# THE CONCEPTUAL DESIGN AND EVALUATION OF AN ACCURACY CONTROL SYSTEM TO SUPPORT THE HULL CONSTRUCTION OF AIRCRAFT CARRIERS

by

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(ABSTRACT)

This report introduces the conceptual design of an accuracy control system for implementation into the modular construction of aircraft carriers at Newport News Shipbuilding.

A needs and feasibility analysis is accomplished for the proposed system. Advanced system planning is discussed. An economic analysis is accomplished on the proposed system detailing the monetary assets and liabilities the system represents.

The objective is to substantiate the potential benefits such a system would generate if incorporated in the carrier construction environment and provide a basis for subsequent system design activities.

# LEGAL NOTICE

No classified material is included in this report. The opinions and recommendations in whole or in part, which are expressed in this report do not reflect those of the management of Newport News Shipbuilding. Any data found in this report is strictly on unofficial estimate by the author for the purpose of completing this report and may not precisely reflect the actual data.

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# Chapter 1

## NEED AND FEASIBILITY ANALYSIS

During the construction of an aircraft carrier Newport News Shipbuilding experiences excessive costs and schedule delays directly attributed to rework. In the carrier environment 20% of the construction cost and 10% of the construction time is lost due to rework. Before the adoption of an accuracy control system in the submarine construction environment its losses due to rework were similar. Currently during the construction of a submarine only 12% of the construction costs and 6% of the construction time is lost due to rework. The submarine construction environment has seen a decrease of approximatly 40% in construction costs and schedule delays due to rework since the establishment of an accuracy control system into its environment.

Because of their complex systems certian modules of the carrier have unusually high losses due to rework. Some of the most prominent areas are:

| Area | Rework Cost | Rework Time |
|---|---|---|
| 1) Flight deck units | 45% | 25% |
| 2) Reactor units | 45% | 25% |
| 3) Innerbottom units | 40% | 20% |
| 4) Bow units | 40% | 20% |
| 5) Transom units | 35% | 15% |

As a result of these losses the need arose to reduce rework in the carrier construction environment. It is felt that reductions in rework similar to those experienced in the submarine construction environment will result if a carrier accuracy control system is developed.

The benefits the company would realize from increased accuracy control of superlift construction are twofold. First better accuracy control would provide the Navy with a higher quality product. Quality has recently been a topic of much concern with the Navy. Better accuracy control would show the Navy (the consumer) that quality is very important to NNS. If NNS was able to increase the accuracy with which an aircraft carrier was built it would mean greater consideration for NNS in future shipbuilding contracts. This is very important considering the increased competition the shipbuilding industry faces now that the Navy buildup has slowed down. The second reason for this choice is that it would have the largest impact on the "bottom line". Rework on the platen or during erection is very costly and time consuming. If NNS was able to minimize this rework by utilizing greater accuracy control in the shops it would have a profound effect on the companies profits.

## 1.1 Background

Newport News Shipbuilding builds aircraft carriers utilizing modular construction. Each module is called a superlift. Structural erection will start on CVN74 in the spring of 1991 and will last three years. Outfitting and testing will continue after structural erection is complete for another two years. At this point the carrier will be delivered to the Navy and the shipyard will receive its final payment. Structural erection will begin on CVN75 two weeks after it ends on CVN74. Work will continue on CVN75 at the same rate as it did on CVN74. A more detailed description of what modular construction entails is found in Section 1.1.1 Modular Construction.

Accuracy control is defined as the methods used to regulate the precision to which an object is constructed. Accuracy control as it relates to shipbuilding is discussed in greater detail in Section 1.1.2 Accuracy Control.

Newport News Shipbuilding currently has only one designated accuracy control group working with the actual construction of ships, and it is located within the industrial engineering department. It was implemented five years ago and contains ten employees. The accuracy control group works almost exclusively with the construction of 688 class attack submarines. There are, however, a few accuracy control projects going on in the construction of carriers. These are carried out by groups mainly concerned with structural yard support. The accuracy control efforts are mainly concentrated on the construction of catapults, nuclear reactor structure, and piping. Their goals are only concerned with the short term elimination of rework during erection, and have only been in operation for the past few years. As it stands, there is currently no accuracy control group dedicated to the construction of superlifts.

The accurate placement of the structure incorporated in the superlift modules is insured by a branch of the fitter department called inspectors. The inspectors are responsible for measuring the placement of structural parts before and after final welding to make certain the correct parts are erected correctly and accurately according to the drawing.

For example, the fitters position and tack weld the structure in place according to the drawing. Before final welding the inspectors examine the structure for correct materials, weld and placement according to the design drawing. If everything is correct the welders complete final welding and the inspectors return to examine the final placement. Tolerances are established by design. If no tolerances are established (which is typical for Aircraft Carrier general structure placement) the rule of thumb is placement within plus or minus 1/4". The actions of the inspectors are not truly accuracy control as defined in this report but are simply necessary for the construction of the ship.

### 1.1.1 Modular Construction

Because of the introduction of modular construction techniques at NNS for use on aircraft carriers there has been an increased need for improved accuracy control. Specific circumstances are discussed in the Identification of Need Section 1.2. The purpose of the following section is to provide a brief synopsis on modular construction itself.

THEODORE ROOSEVELT (CVN71) is the first carrier to be built at NNS using extensive modular construction. The construction of an aircraft carrier is an enormous operation taking approximately 40 million manhours and nearly five years to complete [5, p.28]. Modular Construction is the process of constructing a ship in huge building blocks called superlifts, then assembling the blocks together inside a drydock to form the ship. By carefully designing and planning the fabrication phases, NNS builds sections of the carrier, called subassemblies, in the controlled environment of the shops. These subassemblies are then brought out to a large open area known as the platen where they are pre-outfitted, blasted with abrasive material, painted, and joined together to form superlifts. These superlifts are then lifted over to the dry dock and joined together to form the carrier. There were 169 superlifts, plus numerous minor lifts, which went into assembling CVN71 [5, p.28]. Figure 2 shows how a typical carrier is broken up into superlifts. These units weigh up to 900 metric tons each, and some are the height of a five-story office building [6, p.25]. Each superlift is pre-outfitted with machinery, electrical components, and piping (some to the point where they are almost complete) before being lifted by the third largest crane in the world to the dry dock to be joined together to form the ship. Modular Construction represents the application of systems engineering to the construction process used to build an aircraft carrier. Systems engineering is the application of efforts necessary to (1) transform an operational need into a description of system performance parameters and a preferred system configuration through the use of an iterative process of functional analysis, synthesis, optimization, definition, design, test, and evaluation; (2) integrate related technical parameters

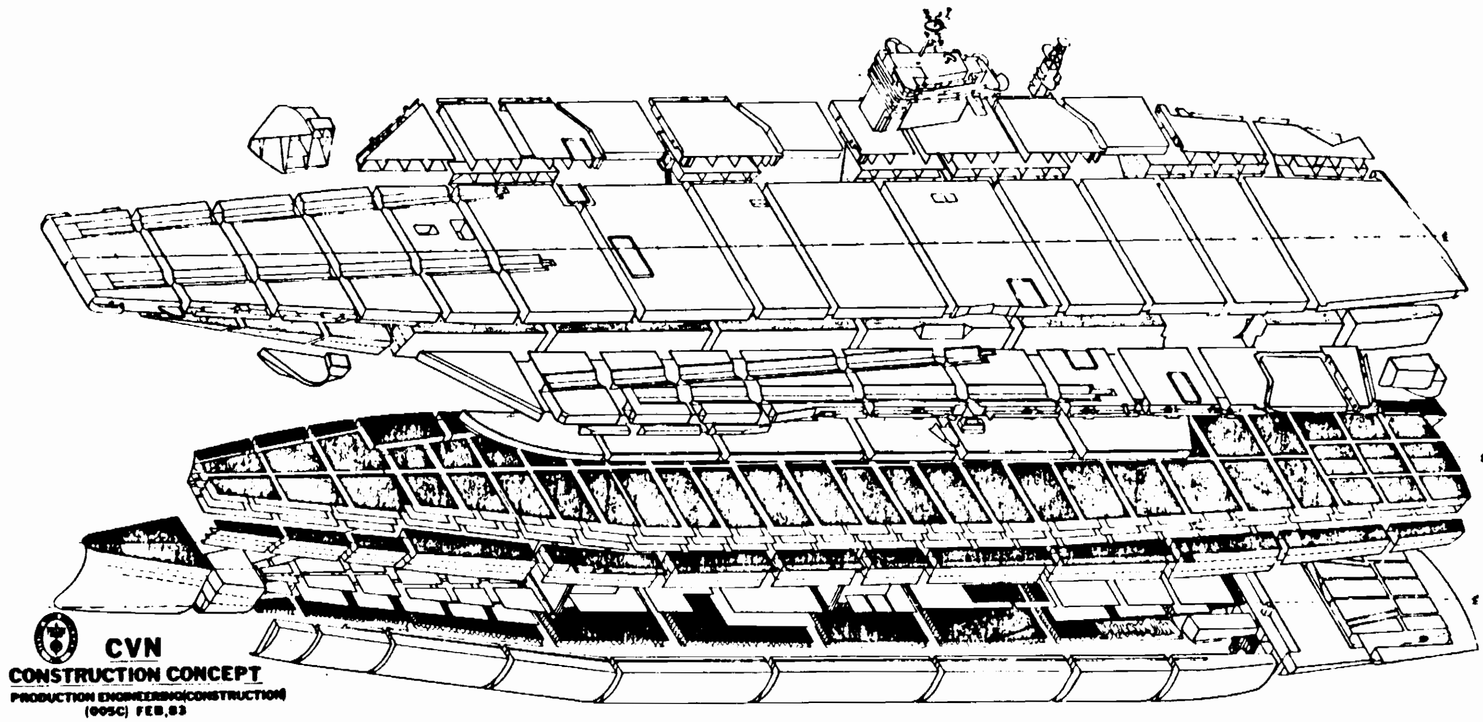



Figure 2. Construction Concept

and assure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and (3) integrate performance, producibility, reliability, maintainability, manability, supportability, and other specialities into the total engineering effort [7, p. 24-25]. There was an operational need to reduce the construction cost and schedule for building an aircraft carrier. After envisioning a preferred cost and time schedule, the process was thoroughly analyzed in order to meet the new parameters. The integration of all the individual disciplines (structural, electrical, mechanical, and piping) was done in such a way that was mutually compatible and that optimized the total system. This was all done taking into consideration and further integrating the performance, producibility, reliability, maintainability, manability, supportability, and other specific aspects of the process. To more adequately comprehend what a long stride modular construction was, one must understand NNS's previous construction process.

CVN's 68-70 were constructed by NNS in shipway #11, using a 310 ton capacity gantry crane for structural subassembly erection and machinery lifts [8, p.60]. This crane, which at the time was the largest in the United States, serviced shipways 10 and 11, where all three ships were constructed [8, p.59]. The piece-meal type of construction previously employed at the yard was done utilizing spauls and a cradle. In order for the shell of the ship to be laid down in approximately its design form, a mold or cradle was built in the dry dock to hold the plates. The individual pieces of the cradle, called spauls were constructed to conform exactly with the ship shell. After the cradle was made, staging was set up all around it to let the workers get to the steel so that they could work on it. Plates were placed into the cradle one at a time and welded together. Onto this shell were welded longitudinals and the keel. Then individual decks were added to the structure. Machinery and outfitting were added when a deck became available. Bulkheads were also added in this piece-meal fashion. All this was accomplished outside in the drydock. Some smaller subassemblies with very little pre-outfitting were used, but because of the limited capacity of the crane, nothing more than 310 tons could be built. One had to cope with all the problems associated with working outside at the mercy of the weather.

The advantages that were realized by Newport News Shipbuilding and by the Navy because NNS adopted the modular construction techniques were significant. CVN70 had approximately 2,000 small assemblies lifted to the ship.

CVN71 had only 1,500 assemblies lifted, of which 169 were superlifts. The upper flight deck assemblies on CVN70 consisted of 150 lifts to the ship. CVN71 had only 14 superlifts comprising the upper flight deck. A typical innerbottom section on CVN70 required 58 sub-assemblies, the same section on CVN71 required only 12. CVN70 had approximately 467 temporary steel and wooden shores, CVN71 had none. Due to the redesigning that was necessary to convert to modular construction about 87% less double curvature plates, requiring heat furnacing to shape were used for CVN71 than on the previous carrier CVN70. Productivity improvement for the carrier have not stopped with CVN71. The innerbottom plating on CVN72 was redesigned and restraked (to redesignate the location where the individual plate ends butt up to each other) to eliminate the ship erection joints which ran through both reactors in this area of the ship on CVN71 and past carriers. This one change drastically reduced the number of man-hours needed to perform non-destructive testing of welds in this area. What took months in the past to inspect and approve can now be done in a week. By continuing the restraking effort on CVN72 below main deck it was possible to rebreak the ship into larger lifting units and reduced the lifts for CVN72 down to 1300 lifts of which 170 were superlifts. Every reduction in the number of lifts reduces the time, number of man-hours, and equipment wear and use costs. The lower side shell and bottom shell areas have been increasingly made into larger fabricated units. Shell plating that use to be ordered in sheets of 9' by 36' are now ordered in sheets of 12' by 40' feet to suit the new erection breaks. From CVN71 to CVN72, the continued restraking and larger superlift construction concept alone has eliminated about 40,000 feet of welds from the baseline to flight deck. "With the increase in the amount of work being done on the platen, NNS was able to significantly increase the percentage of down hand and automatic welding, with concomitant reductions in skill level requirements and weld reject rates [8, p.60]. A comparison of contract award dates, the laying of the keel, and the launch of the carrier for CVN70 and CVN71 is as follows:

| Ship | Award | Keel | Launch |
|---|---|---|---|
| CVN70 | 1/05/74 | 10/11/75 | 3/15/80 |
| CVN71 | 9/30/80 | 10/31/81 | 10/27/84 |

CVN71 was launched 16 months ahead of the original schedule and, as a comparison of the tonnage at launch shows it was a much more completed ship than CVN70 was at launch [8, p.61]. The tonnage vs significant event dates for CVN70 and CVN71 are shown on figure 4. CVN72's keel was laid on November 3, 1984 (five days after the CVN71 was launched) and 16 weeks later there were 10,939 tons of ship erected in the

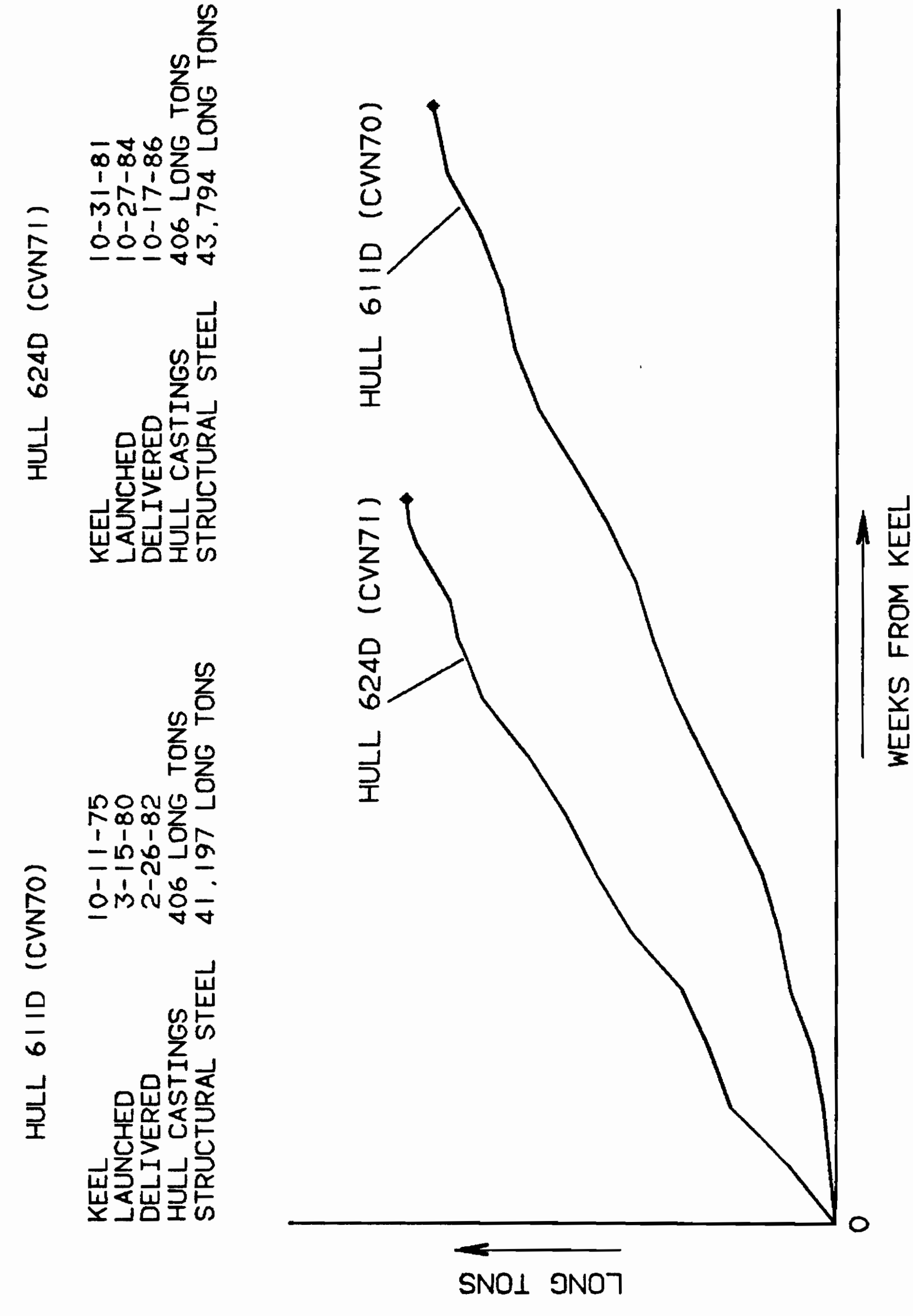



Figure 3. CVN71 vs CVN70 Tons of Ship in Drydock

Source: Irving D. Halper. "Theodore Roosevelt (CVN71) Construction Schedule Compression" Journal of Ship Production, May 1986 shipway and massive amounts of subassembly work complete on platens [8, p.61]. "By comparison, at this same point in time on CVN70 and 71 we have estimated that there were 801 and 7818 tons of ship, respectively, in the shipway" [8, p.61].

As a result of the conversion to modular construction, virtually every function of the design/production/ construction/management involved with the building of an aircraft carrier had to be redesigned in order to adapt to the new methods. Completely new processes were developed and implemented at NNS such as the product work breakdown structure, zone outfitting, and process lanes. There was an increased need for more complete integration of the individual functions such as design, production, and material management. The advances applied to the construction process at NNS due to the use of modular construction can not be successful without an increased emphasis on accuracy control.

### 1.1.2 ACCURACY CONTROL

Accuracy control is a complete system in itself, and is made up of basically three major parts; planning, executing, and evaluating. Accuracy control uses statistical techniques to monitor, control, and continuously improve a process with the goal of increasing productivity. Most U.S. Shipyards do not put enough emphasis on accuracy control and they suffer greatly because of it. Japanese shipyards have been employing modular construction and the product work break down structure for many years and realized very early that a strong commitment to accuracy control will increase productivity and decrease overall costs. This commitment to quality is one of the major reasons, if not the major reason, why Japan has been able to out pace the U.S. in the shipbuilding industry and in many other industries.

Accuracy is sometimes confused with quality. Accuracy deals with the precision to which an object adheres to a standard. Accuracy control is implemented during the construction/production of an item by collecting data, analyzing the data, and from that analysis determining improvements which will increase the accuracy of the object in question. Quality deals with the features, characteristics, attributes, etc. which make an object what it is. The accuracy with which the object is made is one of the attributes by which quality is measured, but so is, for example, the type of material it is made of or its shape. Quality control is accomplished by analyzing a product after it is already constructed. Data is collected on the finished product by inspection. Statistics is used to improve the product by analyzing the completed product dimensions rather than the products individual parts. In some ways quality control and accuracy control can overlap. For example, if a products individual parts are all made accurately as specified by the tolerances established but the finished product does not perform to the degree expected due to tolerance stack up, the quality control people will join with the accuracy control people to mutually determine new tolerances in order to improve the product.

Accuracy control measures points on objects and compares those actual dimensions to the dimensions specified by design. Dimensional check sheets are used to record actual part dimensions. Also recorded on this sheet are other pertinent data such as tolerances to compare and evaluate the accuracy of the parts as they are made, the process used to produce it, the materials that make it up, and the sequence of its construction. Without standardization (comparing apples to apples) all the statistical analysis wouldn't be valid. The result of the evaluation is fed back in the process to help plan future improvements.

Upon adoption of modular construction the shipyard reorganized its construction methods to apply the product work breakdown structure (PBWS). The main feature of PBWS is process lanes which are like assembly lines. The ships fabricated parts and subassemblies are classified and grouped together by construction similarities. In this way assembly line practices can be applied. Because the same construction processes are grouped together the same work situations are sufficiently repeated within each area for statistical methods to be applied by accuracy control. For example there are approximately 200 subassemblies involved with constructing the side shell modules alone. Each subassembly is almost identical. There are literally thousands of longitudinals placed in identical situations on these subassemblies. The accurate placement of these longitudinals makes a perfect opportunity for the use of statistical control.

The causes for variations are grouped into two catagories which are:

1) Special causes - a variation caused by an individual person or machine. This type of variation is not normal and can be attributed to one specific work station.

2) Common causes - a variation caused by a type of work process which is common for the whole construction process.

The role of statistical analysis in accuracy control is to describe and interpret the variations so that solutions can be derived. There will always be some variation, whether the variations are sufficient to require rework depends upon their joining with other parts later on during the construction process. Statistical analysis can weed out the special causes allowing them to be resolved. When only the common causes are left, statistical analysis will provide the average magnitude of variation. This information coupled with the data on the areas which join with this area will provide the overall variation of the final product. If this overall variation is unacceptable, changes to the work process can be made to reduce the individual variations. For example:

If $V$ = overall variation

and $X_1, X_2, \cdots X_n$ = variation of the individual parts then

$V = x_1 + X_2 + \ldots + X_n$

and since the variation is defined as the square of the standard deviation then

If $S_t$ = Standard deviation of the end product and $s_1, s_2, \cdots s_n$ = Standard deviation of the individual parts then

$$s_t^2 = s_1^2 + s_2^2 + \cdots s_n^2$$

It is assumed that the random variables are: continuous, independent, and identically distributed (normal distribution).

Accuracy control is really a cycle of continuous improvement, recording, and evaluating. The accuracy control cycle (shown in Figure 5) begins by planning and by identifying vital points and critical dimensions which are necessary to achieve the accuracy specified for the end product. The plan is executed by actually measuring piece parts and assemblies and recording the data. The measurements are then compared to the specifications. The collected data is then statistically analyzed to identify opportunities for method improvements. To control the process, in-process tolerances and checkpoints are implemented (which are sometimes more demanding or tighter than design). The accuracy control cycle continuously monitors critical processes using x-bar and range charts. The results are always documented and fed back to the trades and engineering. Improvements are developed and rapidly applied to increase the overall ship accuracy. The three main statistical tools used are: the mean (x-bar) which is

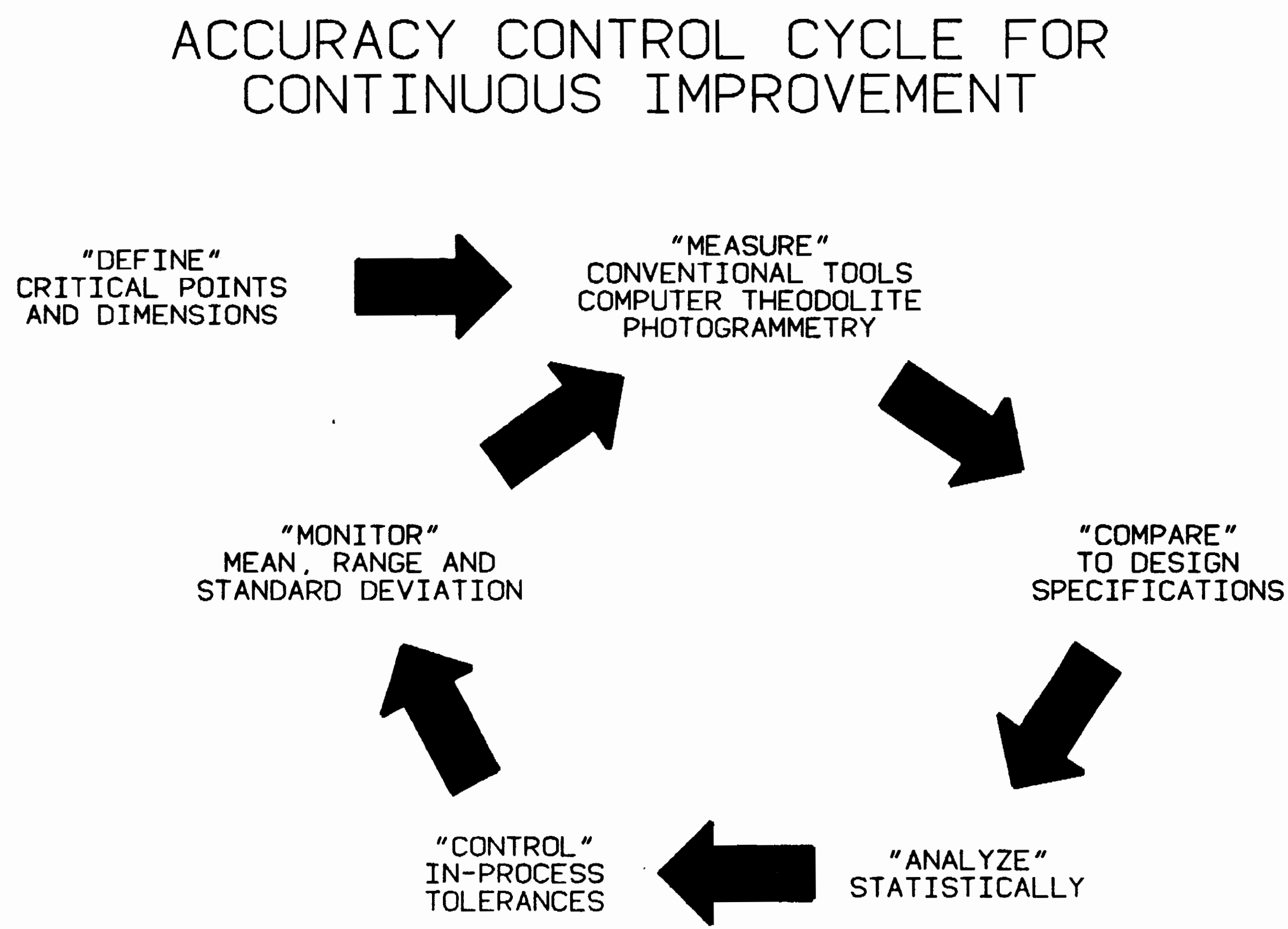



Figure 4. The Accuracy Control Cycle

the arithmetic average of variations in a sample, the range (r) which is the difference between the highest and the lowest value, and the standard deviation which is a measurement of the variations in a sample, and thus a measure of the relative scatter of points around the mean [9,p.5].

