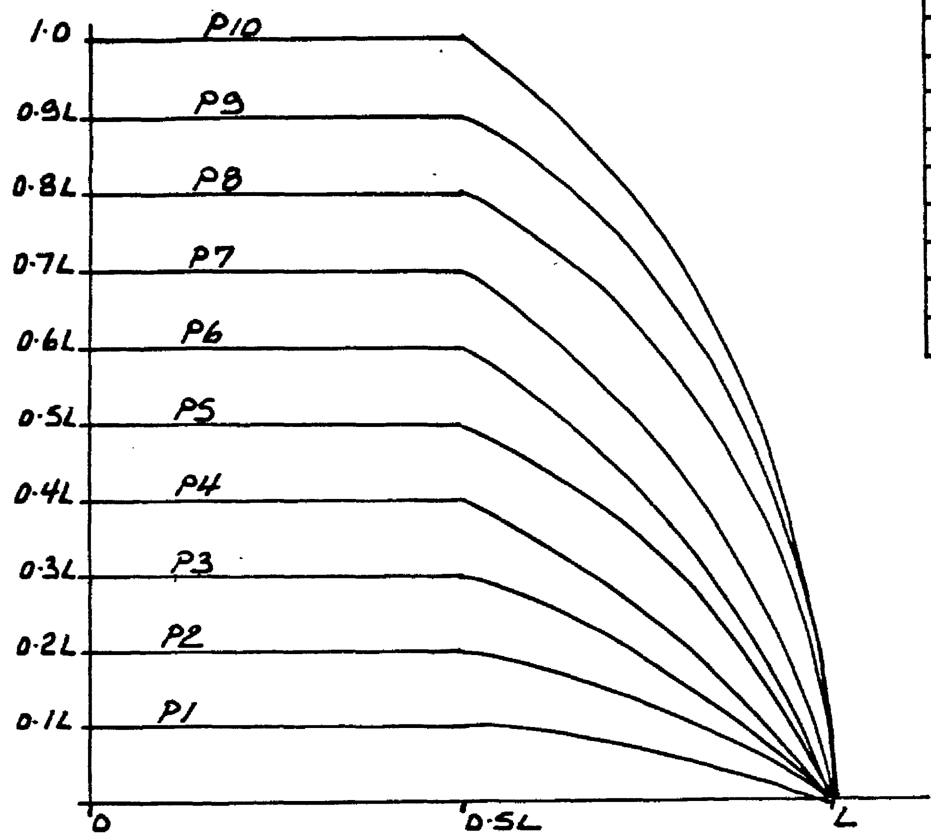
P1 = 2·25L	A1 = ·143
P2 = 2·4L	A2 = ·220
P3 = 2·55L	A3 = ·273
P4 = 2·71L	A4 = ·366
P5 = 2·89L	A5 = ·451
P6 = 3·06L	A6 = ·541
P7 = 3·27L	A7 = ·644

FIGURE 2: PERIMETER AND AREA FOR TYPICAL OUTLINES OF COMPONENTS HAVING ONE SIDE CURVED AND TWO STRAIGHT SIDES.

WIDTH / LENGTH.	0 L.T. 300 MM	1 300 -450 MM	2 450 -600 MM	3 600 -900 MM	4 900 -1200 MM	5 1200 -1600 MM	6 1600 -2000 MM	7 2000 -2500 MM	8 2500 -3000 MM	9 G.T. 3000 MM	TOTALS
0 L.T. 300 MM	2										2
1 300-600 MM	2										2
2 600-1000 MM		2	24	35							61
3 1000-1500 MM	1		28	93	22						144
4 1500-2500 MM	1	4		2	26	16	18	13			80
5 2500-4000 MM				2	40	13	16	14	1		86
6 4000-6000 MM					32	22	18	23	8		103
7 6000-7500 MM					6	2	4	11	16		39
8 7500-9000 MM						2	6	2	2		12
9 G.T. 9000 MM							2	2	4	2	10
TOTALS	6	6	52	132	126	55	64	65	31	2	539

CODE: ━━━ MIDPOINT RATIO G.T. 0.3 (451 COMP³S = 83.7%)
- - - - - MIDPOINT RATIO G.T. 0.2 (525 COMP³S = 97.5%)

FIGURE 3: LENGTH/WIDTH MATRIX FOR COMPONENTS HAVING ONE SIDE CURVED AND MORE THAN TWO STRAIGHT SIDES.



P1 = 2·14L	A1 = 0·078
P2 = 2·28L	A2 = 0·156
P3 = 2·42L	A3 = 0·235
P4 = 2·57L	A4 = 0·324
P5 = 2·73L	A5 = 0·405
P6 = 2·91L	A6 = 0·481
P7 = 3·11L	A7 = 0·575
P8 = 3·30L	A8 = 0·682
P9 = 3·50L	A9 = 0·776
P10 = 3·69L	A10 = 0·869

FIGURE 4: PERIMETER AND AREA FOR TYPICAL OUTLINES OF COMPONENTS HAVING ONE SIDE CURVED AND TWO STRAIGHT SIDES.

APPENDIX K

Programs to estimate plate component perimeters from descriptive code numbers.

```
      INTEGER B
      DIMENSION B(10),C(11)
010   READ(5,20,END=300)A,NBLOC,NUNIT,B,NOFF,THK,C
020   FORMAT(2X,A1,I1,I1,13X,10I1,1X,I3,1X,F4.1,32X,11A1)
      IF(NBLOC.NE.1)GO TO 10
      CP=0
      D1=0
      D2=0
      IF(B(9).EQ.0)D1=250
      IF(B(9).EQ.1)D1=450
      IF(B(9).EQ.2)D1=800
      IF(B(9).EQ.3)D1=1250
      IF(B(9).EQ.4)D1=1600
      IF(B(9).EQ.5)D1=3250
      IF(B(9).EQ.6)D1=5000
      IF(B(9).EQ.7)D1=6750
      IF(B(9).EQ.8)D1=8250
      IF(B(9).EQ.9)D1=11000
      IF(B(10).EQ.0)D2=200
      IF(B(10).EQ.1)D2=375
      IF(B(10).EQ.2)D2=525
      IF(B(10).EQ.3)D2=750
      IF(B(10).EQ.4)D2=1050
      IF(B(10).EQ.5)D2=1400
      IF(B(10).EQ.6)D2=1800
      IF(B(10).EQ.7)D2=2250
      IF(B(10).EQ.8)D2=2750
      IF(B(10).EQ.9)D2=3000
      IF(B(1).NE.4)GO TO 100
      IF(B(2).EQ.0)CP=1.7*D1+1.55*D2
      IF(B(2).EQ.1)CP=D1+D2+(D1**2+D2**2)**0.5
      IF(B(2).EQ.2)CP=2*(D1+D2)
      IF(B(2).EQ.3)CP=2*D1+1.65*D2
      IF(B(2).EQ.4)CP=2*D1+1.3*D2
      IF(B(2).EQ.6)CP=2*D1+D2
      IF(B(2).EQ.7)CP=2*D1+1.3*D2
      IF(B(2).EQ.8)CP=2*D1+1.3*D2
      GO TO 200
100   IF(B(1).NE.7)GO TO 10
      IF(B(2).LT.1)GO TO 40
      IF(B(2).LT.2)GO TO 50
      IF(B(2).LT.3)GO TO 60
      GO TO 200
060   IF(B(9).LE.2)CP=3.14*D1+2*(D1-D2)
      IF(B(9).GT.2)CP=2*D1+1.5*D2
      GO TO 200
050   CP=2*D1+1.5*D2
      GO TO 200
040   CP=2*D1+1.41*D2
200   WRITE(6,30)C,A,NBLOC,NUNIT,B,NOFF,THK,D1,D2,CP
030   FORMAT(2X,11A1,A1,I1,I1,2X,10I1,2X,I3,2X,F4.1,
     C2X,F9.2,2X,F9.2,F12.2)
      PUNCH 70,C,A,NBLOC,NUNIT,B,NOFF,THK,CP
070   FORMAT(2X,11A1,A1,I1,I1,1X,10I1,1X,I3,1X,F4.1,1X,F12.2)
      GO TO 10
300   STOP
```

