Streamlining of Pipe System Completion Processes in a Shipyard Environment

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A.B., Mechanical Engineering and Materials Science, Harvard University (1999)

Submitted to the Department of Materials Science and Engineering
and to the Sloan School of Management
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Abstract

Due to a number of different production issues, the manufacture of template pipes is often delayed. These delays hold up pipe system completion on board the ships in production and can delay payments from the Ministry of Defense. In order to improve the production of template pipes, a number of changes are recommended to the pipe production processes overall. These include improvements in production planning, along with changes in procurement and scheduling methods. These changes in production methods will result in more material available when it is needed and will therefore improve the manufacture of template pipes. Additionally, they will improve the overall availability of pipes when needed as well as reducing inventory of finished pipes and decreasing the amount of rework. A number of other recommendations to improve the overall pipe manufacture process are also identified, including changes in performance measures, production planning, and other potential areas of improvement.

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Oh Danny boy, the pipes, the pipes are calling…
- Traditional folk song

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1 INTRODUCTION

1.1 Project Description

For many, submarines are an object of fascination. From Captain Nemo and his fabulous electric submarine *Nautilus*, all the way to today's present day modern nuclear boats, submarines have captivated and stimulated the imaginations of people all over the world. The idea of diving beneath the depths of the ocean, surviving in the dark underwater world, and emerging intact is one which has an almost magical quality. In the words of Jules Verne in *20,000 Leagues Under the Sea*:

> But in the depths, aboard the *Nautilus*, your heart never fails you. No structural weaknesses to worry about, since the double hull has the rigidity of iron. No rigging to wear out in the rolling and pitching of the sea. No sails for the winds to carry away....No tempests to face, because a few meters below the surface, we can find absolute tranquility (88).

When one thinks of a submarine, one thinks perhaps of a large metal tube, capable of diving to the ocean floor and traveling long distances underwater. Perhaps one ponders the engineering required to produce a vessel which can withstand such pressures and navigate in darkness while carrying out its missions. One does not generally think of pipes. Yet pipes carry the lifeblood of a submarine; they are essential in nearly all of the processes aboard. Every submarine has thousands of pipes on board.

This project was originally intended to improve the on-time completion of pipe systems in submarines. The initial method for this improvement was an analysis of the pipes used to complete pipe systems: pipe templates. In order to fully understand the problem under examination, a description of the situation follows.

The research for this thesis was performed at the Barrow-in-Furness shipyard of BAE SYSTEMS. This shipyard has been existence over a hundred years, and has a long history of producing submarines and surface craft for the Royal Navy. At the time of this research, the shipyard was completing a contract for two surface craft, Landing Platform Docks (LPD), and beginning a new contract for three Astute submarines. The Astute submarines are a new class of submarine, and so the design of most of the boat was original for this contract (although the nuclear reactor design was the same as the last class of nuclear submarine built in the shipyard).

Each submarine has thousands of pipes (the Astute design currently calls for approximately 19,000 pipes.) Upon entering a submarine, pipes are everywhere. All of these pipes are connected into systems. Each system must be assembled piece by piece, and tested as a complete entity before the system can be declared finished. See below for a schematic diagram of this type of system.

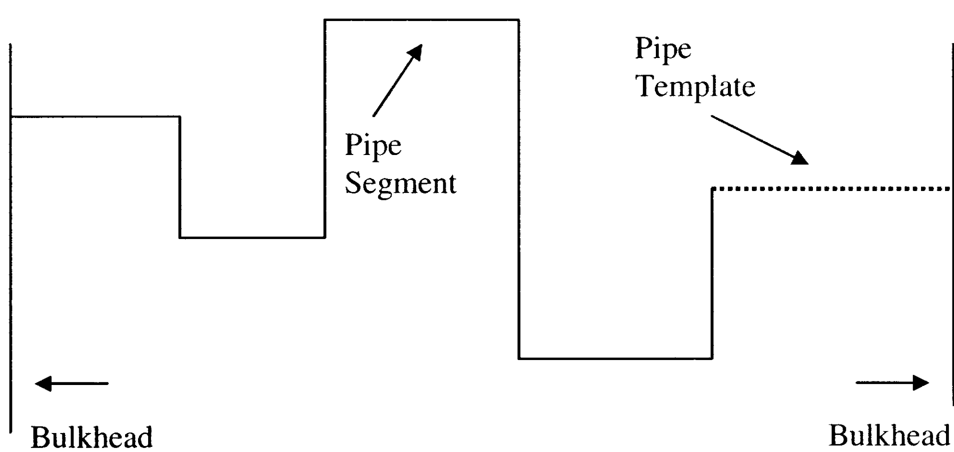

Figure 1.1: Pipe system

Each pipe in the system is made by the pipe shop within a tolerance range of +/- 5 mm. Additionally, as the pipes are assembled and welded, they can stretch or shrink. Therefore, when the system is assembled in total, the actual length can change significantly from the designed length, even if every piece is made within tolerance. However, the system is almost always assembled between two fixed points, often two bulkheads. Therefore, the final length of the system is set. To make up the difference between this set length and the actual length after onboard assembly, a pipe template is used. The pipe template is represented by the dashed line in the diagram above. Pipe templates can be considered the final piece in the puzzle when completing a piping system.