It follows as a direct relationship that when accuracy control increases, productivity increases, costs decrease, construction schedules are reduced, and quality increases because accuracy control decreases rework.

## 1.2 IDENTIFICATION OF NEED

When Newport News Shipbuilding implemented modular construction and the product work breakdown structure many complex changes in material management, design, planning, and scheduling took place. For modular construction and zone outfitting to be successful, rework at the erection site due to inaccuracies in unit and block construction must be minimized. Because no other company in the U.S. builds aircraft carriers, NNS does not have to worry about competition or any of the other marketing factors that many other companies have to deal with. Therefore, some of the pressure for improvement is relieved. However, there are other factors which put pressure on NNS for improvement. NNS must conform to the strict military specifications which are set up by NAVSEA. Government inspectors insure the ship is built to these specifications, and if a deviation is found the shipyard is required to rework the job until it is correct, at its own expense. The price the government pays for a carrier is set long before the carrier is built, along with the specifications and the delivery date. If NNS does not meet the delivery date or some of the specifications (such as weight) the government imposes a fine (sometimes very substantial) on the shipyard which decreases profit. Poor accuracy control increases the possibility that the shipyard will not meet specifications resulting in fines or rework and possibly a delinquent delivery to the Navy, each of which decrease the amount of profit the company realizes.

There are two types of rework, traditional rework and planned rework. Traditional rework involves doing the job over again, reworking part of the job, or doing additional work to a job in order to correct it because something does not meet specifications. Planned rework is the type that we guarantee will have to be performed. An example of planned rework is leaving extra material on assemblies in order to custom fit or make up for weld shrinkage, which would have to be trimmed off at final assembly. Both types of rework have numerous costs associated with them such as:

1) Material Costs
2) Labor Costs (Fitting, Testing, Welding, Etc.)

3) Production Holdups

4) Design Costs

5) Scheduling Changes

6) Planning Costs

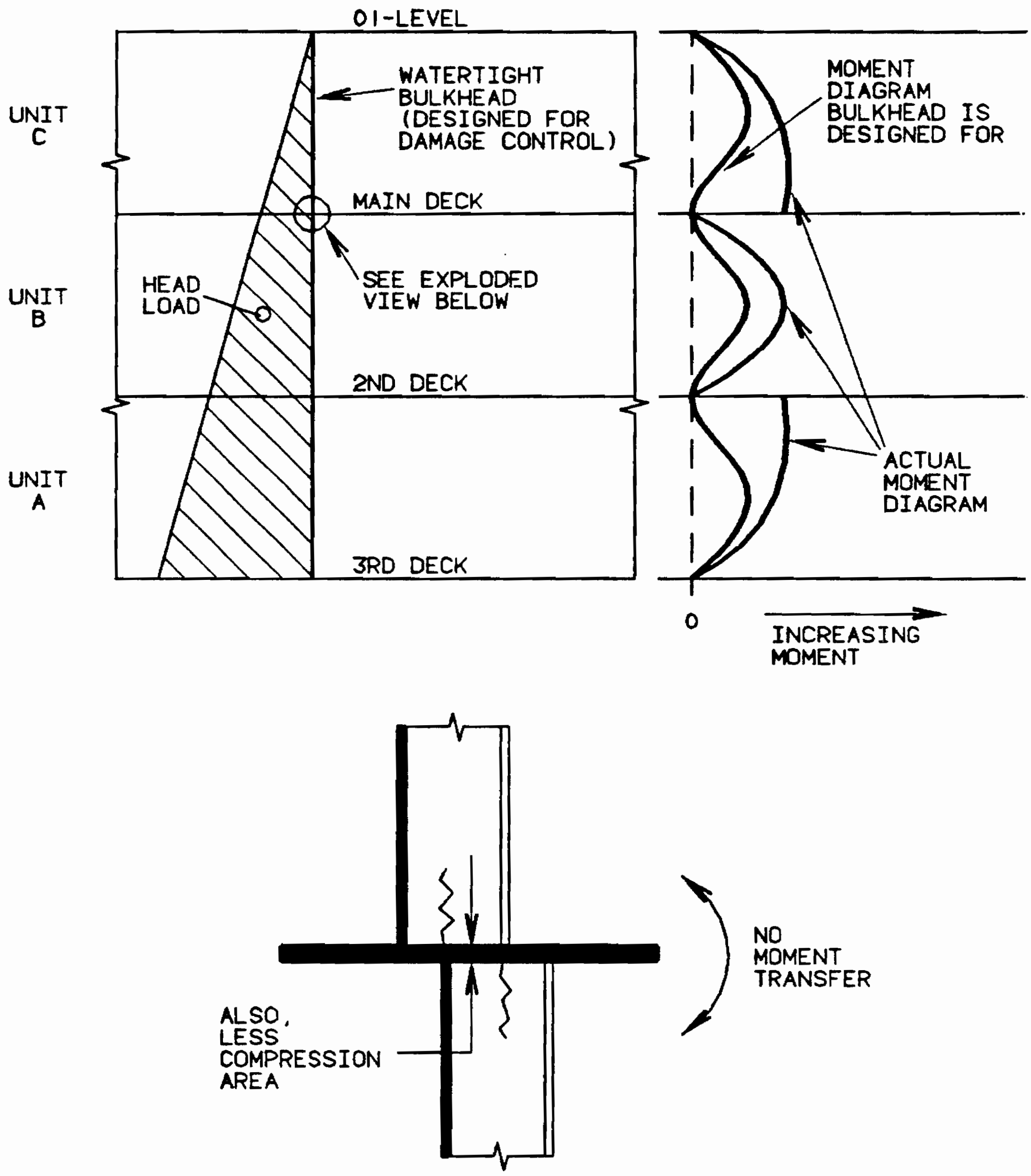
7) Facilities Costs (Cranes, Equipment, Etc.)

The most expensive rework occurs in the shipway after superlifts are erected together to form the ship. The cost of work at this point in construction far exceeds the cost of work in the shop or on the platen. The reason for this is that the further along an area is in the construction process the greater are its direct or indirect effects on other areas of the ship. Correcting a problem in the shop would not require disassembling many other items because at this stage not many items are assembled. Correcting a problem on the platen after all the subassemblies are already joined to form a superlift would require disassembling other areas which are joined to the problem area in order to fix the problem. This would be more costly and time consuming. Correcting a problem which has been discovered after the superlift has been erected onto the ship in the shipway would have serious effects to other areas of the ship and may cause partial disassembly to other superlifts to resolve. This is a very costly and time consuming process. The effects this would have on the erection schedule could be disastrous. Schedule interruptions can be very costly. It would not be far from correct to state that the cost to fix a problem is say, x in the shop and 2x on the platen and 4x on the ship or in the shipway. This report will concentrate on rework in the structural area because that is where the largest costs and the largest construction delays occur. An improvement in this area will have the greatest overall impact.

For example, the fitters department is responsible for fitting the individual pieces of the carrier together to form small assemblies and for fitting those small assemblies together to form subassemblies and in turn fitting the subassemblies together to form the superlifts which are then fitted together to form the ship. The fitters use around 3 million manhours to erect the assemblies, in the three years it takes to erect the structure of a carrier. Directly or indirectly 5% or about 150,000 manhours are used on rework. That's 50,000 manhours per year at $15 per hour costs $750,000 million per year for the fitters alone. When you add in the material, welding, testing, facilities, etc. costs, the total cost is substantial.

A large percentage of the problem originates in the shop where assembly of the decks, bulkheads, foundations, plates, etc. are formed to create a subassembly. These problems add up as each assembly is constructed, and by the time the superlift is ready to be erected on the ship its dimensions are not correct. The root of the problem is tolerance stack-up and the amount of margin left on for erection. In the past when carriers were constructed using the piece meal method in shipway #11 it was found that because of weld shrinkage an extra amount of plate had to be left on when cutting so that when the plates were joined together the final pruduct would come out correct. This extra amount is 1/64" per foot of steel plate and is still added to the steel when it is cut. Newport News Shipbuilding uses computer generated numerical control (NC) tapes and automatic control laser plate cutting equipment to carefully and accurately pre-cut steel plate parts and holes in steel plates. This equipment is also used to accurately mark plates to show where they are to be welded to other plates or shapes. As welding of decks, bulkheads, longitudinals, outfit foundations, piping, etc. is accomplished a pre-cut section will undergo shrinkage, changes in shape, and bulking due to the intense heat. Since assemblies are built simultaneously, and in the shops where better tolerances can be held, the extra material built in when the plate cutting is accomplished is no longer correct. The amount of extra material needed varies throughout the ship. Now it is possible to construct the ship accurately in many places using almost exclusively the margin without extra added for shrinkage. Upper management is aware of this fact, but the cost involved with redesigning the ship and regenerating the parts so that the machines will cut the plates differently is prohibitive. Plus the negative effects on the production schedule would prohibit NNS from meeting delivery dates, therefore NNS deals with the "planned rework". The problem occurs longitudinally, vertically, and transversly. As the ship is constructed from amidships forward and aft areas such as: vertical bulkheads that rise from the innerbottom up several decks, elevator shafts, vertical systems (such as piping), foundations and machinery which occur at horizontal erection breaks, and the complex ship hull shape are not aligning up properly longitudinally or transversely due to the different amount dimensions vary between superlifts below and above erection breaks. This problem also causes serious discrepancies from design such as the example shown in Figure 5. There are strict specifications on the degree of angle and alignment that a transverse or longitudinal bulkhead can be off the vertical plane. When the bulkheads don't line up the only solution is to cut one or both of them out and reinstall them. This practice is very time consuming and expensive.

In addition to the problems of vertical integration there are two other major problems caused by tolerance stack




DESIGNED FOR SINGLE SIMPLY SUPPORTED SPAN
THREE INDEPENDENT SIMPLY SUPPORTED SPANS EXIST
RESULTANT IS LARGER STRESSES

Figure 5. Vertical Misalignment

up and margin amounts. First there is a major amount of rework required when decks do not match up vertically when two superlifts of the same ship level are joined as shown on Figure 6. There are tolerances set by NAVSEA on the degree of angle a deck can be above or below the horizontal plane. When a deck does not line up between superlifts the fitters must cut out one or both of the decks to a sufficient length so that when replaced within the specified tolerance angle they will meet when joined at erection. This rework is also very time consuming and expensive. All work in the problem area must be rescheduled when this problem occurs furthering the detrimental effects.

The third problem (not as common as the other two) which may be attributed to tolerance stack-up and margin amount is erection joint gaps that are not within tolerance limits. Rework must be accomplished by gas cutting and/or buildup by back-strip welding as shown in Figure 7. Margins are committments to rework and their use should be minimized but not at the expense of increasing buildup by back-strip welding.

## 1.3 SYSTEM OPERATIONAL REQUIREMENTS

The prime operating mission of the accuracy control system is to monitor structural accuracy in order to avoid

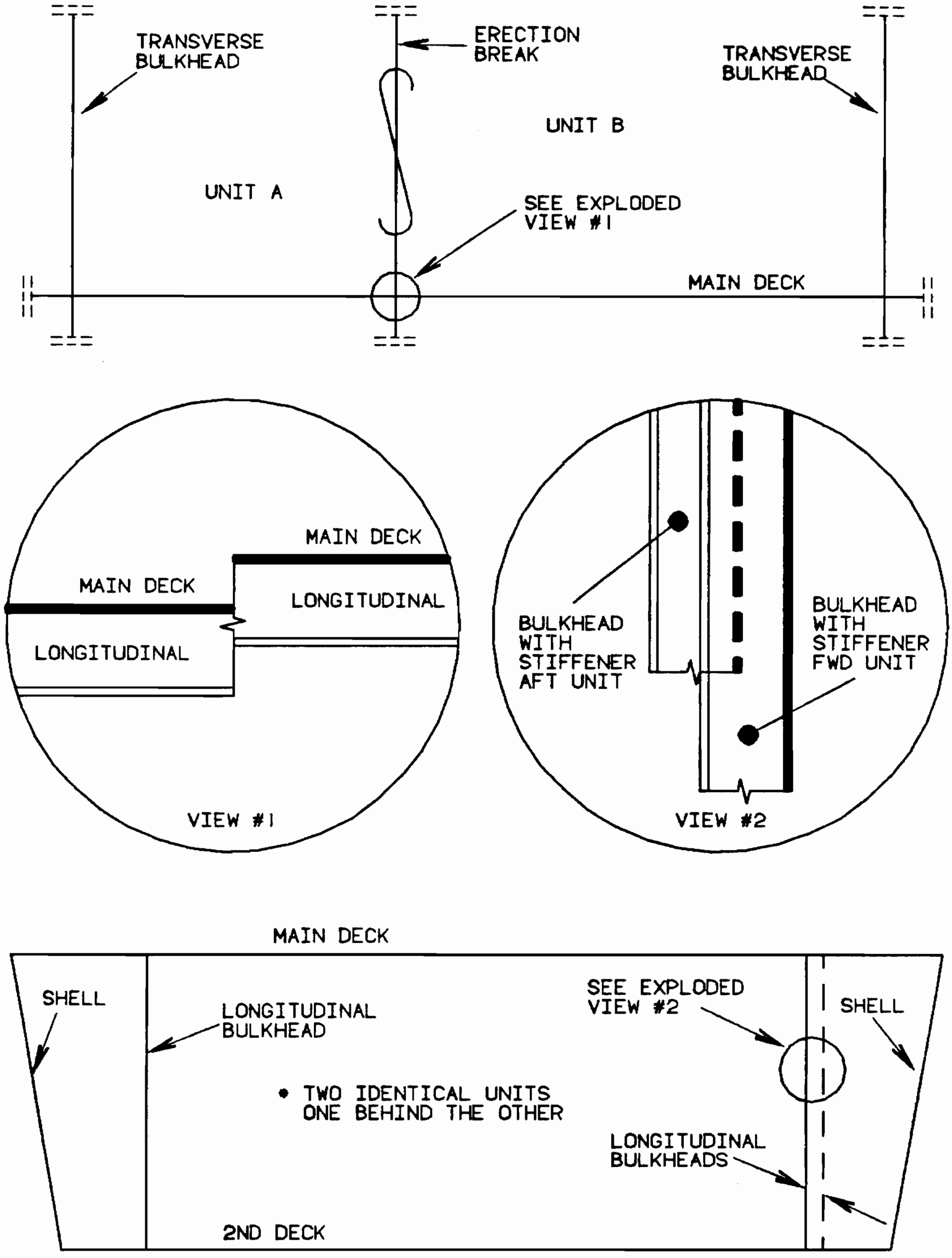



Figure 6. Horizontal Misalignment

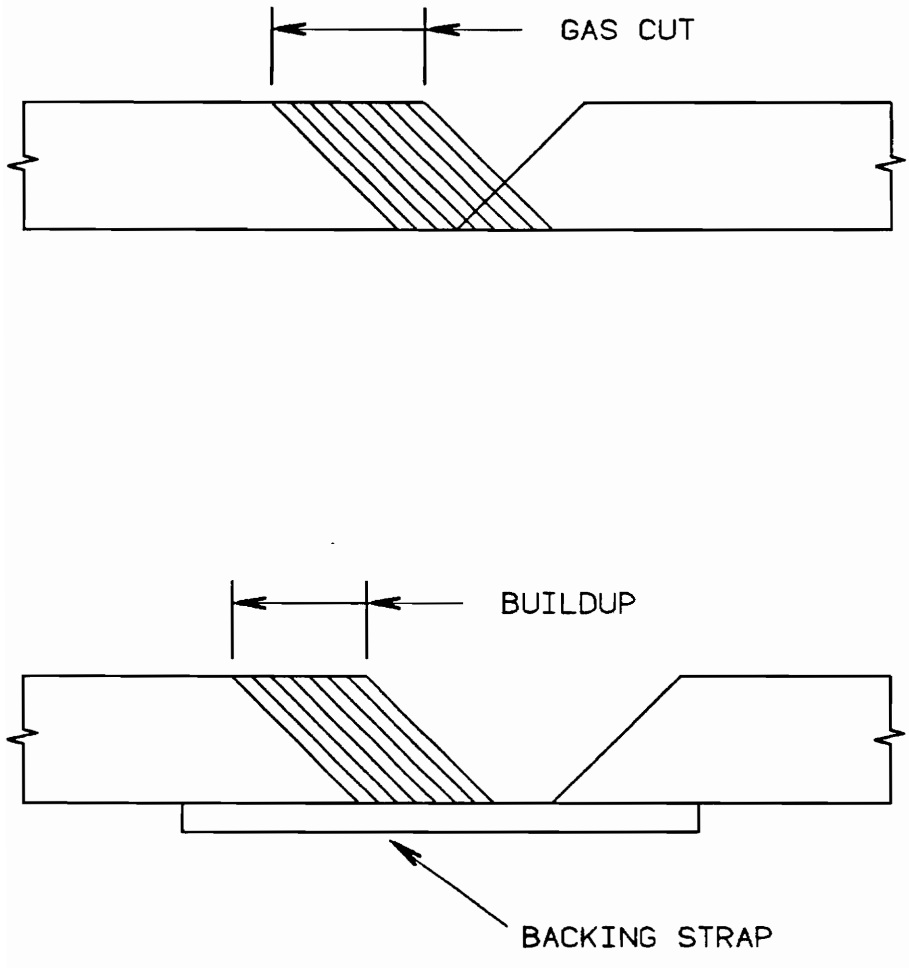



Figure 7. Erection Joint Gaps

delays in construction schedules and decrease overall construction costs by the reduction of structural rework.

This mission can be subdivided into two seperate and distinct goals: short range goals and long range goals. Short range goals consist of the immediate decrease in delays and rework at erection. Some design and construction planning changes will be implemented. Long range goals consist of an improvement to the whole construction process including areas such as: contract negotiations, design, planning, materials, equipment, scheduling, tolerances, overall quality, productivity, and welding sequences.

The physical and performance characteristics of the existing computer equipment and facility are sufficient for the accuracy control systems needs. The measurement equipment needed to support the accuracy control group should be compatible and have the same characteristics as the equipment used by the established measurement sections at the shipyard such as the inspector branch of the fitters department. The personnel included as members of the accuracy control group will need to be full time employees working in the accuracy control group full time. The education and experience necessary for the personnel is discussed in more detail in the Human Factors section 1.4.

The current accuracy control team which works with submarines contains ten employees and has been in existance for the past five years. They are located on the waterfront where the work is being accomplished. Initially the new accuracy control group can be integrated into the old, under the same supervisor. The only difference will be that their primary concern will be with carriers not submarines. The new accuracy control group will use the same building and computer facilities. By studying the current computer usage for the submarine accuracy control group it has been determined that there should be one CADAM and one time share terminal for every five accuracy control employees. The current accuracy control group has not been utilizing the existing computer facilities to a satisfactory level. Therefore, the addition of the initial six new accuracy control group members will not require any additional computer support. Currently there are three time share terminals and three CADAM terminals. CADAM terminals can be operated in both the time share and CADAM options. After two years when the accuracy control group will take on more responsibilities it will become necessary to obtain an additional CADAM terminal to handle the increased workload. As outlined in Section 1.4 Human Factors, the accuracy control group will consist of six employees initially. After 2 years another four employees will be hired to handle the sharp increase in workload. At this time it will be necessary to promote one of the group to supervisor and break away from the submarine accuracy control group in organization only. They will be situated exactly where they were originally utilizing the same facilities.

It has been found by studying the utilization of resources in the submarine accuracy control group that each employee should have his or her own steel tape measure, plumb bob, desk, chair, and drawing board. There should be one digital level, and telephone for every two group members. There should also be one theodolite, bicycle, and one five drawer file cabinet for every three employees in the group. The group will need one laser in order to perform its duties. The initial quantity of resources necessary for the accuracy control system is as follows:

1. Measurement equipment -
   - A. (6) 100 foot steel tape measures
   - B. (3) digital levels
   - C. (6) mechanical plumb bobs
   - D. (2) theodolites
   - E. (1) laser

2. Transportation

   A. (2) Shipyard bicycles

   B. Part time use of existing accuracy control groups vehicle

3. Office equipment and supplies

   A. (6) Desks

   B. (6) Drawing boards

   C. (6) chairs

   D. (3) telephones

   E. (2) 5 drawer file cabinets

   F. Additional reams of paper with which the group will make the many necessary forms and charts

   G. Miscellaneous supplies will be requisitioned from the internal supply department in the same manner which is typical throughout NNS

The initial resources will be required at system inception. The system will become operational three days after inception. The system will not be at peak efficiency until one year after inception allowing for the on the job training to have effect.

The systems inventory is expected to continue as was initally established through the first two years. After this period it will be necessary to obtain the following:

A. (4) Desks

B. (4) Drawing boards

C. (4) Chairs

D. (2) Telephones

E. (1) 5 Drawer file cabinet

F. (4) 100 Foot steel tapes

G. (2) Digital levels

H. (4) Mechanical plumb bobs

I. (2) Shipyard bicycles

J. (1) Theodolite

The system inventory will continue at this level for the next four years at which point the expected life cycle will be over. The operational life cycle is expected to last six years.

The system is expected to be operational during the first shift at NNS (7:30 am through 4:30 pm). Occasionally accuracy control personnel will be expected to monitor jobs which are conducted on second or third shifts in which case overtime will be approved. Measurements will be continously taken around the clock as long as work is being accomplished on jobs which are currently under analysis. These measurements will be taken by inspectors as part of the regular construction process. These measurements will then be submitted to the accuracy control team for analysis during normal operation time. the accuracy control system is expected to be in operation the year round as long as work on the aircraft carriers is being accomplished. As shown in Figure 3, the workload is expected to increase linearly throughout the operational life cycle of the system.

Since the system will be in operation the year round it can be expected that measurements will be taken winter, spring, summer, and fall. The system will operate in the office, on the platen , in the shops, and in the dry dock if necessary.

## 1.4 HUMAN FACTORS

Good system design requires the proper integration of human factors into the process along with hardware, software, data, and other elements [7, p.420]. Since the major portion of this system is the personnel, the choice of the accuracy control group members is quite important. The skill level and the training requirements for personnel are derived from the system operational and maintenance requirements. By examining the tasks to be performed along with other pertinent factors appropriate personnel choices can be made.

Personnel will have to operate in an environment far from optimal. Personnel will experience temperatures ranging through both extremes, very high humidity, extreme noise and a very cluttered, low accessible work environment at the construction site. When analyzing data, personnel will need good communication and visual senses. Because of the conditions, people with physical handicaps will not be able to safely function in the accuracy control group. Many tasks will be performed in a potentially hazardous environment. NNS does not allow any personnel with physical handicaps to go into the construction area.

An outline of the operation and maintenance functions is presented in Section 1.5, System Work Breakdown Structure. The selection of personnel and the training requirements depend directly on the tasks that they are required to accomplish. Since personnel are the major component of this system and personnel costs are relatively high, it is necessary to minimize the number of, and experience of the personnel required to perform system operation and maintenance functions.

The number of personnel required for the carrier accuracy control group is derived directly from the tasks to be performed and the number of areas to be analyzed. The individual areas to be studied will be determined upon inception of the accuracy control system. Areas will be broken down into work packages of similar work load for planning purposes. Production control, engineering, planning, N/C lofting, trade departments, and the accuracy control group will determine the areas of the carrier where the accuracy control system will have the greatest impact. The basic tasks involved with any particular area are outlined in Section 1.5 System Work Breakdown Structure. Also in Section 1.5 the results of a preliminary analysis of the carriers is shown. The preliminary results are as follows:

Year 1) 29 work packages

Year 2) 55 work packages

Year 3) 89 work packages

Year 4) 55 work packages

Year 5) 72 work packages

Year 6) 88 work packages

A work package is basically the same for the carrier accuracy control group and for the submarine accuracy control group. By studying the manhours and work load of the submarine accuracy control group it was found that 1.0 engineers with 1.6 support personnel can complete 24 work packages in one year. Because the carrier accuracy control group is new it will not be working at peak efficiency until the beginning of year two. It is assumed it will be working at 56% of peak for year 1. By dividing the number of work packages by 24 and multiplying the result by 1.0 for engineers and 1.6 for support personnel one will define the personnel requirements for each year of operation of the carrier accuracy control group (except year 1 which would be 56% of result). The requirements are as follows:

| | Engineers | Support Personnel |
|---|---|---|
| Year 1 | 2.2 = 2 | 3.5 = 4 |
| Year 2 | 2.3 = 2 | 3.7 = 4 |
| Year 3 | 3.7 = 4 | 5.9 = 6 |
| Year 4 | 2.3 = 2 | 3.7 = 4 |
| Year 5 | 3.0 | 4.8 = 5 |
| Year 6 | 3.7 = 4 | 5.9 = 6 |

In years four and five you will notice less engineers and support personnel are required than in year three. The full four engineers and six support personnel from year three will be kept in the accuracy control group. It is felt that it would be detrimental to the system to layoff group members for that period and hire new members back again in years five and six. Also in those years, extra time will be desired to maintain the data base, and work on long term goals. These extra tasks which are not included in the work packages will keep the employees busy. Because of the inaccuracies in estimating work packages and manhour requirements it is felt that two engineers and four support personnel are required for the first two years and four engineers and six support personnel are required for the last four years.