PROGRAM TO ESTIMATE COMPONENT PERIMETER

(PROGRAM 1)

ENTRY POINT= 0000H000

COMPONENT NUMBER	CODE NUMBER	Nº. OFF	THICK-NESS	LENGTH MM	WIDTH MM	ESTIMATED PERIMETER.
DBEC0921A11	4205220475	1	12.5	6750.00	1400.00	16300.00
DBEC0471A11	4200020544	2	18.0	1600.00	1050.00	5300.00
DBEC0581A11	4205020544	2	18.0	1600.00	1050.00	5300.00
DBEC0451A11	4205020544	4	18.0	1600.00	1050.00	5300.00
DBEC1411A11	4200020523	1	18.0	800.00	750.00	3100.00
DBEC1401A11	4205020524	2	18.0	800.00	1050.00	3700.00
DBEC1391A11	4205020523	2	18.0	[illegible]	750.00	3100.00
DBEC1381A11	4205020524	2	18.0	[illegible]	1050.00	3700.00
DBEC0461A11	4205020523	2	18.0	[illegible]	750.00	3100.00
DBEC1341A11	4205020524	2	18.0	800.00	1050.00	3700.00
DBEC0601A11	4205020523	2	18.0	800.00	750.00	3100.00
DBEC1351A11	4205020524	2	18.0	800.00	1050.00	3700.00
DBEC0901A11	4200020484	2	12.5	8250.00	1050.00	18600.00
DBEC1331A11	4209020523	1	18.0	800.00	750.00	3100.00
DBEC0951A11	4205320675	2	25.5	6750.00	1400.00	16300.00
DBEC0381A11	4200020543	2	18.0	1600.00	750.00	4700.00
DBEC0361A11	4205020543	2	18.0	1600.00	750.00	4700.00
DBEC0371A11	4205020543	11	18.0	1600.00	750.00	4700.00
DBEC0371A11	4205020543	1	18.0	1600.00	750.00	4700.00
DBEC0981A11	4200320675	2	25.5	6750.00	1400.00	16300.00
DBEC1291A11	7102020445	2	12.5	1600.00	1400.00	5300.00
DBEC1281A11	7102020445	2	12.5	1600.00	1400.00	5300.00
DBEC0011A11	7105020445	2	10.5	1600.00	1400.00	5300.00
DBEC0011A11	7105020445	2	10.5	1600.00	1400.00	5300.00
DBEC0011A11	7105020445	2	10.5	1600.00	1400.00	5300.00
DBEC0051A11	7102020445	2	12.5	1600.00	1400.00	5300.00
DBEC0051A11	4202020445	2	12.5	1600.00	1400.00	6000.00
DBEC0011A11	4205020445	2	10.5	1600.00	1400.00	6000.00
DBEC1001A11	7105220475	2	10.5	6750.00	1400.00	15600.00
DBEC1311A11	7000020445	2	12.5	1600.00	1400.00	5174.00
DBEC0741A11	7100020423	2	12.5	800.00	750.00	2725.00
DBEC1301A11	7000020455	2	12.5	3250.00	1400.00	8474.00
DBEC0271A11	7005020455	2	10.5	3250.00	1400.00	8474.00
DBEC0261A11	7105020455	2	10.5	3250.00	1400.00	8600.00
DBEC0251A11	7105020455	2	10.5	3250.00	1400.00	8600.00
DBEC0241A11	7000020455	2	12.5	3250.00	1400.00	8474.00
DBEC0231A11	7000020455	2	12.5	3250.00	1400.00	8474.00
DBEC0221A11	7005020455	2	10.5	3250.00	1400.00	8474.00
DBEBA011A11	4700020300	6	10.0	250.00	200.00	760.00
DBEC0911A12	4605200595	1	13.0	11000.00	1400.00	23400.00
DBEC0891A12	4200020464	2	12.5	5000.00	1050.00	12100.00
DBEC0711A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0561A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0691A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0551A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0681A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0541A12	4205020523	2	18.0	800.00	750.00	3100.00
DBEC0671A12	4202020523	1	18.0	800.00	750.00	3100.00
DBEC0661A12	4202020523	1	18.0	800.00	750.00	3100.00