The template is a pipe which is made according to a model fitted from the actual system, after all the other pipes have been fitted. This process is referred to as "lifting a template." There are several methods for lifting a template: digitally, using a special electronic tool to digitize the space in which the template pipe will fit; using a wire to fit the space; and using a piece of scrap pipe to measure the gap. These three methods are called, respectively, using the FARO arm (the electronic tool), lifting a wire template, and lifting a hard template. All three methods produce an output which can be used by the pipe shop to fabricate the pipe.

Due to their nature, template pipes cannot be made until all the other pipes in the system have been made and fit into the system on board. Additionally, once the template is lifted and sent to the pipe shop to be fabricated, the template pipe becomes extremely high priority; it is holding up the completion of the entire system.

In spite of their importance, template production is sporadic in the pipe shop. Template pipes are scheduled based on the original production plan, and the materials for the templates are released to the pipe shop based on this plan. However, any delays which occur during the installation of the system affect the templates. Since the templates are the final piece in the system, all of these delays slow down the lifting of the templates, and the templates in question then can show up at the pipe shop for fabrication weeks or even months late. In the meantime, the pipe shop cannot make the pipes for the templates, and thus, with the available materials, they produce other (non-template) pipes in advance of when they are needed, in order to stay productive. In doing this, the future template materials are often consumed, since the materials for the other pipes have not yet become available. Therefore, when the template pipe finally does arrive at the shop, it has not been scheduled into the shop production plan, and the materials for it are often not available.

In these ways, delays in the production of template pipes become the symptom of problems throughout the process. The original problem to be examined in this thesis was to smooth the production of template pipes so that system completion could be completed more effectively. However, understanding of the production methods quickly revealed that in order to more effectively produce template pipes, the entire production process, of all pipes, not just templates, would need improvement.

The issues surrounding pipe production are not unknown in the Barrow shipyard. In fact, six months before the beginning of this research project, a report was issued identifying many of the issues which were identified independently though this project. (Excerpts from this report are included in later chapters.) However, this project seeks to move beyond simply identifying the issues and to provide concrete recommendations for change, both short and long-term.

This project centered on the production of pipe systems in a shipyard environment. Therefore, all of the specific situations apply to this business. However, pipe assemblies are crucial in a large range of production environments, ranging from aircraft to chemical plants. Therefore, the issues examined in this research are applicable in many different situations, and it appears that many businesses face similar issues. This is most evident in other shipyards, but can be extrapolated to a vast array of other environments.

1.2 Thesis Results

Although the entire production process is considered, the bulk of the analysis performed in this thesis focuses on pipe production, and can be applied to the processes in the pipe fabrication facility. Specific recommendations concerning template methods and production scheduling are made after the collected data is examined. Broader recommendations concerning more fundamental issues are also presented; however, these are much larger in scope than this research project.

Within the pipe shop, the most important recommendation is to slow down pipe manufacture to match the demands of production. Currently pipes are made to stock, and a large inventory of finished pipes is held. This leads to material shortages, lost pipes, and causes delays throughout the pipe system fabrication and installation process. A threshold of two weeks is suggested as a limit of pipes made earlier than demanded.

The most crucial problem identified outside of the pipe shop is the lack of consistent planning for production. The constant changes to the master plan and the lack of communication between departments leads to delays and difficulties in completing pipe systems.

Both of these recommendations and additional large-scope suggestions are discussed at length in the conclusions of the thesis.

1.3 Thesis Structure

The thesis is organized in the following manner.

Chapter 2 describes the various departments in the shipyard which contribute to the pipe system fabrication and installation process. This chapter describes each department and its contribution individually. This is considered valuable because many of the causes of delay with template pipes and therefore delay of pipe system completion are the errors which appear early in the process and then propagate through the different departments; as each department operates essentially in isolation, these causes are often overlooked.

Chapter 3 focuses on the organizational processes throughout the shipyard. It has sections devoted to the strategic, political and cultural views of the business, and the ways in which these affect the project recommendations and ultimately, its success.

Chapter 4 presents the data analysis which was used to make and support the thesis recommendations. It begins with a comparison of the various template methods, moving into an analysis of the pipe rework levels based on fabrication timing, and finally examines the overall rework levels and quantifies pipework which is not tracked and costed; this pipework leads to hidden costs to the business.

Chapter 5 uses the data analysis from the previous chapter and provides recommendations of change both within and outside the pipe shop to address the problems discussed. Finally, an evaluation of the project is made.

2 BACKGROUND: THE LIFESPAN OF A PIPE

In order to fully understand all of the processes which contribute to the production of pipe templates and pipe system completion, a careful study was made of all areas of the business which affect pipe assemblies. These included Engineering and Design, Procurement, Logistics, the Pipe Production Shop (PPS), Planning, and Production, where the pipes were installed on board the ship. This study also provided an opportunity to learn about the overall process of shipbuilding, as well as a chance to learn about the day to day operations and culture of the business. This information was used to formulate the recommendations provided in later chapters.