Considering the complexity of the tasks involved, it will be necessary for the initial six members of the accuracy control team to be highly skilled. Two of the first six should have an industrial quality, systems or related engineering bachelors of science degree with 5 to 10 years of shipyard experience. The other four initial members of the accuracy control team should be shipyard employees with more than ten years experience from one of the following departments:

1) production control
2) operations supervisor
3) welding department
4) fitters department
5) riggers department
6) numerical control
7) mold loft

All of the initial six members should be existing shipyard employees. The four additional employees that will be hired in the third year of operation can be of intermediate skill level. Two of the four must have a bachelors of science in a related field but may have less than five years of experience in shipbuilding. The final two members should come from one of the departments listed above but may have from 5 to ten years of shipyard experience. The additional four members of the accuracy control team should also be existing shipyard employees. The reason that existing shipyard employees are desired is because they already have the necessary security clearance and the knowledge of the standard shipyard practices, policies, and procedures.

Some amount of training will be required for every member of the accuracy control team. The main objectives of the training program are:

1) Provide each member with the understanding of the goals of the accuracy control system, of its operation, and of safety.

2) Provide the members of the team coming from the trade departments with a working knowledge of computer operations and the mathematical and statistical fundamentals necessary.

3) Provide the members of the accuracy control team with the college education (but less practical experience) with a better understanding of actual construction practices and procedures.

4) Provide training for replacement personnel throughout the life cycle as required due to attrition.

The first of the objectives will be handled by upper management and the existing accuracy control management. Only the initial six team members will receive this training in such a fashion. This objective will be accomplished in a class during the first three days of operation. The remainder of the training will be accomplished on the job. On the job training is best suited for this situation and will be accomplished by the employees themselves. Each employee has specific knowledge of certain areas but not all areas. By working together and training each other the group will function as a team. Each member will gain the additional knowledge they need by doing the job with other members. This is why each member was chosen with the specific background which was outlined earlier. Since initially (for the first two years) the new accuracy control team will be working with the existing accuracy control team under the same supervisor they will receive all the necessary guidance to manage and run the operation. After the first two years they will have their own supervisor and will be operating independently.

## 1.5 SYSTEM WORK BREAKDOWN STRUCTURE

Figures 8 - 14 represent the conceptual work breakdown structure for the accuracy control system. The work breakdown structure is used in determining requirements for many other system subsections such as: human factors, system management, system operation, system support, and system cost. Further analysis of the work breakdown structure into more discrete units will be accomplished in the preliminary design. These discrete units constitute tasks which will be organized into work packages. These work packages will be used as an important management tool for program planning and budgeting.

Figure 8 depicts the overall system work breakdown structure in very general terms. There are seven main steps after system conception. The system design is part of system conception. The system is designed as a continuously self checking loop. After justifying its existance in step one it goes through the steps necessary to comply with its function.

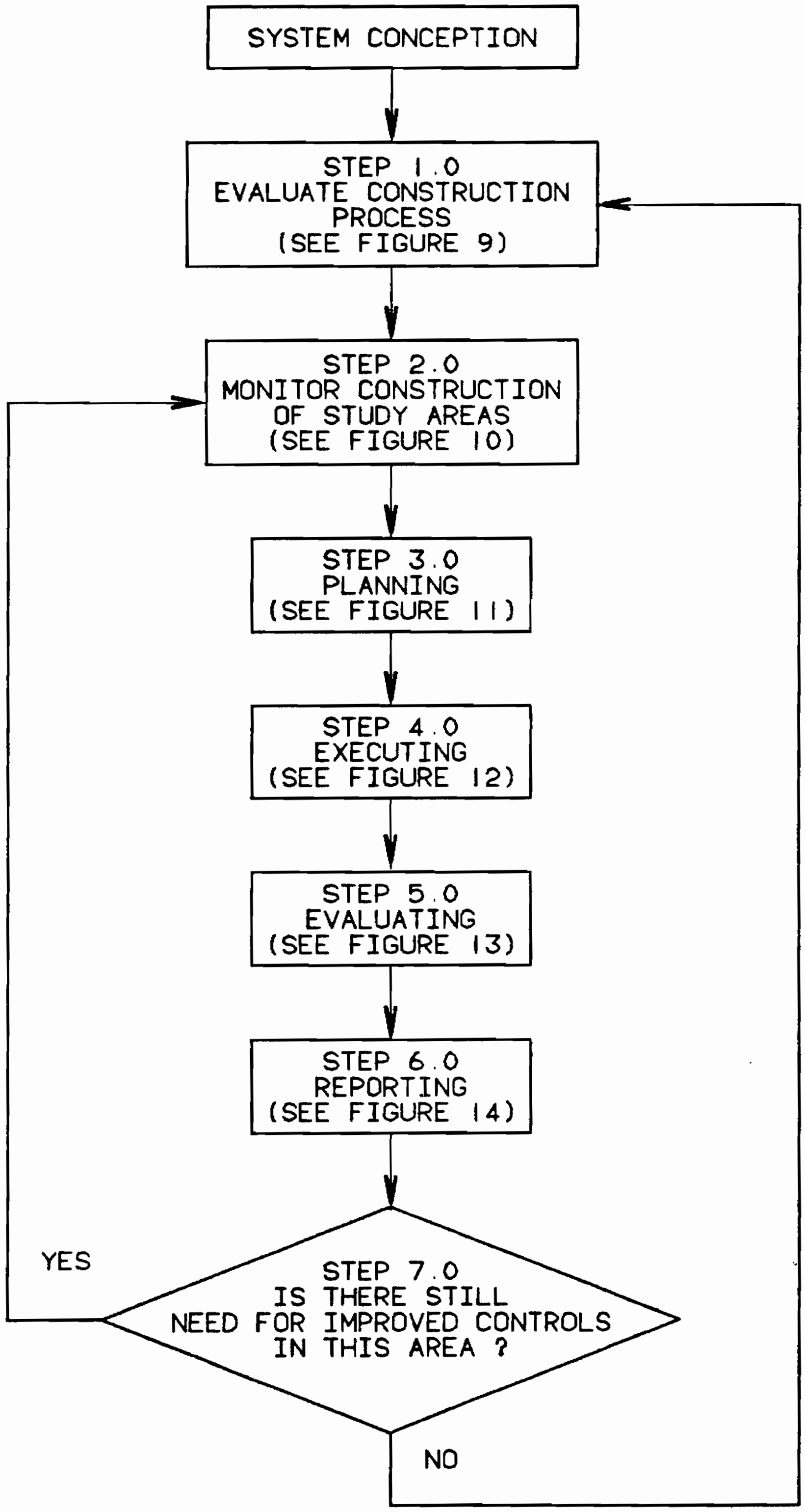



Figure 8. Overall System Work Breakdown Structure

Step seven is a type of self destruct step. If there is still a need for control in an area (determined by management) it continues work in that area. If accuracy control is no longer needed in a particular area it goes back to step one in search of justifying its existance again. This structure is the general process that every accuracy control job, regardless of area, will follow.

The breakdown of step one is shown on figure 9. The object of this step is to gather all the responsible parties together to decide if and where the accuracy control system should concentrate its efforts. The work to be accomplished in this step is to isolate specific problem areas in the construction of the carrier where accuracy control would benefit. These areas would then be prioritized in order of the magnitude their solution would effect the company. At this point if it was found that the problem areas were of significant magnitude to warrent analysis by the accuracy control section then its on to step 2. If there are not areas of significant magnitude to warrent analysis then the accuracy control system would then either be disbanded or applied to other shipyard contracts, which would be determined by management.

In order to design the accuracy control system it was necessary to develop and identify a need for the system. A

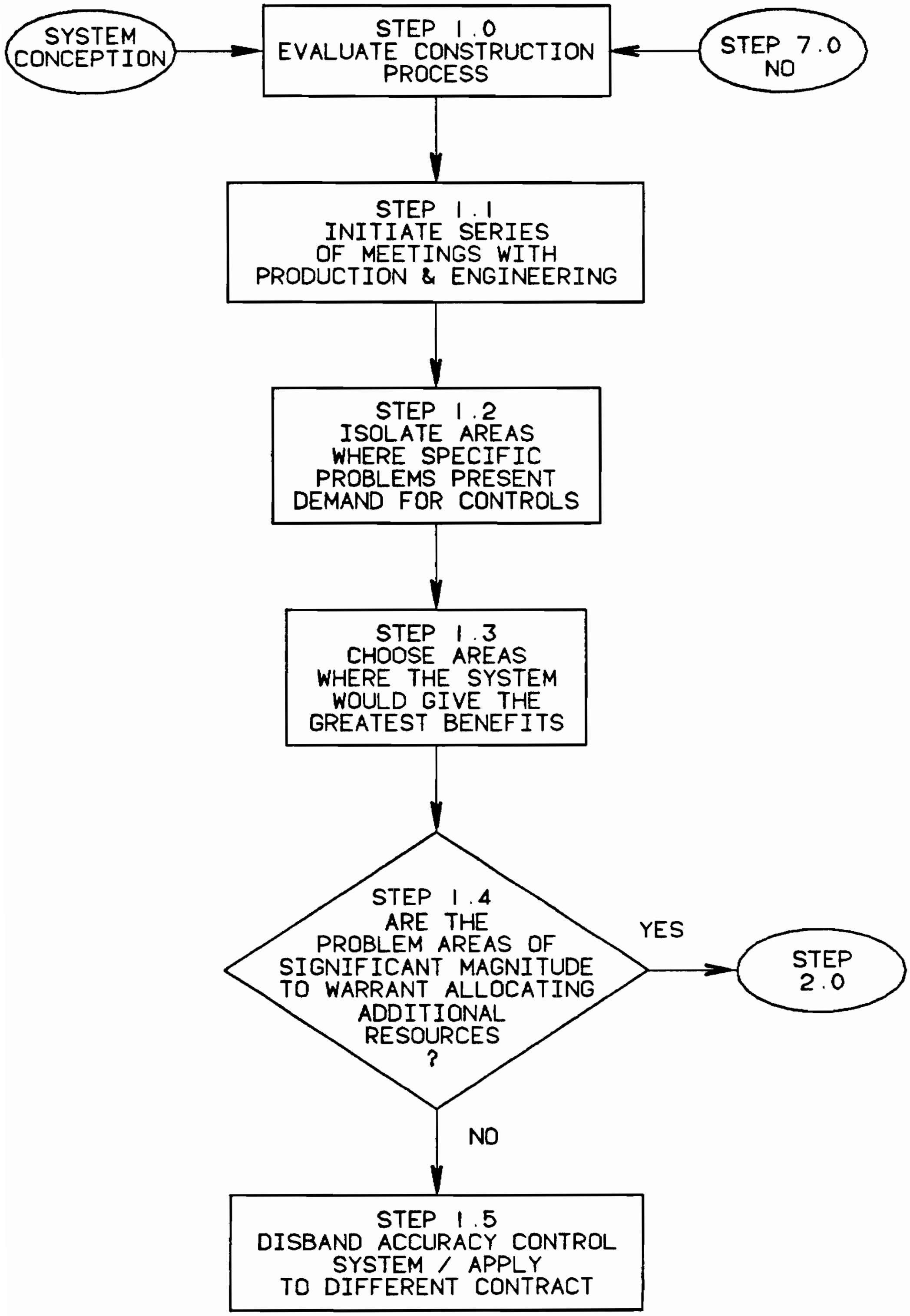



Figure 9. Step 1.0 Breakdown

preliminary step 1 was accomplished in conjunction with several production personnel. The object was to discover if there was truly a need for an accuracy control group dealing with carrier construction. Secondly, it was necessary to perform a preliminary analysis of the aircraft carrier construction process to determine a rough estimate of how many significant areas there were. This data combined with the task breakdown enabled the development of a rough estimate of the number of work packages there would be and their schedule. The work the submarine accuracy control group accomplished served as a model for this rough estimate. The conclusions are as follows:

Year 1) 29 work packages on CVN74

Year 2) 39 work packages on CVN74, 16 on CVN75

Year 3) 57 work packages on CVN74, 32 on CVN75

Year 4) 55 work packages on CVN75

Year 5) 72 work packages on CVN75

Year 6) 88 work packages on CVN75

This information was necessary in order to develop the system operation requirements, personnel requirements, system costs, and indirectly every part of this conceptual design. During the preliminary and detail design it will become necessary to further define this information.

Step 2 shown on Figure 10 consists mainly of studying the area which was choosen to be analyzed. In order to use accuracy control on an area one must first learn everything there is to know about that area concerning accuracy control. A number of questions must be answered such as:

1) What is the areas problem history?
2) What are the existing tolerances?
3) What are the existing weld shrinkage values?
4) What are the existing margin values?
5) What are the existing assembly sequences?
6) What are the existing welding sequences?
7) Are these controls being properly utilized?

It may be that the controls in existance are not the right magnitude. It may be that the controls are not even being used properly. No analysis can take place until the existing situation is determined.

Step 3 (Figure 11) is the first of the three major steps in the accuracy control system. Step 3 consists of the planning and scheduling of all the work that is going to take place on that specific area with respect to the accuracy control group. The proper planning and scheduling is vital

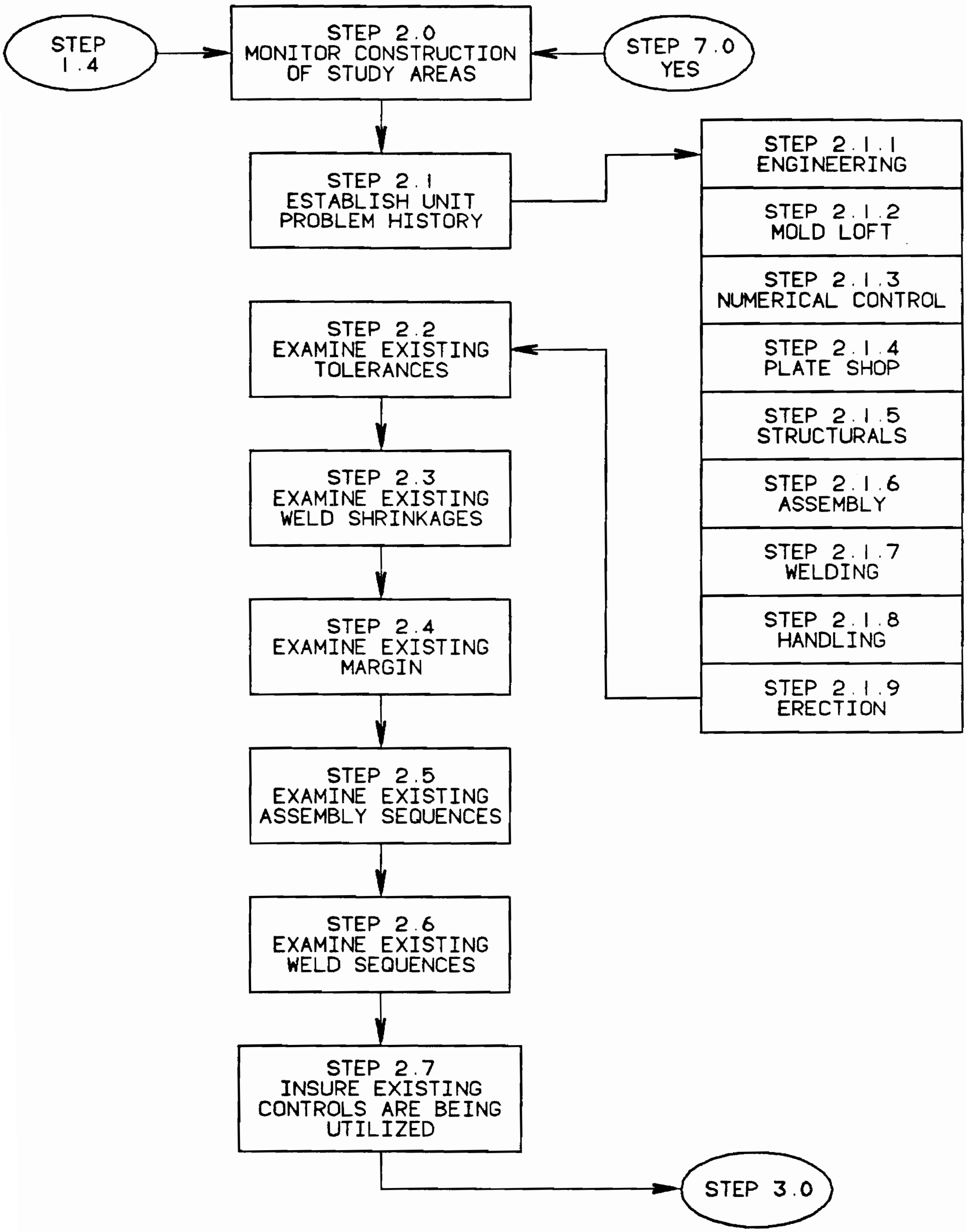



Figure 10. Step 2.0 Breakdown

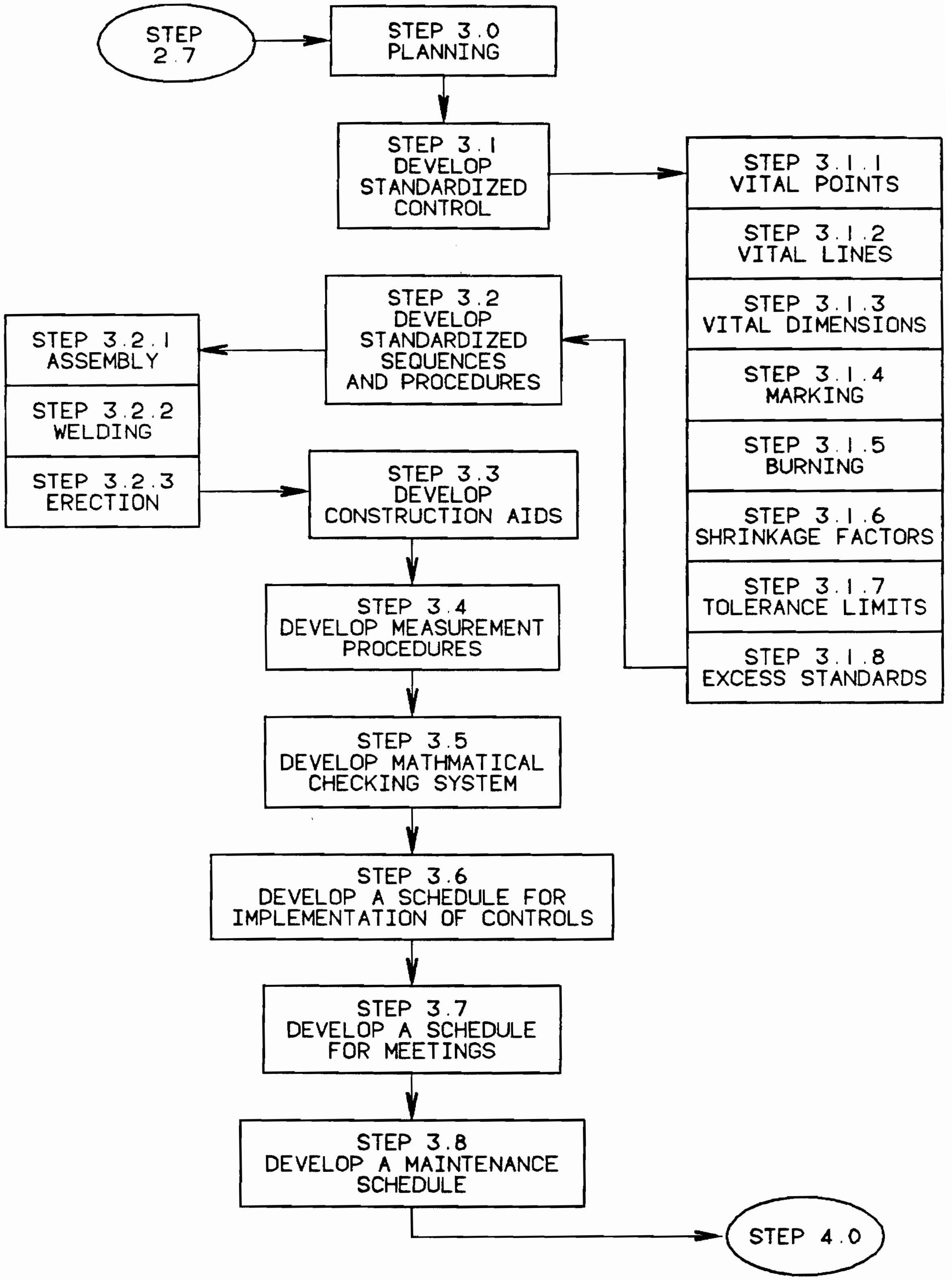



Figure 11. Step 3.0 Breakdown

to the success of any job. The establishment of vital points, lines, dimensions, marking, burning, shrinkage factors, tolerance limits and excess standards must be accomplished. The development of areas such as:

1) Standardized construction sequences and procedures
2) Construction aids
3) Measurement procedures
4) Mathmatical checking system
5) Implementation schedule for controls
6) Schedule of meetings
7) Maintenance schedule

must be completed so that work can progress in an organized fashion. Adequate planning will not guarantee success but inadequate planning will almost always end up in failure.

Step 4 (Figure 12) is the second major step in the accuracy control system. Step 4 consists of the actual work which the group will perform to the area in question. Step 4 contains tasks such as creating the forms and templates, installing the controls in the construction process, installing the sequences and prcedures, measuring and recording data, and maintaining the measurement equipment. Step 4 might be considered the most important step because

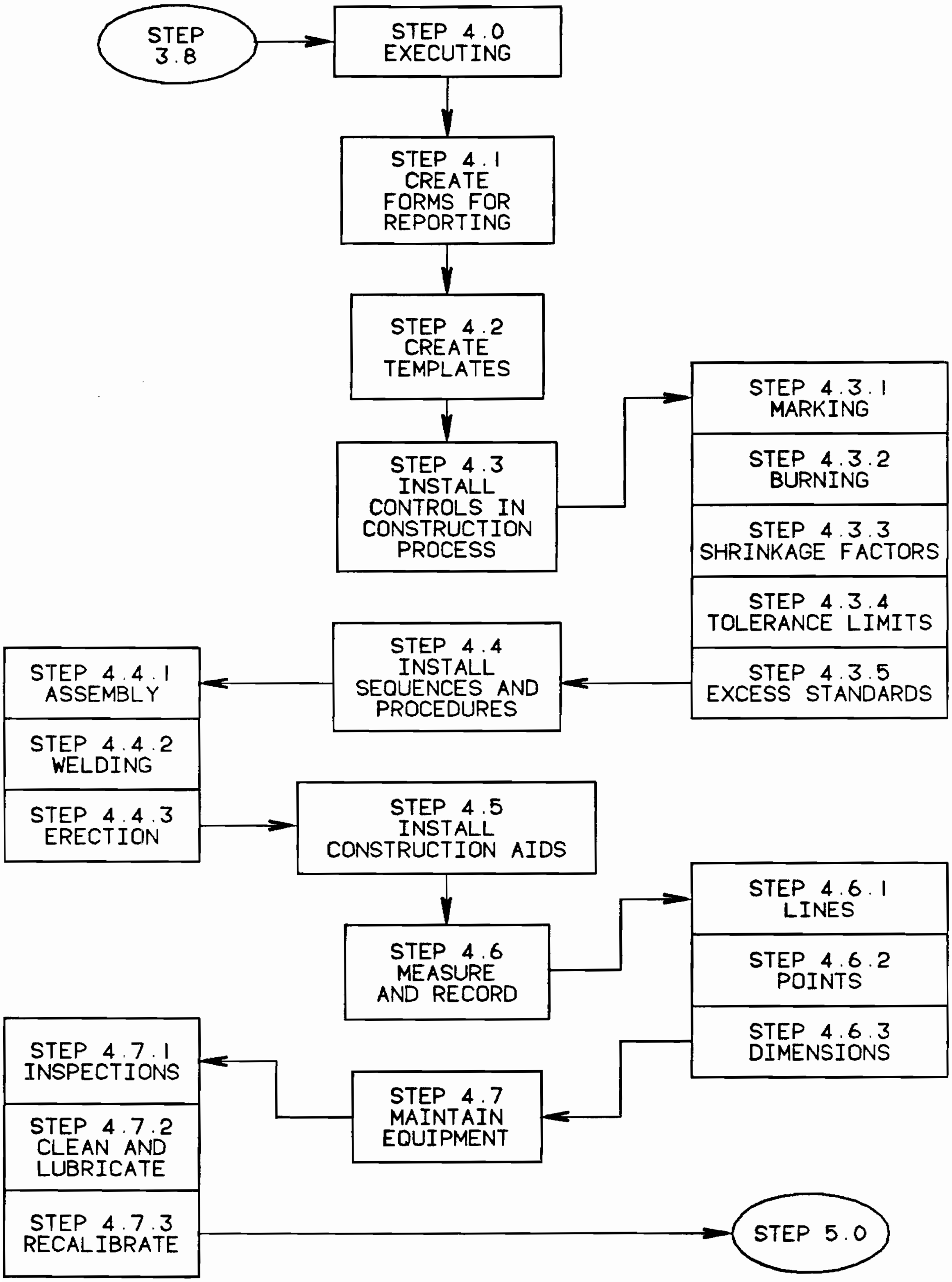



Figure 12. Step 4.0 Breakdown

all the other steps either lead up to or are dependent on the results of this step.

Following along in the logical progression of this system Step 5 (Figure 13) evaluates the data which was obtained in Step 4. This is the third major step. Step 5 consists of: organizing the data obtained from the inspectors and accuracy control group, analysing this data, and developing solutions to the problems.

Step 6 (Figure 14) involves reporting the findings and recommended solutions to all concerned parties. The tasks included in this step include:

1) Creating documentation including data from Step 1 through Step 5 for each individual party concerned.

2) Scheduling a series of meetings with these concerned parties aimed at installing the recommended solutions.

It is up to the responsible parties to agree and install these solutions, install revised solutions, or do nothing at all. The decisions reached during this step lead directly into Step 7.