OUTPUT OF ESTIMATED PLATE PERIMETERS

(PROGRAM 1)

```
      INTEGER B
      DIMENSION A(14),B(10),N(11),TESTP(11),TACTP(11)
      DO 10 I=1,11
      N(I)=0
      TESTP(I)=0
      TACTP(I)=0
  010 CONTINUE
  020 READ(5,30,END=500)A,B,NOFF,ESTP,ACTP
  030 FORMAT(2X,14A1,1X,10I1,1X,I3,6X,F12.2,1X,F8.2)
      ERROR=ACTP-ESTP
      PERROR=ERROR*100/ACTP
      WRITE(6,60)A,B,NOFF,ESTP,ACTP,ERROR,PERROR
  060 FORMAT(2X,14A1,1X,10I1,1X,I3,1X,F8.2,1X,F8.2,1X,F8.2,1X,F5.1)
      IF(B(1).EQ.7)GO TO 300
      IF(B(2).EQ.0)GO TO 200
      IF(B(2).EQ.1)GO TO 210
      IF(B(2).EQ.2)GO TO 220
      IF(B(2).EQ.3)GO TO 230
      IF(B(2).EQ.4)GO TO 240
      IF(B(2).EQ.6)GO TO 250
      IF(B(2).EQ.7)GO TO 260
      IF(B(2).EQ.8)GO TO 270
      GO TO 20
  200 TESTP(1)=TESTP(1)+NOFF*ESTP
      TACTP(1)=TACTP(1)+NOFF*ACTP
      N(1)=N(1)+NOFF
      GO TO 20
  210 TESTP(2)=TESTP(2)+NOFF*ESTP
      TACTP(2)=TACTP(2)+NOFF*ACTP
      N(2)=N(2)+NOFF
      GO TO 20
  220 TESTP(3)=TESTP(3)+NOFF*ESTP
      TACTP(3)=TACTP(3)+NOFF*ACTP
      N(3)=N(3)+NOFF
      GO TO 20
  230 TESTP(4)=TESTP(4)+NOFF*ESTP
      TACTP(4)=TACTP(4)+NOFF*ACTP
      N(4)=N(4)+NOFF
      GO TO 20
  240 TESTP(5)=TESTP(5)+NOFF*ESTP
      TACTP(5)=TACTP(5)+NOFF*ACTP
      N(5)=N(5)+NOFF
      GO TO 20
  250 TESTP(6)=TESTP(6)+NOFF*ESTP
      TACTP(6)=TACTP(6)+NOFF*ACTP
      N(6)=N(6)+NOFF
      GO TO 20
  260 TESTP(7)=TESTP(7)+NOFF*ESTP
      TACTP(7)=TACTP(7)+NOFF*ACTP
      N(7)=N(7)+NOFF
      GO TO 20
  270 TESTP(8)=TESTP(8)+NOFF*ESTP
      TACTP(8)=TACTP(8)+NOFF*ACTP
      N(8)=N(8)+NOFF
      GO TO 20
  300 IF(B(2).EQ.0)GO TO 310
      IF(B(2).EQ.1)GO TO 320
      IF(B(2).EQ.2)GO TO 330
      GO TO 20
  310 TESTP(9)=TESTP(9)+NOFF*ESTP
      TACTP(9)=TACTP(9)+NOFF*ACTP
      N(9)=N(9)+NOFF
      GO TO 20
  320 TESTP(10)=TESTP(10)+NOFF*ESTP
      TACTP(10)=TACTP(10)+NOFF*ACTP
      N(10)=N(10)+NOFF
      GO TO 20
  330 TESTP(11)=TESTP(11)+NOFF*ESTP
      TACTP(11)=TACTP(11)+NOFF*ACTP
      N(11)=N(11)+NOFF
      GO TO 20
  500 WRITE(6,50)(N(I),I=1,11)
  050 FORMAT(11I12)
      WRITE(6,40)(TESTP(I),I=1,11)
      WRITE(6,40)(TACTP(I),I=1,11)
  040 FORMAT(11F12.2)
      STOP
      END
```

PROGRAM TO COMPARE ESTIMATED AND ACTUAL PLATE COMPONENT OUTLINE PERIMETERS

(PROGRAM 2)

COMPONENT NUMBER	CODE NUMBER	Nº OFF	ACTUAL PERIMETER	ESTIMATED PERIMETER	'ERROR'	% ERROR
DBEC0901A11	4200020453	2	8000.00	7400.00	-600.00	-8.1
DBEC0921A11	4205220475	1	16300.00	16000.00	-300.00	-1.9
DBEC0471A11	4200020544	2	6100.00	5000.00	-1100.00	-22.0
DBEC0581A11	4205020544	2	6100.00	5000.00	-1100.00	-22.0
DBEC0451A11	4205020544	4	6100.00	5000.00	-1100.00	-22.0
DBEC1411A11	4200020523	1	3100.00	3300.00	200.00	6.1
DBEC1401A11	4205020524	2	3700.00	3500.00	-200.00	-5.7
DBEC1391A11	4205020523	2	3100.00	3300.00	200.00	6.1
DBEC1381A11	4205020524	2	3700.00	3500.00	-200.00	-5.7
DBEC0461A11	4205020523	2	3100.00	3400.00	300.00	8.8
DBEC1341A11	4205020524	2	3700.00	3400.00	-300.00	-8.8
DBEC0601A11	4205020524	2	3700.00	3400.00	-300.00	-8.8
DBEC1351A11	4205020523	2	3100.00	3300.00	200.00	6.1
DBEC0951A11	4205320675	2	16300.00	16000.00	-300.00	-1.9
DBEC0381A11	4200020543	2	5500.00	4100.00	-1400.00	-34.1
DBEC0361A11	4205020543	2	5500.00	4100.00	-1400.00	-34.1
DBEC0371A11	4205020543	1	5500.00	4100.00	-1400.00	-34.1
DBEC0371A11	4205020543	1	5500.00	4100.00	-1400.00	-34.1
DBEC0981A11	4200320675	2	16300.00	16000.00	-300.00	-1.9
DBEC0051A11	4202020445	2	6800.00	7100.00	300.00	4.2
DBEC0011A11	4205020445	2	6800.00	7000.00	200.00	2.9
DBEC0891A12	4200020464	2	12100.00	11800.00	-300.00	-2.5
DBEC0711A12	4205020523	2	3100.00	3400.00	300.00	8.8
DBEC0561A12	4205020523	2	3100.00	3300.00	200.00	6.1
DBEC0691A12	4205020523	2	3100.00	3500.00	400.00	11.4
DBEC0551A12	4205020523	2	3100.00	3200.00	100.00	3.1
DBEC0681A12	4205020524	2	3700.00	3500.00	-200.00	-5.7
DBEC0541A12	4205020523	2	3100.00	3200.00	100.00	3.1
DBEC0671A12	4202020523	1	3100.00	3500.00	400.00	11.4
DBEC0661A12	4202020523	1	3100.00	3500.00	400.00	11.4
DBEC0531A12	4205020523	2	3100.00	3200.00	100.00	3.1
DBEC0651A12	4205020523	2	3100.00	3500.00	400.00	11.4
DBEC0521A12	4205020523	2	3100.00	3200.00	100.00	3.1
DBEC0641A12	4205020523	2	3100.00	3600.00	500.00	13.9
DBEC0511A12	4205020523	2	3100.00	3100.00	0.0	0.0
DBEC0611A12	4204020524	2	3700.00	3700.00	0.0	0.0
DBEC0721A12	4205020522	2	2650.00	3000.00	350.00	11.7
DBEC0471A12	4204020544	1	6100.00	5000.00	-1100.00	-22.0
DBEC0471A12	4200020544	3	6100.00	5000.00	-1100.00	-22.0
DBEC0581A12	4205020544	2	6100.00	5000.00	-1100.00	-22.0
DBEC0431A12	4200020534	2	4600.00	4800.00	200.00	4.2
DBEC0481A12	4205020434	2	4600.00	4500.00	-100.00	-2.2
DBEC0371A12	4205020542	7	5050.00	4100.00	-950.00	-23.2
DBEC0361A12	4205020542	3	5050.00	4100.00	-950.00	-23.2
DBEC0421A12	4200020533	1	4000.00	4300.00	300.00	7.0
DBEC0391A12	4205020433	1	4000.00	4200.00	200.00	4.8
DBEC0941A12	4204220695	1	24800.00	21400.00	-3400.00	-15.9