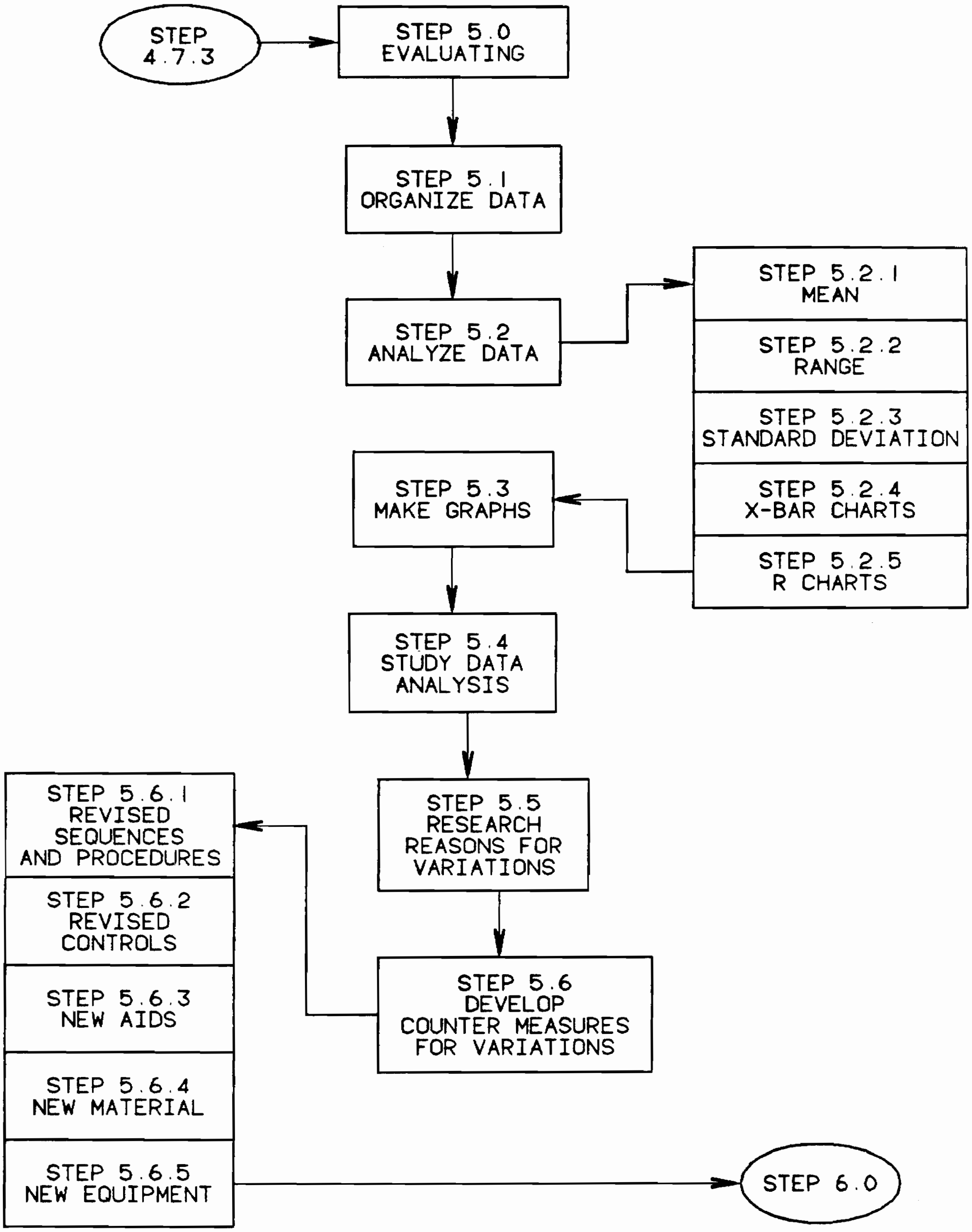



Figure 13. Step 5.0 Breakdown

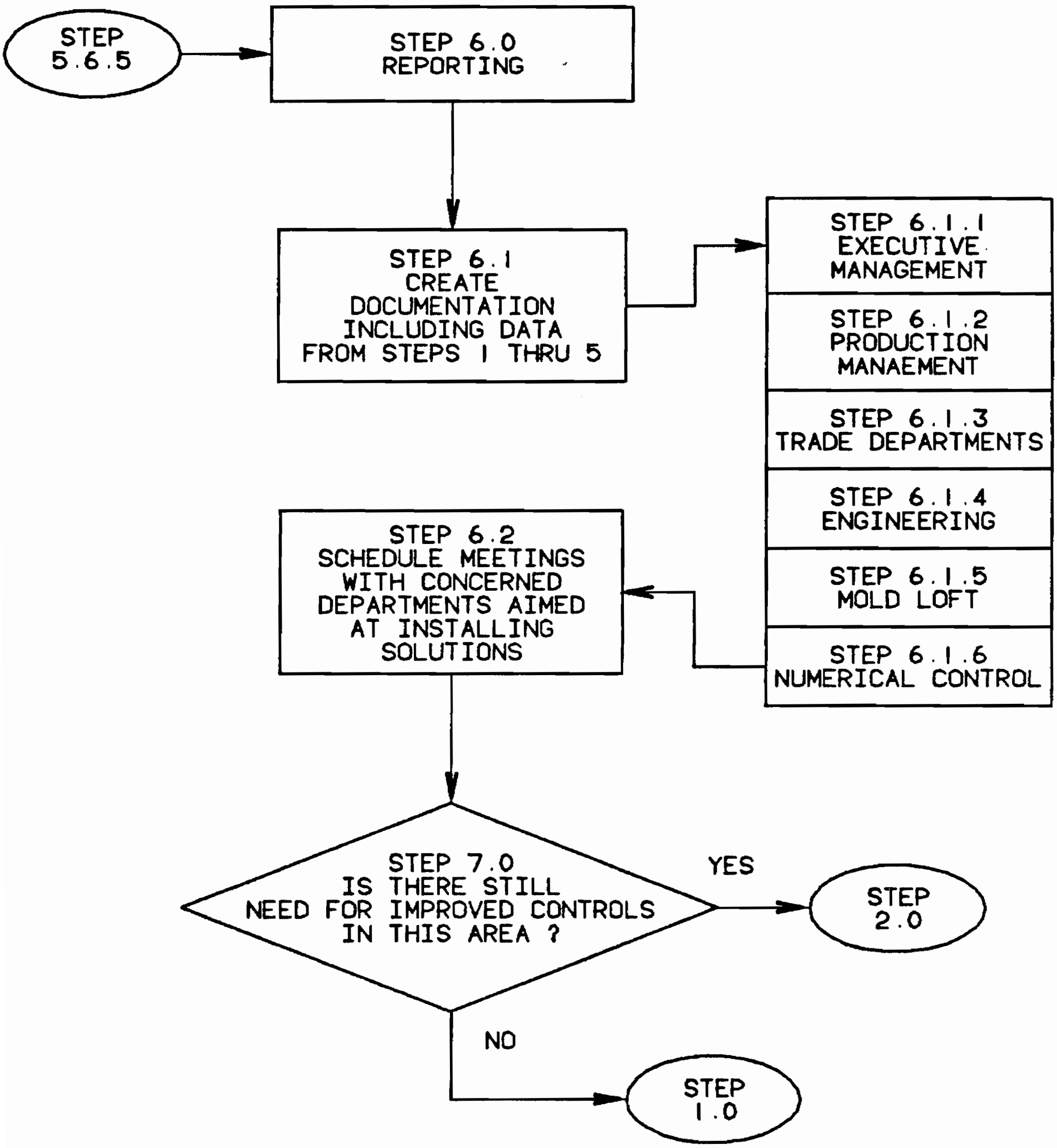



Figure 14. Step 6.0 breakdown

Step 7 (Figure 14) is more of a conclusion than an actual task. Step 7 consists of a question which will be answered by the results of Step 6. The question asks is there still a need for improved controls in this area. If management decides to install the solutions from Step 6 they are answering yes and Step 7 sends the system back to Step 2 where the system starts all over again in the problem area this time with the solutions included. If management decided not to install any solutions they are stating there is no further need to work on this area and Step 7 sends the system back to Step 1 with the purpose of locating a new area to work.

## 1.6 SYSTEM MAINTENANCE CONCEPT

The purpose of the system maintenance concept is to provide a basis for the establishment of supportability requirements and the requirements for total logistic support.

There are three main levels of maintenance which are: organizational maintenance, intermediate maintenance, and depot maintenance. Organizational maintenance is concerned with maintenance of equipment on the operation site. Intermediate maintenance is more serious and is accomplished by more skilled specialized organizations usually mobile.

Depot maintenance is the highest level of maintenance and accomplishes tasks above and beyond the capabilities available at the intermediate level.

The system in question is made up of: the facility, computer equipment, measurement equipment, and personnel.

The system utilizes an existing facility and computer equipment with established maintenance support. The existing facilities (building, office furniture, and computer system) is currently not being used to capacity as stated in Section 1.3, System Operational Requirements. The company has a department established for the purchasing and maintenance of computer support and another for facilities maintenance. These areas are not subject to change by the individual departments. The individual departments work within the ample boundaries set up by the company in regard to this area. This fact plus the fact that the computer support and existing facilities are more than adequate for use by the accuracy control system make it unnecessary to be concerned with the maintenance of their two areas.

The other two components of the system will require a small degree of maintenance. The personnel will require maintenance in areas such as training. Overall personnel requirements are covered in Section 1.4 titled "Human Factors." There is a limited amount of measurement equipment on hand for the members of the accuracy control team to use. Although most of the measurement work will be performed by the inspectors or other specialized groups such as the photogrammetry section some amount of measurement tasks may be required by the accuracy control team. The equipment in question will not be very complex but nevertheless it must be maintained. Equipment such as: levels, steel tapes, plumb bobs, templates, transits, laser, theodolites must be keep in good working condition in order to insure accurate measurements.

The necessary maintenance can be classified in two categories:

1. Corrective maintenance - the unscheduled actions accomplished, as a result of failure, to restore a system to a specified level of performance.
2. Preventive maintenance - the scheduled actions accomplished to retain a system at a specified level of performance by providing systematic, inspection, detection, and/or prevention of impending failures [7, p.375].

Preventive maintenance will be performed at the organizational level (by members of the accuracy control group). Because of the nature of the equipment the amount of preventive maintenance will not be substantial. The tasks the accuracy control group will be expected to perform will consist mainly of keeping the equipment clean and periodically inspecting it to guarantee the equipment will perform as intended. Corrective maintenance will be performed at the depot level. This means if a piece of equipment breaks down it will be sent back to its manufacturer for repair. Because the measurement equipment is rather small in size and of a very specialized nature intermediate maintenance (performed by mobile/fixed specialized organizations besides the manufacturer) is either unavailable or impractical therefore no intermediate maintenance will be required. If a piece of equipment should fail the accuracy control team will decide if it is economically feasible to repair or discard. For less expensive piece of equipment such as levels, discarding the equipment and replacing it will be necessary. For more expensive equipment such as the laser, sending the equipment back to the manufacturer is required because equipment of this nature cannot be repaired otherwise.

Because most of the mesurements will be taken by the inspectors not the accuracy control team. The amount of time the accuracy control group's equipment will be in use will be small. Also, the fact that the type of equipment the group will posess is common at the shipyard, there will be little pressure to have their equipment at the ready level consistently. Because the equipment in question is very basic in nature, it is common at the shipyard, and the system is not very dependent on its use, maintenance other than that of the preventive nature is not of much consequence to the accuracy control system. For the six years of the systems expected life cycle, very little corrective maintenance will be accomplished. Preventive maintenance during the same time period will be accomplished by the accuracy control team according to the schedules documented by the equipment manufacturer and is not expected to utilize significant time or resources to accomplish.

# CHAPTER 2

# ADVANCE SYSTEM PLANNING

## 2.1 SYSTEM SUPPORT REQUIREMENTS

System support (logistic support) is defined as the composite of all considerations necessary to assure the effective and economic support of a system throughout its programmed life cycle [7, p.449]. System support includes the following:

1) Maintenance planning
2) Supply support
3) Test and support equipment
4) Transportation and handling
5) Personnel and training
6) Facilities
7) Data
8) Software

Since the accuracy control system discussed in this design is a relatively small system the support requirements are minimal. The system support requirements are a direct result of the system operational requirements, system maintenance concept, and human factors.

The majority of the system support will be accomplished through normal shipyard channels such as the tool rooms or supply vault. All articles such as paper, pens, folders, desk equipment, and other miscellaneous items can be acquired by simply filling out a form and picking up the necessary materials. Larger equipment such as the theodolite or the desks can be obtained through purchase orders with management approval. This larger equipment will be delivered through the normal shipyard purchasing department channels. Personnel training is discussed in the Human Factors Section 1.4. Facilities and transportation for the accuracy control system already exist at the shipyard. Because the current facilities and transportation are not used to capacity, the relatively small increase incurred by the accuracy control system will not be a problem.

The mainframe computer facilities currently existing at the shipyard are more than sufficient for the accuracy control system. The mainframe memory would be sufficient to cover the data base and all other necessary software. Any programs written by the accuracy control group will be completely contained on the existing mainframe.

Very little extra effort beyond the initial procurement of equipment in the first and third years of operation will be necessary. Therefore, the system support requirements will not be a large issue except in the cost and economic analysis.

## 2.2 System Engineering Management

System Engineering Management involves planning, organizing, staffing, monitoring, and controlling the process of designing, developing, and producing a system that will meet a stated need in an effective and efficient manner [7, p.546]. The conceptual design that this paper represents is part of the design process which when combined with the preliminary design and the detailed design make up the systems technical attributes. It is the function of management to provide the necessary guidance to transform the system from the conceptual state to a full scale functioning system. Too much or too little effort by management may cause the system to be ineffective and/or costly.

Regardless of the organizational hierarchy the accuracy control concept must be infused into every existing shipyard department. It is assumed that key personnel in every department who have the authority to make decisions regarding changes in production will serve as envoys during the accuracy control meetings. Thus these key personnel can be considered "part time" group members.

The accuracy control system has little chance of success without the total committment and support of upper management. Upper management in turn must realize the short-term and long-term goals and the time frame involved.

One of the goals of system engineering management is to develop the project management plan. Much of the project management plan will be accomplished during the preliminary and detail design phases. Some elements the project management plan include are:

1) A definition of major project tasks
2) The schedule for the defined tasks in the form of milestone charts, CPM/Pert networks, Gantt charts, etc.
3) The organization of tasks in terms of work packages and the work breakdown structure
4) The alignment of these work packages with the project organization and its various function groups.
5) The cost estimate for task accomplishment
6) The method for task measurement and control [7, p.549].

One important aspect of system engineering management during conceptual design is the organization hierarchy. The

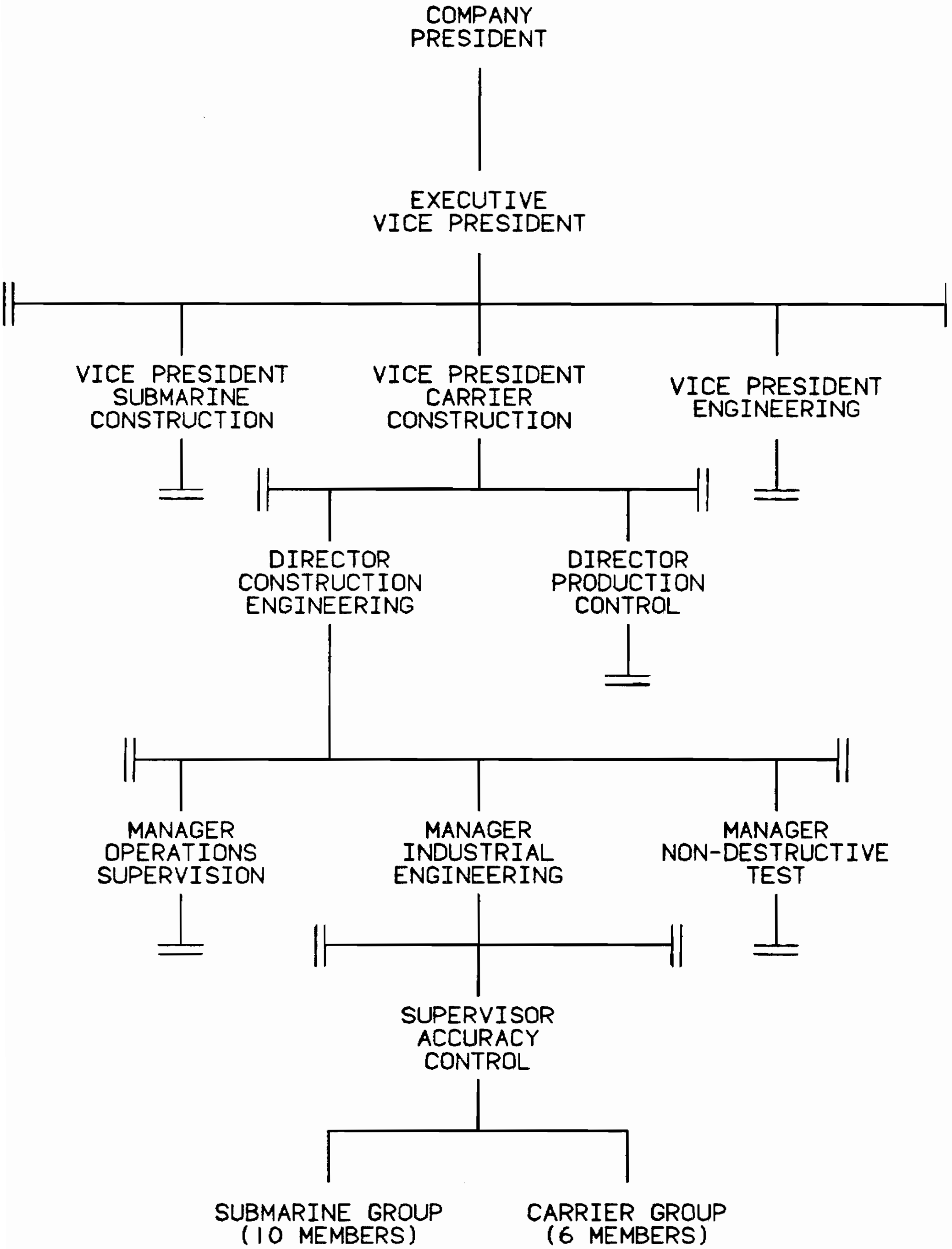



Figure 15. Initial Organizational Hierarchy

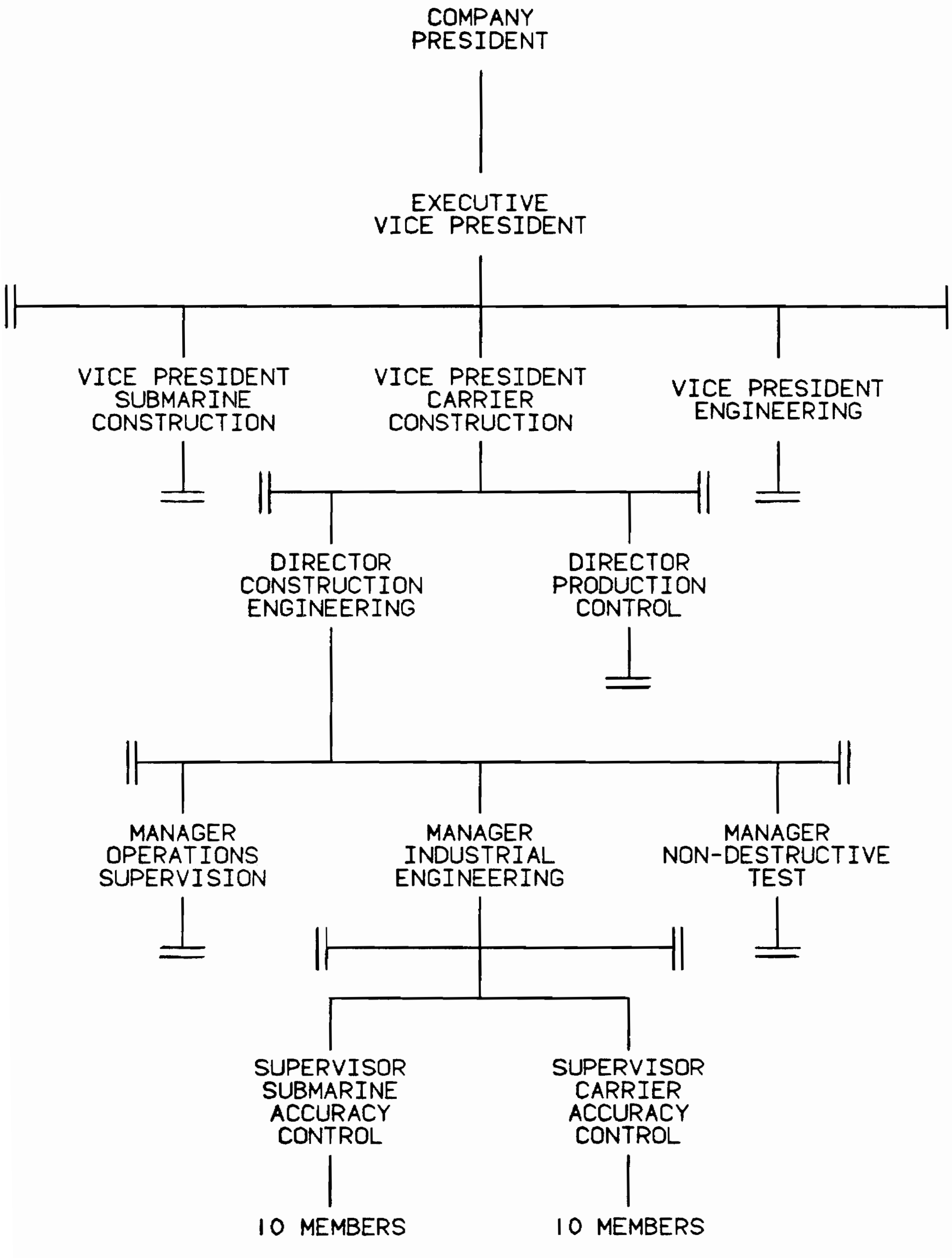



Figure 16. Final Organizational Hierarchy

organizational hierarchy of command as it is commonly referred to is important to the accuracy control system. The information and recommendations the accuracy control group generate must be received by those in a position with the authority to make the changes necessary for improvement. Cooperation between the trades and the accuracy control group is essential in order for it to operate successfully. The accuracy control system can not function without the direct backing from upper management, which can only be accomplished by direct lines of communication. The initial and final placement of the accuracy control group within the organizational hierarchy is shown on Figures 15 and 16. The additional group fits into the existing hierarchy and reports directly to upper management. Since the new accuracy control group fits in with the old, the existing lines of communication will be to their benefit.

## 2.3 SYSTEM OVERVIEW

Some structural work processes which require accuracy control at NNS are:

1) Part Fabrication
2) Cutting
3) Welding

4) Sub-block Assembly
5) Block Assembly
6) Erection

Some questions the Accuracy Control team will face are:

1) What dimensions are vitally important to achieve the required accuracy?
2) How is the required degree of accuracy going to be achieved?
3) In what process should vital dimensions be controlled?
4) What are the tolerances that should be imposed at each work process?

An effective AC system is critically dependent upon unified operations, organized information, qualified team members, qualified members of other shipyard departments assigned as representatives to the AC system, and one operations manager responsible for all of the AC functions who reports directly to top management. A chart depicting the flow of information is shown in Figure 17. The three basic functions involved are planning, executing, and evaluating. Information is continuously cycled through the circuit which includes the AC team, design, engineering, mold

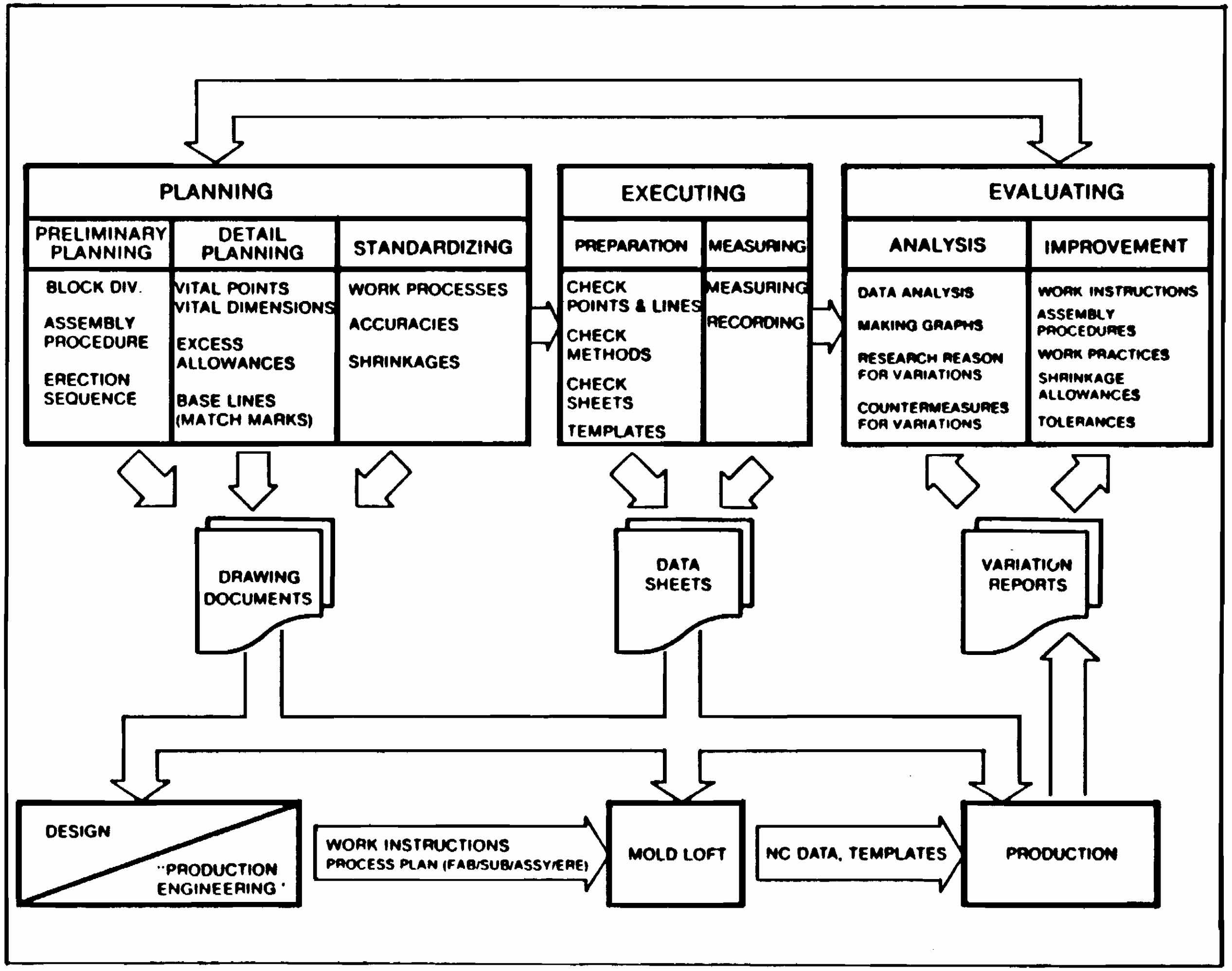



Figure 17. Information Flowchart

Source: L. D. Chirillo. "Process Analysis Via Accuracy Control" U.S. Department of Transportation, NSRP, Washington, D.C., August 1985 loft, and production. Initially the AC team will focus on the immediate improvement of process flows and the minimization of rework during erection. As a data base is established, long term improvements to large scale processes will be implemented [9, p.9-12].

The accuracy control system that is recommended to be implemented at Newport News Shipbuilding can easily be integrated within existing facilities. The accuracy control team will need strong management committment, in some cases it will need a specific time set aside for them in the construction schedule, cooperation from the trades and a place within the organizational structure of the shipyard. The primary functions of the team will be to plan and evaluate problem areas to be studied, take measurements or instruct the trades working the area in question what recordings to take, analyze the data, from the findings of the analysis make recommendations as to where improvements may be made in the process, equipment, schedules, material, tolerances, weld recipes, construction sequence, etc., and communicate their findings to design and construction management. The goals of the accuracy control team are for the short term and for the long term. The short term goals revolve around the need to monitor construction so that rework at erection can be minimized. Design and construction planning changes will also incorporate these short term goals. The long range goals are to improve the entire production process including contract negotiations, design, planning, materials, equipment, scheduling, tolerances, overall quality, productivity, etc. The accuracy control system should be implemented immediately since NNS will lay the keel of CVN74 in early 1991. This will allow the team to start work with the very first assemblies to be built. Short term goals should be realized just a few months after inception and continue throughout construction. NNS has been awarded the contracts for two carriers concurrently which makes this the perfect opportunity to start such a group. Long term goals probably will not be seen until enough data has been collected and analyzed which more than likely will not happen until the laying of the keel for CVN75. The life of the team is about six years or until the structure for the next two carriers is built. At the end of it's life cycle the accuracy control team can apply it's resources and experience on other projects the shipyard will be undertaking at the time. If there is not enough work for the accuracy control group, its members will be employed by other area's of the shipyard where their experience may prove beneficial.

The current accuracy control team which works with submarines contains ten employees and has been in existance for the past five years. They are located in building 160 which is right on the waterfront where the work is being accomplished. Initially the new accuracy control group can be integrated right into the old, under the same supervisor. The only difference will be that their primary concern will be with carriers not submarines. They will use the same building and computer facilities. Additional equipment and supplies will be needed but the overall actual start-up cost will be minimal. In approximately three years, when the work load increases with the increase in construction, more employees will be hired maxing out at ten. At this time it will be necessary to promote one of the group to supervisor and break away from the other accuracy control group in organization only. The accuracy control group will be situated exactly where they were initially. The start-up resources and costs that will be used in the economic justification are outlined in Section 3.1 costs.

Structural erection increases in an approximately linear fashion from start-up in Spring 1991 through to launch roughly three years later where it drops off for a few weeks and starts back again with the next carrier. Occasionally as with CVN72 and CVN73 the construction of the next ship starts in the outboard section of the shipway before the existing ship is finished. When they launch the carrier they make the portion of the new carrier watertight and simply move it out first, after the finished carrier leaves, they put the unfinished carrier where the finished one just was. This is called the dry dock and a half method, and serves to further overlap the design/construction/material procurement stages in order to increase productivity, and compress construction schedules. NNS currently plans to use the drydock and a half method for CVN74 and CVN75. This means a constant flow of work for the accuracy control team for at least six years. The workload will actually increase every year for the six years without dropping off after completion of the first carrier. This is true due to the extra effort required to apply data accumulated from the first ship to the construction of the second.

The most important part of this whole process is the accurate recording of data including measurements, sequences, materials, weld receipes, and equiment used. Even though rework will decrease, there will always be some, and this must also be recorded and fed back into the system. Rework can be attributed to certain work stages in construction and can be reduced by altering design, construction procedures, material excesses, equipment, etc. The start-up procedure for an accuracy control system at Newport News Shipbuilding to work in carrier modular construction can be summarized by the following steps:

1) NNS management must be totally committed to forming and supporting an accuracy control system for use in carrier modular construction.

2) The yard personnel must choose an area of the carrier or a step in the construction process where accuracy control will have the greatest impact, for start-up of the system.

3) Meetings must be set up involving engineering, planning, shop and trades foremen, Numerical Control Design Loft, quality assurance, and welding engineering so that everyone knows what is happening and has a chance to contribute.

4) Written assembly and welding sequences must be drawn up by engineering with input from planning and production and based on the Group Index Schedule.

5) Initial estimated tolerances must be established by engineering based on input from planning and production.

6) Establishment initial amounts of margin for plates and assemblies must be made by engineering based on input from N/C loft, planning, and production.

7) Check sheets for the data to be recorded in the areas chosen in Step 2 must be developed by the accuracy control group with input by engineering, planning, and production.

8) The welding and assembly procedures must be reviewed and, where there are changes, implemented by production.

9) Data must be collected by the inspectors and occasionally by the accuracy control group.

10) Analysis of data, sequences, and processes by the accuracy control group.

11) Communicating information and recommendations to design, engineering, planning, production, etc. Also this information along with whatever changes that were implemented because of it, must be fed back into the accuracy control group [9, p.13].

In order for the accuracy control group to be successful, management must understand its short term and long term goals. Short term goals deal with the efforts involved with monitoring the construction of interim parts in order to minimize rework during erection. Long term goals deal with the analysis of data collected over time to make improvements on a more broader scope, such as improving the individual design and construction processes themselves. Short term goals will be realized almost immediately, but it is the long term goals that, in time, will be the most beneficial. The full benefits of the long term goals cannot be realized until a sufficiently large data base is collected. Accuracy control will become increasingly difficult in areas where the product work breakdown structure has not become fully impelemented. Because of the relatively recent transition to modular construction most production management realizes the need for increased accuracy control, but giving up the time and effort to take the data needed will require a push from upper management. The stable workload of Naval ship construction at NNS provides a very favorable climate for the start-up of an accuracy control system.

An initial problem area in the carrier construction process must be chosen by production and engineering as a starting point. This area must be chosen in advance of construction giving engineering and production enough time to develop the sequences and tolerances that were outlined earlier. When choosing an area for initiation of the accuracy control program, use of Pareto analysis is mandatory. Rework costs are always maldistributed. There are many areas throughout the carrier construction process where the application of accuracy control would save money but a relatively few of the areas account for the bulk of the costs. This principle of the "vital few and the trivial many" was conceived by Vilfredo Pareto and is used as a means of attacking the bulk of the problem with the least amount of analytical study. The lead time needed for this preliminary work should not be underestimated. If the accuracy control team is implemented this year it will give engineering and production several months to choose the initial area, write assembly and welding sequences, tolerance limits, margin, etc.

Engineering, production, planning, design, N/C lofting, trades (foreman level), quality assurance, and welding engineering must get together in a series of meetings, approximately once a month. Also smaller meetings between for example, engineering and production, must be set-up. These meetings will serve to transfer the information between the various departments and to gather recommendations and opinions. Everyone must be made aware of the need of accuracy control, of the short and long term goals, and of the need for complete cooperation. Perhaps most importantly though is the need to mutually agree upon subjects like; tolerances, margins, standards, assembly and welding sequences. All present must be made aware of the importance of the data collection and the strict compliance to the assembly and welding sequences. Channels of communication must be set-up between certain departments to insure the transfer of problems which will arise. The start-up of the accuracy control system is a difficult procedure but with the choice of a specific start-up area and plenty of communication it can be accomplished. The choice of the superlift or lifts that comprise the area with the biggest production problem like machinery rooms, reactors, turbines, elevators, etc. would be a good start. In time as the system is implemented employees will become more adjusted to the process and begin to feel that it's a necessary part of production. Also in time representatives from the various effected departments will be chosen to "take up the torch" so to speak and represent their area at the meetings. As the learning curve develops, more and more jobs or problems will be taken on.

Tolerance limits, margin, and stretch need to be well defined. Margin (the amount left on the edge of plates and shapes for trimming during erection) and stretch (the amount left on plates and shapes to compensate for welding shrinkage) are already defined at NNS. The tolerance limits in most cases are not well defined and currently are accomplished by means of templates or by inspectors without consideration for the effect on other areas. The tolerance limits must initially be estimated and included in work packages. As time passes and the accuracy control team has a chance to analyze enough data, tolerance limits will be revised and refined. Also critical tolerance limits can be specified informing production as to where they have to be extra precise.

Based on the GIS, which is the main work package planning and scheduling document for NNS, detailed assembly and welding sequences must be established and adhered to by production. The initial sequences will be subject to change as the accuracy control team collects and analyzes data and attempts to make improvements. Production must agree on, understand, and follow these procedures because statistical data analysis is of little value if we are not comparing "apples to apples". If a subassembly is built from forward to aft and an identical assembly is built aft to forward we cannot compare the two because variances in their dimensions might be due to the sequence of assembly or welding. Standardizing this will cut out one more variable.

After reviewing design drawings and consulting with engineering, critical dimensions can be established by the accuracy control team and check sheets can be developed. Check sheets will vary from job to job and should include the tolerances previously discussed. Check sheets are not only necessary to the accuracy control team but will help to inform the trades actually where the critical areas of the particular assembly are and will make them conscious of the need to be super accurate in that area.

Actual measurements and data collection should become a normal part of production. Production planning must take allowance for the time required to check work and then to measure and record data. Either the accuracy control team will take the measurements or, in most cases, one of the measurement departments at NNS will take them (such as the photogrammetry department). The choice will be made by mutual agreement between production and the accuracy control group. The measurements will be used to improve the construction process in a number of ways. Measurements utilizing tolerances insure the structure is built as designed.

Unacceptable work will be reworked in the early stages of construction, in the shop, and not passed on to the later stages of construction where rework is more costly. Measurements of a critical piece of structure on two separate units before being joined will indicate where excess margin is located so that it may be trimmed before joining, in this way margin "stack-up" may not occur. The accumulation of data over time for different work stages or stations will eventually point out problem areas in the construction process. These are only a few of the short term goals that the accuracy control system will accomplish.

The two main types of analysis performed on the collected data is the mean value and the standard deviation. Obtaining a mean and standard deviation for each process under control makes it possible to:

1) Express the standard deviation of variations at erection as a combination of the deviations of variations from preceding work processes.
2) Determine an order of priority for re-establishing preceding work in order to reduce accumulation of variations for the final work process.
3) Establish accuracy standards.
4) Revise procedures.
5) Change design in order to enhance productivity.
6) Alter work sequences to enhance productivity.
7) Identify areas which need improvement. [2, pg. 11]

Statistical analysis is used to describe and interpret the measured variations found on the thousands of similar areas of the ship. Statistical analysis can weed out the special causes so that they may be resolved. When only the common causes are left the mean variations of all the individual parts will provide an overall variation. If this overall variation is unacceptable, changes to the individual work processes will be made to decrease the variations of the individual parts.

For most work processes the planned mean value for variations is zero. The most significant reason to analyze the standard deviation is that it provides a relationship between the accuracies of earlier work processes and the accuracy of the final process.

Sustaining a data base of all the measurements and analysis information is a very important part of the accuracy control system. By grouping similar problems and studying the results it will become possible to improve on large scale long term processes.

Communicating the measurement data and analysis results to other departments is another very important function of the accuracy control system. A series of meetings between the accuracy control group and other departments such as engineering, mold loft, trades, and production control will enhance communication. By discussing the problems and recommended solutions with other departments an integrated effort can be accomplished. It is important that every department be involved in order to study the effects on the rest of the enviornment a change might produce, and explore each department's contribution.

Long term goals will be accomplished when enough accumulated data is analyzed allowing major evolutionary changes to all aspects of the construction process. It is possible that changes in assembly and welding sequences, major scheduling and planning, design, material, processes, equipment, lifting and handling will occur in time. This will significantly cut down on rework in the later stages of construction.

The group will begin working with other members of the existing accuracy control section which will aid in its inception. The learning curve will advance at a much faster rate as new members learn from the experience of the older members. The new team will consist of six members, two of which will be industrial engineers or in a related field such as systems or quality. The last four should come directly from the yard and have experience in production and construction activities. All members should be made familiar with engineering statistics and quality control. All members should be taught the theories of W. Edwards Deming on quality and the practices of Genichi Taguchi the emminent Japanese statistician. Statistical analysis must be performed according to the practices of Mr. Taguchi and not in accordance to traditional American practices. Followers of the Taguchi principles believe that samples of data must be centered around the target dimension in order to be acceptable not just within tolerances (like the traditionalists believe). Taguchi's methods eliminate tolerance stack up to a great degree where traditional methods accept it. One of the major reasons that problems exist is because of tolerance stack up. An example of tolerance stack up could occur when there are five plates which make up a unit. Each plate is butted end to end and has a tolerance of $\pm$.25 inches. If every plate is +.25 inches long instead of randomly being -.25 and +.25 inches, the overall length when joined will be unacceptable, even though each individual plate was acceptable.

As the accuracy control team's work load increases with construction increases, more employees will be incorporated into the group. Initially the accuracy control system will be seen as an impediment to progress but after time passes it will be accepted, even sought after. In addition to taking measurements and evaluating data, the accuracy control team will become trouble shooters assisting production in many problems. Since communication between the accuracy control team and production management will be strong the authority to install change will be there and response will be quick. An overall view of the construction process will be taken by the team, grouping similar problems together in order to limit their occurrence in the future. It cannot be emphasized enough that the major benefits of the accuracy control system are in the long term goals which may not be realized for five years or so, even though short term goals will be seen in as little as one year. All personnel involved must understand the time frame.

## 2.4 DEMONSTRATED EXAMPLE

The internal structure of an aircraft carrier is condifential. This fact plus the fact that NNS will not permit outside interests to learn detailed construction planning or procedures for any area of the carrier prohibits the use of an actual example. It is necessary, therefore, to create a fictitious example which represents a realistic area of the carrier. It must be understood that the figures, numbers, procedures, etc. are completely fictitious. Nothing contained in this section is real, but the example is engineeringly sound and is realistic. The example is also very simplistic compared to the real thing, for the purpose of ease in explanation.

Assume an accuracy control system has been implemented at NNS conforming to the design outlined in this paper. After studying the rework costs production management has determined that 80% of the rework costs come from only five areas of the ship. The five areas are;

1) Area A - 40% of rework costs.

2) Area B - 15% of rework costs.

3) Area C - 10% of rework costs.

4) Area D - 10% of rework costs

5) Area E - 5% of rework costs.

After a series of meetings it was decided that initially the accuracy control team (from now on known as AC team) will work on area A. Area A was chosen because it is the first area of the ship to be constructed and more importantly it is the area where the highest concentration of rework costs exist, therefore, has the highest potential benefit. Area A is shown in Figure 18. Figures 19 and 20 show how the area is broken down into subassemblies. The material used in each subassembly is exactly the same. The area is a machinery space and has significant vertical integration. There are six watertight bulkheads which are also used to support foundations. It is of the utmost importance that each bulkhead is aligned vertically. Specifications state that they must be within $\pm$ 1/32 of an inch of each other horizontally. The unit must be 110 feet long plus or minus one inch. The vertical or transverse dimension will not be considered in this example for clarity and ease of comprehension. Each assembly is attached to the shell plating outboard and a longitudinal bulkhead inboard. The length of each assembly plus stretch and margin falls easily

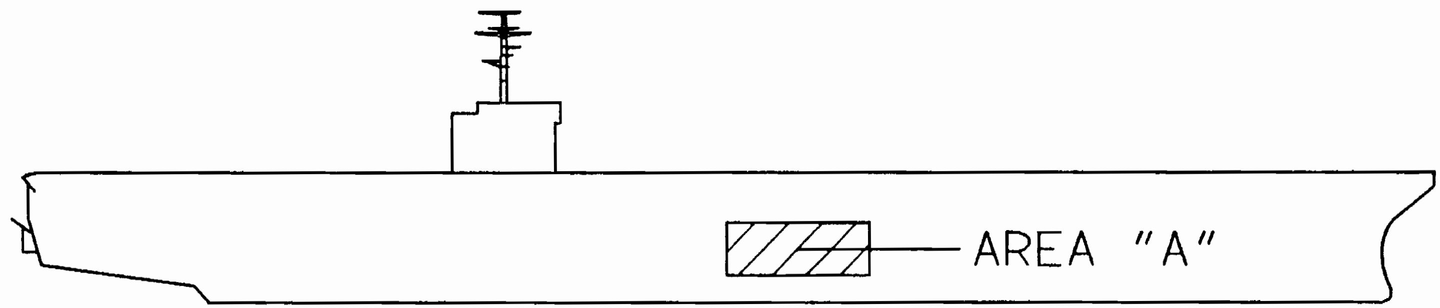



Figure 18. Area "A" Withen Aircraft Carrier

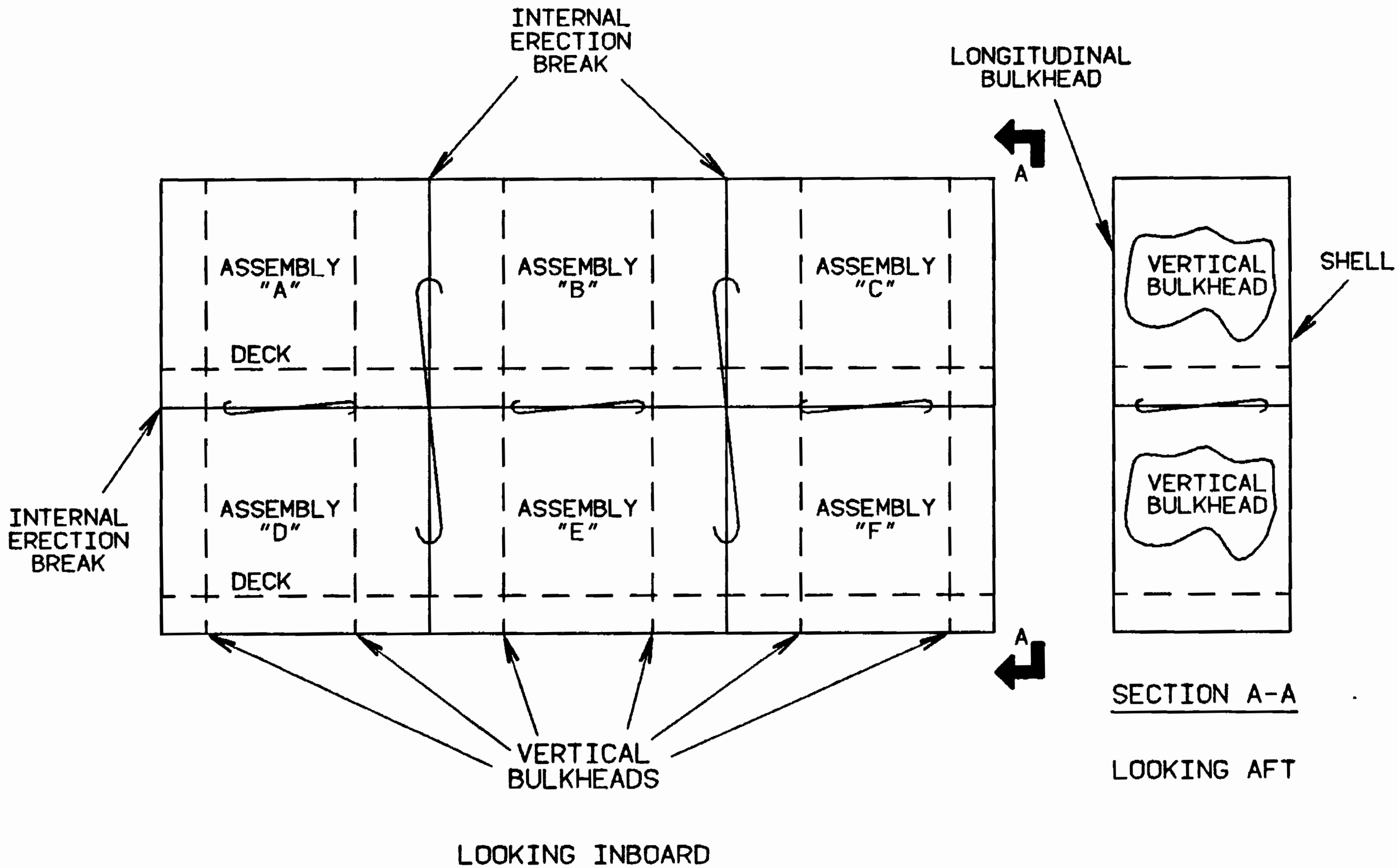



Figure 19. Area "A" Shown as a Superlift

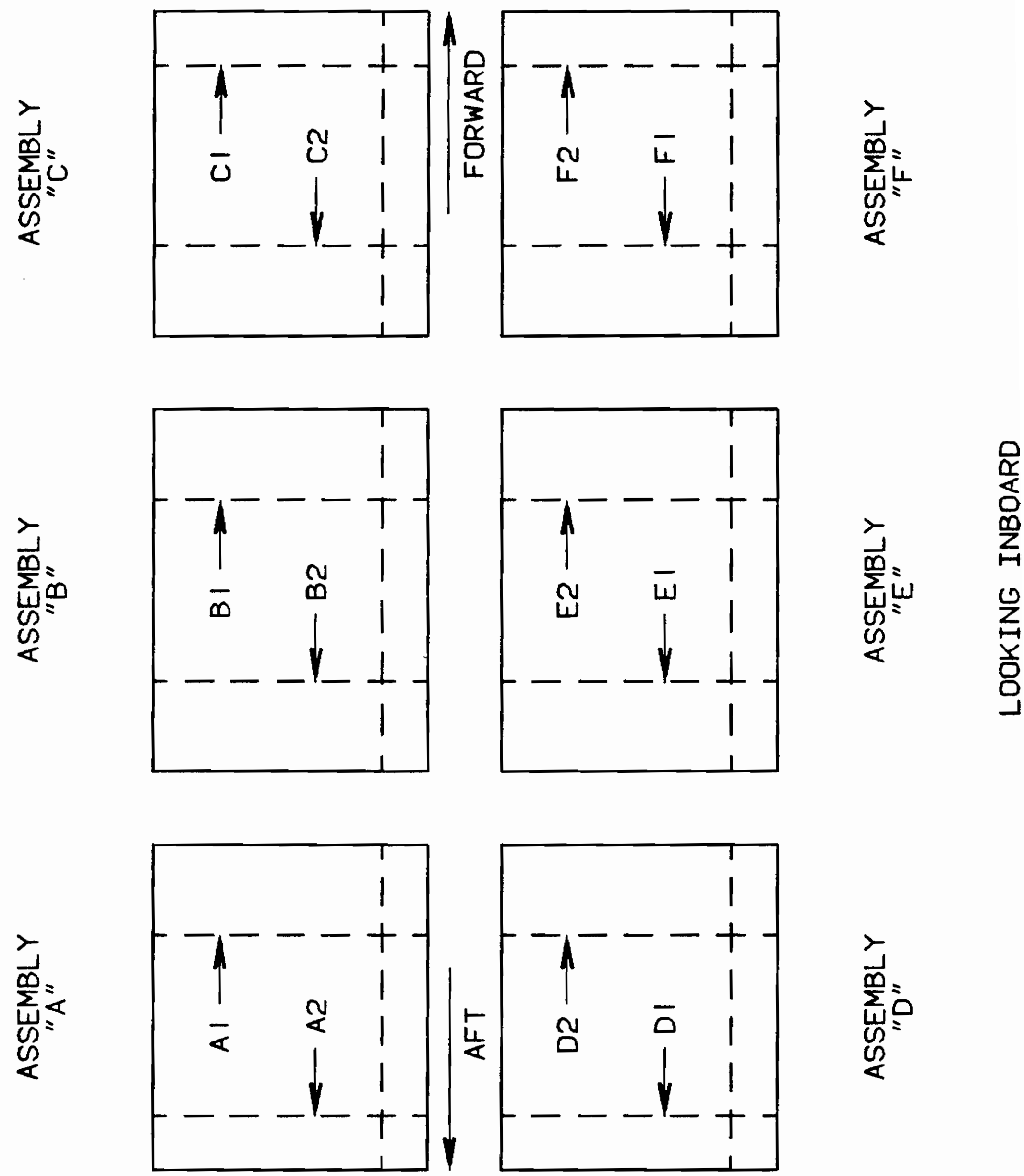



Figure 20. Individual Subassemblies That Make up Superlift

within the longest length of a plate so each part of the assembly is made up of one plate and has no internal butts. The plates are cut using a N/C burn machine with insignificant error. Each plate has 1/64th inch per foot added to it for weld shrinkage and four inches added to it for margin (2" each edge). The six foot dimension at each end of the assembled superlift has a tolerance of plus or minus 1/32 inch. Each plate is marked by the N/C machine for the placement of the bulkheads with insignificant error. Automatic welding of the bulkheads is accomplished by a welding machine utilizing an assembly jig; therefore, the bulkheads are perpendicular to the other plates of the assembly and parallel to each other. The edges and corner angles are found to have no significant error. The lower assemblies are assembled and welded from forward to aft and the upper assemblies are assembled and welded from aft to forward. The initial tolerance for the welding of the vertical bulkheads to the other plates in the assembly is 1/32 inch either forward or aft of its marked position. Because the assemblies are built in the shop no weld shrinkage occurs between the assemblies as they are joined. When the N/C burn machine cuts and marks the plates it starts at the edge leaving two inches of margin and one half of the weld shrinkage value. Then it measures and marks each bulkhead and measures to the end of the assembly leaving the other one half of the weld shrinkage valve and the two inches of margin, and cuts the plate. Therefore, each shell plate, deck plate and longitudinal bulkhead plate in subassemblies A, C, D, and F is 36' and 4 - 9/16" long, with 2 - 9/32 inches extra at each edge. The plates making up subassemblies B and E are 40' and 4-5/8" long. There is supposed to be 20' between each internal bulkhead. The initial tolerance for the 20 foot dimension between the bulkheads is 1/16". As a reminder, the weld shrinkage values were added in the past because the length of a plate was found to shrink 1/64" when welded in the dry dock. Now that modular construction was implemented and plates are welded in the shop plates do not shrink at the same rate that they used to. Some plates do not shrink at all. It is not economically feasible to redesign the amount of extra material needed for weld shrinkage or to eliminate it altogether. The check sheet is developed by the AC team and is shown in figures 21 and 22. All the parts are labeled and all dimensions with tolerances are shown on the check sheet. For the purpose of this example all measurements are assumed to be correct. In a real life situation some amount of error will be calculated into the measurement. All the subassemblies were built simultaneously and the AC team was there to measure each bulkhead as it was put in. Bulkheads are tack welded into place (small amounts of weld applied only to hold apiece in place) before permanent welding is