OUTPUT OF COMPARISON OF ESTIMATED AND ACTUAL PLATE COMPONENT PERIMETERS (PROGRAM 2)

```
          DIMENSION A(14),N(10)
          WRITE(6,70)
      070 FORMAT(91H PART NUMBER   CODE NUMB NOFF EST.PERIM   ACT.PERIM NU H
         COLE EST.H, ERR.H, % ERR %H.ER %T.ER)
    C  PERROR(% ERR)=% ERRORIN HOLE SIZES
    C  HERROR(%H.ER)=ERROR IN TOTAL CUTTING LENGTH ESTIMATE DUE TO HOLE LENGTH
    C  ESTIMATE
    C  TERROR(%T.ER(=% ERROR DUE TO HOLE LENGTH ESTIMATE AND PERIMETER ESTIMATE.
          EHOLES=0
          ERHOLE=0
          PERROR=0
          HERROR=0
          TERROR=0
      020 READ(5,30,END=80)A,N,NOFF,ESTP,ACTP,NHOLES,HOLES
      030 FORMAT(2X,14A1,1X,10I1,1X,I3,6X,F12.2,1X,F8.2,9X,I2,1X,F5.0)
          IF(N(4).LT.3)GO TO 20
          IF(N(4).EQ.7)GO TO 20
          IF(N(4).EQ.8)GO TO 20
          IF(N(9).LT.6)GO TO 40
          EHOLES=2068*N(9)-7750
          GO TO 50
      040 EHOLES=510*N(9)+200
      050 ERHOLE=EHOLES-HOLES
          PERROR=ERHOLE*100/HOLES
          HERROR=ERHOLE*100/(HOLES+ACTP)
          TERROR=(HOLES+ACTP-ESTP-EHOLES)*100/(HOLES+ACTP)
          WRITE(6,60)A,N,NOFF,ESTP,ACTP,NHOLES,HOLES,EHOLES,ERHOLE,PERROR,
         CHERROR,TERROR
      060 FORMAT(14A1,1X,10I1,1X,I3,F12.2,1X,F8.2,I3,1X,F5.0,F7.0,F7.0,F6.1,
         CF6.1,F6.1)
          GO TO 20
      080 STOP
          END
```

PROGRAM TO ESTIMATE PLATE COMPONENT CUT-HOLE PERIMETERS AND COMPARE WITH ACTUAL PERIMETERS

(PROGRAM 3)

PART NUMBER	CODE NUMB	NOFF	EST.PERIM	ACT.PERIM	NU	HOLE	EST.H.	ERR.H.	% ERR	%H.ER	%T.ER
DBEC0661A12	4204020523	1	3100.00	3500.00	1	1350.	1220.	-130.	-9.6	-2.7	10.9
DBEC0611A12	4204020524	2	3700.00	3700.00	1	1350.	1220.	-130.	-9.6	-2.6	2.6
DBEC0471A12	4204020544	1	6100.00	5000.00	1	1350.	2240.	890.	65.9	14.0	-31.3
DBEC0051A12	4204020445	1	6800.00	7000.00	1	2000.	2240.	240.	12.0	2.7	-0.4
DBEC0981A11	4204320675	2	16300.00	16000.00	3	5350.	6726.	1376.	25.7	6.4	-7.9
DBEC0971A12	4204220695	1	24800.00	21400.00	4	8000.	10862.	2862.	35.8	9.7	-21.3
DBEC0941A12	4204220695	1	24800.00	21400.00	4	8000.	10862.	2862.	35.8	9.7	-21.3
DBEC0941A12	4204220695	1	24800.00	21400.00	4	8000.	10862.	2862.	35.8	9.7	-21.3
DBEC0721A12	4205020522	2	2650.00	3000.00	1	1350.	1220.	-130.	-9.6	-3.0	11.0
DBEC1391A11	4205020523	2	3100.00	3300.00	1	1350.	1220.	-130.	-9.6	-2.8	7.1
DBEC0461A11	4205020523	2	3100.00	3400.00	1	1350.	1220.	-130.	-9.6	-2.7	9.1
DBEC1351A11	4205020523	2	3100.00	3300.00	1	1200.	1220.	20.	1.7	0.4	4.0
DBEC0711A12	4205020523	2	3100.00	3400.00	1	1350.	1220.	-130.	-9.6	-2.7	9.1
DBEC0561A12	4205020523	2	3100.00	3300.00	1	1350.	1220.	-130.	-9.6	-2.8	7.1
DBEC0691A12	4205020523	2	3100.00	3500.00	1	1350.	1220.	-130.	-9.6	-2.7	10.9
DBEC0551A12	4205020523	2	3100.00	3200.00	1	1200.	1220.	20.	1.7	0.5	1.8
DBEC0541A12	4205020523	2	3100.00	3200.00	1	1200.	1220.	20.	1.7	0.5	1.8
DBEC0651A12	4205020523	2	3100.00	3500.00	1	1350.	1220.	-130.	-9.6	-2.7	10.9
DBEC0521A12	4205020523	2	3100.00	3200.00	1	1200.	1220.	20.	1.7	0.5	1.8
DBEC0641A12	4205020523	2	3100.00	3600.00	1	1350.	1220.	-130.	-9.6	-2.6	12.7
DBEC0531A12	4205020523	2	3100.00	3200.00	1	1200.	1220.	20.	1.7	0.5	1.8
DBEC0511A12	4205020523	2	3100.00	3100.00	1	1200.	1220.	20.	1.7	0.5	-0.5
DBEC1401A11	4205020524	2	3700.00	3500.00	1	1200.	1220.	20.	1.7	0.4	-4.7
DBEC1381A11	4205020524	2	3700.00	3500.00	1	1200.	1220.	20.	1.7	0.4	-4.7
DBEC1341A11	4205020524	2	3700.00	3400.00	1	1200.	1220.	20.	1.7	0.4	-7.0
DBEC0601A11	4205020524	2	3700.00	3400.00	1	1350.	1220.	-130.	-9.6	-2.7	-3.6
DBEC0681A12	4205020524	2	3700.00	3500.00	1	1350.	1220.	-130.	-9.6	-2.7	-1.4
DBEC0391A12	4205020433	1	4000.00	4200.00	1	1500.	1730.	230.	15.3	4.0	-0.5
DBEC0391A12	4205020433	1	4000.00	4200.00	1	1300.	1730.	430.	33.1	7.8	-4.2