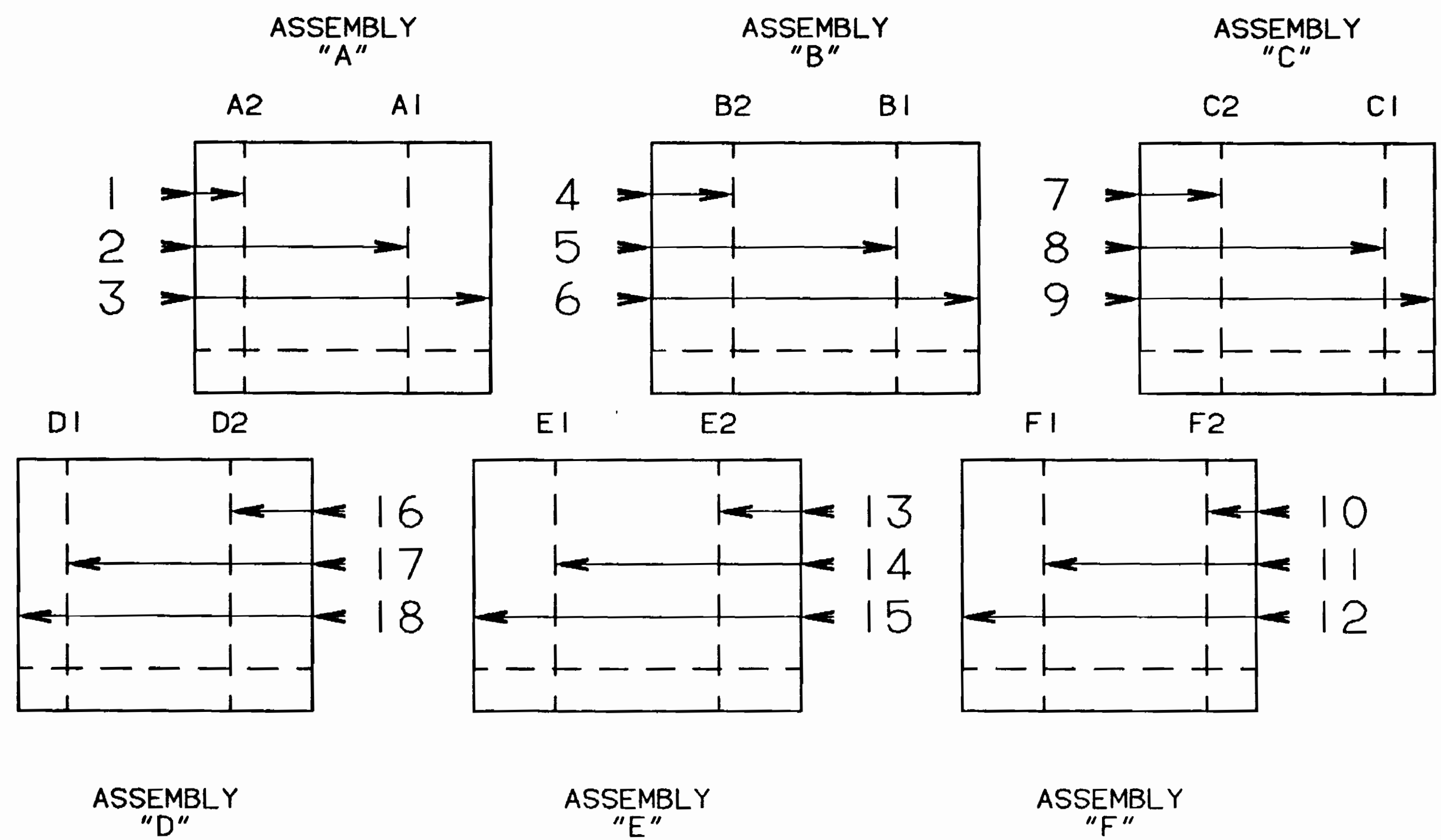



Figure 21. Critical Dimensions

| # | DESIGN DIMENSION | TOLERANCE | ACTUAL DIMENSION | DIFFERENCE | MARGIN ADDED | STRETCH ADDED | DIMENSION ERROR |
|---|---|---|---|---|---|---|---|
| 1 | 6′ | 1/32″ | 6′- 2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ AFT |
| 2 | 26′ | 1/32″ | 26′- 2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ AFT |
| 3 | 36′ | 1/3″ | 36′- 4 9/16 | 4 9/16″ | 4″ | 9/16″ | 0″ |
| 4 | 10′ | 1/32″ | 10′-2 11/32 | 2 11/32″ | 2″ | 5/16″ | 1/32″ FWD |
| 5 | 30′ | 1/32″ | 30′- 2 11/32 | 2 11/32″ | 2″ | 5/16″ | 1/32″ FWD |
| 6 | 40′ | 1/3″ | 40′- 4 5/8 | 4 5/8″ | 4″ | 5/8″ | 0″ |
| 7 | 10′ | 1/32″ | 10′-2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ AFT |
| 8 | 30′ | 1/32″ | 30′- 2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ AFT |
| 9 | 36′ | 1/3″ | 36′- 4 9/16 | 4 9/16″ | 4″ | 9/16″ | 0″ |
| 10 | 6′ | 1/32″ | 6′- 2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ FWD |
| 11 | 26′ | 1/32″ | 26′- 2 8/32 | 2 8/32″ | 2″ | 9/32″ | 1/32″ FWD |
| 12 | 36′ | 1/3″ | 36′- 4 9/16 | 4 9/16″ | 4″ | 9/16″ | 0″ |
| 13 | 10′ | 1/32″ | 10′-2 9/32 | 2 9/32″ | 2″ | 5/16″ | 1/32″ FWD |
| 14 | 30′ | 1/32″ | 30′-2 11/32 | 2 11/32″ | 2″ | 5/16″ | 1/32″ AFT |
| 15 | 40′ | 1/3″ | 40′- 4 5/8 | 4 5/8″ | 4″ | 5/8″ | 0″ |
| 16 | 10′ | 1/32″ | 10′-3 9/32 | 3 9/32″ | 2″ | 9/32″ | 1.0″ AFT |
| 17 | 30′ | 1/32″ | 30′-2 9/32 | 2 9/32″ | 2″ | 9/32″ | 0″ |
| 18 | 36′ | 1/3″ | 36′- 4 9/16 | 4 9/16″ | 4″ | 9/16″ | 0″ |

Figure 22. Check Sheet Data

accomplished. The AC team was able to gather data and do the initial analysis before permanent welding was accomplished. The data that was collected is shown on Figure 22. Initial analysis determines if piece placement is correct, the amount of margin to be trimmed off, and from which end. Initial analysis must be performed quickly so that recommendations can be given back to the trades before too much permanent work has been accomplished and before the subassemblies have been moved out to the platen to be joined. Initial analysis provides the answers needed to fulfill short term goals by reducing rework at the later stages of construction where it is more costly. Statistical analysis of the data is performed after the initial analysis, and when combined with historical data from all over the ship, will be used to improve the construction process which is the long term goal of accuracy control. By studying the critical dimensions and the data one can determine the placement error. The design dimension plus the margin added plus the stretch added should equal the actual dimension. If it does not, the difference is the dimension or placement error. By looking at which direction the measurement was taken one can determine if the error is forward or aft. Initial analysis of the data from the check sheet lead to the following conculsions:

1) Bulkhead A1 and A2 are both 1/32" aft of their intended position but are within tolerance.

2) Bulkhead B2 is 1/32" forward of it's intended position but within tolerance.

3) Bulkhead B1 is 1/32" forward of it's intended position but is within tolerance.

4) Bulkheads C1 and C2 are both 1/32" aft of their intended position but are both within tolerance.

5) Bulkhead D1 is accurately positioned.

6) Bulkhead D2 is 1" aft of it's intended position and is not within tolerance.

7) Bulkhead E1 is 1/32" aft of it's intended position and is within tolerance.

8) Bulkhead E2 is 1/32" forward of it's intended position and is within tolerance.

9) Bulkhead F1 is 1/32" fwd of it's intended position and is within tolerance.

10) Bulkhead F2 is 1/32" fwd of it's intended position and is within tolerance.

Recall that the most important aspect of their subassemblies is that when assembled the upper and lower bulkheads must align within 1/32 of an inch. This is insured by triming different amounts from the forward and aft ends of the assembly or by repositioning one of the bulkheads.
Recall the margin and stretch are excess material added for insuring that final assembly will be accurate after being

trimed. The recommendations about to be made were derived from these conclusions and represent short term goals. In order to cut costs and reduce rework the following recommendations are presented:

1) Bulkhead D2 is not within tolerance and must be cut off and repositioned 1" forward before it's final welding is initiated.
2) The amount of margin to be trimmed off subassembly D is: 2-9/16" off the forward edge and 2 -9/16 off the aft edge.
3) In order for the vertical bulkheads to align between subassemblies A and D the margin to be trimmed from subassembly A must be: 2 -8/32" off the aft edge and 2 -10/32" off the forward edge.
4) The amount of margin to be cut off of subassembly B is: 2 -5/16" off the aft edge and 2 -5/16" off the forward edge.
5) Bulkhead E1 must be cut loose from its position and repositioned 1/16" forward. The amount of margin to be cut from subassembly E is: 2 -10/32" off the aft edge and 2 -8/32" off the forward edge. This repositioning coupled with the different margin trimming will allow the bulkheads in subassembly E to line up with the bulkheads in subassembly B within the specified 1/32" tolerance.

6) The amount of margin to be cut from subassembly C is: 2-8/32" off of the aft edge and 2-10/32" off of the forward edge.

7) The amount of margin to be cut from subassembly F is: 2-8/32" off of the forward edge and 2-10/32" off of the aft edge.

8) The tolerances for the positioning of the vertical bulkheads within the subassemblies should be changed from 1/32" to 1/64" because it allows for the possibility of unacceptable tolerance stackup.

These recommendations will result in a more quality product and a significant decrease in the more costly rework done on the platen. By accomplishing the rework in the shop before the unit is assembled, we have avoided some serious problems, excess costs, and schedule delays further in the construction process. If the module had been assembled after only fixing the one bulkhead which was out of tolerance and brought out to the platen for pre-outfitting it would not have been acceptable. The unit would have to have been disassembled and fixed rather than being fixed in the shop before assembly there by saving the yard from having to do over what it had previously done.

The measurement data is then added to a data base with the readings from the thousands of other similar areas from all the other superlifts, where it will be grouped into common problems and statistically analyzed in order to fulfill the long term goals. In order to show an example of a few statistical techniques, the data on the check sheet will be used. Valid conclusions cannot correctly be drawn from analyzing such small amounts of data but for the sake of demonstration, they will be performed. The mean, range, and standard deviation calculations are shown on figures 23 and 24. The differences between the design dimension and the actual dimensions should be plotted to insure that they are centered around the design dimension and are not grouped either positive or negative of design. From the statistical analysis production management will be in a position to improve on such aspects of construction as: welding and assembly sequences, construction schedules, equipment, facilities, unusual problem areas, etc.

| # | DESIGN DIMENSION (INCLUDING MARGIN & STRETCH) | ACTUAL DIMENSION | DIFFERENCE \| X \| | DIFFERENCE SQUARED |
|---|---|---|---|---|
| 1 | 6'- 2 9/32 | 6'- 2 8/32 | .03125 | 9.77 EE-4 |
| 2 | 26'- 2 9/32 | 26'- 2 8/32 | .03125 | 9.77 EE-4 |
| 4 | 10'-2 10/32 | 10'-2 11/32 | .03125 | 9.77 EE-4 |
| 5 | 30'- 2 10/32 | 30'- 2 9/32 | .03125 | 9.77 EE-4 |
| 7 | 10'-2 9/32 | 10'-2 8/32 | .03125 | 9.77 EE-4 |
| 8 | 30'- 2 9/32 | 30'- 2 8/32 | .03125 | 9.77 EE-4 |
| 10 | 6'- 2 9/32 | 6'- 2 8/32 | .03125 | 9.77 EE-4 |
| 11 | 26'- 2 9/32 | 26'- 2 8/32 | .03125 | 9.77 EE-4 |
| 13 | 10'-2 10/32 | 10'-2 9/32 | .03125 | 9.77 EE-4 |
| 14 | 30'-2 10/32 | 30'-2 11/32 | .03125 | 9.77 EE-4 |
| 16 | 10'-2 9/32 | 10'-3 9/32 | 1.00 | 1.00 |
| 17 | 30'-2 9/32 | 30'-2 9/32 | 0 | 0 |
| | | TOTALS | 1.1875 | +1.00977 |

* NOTE STATISTICAL ANALYSIS IS FOR BULKHEAD PLACEMENT ONLY. ORIGINAL MEASUREMENTS UESD. CORRECTED MEASUREMENTS ARE NOT SHOWN.

ARITHMETIC MEAN = | SUM OF DIFFERENCES | / NUMBER OF VALUES (OF DIFFERENCES)

= 1.1875" / 12
= .0906"

RANGE = DIFFERENCE BETWEEN THE LOWEST AND HIGHEST VALUES (OF DIFFERENCES)

= 1 - -.03125
= 1.03125"

Figure 23. Mean and Range Calculations

STANDARD DEVIATION = THE SQUARE ROOT OF THE SUM OF THE SQUARED DIFFERENCES DIVIDED BY THE NUMBER OF VALUES. (FROM DESIGN DIMENSION)

$$= (1.00977/12)^{-1/2}$$

$$= .2901$$

Figure 24. Standard Deviation Calculations

CHAPTER 3

# ECONOMIC EVALUATION

In order for management to justify the implementation of an accuracy control system or to compare it to other possible solutions to the problem, which are believed to exist but which are not formally proposed, an economic evaluation is performed. The accuracy control system will be evaluated within a framework that will permit it to be easily compared to other opportunities which may be specified in the future, plus justify its implementation by showing a positive return on investment. The techniques utilized in this analysis are the present worth, the annual equivalent, the rate of return, and the service life calculations. A number of estimations will be made in order to evaluate the AC-system. Initial costs, annual costs, annual benefits, etc. will all be estimated to provide the necessary data to perform the analysis. For convenience the net costs and benefits that may occur during the year will be assumed to occur at the end of that year. "There is some small error in the practice of considering cash flow as year end amounts. This error is insignificant, however, in comparison to the usual errors in estimates, except under extremely high interest rates" [7, p.66]. Because of the errors associated with these estimates a sensitivity analysis will be performed to evaluate the possible effect on the systems overall profitability. The specific sensitivity analysis which will be performed are the decision reversal analysis, the single attribute sensitivity analysis, and the multi-attribute sensitivity analysis. By reviewing the estimates made in the economic evaluation any decision maker can come up with his or her own estimates and use the sensitivity analysis to determine if the AC-system is profitable when utilizing his or her own estimated initial cost and benefit values.

## 3.1 Life Cycle Cost Analysis

When estimating costs and benefits it is important that one review the overall system and any possible influences to other parts of the company the implementation of the system might have. The estimates for the initial costs are as follows:

1) Facilities - $0 - There is no need to build or spend money finding a facility, one already exists, therefore the initial cost is nothing. The cost to use the facility is considered a year end cost and is shown under the annual costs.
2) Research and development - $15,000 - Includes 833 manhours spent in design and planning at $18 a manhour.

3) Measurement equipment - $15,000 - Includes the following:

   A. (1) tape measures at $50 each
   B. (5) digital levels at $100 each
   C. (10) plumb bobs at $25 each
   D. (3) theodolites at $1,000 each
   E. (1) laser at $10,750 each

4) Six employees - $0 - No money will be spent initially recruiting new employees since employees will be drafted from existing departments. Their salaries will be considered as year end costs and is shown under the annual costs.

5) Miscellaneous supplies and equipment - $25,000 - Includes the following:

   A. (10) desks at $700 each
   B. (10) drawing boards at $500 each
   C. (10) chairs at $300 each
   D. (5) telephones (installed) at $300 each
   E. (3) 5 drawer file cabinets at $200 each
   F. Miscellaneous supplied such as: paper, pentels, pens, ink, etc. for $7,900

6) Cost associated with production schedule delays - $17,000 - Includes manhours lost during initial start up by inspectors and other related

employees. A total of 1,133 manhours at $15 a manhour is estimated.

7) Lost manhours due to meetings - $10,000 - Includes 588 manhours at $17 per hour.

8) Manhours spent in engineering and design - $18,000 - Includes 947 manhours at $19 per hour spent on activities such as: establishing initial tolerances, creating assembly and welding sequences, and construction aids.

The total initial cost is estimated to be $100,000 and invested at time 0. Annual costs will occur over the estimated life of six years and are expected to grow each year as the workload increases. Annual costs and their yearly increases are estimated to be as follows:

1) Salaries - $180,000/yr - Cost increases $10,000 each year plus a one time cost of $120,000/yr in year three and a yearly increase of $7,000 in years four through six. This will cover an average salary of $30,000 for the group members with yearly increased to cover the raises that they will receive.

2) Facilities - $2,000/yr - This covers the annual cost for using the space plus maintenance. Even

though the building already exists there is a cost associated with its use because that space has value.

3) Computer support - $25,000/yr - Cost increases $2,000 each year plus a one time cost of $3,000 in year three to cover an additional terminal. These costs include mainframe time plus computer maintenance.

4) Supplies - $5,000/ur - Cost increases $1,000 each year plus a one time cost increase of $1,000 in year three to cover new employees additional supplies.

5) Miscellaneous overhead - $2,000 - Cost increases $1,000 each year.

6) Production delay costs - $5,000/yr - Cost increases $5,000 each year and includes 333 manhours, increasing 333 manhours each year at $15 per manhour.

7) Manhours lost through meetings - $3,000/yr - cost increases $1,000 each year. Cost includes 176 manhours per year increasing 59 manhours per year at $17 per manhour.

The life cycle cost breakdown is shown on figure 25. The cost allocation by program year is shown on figure 26.

| LIFE CYCLE COST BREAKDOWN | | |
|---|---|---|
| COST CATEGORY | COST $ | % OF TOTAL |
| 1) RESEARCH AND DEVELOPMENT | | |
| A) DESIGN MANHOURS | 6,000 | .26 % |
| B) PLANNING MANHOURS | 9,000 | .40 % |
| SUBTOTAL | 15,000 | .66 % |
| 2) INITIAL LOGISTICS SUPPORT | | |
| A) MEASUREMENT EQUIPMENT | 15,000 | .66 % |
| B) INITIAL PRODUCTION DELAYS | 17,000 | .75 % |
| C) INITIAL MEETING MANHOURS | 10,000 | .44 % |
| D) INITIAL ENGINEERING MANHOURS | 18,000 | .79 % |
| E) SUPPLIES AND EQUIPMENT | 25,000 | 1.19 % |
| SUBTOTAL | 85,000 | 3.75 % |
| 3) OPERATION AND SUPPORT COST | | |
| A) SALARIES | 1,755,000 | 77.35 % |
| B) FACILITIES | 12,000 | .53 % |
| C) COMPUTER SUPPORT | 188,000 | 8.29 % |
| D) SUPPLIES | 49,000 | 2.16 % |
| E) MISCELLANEOUS OVERHEAD | 27,000 | 1.19 % |
| F) PRODUCTION DELAY MANHOURS | 105,000 | 4.63 % |
| G) MEETING MANHOURS | 33,000 | 1.45 % |
| SUBTOTAL | 2,169,000 | 95.59 % |
| GRAND TOTAL | 2,269,000 | 100 % |

Figure 25. Life Cycle Cost Breakdown

**COST ALLOCATION BY PROGRAM YEAR**

| COST CATEGORY | COST PER YEAR $ | | | | | | |
|---|---|---|---|---|---|---|---|
| | YEAR 0 | YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 | YEAR 5 | YEAR 6 |
| 1) RESEARCH AND DEVELOPMENT | | | | | | | |
| A) DESIGN MANHOURS | 6,000 | --- | --- | --- | --- | --- | --- |
| B) PLANNING MANHOURS | 9,000 | --- | --- | --- | --- | --- | --- |
| SUBTOTAL | 15,000 | --- | --- | --- | --- | --- | --- |
| 2) INITIAL LOGISTICS SUPPORT | | | | | | | |
| A) MEASUREMENT EQUIPMENT | 15,000 | --- | --- | --- | --- | --- | --- |
| B) INITIAL PRODUCTION DELAYS | 17,000 | --- | --- | --- | --- | --- | --- |
| C) INITIAL MEETING MANHOURS | 10,000 | --- | --- | --- | --- | --- | --- |
| D) INITIAL ENGINEERING MANHOURS | 18,000 | --- | --- | --- | --- | --- | --- |
| E) SUPPLIES AND EQUIPMENT | 25,000 | --- | --- | --- | --- | --- | --- |
| SUBTOTAL | 85,000 | --- | --- | --- | --- | --- | --- |
| 3) OPERATION AND SUPPORT COST | | | | | | | |
| A) SALARIES | --- | 180,000 | 190,000 | 320,000 | 337,000 | 355,000 | 373,000 |
| B) FACILITIES | --- | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| C) COMPUTER SUPPORT | --- | 25,000 | 27,000 | 31,000 | 33,000 | 35,000 | 37,000 |
| D) SUPPLIES | --- | 5,000 | 6,000 | 8,000 | 9,000 | 10,000 | 11,000 |
| E) MISCELLANEOUS OVERHEAD | --- | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 |
| F) PRODUCTION DELAY MANHOURS | --- | 5,000 | 10,000 | 15,000 | 20,000 | 25,000 | 30,000 |
| G) MEETING MANHOURS | --- | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 |
| SUBTOTAL | --- | 222,000 | 242,000 | 385,000 | 412,000 | 440,000 | 468,000 |
| GRAND TOTAL | 100,000 | 222,000 | 242,000 | 385,000 | 412,000 | 440,000 | 468,000 |

Figure 26. Cost Allocation by Program Year

## 3.2 Life Cycle Benefit Analysis

The expected benefits associated with the implementation of the AC-system are derived as a direct result of the reduction of rework. Benefits are seen mainly in the form of reduced manhours spent in the construction of the ship and a reduced construction schedule which results in the shipyard being awarded early delivery monetary compensation. The departments which will realize the greatest manhour reduction are:

1) Fitters
2) Riggers
3) Welders
4) NDT (nondestructive test)
5) Inspectors
6) Engineering and Design
7) Production Management

There are other benefits associated with the implementation of the AC-system such as:

1) Higher Quality Product
2) Increase Employee Satisfaction
3) Increased Adherence to Specifications

4) Better Reputation Within the Shipbuilding Industry
5) Happier Consumer (Government)
6) Favorable Future Contract Consideration
7) More Efficient Use of Facilities and Equipment
8) Freeing Up Workers Earlier to Work on Other Contracts

These benefits are hard to quantify in monetary terms and therefore will not be included in the economic analysis but still must be recognized. Another benefit associated with increased accuracy control is that less time and manpower will be spent on rework and the overall construction time will be shortened. It was found by studying the effects the submarine accuracy control system had on the submarine construction schedule that there is a direct correlation between the number of work packages completed and the number of days earlier a submarine was constructed. Submarine and carrier rework is conducted at the same rate. Work packages for the two accuracy control systems are designed to be equivalent in every detail. Therefore, it is safe to assume that the same correlation will exist between the carrier accuracy control system and the carrier construction schedule. For every 8.5 work packages completed on submarines one day of construction time was saved. This happens as a result of reduced construction time spent on rework. By dividing the number of work packages expected to be completed per year for carriers one can estimate the number of days saved, hence the number of days earlier the carrier can be delivered. The work package schedule is shown in Section 1.5 System Work Breakdown Structure. The amount of days saved on each ships construction schedule are as follows:

| | CVN74 | CVN75 |
|---|---|---|
| year 1 | 3 days | - |
| year 2 | 5 days | 2 days |
| year 3 | 7 days | 4 days |
| year 4 | - | 6 days |
| year 5 | - | 8 days |
| year 6 | - | 10 days |

This construction schedule compression is expected to result in a total of a 15 day and a 30 day early delivery on CVN74 and CVN75 respectively. This early delivery means the shipyard will receive full payment early enabling them to close out accounts, reduce inventory, invest profits, etc. earlier. The overall cost of an aircraft carrier to the Navy is approximately $3.1 billion. The interest earned on investing the payment earlier and the interest saved on paying off accounts earlier is a direct result of accuracy control and will be considered in the cash flow as benefits which are realized in years five and nine. The reason that the benefits will be realized in years five and nine is because that is when the shipyard will receive its final payment. The Navy pays for a carrier in three payments. The first payment occurs when the keel tract is completed, the second occurs when certain key compartments are completed (such as the carriers two nuclear reactors), and the third occurs upon delivery. CVN74 will be delivered in year five and CVN75 will be delivered in year nine. The interest rate this large sum of money is expected to make if invested is 10%. The final payment made for both CVN74 and CVN75 is approximately $127,750,000. Since we're only concerned with a 15 and 30 day period, the 10% apr converts to a .0274% daily interest rate. This converts to approximately $35,000 per day in interest. The $35,000 per day payment is assumed not to be reinvested but instead as a simple payment. Inaccuracies in estimating the final payment make this conservative approach desirable. Errors in estimating these sums are accounted for in the sensitivity analysis calculations performed in Sections 3.4, 3.5, and 3.6. The total benefits from the 15 day early delivery on CVN74 and the 30 days early delivery on CVN75 are $525,000 and $1,050,000 respectively. Because year nine lies outside the expected life of the ac-system, it will be brought back to year six taking into consideration the time value of money with a MARR of 10%.

Other monetary benefits result from minimizing rework such as manhour reduction and reduced material consumption. There are mainly seven departments which realize these savings. Each department saves a different percentage of manhours when rework is decreased on a job. These percentages were found to hold true regardless of which area. By studying the effects the submarine accuracy control group had on the seven departments in submarine construction it was possible to derive the percentage savings each department realized. These percentages were as follows:

| Department | Percentage of savings |
|---|---|
| 1) Fitters | 35.3% |
| 2) Riggers | 11.8% |
| 3) Welders | 23.5% |
| 4) N.D.T. | 5.9% |
| 5) Inspectors | 3.5% |
| 6) Engineering | 11.8% |
| 7) Production Management | 8.2% |

Different areas of construction require different numbers of employees to construct. The accuracy control system will effect different areas of construction with varying impacts on rework. By conducting a preliminary analysis on the carrier construction process (discussed in Section 1.5 System Work Breakdown Structure) it was possible to estimate a yearly total manhour and material savings shown as follows:

| year | total manhour savings | material savings |
|---|---|---|
| 1 | 5,000 | $15,000 |
| 2 | 10,000 | $31,500 |
| 3 | 17,500 | $52,500 |
| 4 | 15,000 | $45,000 |
| 5 | 17,500 | $52,500 |
| 6 | 21,000 | $63,000 |

This information combined with the department percentages and an average manhour cost of $17, enabled the author to calculate the annual monetary benefits the reduction of rework would produce. The life cycle benefit breakdown is shown on figure 27. The benefit allocation by program year is shown on figure 28.

| LIFE CYCLE BENEFIT BREAKDOWN | | | |
|---|---|---|---|
| BENEFIT CATEGORY | | COST $ | % OF TOTAL |
| 1) MANHOUR REDUCTION | WEIGHTED % | | |
| A) FITTERS | 30 % | 519,000 | 15.70 % |
| B) RIGGERS | 10 % | 173,000 | 5.23 % |
| C) WELDERS | 20 % | 346,000 | 10.47 % |
| D) NDT ( NON-DESTRUCTIVE TEST ) | 5 % | 86,500 | 2.62 % |
| E) INSPECTORS | 3 % | 51,900 | 1.57 % |
| F) ENGINEERING AND DESIGN | 10 % | 173,000 | 5.23 % |
| G) PRODUCTION MANAGEMENT | 7 % | 121,100 | 3.66 % |
| H) MATERIAL | 15 % | 259,500 | 7.85 % |
| SUBTOTAL | | 1,730,000 | 52.34 % |
| 2) SCHEDULE REDUCTION | | | |
| A) HULL CVN 74 | | 525,000 | 15.89 % |
| B) HULL CVN 75 | | 1,050,000 | 31.77 % |
| SUBTOTAL | | 1,575,000 | 47.66 % |
| GRAND TOTAL | | 3,305,000 | 100 % |

WEIGHTED PERCENT = THE PERCENT EACH DEPARTMENT CONTRIBUTES TO THE TOTAL

Figure 27. Life Cycle Benefit Breakdown

## BENEFIT ALLOCATION BY PROGRAM YEAR

| BENEFIT CATEGORY | BENEFIT PER YEAR $ | | | | | | |
|---|---|---|---|---|---|---|---|
| | YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 | YEAR 5 | YEAR 6 | YEAR 9 |
| 1) MANHOUR REDUCTION | | | | | | | |
| A) FITTERS | 30,000 | 63,000 | 105,000 | 90,000 | 105,000 | 126,000 | --- |
| B) RIGGERS | 10,000 | 21,000 | 35,000 | 30,000 | 35,000 | 42,000 | --- |
| C) WELDERS | 20,000 | 42,000 | 70,000 | 60,000 | 70,000 | 84,000 | --- |
| D) NDT ( NON-DESTRUCTIVE TEST ) | 5,000 | 10,500 | 17,500 | 15,000 | 17,500 | 21,000 | --- |
| E) INSPECTORS | 3,000 | 6,300 | 10,500 | 9,000 | 10,500 | 12,600 | --- |
| F) ENGINEERING AND DESIGN | 10,000 | 21,000 | 35,000 | 30,000 | 35,000 | 42,000 | --- |
| G) PRODUCTION MANAGEMENT | 7,000 | 14,700 | 24,500 | 21,000 | 24,500 | 29,400 | --- |
| H) MATERIAL | 15,000 | 31,500 | 52,500 | 45,000 | 52,500 | 63,000 | --- |
| SUBTOTAL | 100,000 | 210,000 | 350,000 | 300,000 | 350,000 | 420,000 | --- |
| 2) SCHEDULE REDUCTION | | | | | | | |
| A) HULL CVN 74 | 3 DAYS | 5 DAYS | 7 DAYS | --- | 525,000 | --- | --- |
| B) HULL CVN 75 | --- | 2 DAYS | 4 DAYS | 6 DAYS | 8 DAYS | 10 DAYS | 1,050,000 |
| SUBTOTAL | --- | --- | --- | --- | 525,000 | --- | 1,050,000 |
| GRAND TOTAL | 100,000 | 210,000 | 350,000 | 300,000 | 875,000 | 420,000 | 1,050,000 |

* NOTE: EVEN THOUGH THE SCHEDULE REDUCTION BENEFITS ARE ATTRIBUTED TO DIFFERENT YEARS THE TOTAL BENEFIT IS NOT REALIZED UNTIL YEAR NINE FOR CVN75 AND YEAR FIVE FOR CVN74 WHICH IS WHEN PAYMENT IS RECIEVED. THE NUMBER OF DAYS INDICATED SIGNIFIES THE NUMBER OF DAYS THE PARTICULAR SHIP CAN BE DELIVERED EARLIER BECAUSE OF EFFORTS BY THE ACCURACY CONTROL GROUP FOR THAT YEAR.

Figure 28. Benefit Allocation by Program Year

## 3.3 ECONOMIC APPRAISAL

An economic appraisal is performed in order to properly assess the fiscal aspects of an investment opportunity. One dollar gained now is worth more than one dollar gained six years from now because that one dollar can be invested at a particular interest rate. This principle is known as the time value of money. The costs outlined in the life cycle cost analysis must be compared to the benefit outlined in the life cycle benefit analysis to insure that the minimal rate of return on investment is achieved. Also if another alternative arises which will fulfill the mission definition, an economic analysis is one way in which these two alternatives may be compared. The minimal acceptable rate of return (MARR) for these calculations will be 10%.

### 3.3.1 CASH FLOW DIAGRAM

To aid in identifying and recording all the complex costs and benefits over time a fiscal "free body diagram" is produced. This diagram, called a cash flow diagram, is shown on figure 29, page 121.

### 3.3.2 NET PRESENT WORTH

One basis for comparing the costs and benefits over time is the net present worth (NPW). The NPW represents all costs and benefits as if they occurred right now. All costs and benefits not occurring now are brought back to the present time using the MARR as the interest rate. This way if a positive amount occurs after summing all the present worths of the costs and benefits the return on investment exceeds the MARR. The NPW for the accuracy control system is $348,163. The NPW calculations are shown on Figure 30. The positive NPW indicates a profitable investment and therefore justifies implementing the accuracy control system.

### 3.3.3 ANNUAL EQUIVALENT WORTH

The annual equivalent worth (AEW) is another basis for comparison similar to the NPW. After the NPW is calculated the value is converted into a series of equal annual payments or receipts. This type of presentation helps management decide on investments. Of course a positive value means a rate of return exceeding the MARR. The AEW for the accuracy control system is $79,940. The AEW calculations are shown on figure 30. This value of AEW also justifies implementation of the accuracy control system.

### 3.3.4 INTERNAL RATE OF RETURN

The internal rate of return (IRR) is a common index of profitability. The IRR is defined as the interest rate which causes the equivalent receipts of a cash flow to equal the equivalent disbursements of that cash flow. [7, pg 148 ] An IRR above the MARR means the investment shows a profit greater than that which is minimally acceptable. The IRR is one of the best ways to rate alternatives against each other. The IRR for the accuracy control system is 30.31% which is considerably higher than the MARR. The IRR calculations are shown on figures 30 and 31.

### 3.3.5 THE BREAK EVEN PERIOD

The break even period, also called the discounted payback period, is the length of time required to recover the investment costs considering the time value of money. The MARR of 10% is used as the interest rate. The break even period for the accuracy control system is 2.18 years, and the calculations are shown on figures 32 and 33.

This case presents an unusual situation due to the size of the payment in years 5 and 9. Every day earlier the shipyard receives its payment, tens of thousands of dollars in interest is earned on the money (or is saved on early payment of debt). Due to the nature of the accuracy control system, every year the system is in operation represents a time savings during erection. Correcting earlier inaccuracies decreases the amount of rework during erection thus saving time permitting an earlier delivery of the contract. Therefore, even if the AC-system is only in service for one year a certain amount of time will be saved during final erection which is directly attributed to the ac-system efforts, and this time results in early delivery. So for the purposes of the evaluation the 15 day early delivery on CVN74 and the 30 day early delivery on CVN75 will be divided among the years of operation for the system and brought back to a present worth. For example, three days of early delivery for CVN74 can be directly attributed to the first year of operation of the accuracy control system. Therefore, if the system life ends after only one year, the money earned from the three day early delivery will be received as a benefit in year 5 and brought back to year 1 with an interest rate of 10%.

### 3.4 DECISION REVERSAL EVALUATION

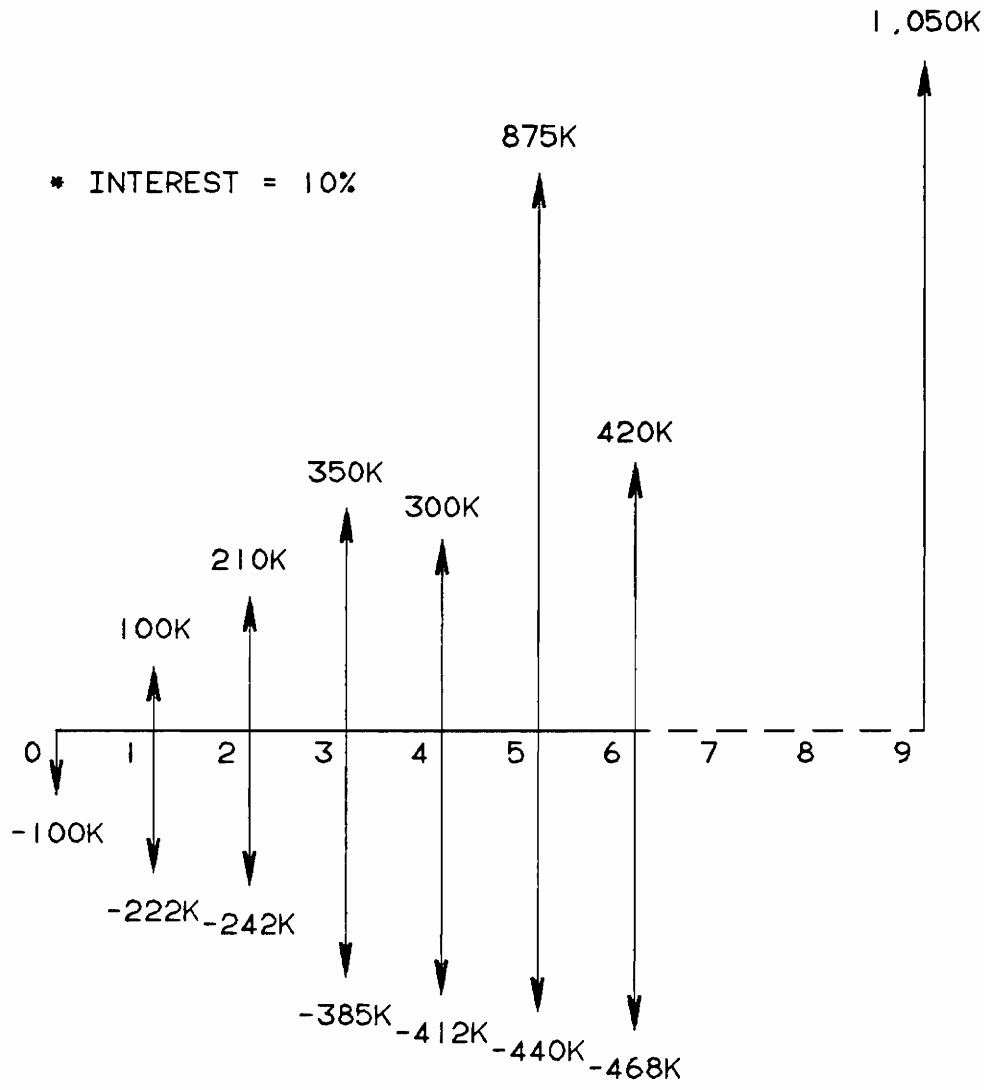
Because these evaluations are only as good as the estimates that they are based on a sensitivity analysis is performed to see what would happen if there is an error in the estimates. First a decision reversal calculation is performed as shown in figures 34, 45, and 36. This calculation shows how much an original estimate would have to change in order for the alternative to no longer be profitable. It also shows which attribute (costs, benefits, life, interest) is the most crucial to the decision making process. The annual cost is the most crucial attribute in the decision of whether or not to continue with the AC-system. If the estimated annual costs increase 21.6% the accuracy control system is no longer profitable. This analysis assumes that there is no monetary penalty for late delivery of the carrier to the Navy, and doesn't consider any other monetary loss from late delivery.

## 3.5 SINGLE ATTRIBUTE SENSITIVITY ANALYSIS

The single attribute sensitivity analysis is performed in order to provide management with information on how the profitability of the accuracy control system would change with changes in the annual costs, annual benefits, MARR, and 30 day early delivery. The calculations are shown on figures 37, 38, and 39. The curves show the changes to the AEW versus changes in the previously mentioned attributes for increments of 10%. this is a very important tool for risk and uncertainty decision making.

## 3.6 MULTI-ATTRIBUTE SENSITIVITY ANALYSIS

The multi-attribute sensitivity analysis calculations are shown on figures 40, 41, and 42. This analysis serves as a tool for management to use in deciding whether or not to continue with the accuracy control system in the face of changing system lives, costs, and benefits. Curves are shown for system lives of 3, 4, 5, and 6 years. If both the benefits and costs change simultaneously, management can use the curves for the appropriate system life to quickly determine if the accuracy control system is profitable or not. Life cycle costs and benefits were choosen for this analysis because they are the two most sensitive attributes to a profitable system.




BENEFIT IN YEAR 9 WILL BE BROUGHT BACK TO YEAR 6. IT IS A DIRECT BENEFIT OF THE SYSTEM BUT IS NOT WITHIN THE SYSTEMS EXPECTED LIFE.

Figure 29. Cash Flow Diagram

THE NET PRESENT WORTH CALCULATION
(IN THOUSANDS OF DOLLARS)

$$NPW = (-100)+(-122)(P/F,10\%,1)+(-32)(P/F,10\%,2)+(-35)(P/F,10\%,3)+(-112)(P/F,10\%,4)+(+435)(P/F,10\%,5)+(+740.865)(P/F,10\%,6) =$$

$$NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(-35)(.7513)+(-112)(.6830)+(+435)(.6209)+(+740.865)(.5645) = = +348.163$$

THE ANNUAL EQUIVALENT WORTH CALCULATION
(IN THOUSANDS OF DOLLARS)

$$AEW = (NPW)(A/P,10\%,6) = (348.163)(.2296) = +79.94$$

THE INTERNAL RATE OF RETURN CALCULATION
(IN THOUSANDS OF DOLLARS)

( SOLVE THE NPW EQUATION SET TO "0", FOR THE INTEREST )

TRY I = 20%

$$NPW = (-100)+(-122)(.8333)+(-32)(.6944)+(-35)(.5787)+(-112)(.4823)+(+435)(.4019)+(+740.865)(.3349) = = +124.79$$

TRY I = 30%

$$NPW = (-100)+(-122)(.7692)+(-32)(.5917)+(-35)(.4552)+(-112)(.3501)+(+435)(.2693)+(+740.865)(.2072) = = +2.73$$

Figure 30. NPW, AEW, and IRR Calculations

TRY I = 31%

NPW = (-100)+(-122)(.7634)+(-32)(.5827)+(-35)(.4448)+
(-112)(.3396)+(+435)(.2592)+(+740.865)(.1979) =
= -6.02

TRY I = 30.5%

NPW = (-100)+(-122)(.7663)+(-32)(.5872)+(-35)(.4500)+
(-112)(.3448)+(+435)(.2642)+(+740.865)(.2025) =
= -1.69

TRY I = 30.25%

NPW = (-100)+(-122)(.7678)+(-32)(.5894)+(-35)(.4526)+
(-112)(.3474)+(+435)(.2668)+(+740.865)(.2048) =
= +.50

INTERPOLATION RESULTS IN AN ROR = 30.31%

Figure 31. The Internal Rate of Return Calculations Ccntd

THE SERVICE LIFE EVALUATION (PAY-OUT PERIOD)
(IN THOUSANDS OF DOLLARS)

THE SERVICE LIFE IS THE AMOUNT OF TIME THE SYSTEM WILL TAKE TO PAY FOR ITSELF.

YEARS OF OPERATION VS. EARNED DAYS OF EARLY DELIVERY

| YR | CVN74 | CVN75 |
|---|---|---|
| 1 | 3 | 0 |
| 2 | 5 | 2 |
| 3 | 7 | 4 |
| 4 | 0 | 6 |
| 5 | 0 | 8 |
| 6 | 0 | 10 |

LIFE = 1 YEAR
NPW = (-100)+(-122)(.9091)+(3)(35)(P/F,10%,5) = -145.72

LIFE = 2 YEARS
NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(8)(35)(P/F,10%,5)
+(2)(35)(P/F,10%,9) = -33.82

LIFE = 3 YEARS
NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(-35)(.7513)+
(15)(35)(P/F,10%,5)+(6)(35)(P/F,10%,9) = +151.38

LIFE = 4 YEARS
NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(-35)(.7513)+
(-112)(.6830)+(15)(35)(P/F,10%,5)+(12)(35)(P/F,10%,9)
= +163.94

LIFE = 5 YEARS
NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(-35)(.7513)+
(-112)(.6830)+(-90)(.6209)+(15)(35)(P/F,10%,5)+
(20)(35)(P/F,10%,9) = +226.82

LIFE = 6 YEARS
NPW = (-100)+(-122)(.9091)+(-32)(.8264)+(-35)(.7513)+
(-112)(.6830)+(-90)(.6209)+(-48)(.5645)+(15)(35)
(P/F,10%,5)+(30)(35)(P/F,10%,9) = +348.163

Figure 32. The Service Life Evaluaticn

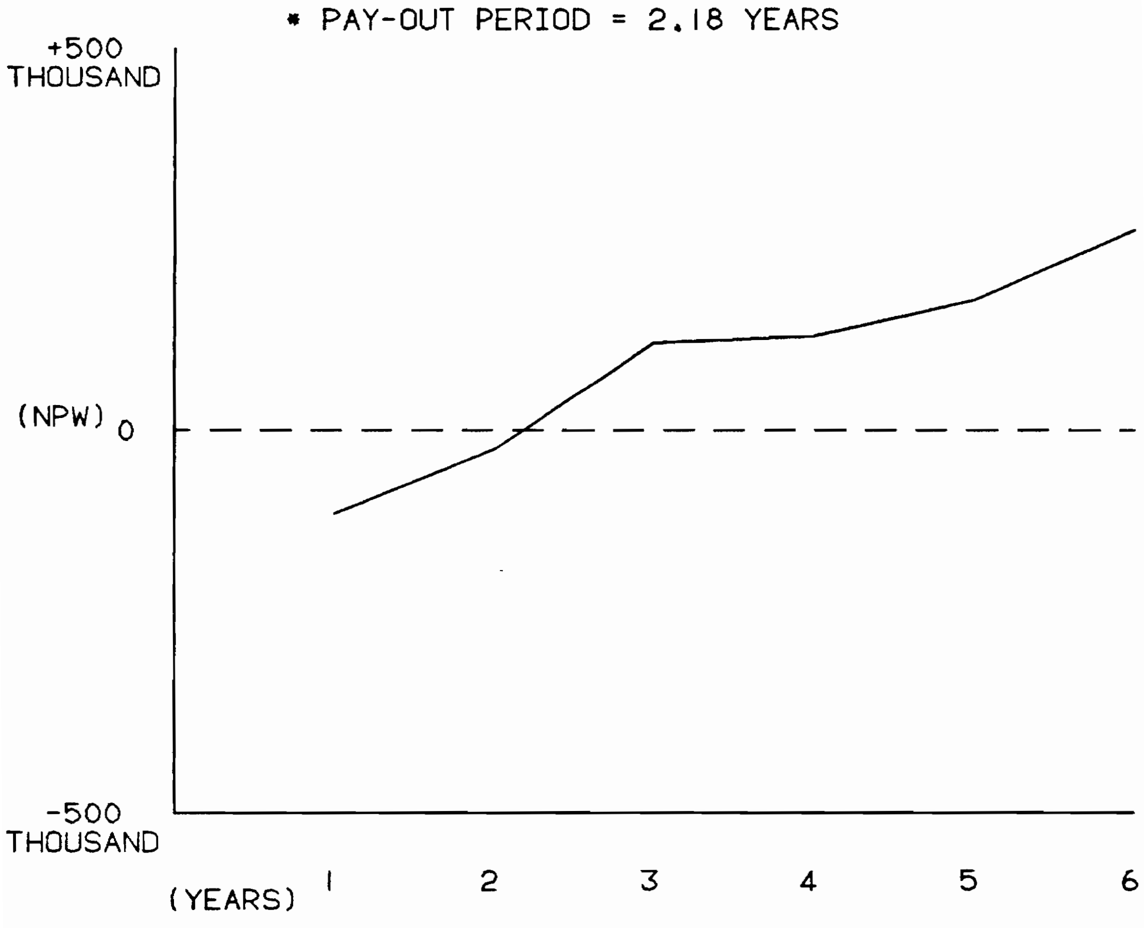



Figure 33. The Service Life Evaluation Graph

THE DECISION REVERSAL CALCULATION
(IN THOUSANDS OF DOLLARS)

THE DECISION REVERSAL ANALYSIS WILL SHOW HOW MUCH EACH ATTRIBUTE CAN CHANGE FOR THE WORSE BEFORE THE NPW BECOMES NEGATIVE. THE RESULTS ARE SUMMED UP IN A TABLE AT THE END OF THE CALCULATIONS.

COSTS INCLUDING INITIAL INVESTMENT

NPW = (-100)+(-222)(.9091)+(-242)(.8264)+(-385)(.7513)+
(-412)(.6830)+(-440)(.6209)+(-468)(.5645) =
= -1,609.84

AEW = (-1609.84)(.2296) = -369.62

BENEFITS ALL INCLUSIVE

NPW = (100)(.9091)+(210)(.8264)+(350)(.7513)+
(300)(.6830)+(875)(.6209)+(1,208.865)(.5645) =
= 1,958.00

AEW = (1958)(.2296) = 449.56

BENEFITS LESS BENEFITS DUE TO EARLY DELIVERY

NPW = (100)(.9091)+(210)(.8264)+(350)(.7513)+
(300)(.6830)+(350)(.6209)+(420)(.5645) =
= 1186.71

AEW = (1186.81)(.2296) = 272.47

AEW (15 DAY EARLY DELIVERY) = (525)(.6209))(.2296)
= 74.84

AEW (30 DAY EARLY DELIVERY) = (788.865)(.5645)(.2296)
= 102.24

Figure 34. The Decision Reversal Calculation

DECISION REVERSAL FOR BENEFITS LESS EARLY DELIVERY BONUS

-369.62+ I +74.84+102.24 = 0

I = +192.54

DECISION REVERSAL FOR BENEFITS FROM 15 DAY EARLY DELIVERY

-369.62+272.47+ I +102.24 = 0

I = -5.09

DECISION REVERSAL FOR BENEFITS FROM 30 DAY EARLY DELIVERY

-369.62+272.47+74.84+ I = 0

I = +22.31

DECISION REVERSAL FOR EXPECTED LIFE IS THE PAY-OUT PERIOD

= 2.18 YEARS

DECISION REVERSAL FOR MARR IS THE RATE OF RETURN

= 30.31%

DECISION REVERSAL FOR COSTS

I +272.47+74.84+102.24 = 0

I = -449.55

Figure 35. The Decision Reversal Calculation Contd

| ATTRIBUTE | EXPECTED (AEW) VALUE | DECISION REVERSAL (AEW) VALUE | AMOUNT CHANGED | % CHANGED |
|---|---|---|---|---|
| MONETARY BENEFIT FROM 15 DAY EARLY DELIVERY | 74.84 | -5.09 | VALUE DROPPED BELOW 0, WILL NOT EFFECT DECISION (ASSUME NO LATE PENALTY) | |
| MONETARY BENEFIT FROM 30 DAY EARLY DELIVERY | 102.24 | 22.31 | 79.93 | 78.2% OR 23.5 DAYS LESS |
| ANNUAL BENEFITS | 272.47 | 192.54 | 79.93 | 29.3% |
| ANNUAL COSTS | -369.62 | -449.55 | 79.93 | 21.6% |
| EXPECTED LIFE | 6 YEARS | 2.18 YEARS | 3.82 YEARS | 63.7% |
| MARR | 10% | 30.31% | 20.31% | 203.1% |

* NOTE VALUES IN THOUSANDS OF DOLLARS UNLESS OTHERWISE NOTED.