OUTPUT OF HOLE PERIMETER ESTIMATES AND COMPARISON WITH ACTUAL VALUES. (PROGRAM 3)

```
      DIMENSION N(10),C(10)
      WRITE(6,10)
  010 FORMAT(T5,'PART NUMBER',T18,'CODE NUMBER',T30,'NUMBER OFF',T41,
     C'PERIMETER',T52,'HOLE LENGTH',T65,'SLOT LENGTH',T78,
     C'EST.PERIMETER')
  020 READ(8,30,END=500)A,NBLOC,NUNIT,N,NOFF,C
  030 FORMAT(2X,A1,I1,I1,13X,10I1,1X,I3,37X,10A1)
      IF(NBLOC.NE.1)GO TO 20
      CP=0
      CH=0
      CS=0
      CT=0
      D1=0
      D2=0
      IF(N(9).EQ.0)D1=250
      IF(N(9).EQ.1)D1=450
      IF(N(9).EQ.2)D1=800
      IF(N(9).EQ.3)D1=1250
      IF(N(9).EQ.4)D1=1600
      IF(N(9).EQ.5)D1=3250
      IF(N(9).EQ.6)D1=5000
      IF(N(9).EQ.7)D1=6750
      IF(N(9).EQ.8)D1=8250
      IF(N(9).EQ.9)D1=11000
      IF(N(10).EQ.0)D2=200
      IF(N(10).EQ.1)D2=375
      IF(N(10).EQ.2)D2=525
      IF(N(10).EQ.3)D2=750
      IF(N(10).EQ.4)D2=1050
      IF(N(10).EQ.5)D2=1400
      IF(N(10).EQ.6)D2=1800
      IF(N(10).EQ.7)D2=2250
      IF(N(10).EQ.8)D2=2750
      IF(N(10).EQ.9)D2=3000
      IF(N(1).NE.4)GO TO 100
      IF(N(2).EQ.0)CP=1.7*D1+1.55*D2
      IF(N(2).EQ.1)CP=D1+D2+(D1**2+D2**2)**0.5
      IF(N(2).EQ.2)CP=2*(D1+D2)
      IF(N(2).EQ.3)CP=2*D1+1.65*D2
      IF(N(2).EQ.4)CP=2*D1+1.3*D2
      IF(N(2).EQ.6)CP=2*D1+D2
      IF(N(2).EQ.7)CP=2*D1+1.3*D2
      IF(N(2).EQ.8)CP=2*D1+1.3*D2
      GO TO 200
  100 IF(N(1).NE.7)GO TO 20
      IF(N(2).LT.1)GO TO 140
      IF(N(2).LT.2)GO TO 150
      IF(N(2).LT.3)GO TO 160
      GO TO 200
  160 IF(N(9).LE.2)CP=3.14*D1+2*(D1-D2)
      IF(N(9).GT.2)CP=2*D1+1.5*D2
      GO TO 200
  150 CP=2*D1+1.5*D2
      GO TO 200
  140 CP=2*D1+1.41*D2
  200 IF(N(4).LT.3)GO TO 300
      IF(N(4).EQ.7)GO TO 300
      IF(N(4).EQ.8)GO TO 300
      IF(N(9).LT.6)GO TO 210
      CH=2068*N(9)-7750
      GO TO 300
  210 CH=510*N(9)+200
  300 IF(N(4).EQ.2)GO TO 310
      IF(N(4).EQ.5)GO TO 310
      GO TO 400
  310 CS=130*N(9)+400
  400 CT=CP+CH+CS
      WRITE(6,410)C,A,NBLOC,NUNIT,N,NOFF,CP,CH,CS,CT
  410 FORMAT(1X,10A1,1X,A1,I1,I1,2X,10I1,8X,I3,F10.1,F12.1,F12.1,F20.1)
      GO TO 20
  500 STOP
      END
```

PROGRAM TO ESTIMATE TOTAL CUTTING LENGTH OF PLATE COMPONENTS (OUTLINE + HOLES + SLOTS)

(PROGRAM 4.)

PART NUMBER	CODE NUMBER	NUMBER OFF	PERIMETER	HOLE LENGTH	SLOT LENGTH	EST.PERIMETER
DBEC092 A11	4205220475	1	16300.0	6726.0	1100.0	24126.0
DBEC047 A11	4200020544	2	5300.0	0.0	0.0	5300.0
DBEC058 A11	4205020544	2	5300.0	2240.0	800.0	8340.0
DBEC045 A11	4205020544	4	5300.0	2240.0	800.0	8340.0
DBEC141 A11	4200020523	1	3100.0	0.0	0.0	3100.0
DBEC140 A11	4205020524	2	3700.0	1220.0	600.0	5520.0
DBEC139 A11	4205020523	2	3100.0	1220.0	600.0	4920.0
DBEC138 A11	4205020524	2	3700.0	1220.0	600.0	5520.0
DBEC046 A11	4205020523	2	3100.0	1220.0	600.0	4920.0
DBEC134 A11	4205020524	2	3700.0	1220.0	600.0	5520.0
DBEC060 A11	4205020523	2	3100.0	1220.0	600.0	4920.0
DBEC135 A11	4205020524	2	3700.0	1220.0	600.0	5520.0
DBEC099 A11	4200020484	2	18600.0	0.0	0.0	18600.0
DBEC133 A11	4209020523	1	3100.0	1220.0	0.0	4320.0
DBEC095 A11	4205320675	2	16300.0	6726.0	1100.0	24126.0
DBEC038 A11	4200020543	2	4700.0	0.0	0.0	4700.0
DBEC036 A11	4205020543	2	4700.0	2240.0	800.0	7740.0
DBEC037 A11	4205020543	11	4700.0	2240.0	800.0	7740.0
DBEC037 A11	4205020543	1	4700.0	2240.0	800.0	7740.0
DBEC098 A11	4200320675	2	16300.0	0.0	0.0	16300.0
DBEC129 A11	7102020445	2	5300.0	0.0	800.0	6100.0
DBEC128 A11	7102020445	2	5300.0	0.0	800.0	6100.0
DBEC001 A11	7105020445	2	5300.0	2240.0	800.0	8340.0
DBEC001 A11	7105020445	2	5300.0	2240.0	800.0	8340.0
DBEC001 A11	7105020445	2	5300.0	2240.0	800.0	8340.0
DBEC005 A11	7102020445	2	5300.0	0.0	800.0	6100.0
DBEC005 A11	4202020445	2	6000.0	0.0	800.0	6800.0
DBEC001 A11	4205020445	2	6000.0	2240.0	800.0	9040.0
DBEC100 A11	7105220475	2	15600.0	6726.0	1100.0	23426.0
DBEC131 A11	7000020445	2	5174.0	0.0	0.0	5174.0
DBEC074 A11	7100020423	2	2725.0	0.0	0.0	2725.0

OUTPUT OF TOTAL PLATE COMPONENT CUTTING LENGTHS

(PROGRAM 4)

APPENDIX L

Weld times derived from Welding Institute Standard Data.