Figure 36. The Decision Reversal Calculation Table

## SINGLE ATTRIBUTE SENSITIVITY ANALYSIS

ORIGINAL ESTIMATED VALUES FOR: 30 DAY EARLY DELIVERY BENEFITS, ANNUAL BENEFITS, ANNUAL COSTS, AND THE MARR WILL BE VARIED ± 50% IN INTERVALS OF 10%. THIS IS INTENDED TO PROVIDE THE DECISION MAKERS WITH INFORMATION CONCERNING THE POTENTIAL FOR REVERSALS IN PREFERENCE DUE TO AN ERROR IN ESTIMATING.

| CHANGE IN AEW ATTRIBUTE VALUES | | | | |
|---|---|---|---|---|
| % CNG | 30 DAY EARLY DELIVERY | ANNUAL BENEFITS | ANNUAL COSTS | MARR |
| +50% | 153.36 | 408.70 | -554.43 | 15 |
| +40% | 143.14 | 381.45 | -517.47 | 14 |
| +30% | 132.91 | 354.21 | -480.51 | 13 |
| +20% | 122.69 | 326.96 | -443.54 | 12 |
| +10% | 112.46 | 299.72 | -406.58 | 11 |
| 0% | 102.24 | 272.47 | -369.62 | 10 |
| -10% | 92.02 | 245.22 | -332.66 | 9 |
| -20% | 81.79 | 217.98 | -295.70 | 8 |
| -30% | 71.57 | 190.73 | -258.73 | 7 |
| -40% | 61.34 | 163.48 | -221.77 | 6 |
| -50% | 51.12 | 136.23 | -184.81 | 5 |

* VALUES IN THOUSANDS OF DOLLARS UNLESS OTHERWISE NOTED

30 DAY EARLY DELIVERY (AEW)
-22.31 + X =

ANNUAL BENEFITS (AEW)
-192.54+ X =

ANNUAL COSTS (AEW)
449.55 + X =

Figure 37. Single Attribute Sensitivity Analysis

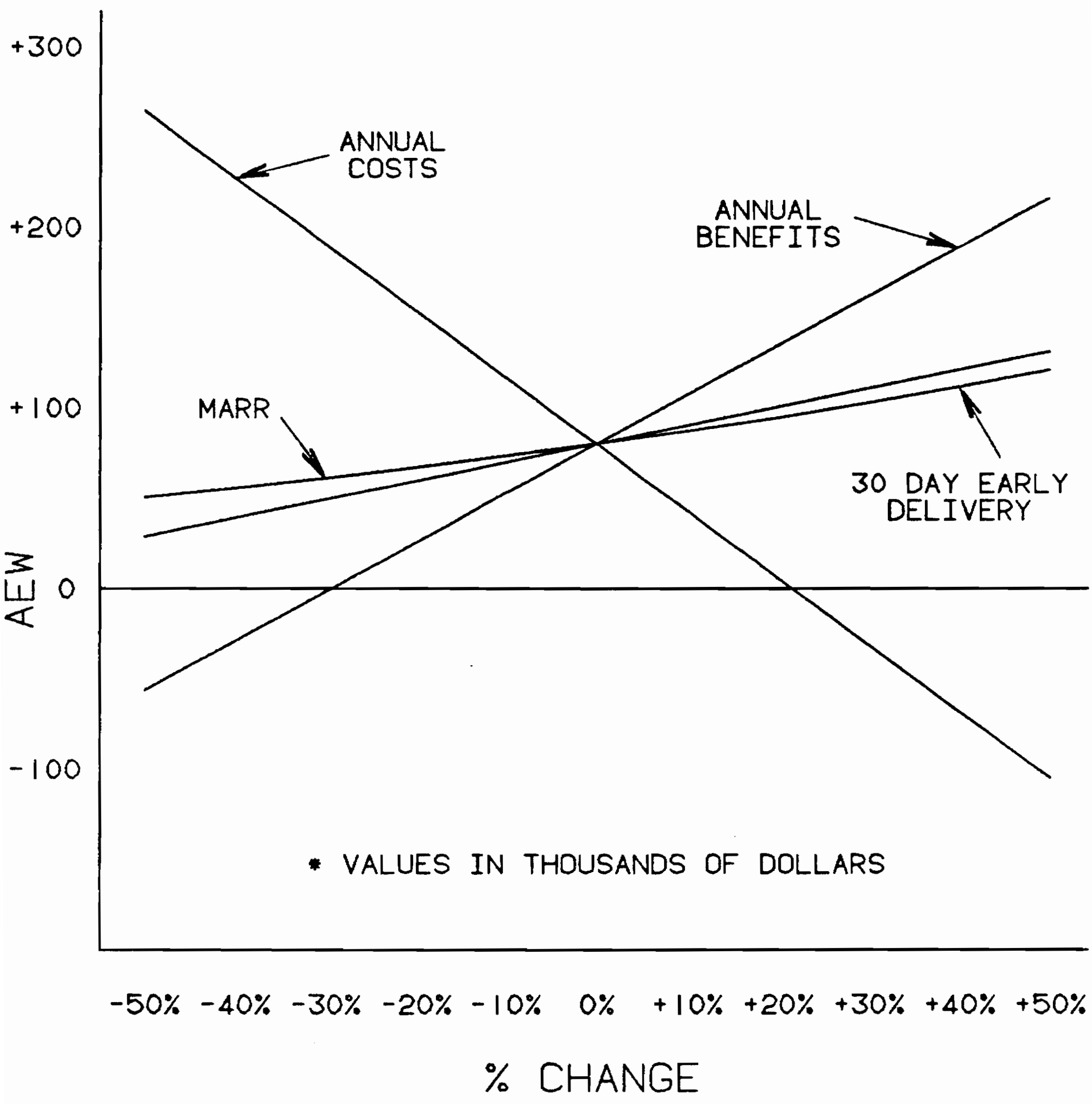
MARR VALUE IS FOUND BY SUBSTITUTING IN THE CORRESPONDING INTEREST VALUE AND SOLVING FOR THE AEW

(-100 + -122( ) + -32( ) + -35( ) + -112( ) + 435( ) + 740.865( ) )(.2296) =

| AEW ATTRIBUTE VALUES | | | | |
|---|---|---|---|---|
| % CNG | 30 DAY EARLY DELIVERY | ANNUAL BENEFITS | ANNUAL COSTS | MARR |
| +50% | 131.05 | 216.16 | -104.88 | 120.78 |
| +40% | 120.83 | 188.91 | -67.92 | 111.59 |
| +30% | 110.61 | 161.67 | -30.96 | 102.82 |
| +20% | 100.38 | 134.42 | 6.01 | 94.70 |
| +10% | 90.16 | 107.17 | 42.97 | 87.08 |
| 0% | 79.93 | 79.93 | 79.93 | 79.93 |
| -10% | 69.71 | 52.68 | 116.89 | 73.24 |
| -20% | 59.49 | 25.43 | 153.85 | 66.95 |
| -30% | 49.26 | -1.82 | 190.82 | 61.07 |
| -40% | 39.04 | -29.06 | 227.78 | 55.54 |
| -50% | 28.81 | -56.31 | 264.74 | 50.33 |

* VALUES IN THOUSANDS OF DOLLARS UNLESS OTHERWISE NOTED

Figure 38. Single Attribute Sensitivity Analysis Contd




Firure 39. Single Attribute Sensitivity Analysis Graph

## MULTI- ATTRIBUTE SENSITIVITY ANALYSIS

THE MULTI- ATTRIBUTE SENSITIVITY ANALYSIS SERVES AS A TOOL FOR MANAGEMENT TO USE IN DECIDING WHETHER OR NOT TO CONTINUE WITH THE AC-SYSTEM IN THE FACE OF CHANGING LIVES, COSTS, AND BENEFITS. FOR YEARS 3, 4, 5, AND 6 A CURVE WILL BE PLOTTED REPRESENTING THE AEW OF THE SYSTEM. A POINT ABOVE THE CURVE HAS A POSITIVE AEW AND A POINT BELOW THE CURVE HAS A NEGATIVE AEW. TO USE THIS TOOL ONE ESTIMATES THE LIFE OF THE SYSTEM (ADJUSTING FOR ANY NEW INFORMATION GAINED), THEN CALCULATES THE PERCENT CHANGE IN EITHER COSTS OR BENEFITS THUS FAR. LOOK AT THE POINT ALONG THE AXIS CORRESPONDING TO THE PERCENTAGE CHANGE OF THE ATTRIBUTE, THEN UP OR OVER TO THE GRAPH REPRESENTING THE THE EXPECTED LIFE. THE POINT ON THE OTHER AXIS CORRESPONDING TO THE POINT ON THE GRAPH IS THE AMOUNT THE OTHER ATTRIBUTE MUST BE (OR HIGHER FOR BENEFITS,LOWER FOR COSTS) IN ORDER TO MAINTAIN A POSITIVE AEW.

X AXIS = COSTS
Y AXIS = BENEFITS

LIFE = 6 YEARS

$$0 = -369.62(1+X) + 272.47(1+Y) + 74.84 + 102.24$$
$$= -369.62X - 369.62 + 272.47Y + 272.47 + 177.08$$
$$= -369.62X + 272.47Y + 79.93$$
$$Y = 1.36X - .29$$

X AXIS = .21
Y AXIS = -.29

Figure 40. Multi-Attribute Sensitivity Analysis

LIFE = 5 YEARS

$$
\begin{aligned}
0 &= -354.98(1+X) + 250.51(1+Y) + 86.00 + 78.31 \\
&= -354.98X - 354.98 + 250.51Y + 250.51 + 164.31 \\
&= -354.98X + 250.51Y + 59.84 \\
Y &= 1.42X - .24
\end{aligned}
$$

X AXIS = .17
Y AXIS = -.24

LIFE = 4 YEARS

$$
\begin{aligned}
0 &= -338.36(1+X) + 231.04(1+Y) + 102.84 + 56.2 \\
&= -338.36X - 338.36 + 231.04Y + 231.04 + 159.04 \\
&= -338.36X + 231.04Y + 51.72 \\
Y &= 1.46X - .22
\end{aligned}
$$

X AXIS = .15
Y AXIS = -.22

LIFE = 3 YEARS

$$
\begin{aligned}
0 &= -318.09(1+X) + 212.07(1+Y) + 131.07 + 35.81 \\
&= -318.09X - 318.09 + 212.07Y + 212.07 + 166.88 \\
&= -318.09X + 212.07Y + 60.86 \\
Y &= 1.50X - .29
\end{aligned}
$$

X AXIS = .19
Y AXIS = -.29

Figure 41. Multi-Attribute Sensitivity Analysis Contd

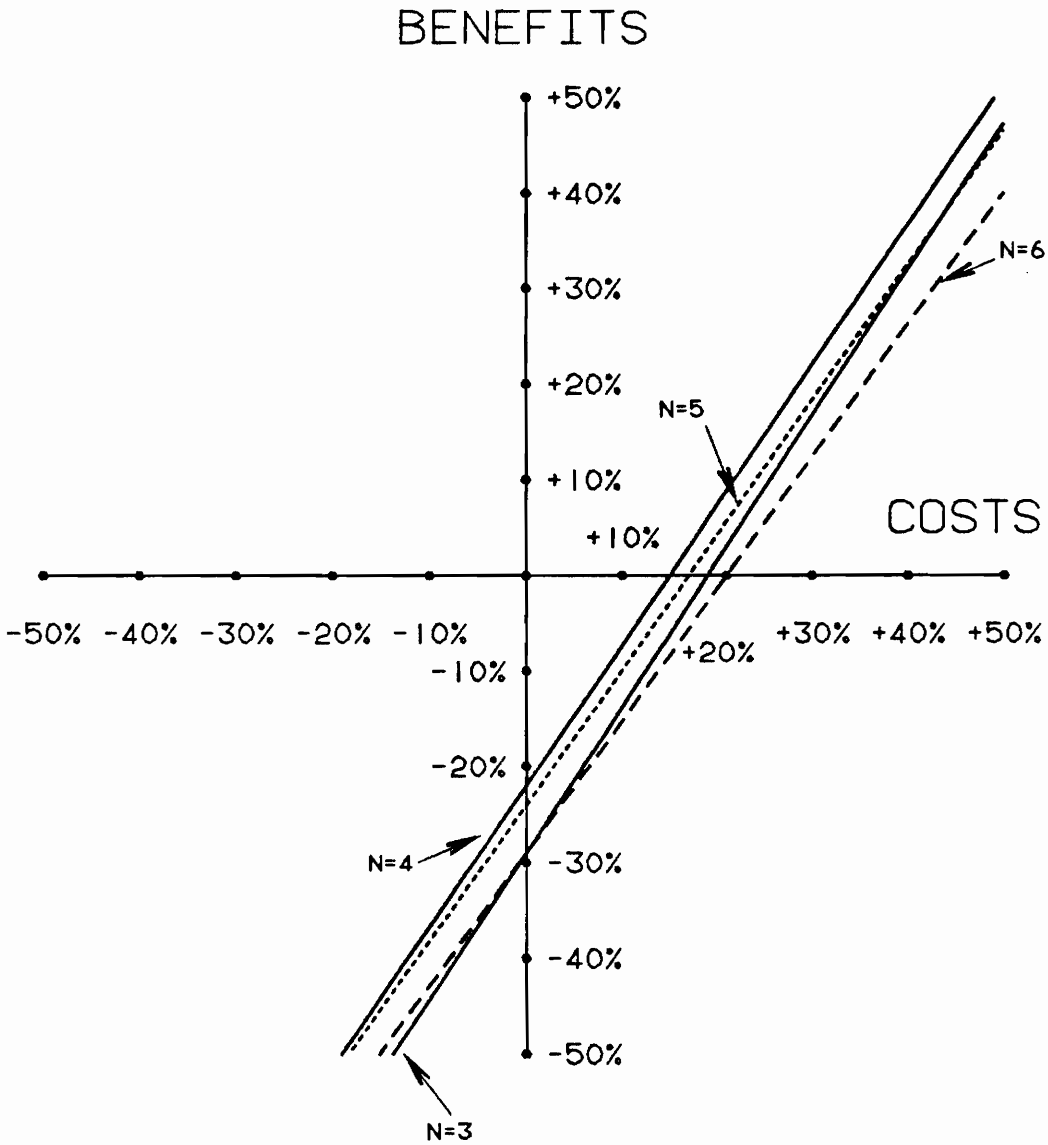



Figure 42. Multi-Attribute Sensitivity Analysis Graph

# CHAPTER 5

## CONCLUSIONS AND RECOMMENDATIONS

The net present value of the AC-system was found to be \$348,163, which translates to an annual equivalent value of \$79,940. The rate of return is 30.31% and the system will pay for itself in 2.19 years. It was found that the annual costs were the most critical variable followed by the annual benefits. It is very important that these two variables are closely monitored throughout the life of the AC-system. Because of the strong possibility for change in the estimates during the life of the system a single attribute and a cost/benefit multiattribute sensitivity analysis was performed. These calculations will provide the decision maker with the necessary information to quickly decide whether or not to continue with the AC-system or cancel it.

The conclusion, based on the analysis, is that Newport News Shipbuilding should implement an accuracy control system such as is designed in this report. Not only will this be a profitable venture but it will improve the quality of the finished product at a profit. The benefits of greater accuracy control in the aircraft carrier construction process are far reaching both objectively and subjectively. The economic analysis has shown that the addition of the accuracy control system would be profitable for NNS but there are also other benefits involved such as:

1) A higher quality product
2) Increased employee satisfaction
3) Decreased construction schedule
4) Better reputation within the shipbuilding industry
5) Happier consumer (government)
6) Favorable future contract considerations

The indirect monetary benefits could well outweight the direct benefits outlined in the economic analysis. Increasing the quality of a product is a goal worth striving for itself and when a company can achieve this goal and make a profit doing so, it is truly an opportunity worth exploiting. This conceptual design is a strong base which will lead eventually to preliminary and detailed design activities.

Preliminary analysis indicates several modules of the carrier have significantly higher rates of rework than the average. The rework is higher on these modules because of the complex systems they contain and they are recommended as good starting locations for the accuracy control system. These modules include:

1) Flight deck units
2) Reactor units
3) Innerbottom units
4) Bow units
5) Transom units

Accuracy control should be incorporated early in the life cycle of a product. This systems development is late in the Nimitz class carriers life cycle but is expected to influence the next class of carriers greatly. This system can be used as a sample for the AC-system developed for the new class of carriers and can be used as an important tool in the new carrier class development. This AC-system will show the deficiencies of the current carrier design and construction process so that improvements may be developed early in the new carrier class life cycle.

Upon completion of the accuracy control system's life cycle a number of options are available. First if it is found by economic evaluation to no longer be feasible it can be disbanded. The employees can go back to their original departments improved by their experiences. The mark left by the accuracy control system on the overall construction process will be permanent. The chances are though that the accuracy control system will be kept intact and will be applied to another contract. Most of the costs of developing the system will have already been disbursed and the additional resources necessary to continue to operate the system will be minimal.

Other areas where the accuracy control system may be applied are additional aircraft carrier contracts. No one believes that the John C. Stennis and the United States will be the last two carriers built at Newport News Shipbuilding. As long as NNS is in operation there will be a need for accuracy control. As the military naval build-up declines there is a strong belief that commercial shipbuilding will be on the up-swing. In order for NNS to be at the competitive level necessary to win commercial contracts they must have a strong accuracy control system. Todays commercial shipbuilding industrial shift to the Far East has already proven that.

It is possible that the shipyard will branch out into other types of construction where the accuracy control system will be beneficial. For example, in the construction of suspension bridges or locomotives and railroad cars.

All things considered, the potential benefits both subjective and objective, far outweigh the costs with regard to the implementation of an accuracy control system at Newport News Shipbuilding.

Secondly, it is worth investigating the other areas that have been pointed out in the beginning of Chapter 2. Similar analysis may provide other possible profitable improvements that NNS may wish to exploit.

## REFERENCES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[7] Blanchard, Benjamin S., and Wolter J. Fabrycky. Systems Engineering and Analysis, Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1981.

[8] Halper, Irving d. "THEODORE ROOSEVELT (CVN71) Construction Schedule Compression" Journal of Ship Production, May 1986.

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# APPENDIX

# A

# DEFINITION OF TERMS

# Definitions of Terms

| | | |
|---|---|---|
| Aft | - | Toward, at, or near the stern. |
| Amidships | - | At or near the midship section of the ship. |
| Assembly | - | A structural item consisting of a single panel made up from individual plates, shapes, and subassemblies, such as a deck, shell, bulkhead, etc. |
| Bow | - | The forward end of the ship. |
| Bulkhead | - | (BHD) A vertical partition corresponding to the wall of a room, extending either athwartships or fore and aft. A steel partition in a ship. |
| Butt | - | The joint formed when two parts are placed edge to edge. |
| Compartment | - | A part of a ship corresponding to the floor of a building. |
| Displacement | - | The total weight of the ship when afloat, including structure, machinery, equipment, supplies, and personnel. |
| Draft | - | The vertical distance of the lowest point of the ship below the surface of the water, when afloat. |
| Forward | - | Near, at, or toward, the bow of the ship. |
| HBCM | - | (Hull Block Construction Method) The process of construction a ship in large |

modules. The individual modules are constructed in a steel fabrication shop, and on an erection platten. Most modules are preoutfitted as much as practical.

Inboard - Inside of a ship, toward or nearer the centerline.

Knot - A nautical mile per hour, about one and one-seventh statute miles per hour.

Modular Construction - See HBCM

Modularity - The design of identical system details for identical equipment. For example, a ship with identical diesel generators, the detailed design of associated equipment units, connecting piping, etc., would be identical.

Outboard - Away from the centerline.

Outfit - A broad definition of all non-structural equipment and systems which are to be installed in or on a ship, including machinery.

Shell - The plates forming the outer skin of the hull.

Stern - The after or back end of a vessel.

Subassembly - A structural item which is fabricated from processed plates and shapes, and which when completed will be incorporated with other subassemblies into an assembly or module.

Superlift - (Module) The name given to the large blocks used to construct a ship with HBCM. The name originates from the proces of lifting the block to the shipway from the platen by a crane. Some of the lifts are the largest accomplished by man.

Transverse - (Athwartships) At right angles to the ship's centerline.

Unit - See superlift.

ZOM - (Zone Outfitting Method) The process of installing equipment on a subassembly, superlift, or onboard a ship organized by defined areas called zones.

ZPM - (Zone Painting Method) The process of painting a ship before the superlifts are erected in the shipway in order to reduce costs and time.

APPENDIX

B

NEWPORT NEWS SHIPBUILDING

NEWPORT NEWS SHIPBUILDING

Newport News Shipbuilding and Dry Dock Company (NNS), is located in Newport News Virginia, and is presently a major component of Tenneco Incorporated. Tenneco is a diversified energy company with headquarters in Houston Texas [1, p.1]. Newport News Shipbuilding was founded in 1886, by an industrialist named Collis P. Huntington [1, p.1]. NNS became a part of Tenneco Incorporated in 1968. Edward J. Campbell is currently the President and Chief Executive Officer [1, p.1]. Newport News Shipbuilding is the world's largest and most diversified shipyard, and with over 26,000 employees, it is the largest private employer in the Commonwealth of Virginia [2, p.1].

More than 700 ships have been built at NNS [1, p.1]. Over 40 of these were nuclear-powered warships delivered to the U.S. Navy [1, p.1]. Some of the largest commercial vessels built in the western hemisphere were constructed at NNS including three 125,000 cubic-meter capacity liquefied natural gas tankers and two 397,000 deadweight-ton oil tankers [1, p.1]. The Company is now involved almost exclusively in the design, construction, repair, overhaul and refueling of U.S. Navy ships.

NNS consists of a 475 acre complex situated on the shore of the James River. The companies facilities include eight piers, four shipways (including shipway #12 whose drydock 900 metric ton capacity gantry crane the largest in the western hemisphere), seven dry docks, two outfitting berths, an 11 acre steel production facility, a 6 1/2 acre steel fabrication shop, a complete foundry capable of producing steel castings up to sixty-two tons and non-ferrous castings up to six tons, forge facility, machine shops, electrical shops, pipe shops, and most recently a submarine modular outfitting facility and ring-module shop.

AIRCRAFT CARRIERS

Newport News Shipbuilding has delivered 25 aircraft carriers, the first of which was delivered in 1934 [3, p. 245]. NNS has built all of the Navy's six nuclear powered aircraft carriers and is the lead design yard for the NIMITZ class carriers. Five NIMITZ class carriers have been delivered, one of these being the USS ABRAHAM LINCOLN, which was delivered late last year. The NIMITZ class carrier GEORGE WASHINGTON is presently under construction and is due to be delivered in 1991. NNS has recently been awarded a contract for two more NIMITZ class carriers, to be named the JOHN C. STENNIS (CVN 74) and the UNITED STATES (CVN75), with delivery dates sometime in the 1990's [4, p.1]. Some interesting facts and specifications on the NIMITZ class carrier USS ABRAHAM LINCOLN are given in figure 1, including displacement, accommodations, length, and ship speed.

KEEL LAID: NOVEMBER 3, 1984

EXPECTED DELIVERY: 1989

PROPULSION: TWO NUCLEAR REACTORS

LENGTH: 1,092 FEET

WIDTH: 252 FEET

BEAM AT WATERLINE: 134 FEET

AREA OF FLIGHT DECK: 4.5 ACRES

COMBAT LOAD DISPLACEMENT: 95,000 TONS

SPEED: OVER 30 KNOTS

NUMBER OF PROPELLERS: FOUR

NUMBER OF RUDDERS: TWO

NUMBER OF ANCHORS: TWO

WEIGHT OF EACH ANCHOR: 60,000 POUNDS

NUMBER OF AIRCRAFT ELEVATORS: FOUR

SIZE OF ELEVATORS: 3,880 SQUARE FEET EACH

NUMBER OF CATAPULTS: FOUR

ACCOMMODATIONS: 6,250

MEALS SERVED ABOARD DAILY: 18,150

NUMBER OF COMPARTMENTS AND SPACES: OVER 3,360

NUMBER OF TELEPHONES: 2,000

CAPACITY OF AIRCONDITIONING PLANTS: 2,520 BTU'S (ENOUGH TO SERVE OVER 800 HOMES)

DAILY CAPACITY OF DISTILLING PLANTS: 400,000 GALLONS (ENOUGH TO SUPPLY THE DAILY NEEDS OF OVER 2,000 HOMES)

TOTAL NUMBER OF LIGHTING FIXTURES: 29,600

LENGTH OF ALL CABLE AND WIRING: EQUAL TO 4,300 TIMES THE LENGTH OF THE SHIP.

ALL CHAIRS LINED UP, WOULD EXTEND TWO MILES

Figure 1. About Abraham Lincoln ( CVN72 )

Source: "Christening and Launching of the Aircraft Carrier Abraham Lincoln CVN72" ( Newport News Shipbulding Christening Information, 1988 )

VITA

Vincent Daniel Pascual was born in Manhattan, New York on May 16, 1961. In 1979, he graduated from Carmel High School. He received his Bachelor of Science in Ocean Engineering from Florida Institute of Technology in December, 1984. He began graduate study in Systems Engineering at Virginia Polytechnic Institute and State University in June, 1987.

In 1985, Mr. Pascual began his career at Newport News Shipbuilding as an Engineer I in the Hull Technical Department. Initially, his responsibilities included structural design and analysis in support of the erection of the superlift (module) units for the aircraft carrier THEODORE ROOSEVELT. His work involved weld receipe design and analysis, structural design in support of lifting modules, and computer based structural analysis.

Presently, Mr. Pascual is a senior engineer in the Hull Technical Department and his primary responsibilities include engineering support of launching, docking, and resolving miscellaneous structural problems which arise during the construction of aircraft carriers. Additional responsibilities include research in areas of contract discrepancies, accuracy control, assistant chairman of the NNS measurement and alignment standing committee, structural design and analysis in support of superlifts, and computer coordinator for 35 employees.

Mr. Pascual is a member of the Society of Naval Architects and Marine Engineers.

Vincent Daniel Pascual