FILLET WELDING - DOWNHAND

ELECTRODE CLASS = E3
ELECTRODE LENGTH = 1.6 FT (d)

DERIVATION FORMULA FOR TOTAL JOINT COMPLETION:-

$$T_J = \cdot 258 + \ell \left[\frac{\cdot 164 f}{d} + (t_1 + t_2) \right]$$

WELDING FACTORS (FROM W.I. STANDARD DATA)

LEG LENGTH (IN)	3/16"	1/4"	3/8"
NUMBER OF RUNS	1	1	1 TO 3
ELECTRODE SIZE (FT.)	0.192	0.192	0.192
FT. ELECTRODE PER FT. FILLET (f)	1.2	1.8	3.7
DESLAG TIME (STD.MIN/FT) (t_2)	0.4	0.6	1.3
ARC TIME (STD.MIN FT) (t_1)	1.4	2.0	4.4
FORMULA FOR TOTAL JOINT TIME.	·258 + 1.93ℓ	·258 + 2.8ℓ	·258 + 6.1ℓ

SYNTHETIC TABLES - PLATE PARTS

CODE DIGIT	ℓ MIDPOINT FT.	ω MIDPOINT FT.	3/16" LEG TIME FOR ℓ	3/16" LEG TIME FOR ω	1/4" LEG TIME FOR ℓ	1/4" LEG TIME FOR ω	3/8" LEG TIME FOR ℓ	3/8" LEG TIME FOR ω
0	0.82	0.66	1.8	1.5	2.6	2.1	5.3	4.3
1	1.47	1.23	3.1	2.6	4.4	3.7	9.2	7.8
2	2.62	1.72	5.3	3.6	7.6	5.1	16.2	10.7
3	4.10	2.46	8.2	5.0	11.7	7.1	25.3	15.3
4	6.56	3.44	13.0	6.9	18.6	9.9	40.3	21.2
5	10.65	4.59	20.8	9.1	30.0	13.1	65.2	28.3
6	16.40	5.91	31.9	11.7	46.1	16.8	100.3	36.3
7	22.10	7.38	42.9	14.5	62.1	20.9	135.1	45.3
8	27.10	9.02	52.6	17.7	76.1	25.5	165.6	55.3
9	32.80	11.49	63.5	22.4	92.0	32.4	200.3	70.0
DESIGNATED SUB-PROGRAM NAME.			FWLD01	FWLD04	FWLD02	FWLD05	FWLD03	FWLD06

```
    9 IF(IA119(24).LT.2)GO TO 10
      WRITE(66,69)IA119
   69 FORMAT(21H TT.PL.AT SS.1SD.WLD 19A1,9I1,12A1)
      GO TO 90
   10 WRITE(66,70)IA119
   70 FORMAT(21H TT.PL.AT SS.2SD.WLD.19A1,9I1,12A1)
      GO TO 90
   11 WRITE(66,71)IA119
   71 FORMAT(13H SHELL PLATE 19A1,9I1,12A1)
      GO TO 90
   12 IF(IA119(22).GT.0)GO TO 13
      WRITE(66,72)IA119
   72 FORMAT(15H SMALL BRACKET 19A1,9I1,12A1)
      CALLFWLD01(IA119,T1)
      T1=1.5*T1
      WRITE(66,101)T1
      CALL FWLD44(IA119,T1)
      T1=1.5*T1
      WRITE(66,102)T1
      GO TO 90
   13 WRITE(66,73)IA119
   73 FORMAT(12H FRM.FT.BKT.19A1,9I1,12A1)
   14 IF(IA119(20).GT.1)GO TO 22
      IF(IA119(21).LT.2)GO TO 21
      IF(IA119(21).LT.4)GO TO 19
      IF(IA119(21).LT.6)GO TO 17
      IF(IA119(27).LT.3)GO TO 16
   22 WRITE(66,74)IA119
   74 FORMAT(13H INVESTIGATE 19A1,9I1,12A1)
      GO TO 90
   16 WRITE(66,75)IA119
   75 FORMAT(16H OPEN FLR.STFNR 19A1,9I1,12A1)
      GO TO 90
```

MAIN PROGRAM

```
17 IF(IA119(28).EQ.6)GO TO 18
   WRITE(66,76)IA119
76 FORMAT(13H U/BHD.STFNR 19A1,9I1,12A1)
   GO TO 90
18 WRITE(66,77)IA119
77 FORMAT(11H GDR.STFNR.19A1,9I1,12A1)
19 IF(IA119(21).EQ.3)GO TO 20
   WRITE(66,79)IA119
79 FORMAT(15H LONGL.SQ.ENDS 19A1,9I1,12A1)
   GO TO 90
20 WRITE(66,80)IA119
80 FORMAT(17H LONGL.SCALLOPED 19A1,9I1,12A1)
   GO TO 90
21 IF(IA119(27).LT.2)GO TO 23
   GO TO 22
23 WRITE(66,78)IA119
78 FORMAT(13H FLOOR STFNR 19A1,9I1,12A1)
81 FORMAT(19A1,9I1,12A1)
90 CONTINUE
   END
```

MAIN PROGRAM (END)

```
      SUBROUTINE FWLD01(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(27).EQ.0)GO T0229
      IF(IA119(27).EQ.1)GO TO 228
      IF(IA119(27).EQ.2)GO TO 227
      IF(IA119(27).EQ.3)GO TO 226
      IF(IA119(27).EQ.4)GO TO 225
      IF(IA119(27).EQ.5)GO TO 224
      IF(IA119(27).EQ.6)GO TO 223
      IF(IA119(27).EQ.7)GO TO 222
      IF(IA119(27).EQ.8)GO TO 221
      T1=63.5
      GO TO 220
221   T1=52.6
      GO TO 220
222   T1=42.9
      GO TO 220
223   T1=31.9
      GO TO 220
224   T1=20.8
      GO TO 220
225   T1=13.0
      GO TO 220
226   T1=8.2
      GO TO 220
227   T1=5.3
      GO TO 220
228   T1=3.1
      GO TO 220
229   T1=1.8
220   RETURN
      END
```

FILLET. DOWNHAND. 3/16" LEG. LENGTHS

```
      SUBROUTINE FWLD02(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(27).EQ.0)GO T0239
      IF(IA119(27).EQ.1)GO TO 238
      IF(IA119(27).EQ.2)GO TO 237
      IF(IA119(27).EQ.3)GO TO 236
      IF(IA119(27).EQ.4)GO TO 235
      IF(IA119(27).EQ.5)GO TO 234
      IF(IA119(27).EQ.6)GO T0233
      IF(IA119(27).EQ.7)GO TO 232
      IF(IA119(27).EQ.8)GO T0231
      T1=92.0
      GO TO 230
231   T1=76.1
      GO TO 230
232   T1=62.1
      GO TO 230
233   T1=46.1
      GO TO 230
234   T1=30.0
      GO TO 230
235   T1=18.6
      GO TO 230
236   T1=11.7
      GO TO 230
237   T1=7.6
      GO TO 230
238   T1=4.4
      GO TO 230
239   T1=2.6
230   RETURN
      END
```

FILLET. DOWNHAND 1/4" LEG. LENGTHS.

SUBROUTINES FOR WELD TYPES

```
      SUBROUTINE FWLD03(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(27).EQ.0)GO TO209
      IF(IA119(27).EQ.1)GO TO 208
      IF(IA119(27).EQ.2)GO TO 207
      IF(IA119(27).EQ.3)GO TO 206
      IF(IA119(27).EQ.4)GO TO 205
      IF(IA119(27).EQ.5)GO TO 204
      IF(IA119(27).EQ.6)GO TO 203
      IF(IA119(27).EQ.7)GO TO 202
      IF(IA119(27).EQ.8)GO TO 201
      T1=200.3
      GO TO 200
  201 T1=165.6
      GO TO 200
  202 T1=135.1
      GO TO 200
  203 T1=100.3
      GO TO 200
  204 T1=65.2
      GO TO 200
  205 T1=40.3
      GO TO 200
  206 T1=25.3
      GO TO 200
  207 T1=16.2
      GO TO 200
  208 T1=9.2
      GO TO 200
  209 T1=5.3
  200 RETURN
      END
```

FILLET. DOWNHAND 3/8" LEG. LENGTHS.

```
      SUBROUTINE FWLD46(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(28).EQ.0)GO TO219
      IF(IA119(28).EQ.1)GO TO 218
      IF(IA119(28).EQ.2)GO TO 217
      IF(IA119(28).EQ.3)GO TO 216
      IF(IA119(28).EQ.4)GO TO215
      IF(IA119(28).EQ.5)GO TO 214
      IF(IA119(28).EQ.6)GO TO 213
      IF(IA119(28).EQ.7)GO TO 212
      IF(IA119(28).EQ.8)GO TO 211
      T1=63.5
      T1=107.9
      GO TO 210
  211 T1=84.8
      GO TO 210
  212 T1=69.4
      GO TO 210
  213 T1=55.6
      GO TO 210
  214 T1=43.3
      GO TO 210
  215 T1=32.5
      GO TO 210
  216 T1=23.3
      GO TO 210
  217 T1=16.4
      GO TO 210
  218 T1=11.8
      GO TO 210
  219 T1=6.5
  210 RETURN
      END
```

FILLET. VERTICAL 3/8" LEG WIDTHS.

SUBROUTINES FOR WELD TYPES

```
      SUBROUTINE FWLD44(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(28).EQ.0)GO TO 249
      IF(IA119(28).EQ.1)GO TO 248
      IF(IA119(28).EQ.2)GO TO 247
      IF(IA119(28).EQ.3)GO TO 246
      IF(IA119(28).EQ.4)GO TO 245
      IF(IA119(28).EQ.5)GO TO 244
      IF(IA119(28).EQ.6)GO TO 243
      IF(IA119(28).EQ.7)GO TO 242
      IF(IA119(28).EQ.8)GO TO 241
      T1=35.9
      GO TO 240
  241 T1=28.2
      GO TO 240
  242 T1=23.1
      GO TO 240
  243 T1=18.6
      GO TO 240
  244 T1=14.5
      GO TO 240
  245 T1=13.9
      GO TO 240
  246 T1=7.9
      GO TO 240
  247 T1=5.6
      GO TO 240
  248 T1=4.1
      GO TO 240
  249 T1=2.3
  240 RETURN
      END
```

FILLET. VERTICAL. 3/16" LEG. WIDTHS

```
      SUBROUTINE FWLD45(IA119,T1)
      DIMENSION IA119(40)
      IF(IA119(28).EQ.0)GO TO 259
      IF(IA119(28).EQ.1)GO TO 258
      IF(IA119(28).EQ.2)GO TO 257
      IF(IA119(28).EQ.3)GO TO 256
      IF(IA119(28).EQ.4)GO TO 255
      IF(IA119(28).EQ.5)GO TO 254
      IF(IA119(28).EQ.6)GO TO 253
      IF(IA119(28).EQ.7)GO TO 252
      IF(IA119(28).EQ.8)GO TO 251
      T1=52.8
      GO TO 250
  251 T1=41.5
      GO TO 250
  252 T1=34.0
      GO TO 250
  253 T1=27.3
      GO TO 250
  254 T1=21.2
      GO TO 250
  255 T1=16.0
      GO TO 250
  256 T1=11.5
      GO TO 250
  257 T1=8.1
      GO TO 250
  258 T1=5.9
      GO TO 250
  259 T1=3.3
  250 RETURN
      END
```

FILLET. VERTICAL. 1/4" LEG. WIDTHS.

SUBROUTINES FOR WELD TYPES.

Note

The programming in this appendix, although functional, is inefficient. Subroutines FWLD01, FWLD02, FWLD03, FWLD44, FWLD45, and FWLD46 can be replaced by a single subroutine (say FWLD) as shown.

```
SUBROUTINE FWLD (IA119,T1,N)
DIMENSION IA119(40), BLOCK (10,6)
COMMON BLOCK
K = 27
IF (N.GT.3) K=28
T1=BLOCK (IA119(K)+1,N)
RETURN
END
```

This would be called from the main program by statements of the form CALL FWLD (IA119,T1,N) where:-

```
N=1 for previous FWLD01
N=2  "      "    FWLD02
N=3  "      "    FWLD03
N=4  "      "    FWLD44
N=5  "      "    FWLD45
N=6  "      "    FWLD46
```

BLOCK is a data block common to the main program and subroutines and which represents times for joint lengths. It would take the form

```
T10  T11  T12  T13  T14  T15  T16  T17  T18  T19
T20  T21  T22  T23  T24  T25  T26  T27  T28  T29
T30                                            |
T40                 ETC.                       |
T50                                            |
T60 ------------------------------------->     v
```

Where TNm is the weld time for the length code range m formerly incorporated into the subroutine which is now represented by N. (i.e. T10 1.8 mm, found in former subroutine FWLD01)

This method has several advantages

1 It reduces the number of programming statements by about 200

2 It allows easier alteration of time data in the program

3 It allows further subroutines to be added easily as time data becomes available

4 The program need not be recompiled for different applications if BLOCK is held as a separate data file.

I would like to thank Dr. J. Latham, University of Glasgow, for his time and effort in advising me in this matter.

SYNTHETIC TABLES - SECTION PARTS

CODE DIGIT	ℓ MIDPOINT FT	ω MIDPOINT FT	3/16" LEG	1/4" LEG	3/8" LEG
0	400	1.31	2.79	3.93	8.25
1	900	2.95	5.95	8.52	18.25
2	1600	5.25	10.39	15.00	32.28
3	2500	8.20	16.08	23.22	50.28
4	3500	11.48	22.41	32.40	70.29
5	4500	14.76	28.74	41.60	90.29
6	5500	18.04	35.07	50.77	110.30
7	6500	21.32	41.40	59.95	130.31
8	7500	24.61	47.76	69.17	150.38
9	9500	31.17	60.41	87.53	190.40
DESIGNATED SUBPROGRAM NAME					

FILLET WELDING - VERTICAL

ELECTRODE CLASS = E3
ELECTRODE LENGTH = 1·6 FT (d)

DERIVATION FORMULA FOR TOTAL JOINT COMPLETION:-

$$T_J = \cdot 258 + \ell \left[\frac{\cdot 164 f}{d} + (t_1 + t_2) \right]$$

WELDING FACTORS (FROM W. I. STANDARD DATA)

LEG LENGTH (IN)	3/16"	1/4"	3/8"
NUMBER OF RUNS	1	1	1 & 2
ELECTRODE SIZE FT	0·160	0·160	0·160
FT. ELECTRODE PER FT. FILLET (f)	1·8	2·5	5·2
DESLAG TIME (STD. MIN FT) (t_2)	0·6	0·9	1·7
ARC TIME (STD. MIN FT) (t_2)	2·3	3·4	7·1
FORMULA FOR TOTAL JOINT TIME:	·258+ 3·1 ℓ	·258+4·57 ℓ	·258+9·37 ℓ

SYNTHETIC TABLES

CODE DIGIT	ℓ MIDPOINT FT.	w MIDPOINT FT.	3/16" LEG TIME FOR ℓ	3/16" LEG TIME FOR w	1/4" LEG TIME FOR ℓ	1/4" LEG TIME FOR w	3/8" LEG TIME FOR ℓ	3/8" LEG TIME FOR w
0	0·82	0·66	2·8	2·3	4·0	3·3	7·9	6·5
1	1·47	1·23	4·8	4·1	6·8	5·9	14·0	11·8
2	2·62	1·72	8·4	5·6	12·2	8·1	24·8	16·4
3	4·10	2·46	13·0	7·9	19·0	11·5	38·7	23·3
4	6·56	3·44	20·6	10·9	30·2	16·0	61·7	32·5
5	10·65	4·59	33·3	14·5	48·9	21·2	100·0	43·3
6	16·40	5·91	51·1	18·6	75·2	27·3	153·9	55·6
7	22·10	7·38	68·8	23·1	101·2	34·0	207·3	69·4
8	27·10	9·02	84·3	28·2	124·1	41·5	254·2	84·8
9	32·80	11·49	101·9	35·9	150·2	52·8	307·6	107·9
DESIGNATED SUB-PROGRAM NAME			FWLD41	FWLD44	FWLD42	FWLD45	FWLD43	FWLD46

SYNTHETIC TABLES – SECTION PARTS

CODE DIGIT	ℓ MIDPOINT FT	W MIDPOINT FT	3/16" LEG	1/4" LEG	3/8" LEG
0	400	1.31	4.32	6.24	12.53
1	900	2.95	9.40	13.74	27.90
2	1600	5.25	16.53	24.25	49.45
3	2500	8.20	25.68	37.73	77.09
4	3500	11.48	35.85	52.72	107.82
5	4500	14.76	46.01	67.71	138.56
6	5500	18.04	56.18	82.70	169.29
7	6500	21.32	66.35	97.69	200.03
8	7500	24.61	76.55	112.72	230.85
9	9500	31.17	96.88	142.70	292.32
DESIGNATED SUBPROGRAM NAME					

APPENDIX M

Program to estimate assembly work content from descriptive code numbers of components.

```
      DIMENSION IA119(40)
      EXTERNAL FWLD03,FWLD46
      COMMON IA119
      DO 90 I=1,2
      READ(50,81)IA119
      IF(IA119(20).LT.4)GO TO 14
      IF(IA119(28).LT.4.OR.IA119(28).GT.5.OR.IA119(22).GT.5)GO TO 7
      IF(IA119(20).GT.6)GO TO 4
      IF(IA119(21).NE.2)GO TO 3
      IF(IA119(22).NE.0)GO TO 3
      IF(IA119(24).GT.1)GO TO 2
      IF(IA119(23).GT.0)GO TO 1
      WRITE(66,60)IA119
   60 FORMAT(15H W/T.INN.FLOOR 19A1,9I1,12A1)
      CALL FWLD03(IA119,T1)
      WRITE(66,101)T1
  101 FORMAT(22H D/H.F.WELD.TIME(MIN)=F5.2)
      CALL FWLD46(IA119,T1)
      T1=2*T1
      WRITE(66,102)T1
  102 FORMAT(23H VERT.F.WELD.TIME(MIN)=F5.1)
      GO TO 90
    1 WRITE(66,61)IA119
   61 FORMAT(11H INN.FLOOR 19A1,9I1,12A1)
      CALL FWLD01(IA119,T1)
      WRITE(66,101)T1
      CALL FWLD44(IA119,T1)
      T1=2*T1
      WRITE(66,102)T1
      GO TO 90
    2 WRITE(66,62)IA119
   62 FORMAT(18H LONGITUDINAL GDR.19A1,9I1,12A1)
      CALL FWLD02(IA119,T1)
      WRITE(66,101)T1
      GO TO 90
```

MAIN PROGRAM

```
    3 WRITE(66,63)IA119
   63 FORMAT(18H GDR.END/FLGD.FLR.19A1,9I1,12A1)
      CALL FWLD02(IA119,T1)
      WRITE(66,101)T1
      CALL FWLD45(IA119,T1)
      WRITE(66,102)T1
      GO TO 90
    4 IF(IA119(22).LT.1)GO TO 5
      WRITE(66,64)IA119
   64 FORMAT(15H STFWD.OUT.FLR.19A1,9I1,12A1)
      CALL FWLD01(IA119,T1)
      WRITE(66,101)T1
      GO TO 90
    5 IF(IA119(23).GT.0)GO TO 6
      WRITE(66,65)IA119
   65 FORMAT(13H OUT.W/T.FLR.19A1,9I1,12A1)
      CALL FWLD03(IA119,T1)
      WRITE(66,101)T1
      CALLFWLD46(IA119,T1)
      WRITE(66,102)T1
      GO TO 90
    6 WRITE(66,66)IA119
   66 FORMAT(9H OUT.FLR.19A1,9I1,12A1)
      CALL FWLD01(IA119,T1)
      WRITE(66,101)T1
      CALL FWLD44(IA119,T1)
      WRITE(66,102)T1
      GO TO 90
    7 IF(IA119(28).LT.4)GO TO 12
      IF(IA119(22).GT.0)GO TO 11
      IF(IA119(20).EQ.7)GO TO 9
      IF(IA119(24).LT.2)GO TO 8
      WRITE(66,67)IA119
   67 FORMAT(18H TT.PL.1 SIDE WLD.19A1,9I1,12A1)
      GO TO 90
    8 WRITE(66,68)IA119
   68 FORMAT(18H TT.PL.2 SIDE WLD.19A1,9I1,12A1)
      GO TO 90
```

MAIN PROGRAM