Each department listed above has a strong tie to the production of pipes, either in their fabrication or their eventual use. In Engineering, the drawings of the pipe assemblies are produced and template pipes were identified in the systems. In Procurement, the materials for making the pipes are ordered. In Logistics, the finished pipes are stored and delivered to the site when needed. The PPS handles demand and produces the actual pipes. Planning and Production are closely tied, so that Production's activities are theoretically controlled by the associated planners. Planning identifies the pipes needed by Production, which controls the actual installation of those pipes.

These business divisions were examined in reverse order of the pipe lifeline; in effect, from the end of the pipe's life all the way to its conception. In this chapter, each section of the business is examined in turn. This provides both a background to the environment in the shipyard, and also a detailed examination of the processes involved in pipe production. Strategic, political and cultural aspects of the organization are examined in detail in the next chapter.

2.1 Production

In the Barrow shipyard, Production formerly consisted of two main areas: surface craft and submarines. Due to recent organizational restructuring, the business has been restricted to only submarines. However, there was one last surface ship under construction at the shipyard at the time of this study, and data from this ship was used in the analysis, together with data from the submarine under construction. The ship is a Landing Platform Dock (LPD). The current class of submarines under contract in the shipyard is the Astute class. The Astute submarines are nuclear, so there are a number of different levels which indicate the grade of the pipe; nuclear pipes require a great deal more testing and quality control than ordinary (non-nuclear) pipes. The first of these submarines is currently on the production floor, with some of the structural fabrication beginning for the second. Three submarines in the Astute class have been ordered; it is expected that this will eventually come to a total of six.

The two construction environments are very different; however, it seems that the differences are due much more to the different build methodology of each project, as opposed to inherent differences between the two types of ships. In pipe production, there is little difference in the general process, though there are some differences between the actual pipes needed.

2.1.1 Templates in the Production Environment

The surface ship studied (LPD02) is in a late stage of construction, due to be completed approximately 6 months after the completion of this research project. It is the second of this type of ship built at this shipyard; the first (LPD01) was delivered to the Ministry of Defense several months before the beginning of the research. However, due to the fact that the production of the two ships was in close succession, in effect, both ships were a "first in class" effort, and a minimal amount of learning from the production of the first ship could be applied to the second ship. However, the similarity between the two ships did lead to a situation in which materials which were intended for the second ship were used for the first ship if its own materials were not available. This disrupted the production schedule of the second ship, and the effects of this problem were felt well after the first ship had been launched.

The observations of the LPD production environment centered on the installation of pipes, which was the part of production most relevant to the project topic. Both the lifting of pipe templates for system completion and the installation of normal pipes were observed.

All three methods of template lifting mentioned in the previous chapter were observed on LPD02. The first examined was the use of the FARO arm (the electronic tool used to digitize the space around the pipe system). Since the FARO arm is a tool which requires a very specific set of skills to use, a team devoted to its use is used on board the ship. The FARO arm is a mechanical device, consisting of a metal arm which is attached by clamps to an immovable surface. It interfaces directly to a computer for data collection. The tip of the arm is positioned around the space where the template pipe will be installed, and the details of the positions in space are recorded. From these data points, an isometric drawing of a pipe is drawn by the FARO team and sent to the pipe shop for fabrication.

When the FARO arm is required, the FARO team is called onto specific locations when a template pipe was to be lifted. All three members of the team have experience in pipe fitting, so are familiar with pipe systems. However, when observed, there was often a significant time delay in the lifting of the template due to the time required for the team to arrive, waiting on board for specific instructions from the pipe fitters, and various other factors. The FARO team estimates that templates lifted using the FARO arm are accurate and usable approximately 90% of the time; actual data was collected from the pipe shop on the accuracy rate of the FARO arm, as well as the other template methods, and is examined in a later chapter.

Next, wire templates were studied and compared to the FARO templates. Wire templates are simply scrap pieces of wire which are fitted into the empty space and bent around any obstacles, often over the pipe fitter's knee. In observing the situations in which wire templates were used as the method of lifting a template pipe, a number of differences with the FARO arm method were immediately apparent. According to the pipe fitters, in some cases, the wire templates are easier to lift and much quicker than using the FARO arm, which requires a significant amount of setup. Additionally, wire templates can be lifted by any of the pipe fitters, so there was no delay as in the case of calling the FARO team to do the job; as soon as the template is required, it can be lifted by the worker who had fit the other pipes in the system. The pipe fitters who often used wire templates also expressed frustration at the lack of success with fitting pipes made from FARO arm drawings. According to them, the success rate with FARO templates was, at best, approximately 50%. The pipe fitters also claimed that wire templates were nearly 100% successful.

Hard templates, like wires, can be made by any of the pipe fitters on the ship. They require more material than the wire, as they are actually made out of a length of scrap pipe. They also require a great deal more time to lift. While a wire is simply bent into the shape of the required pipe and fit to both open ends of the system, a hard template usually has flanges welded to the ends, and is a great deal more difficult to bend. So the costs of using a hard template are greater in both material and labor; hard templates can take days to lift. The effectiveness of this method is declared to be by far the best by the pipe fitters who use it; this will be examined in a later chapter using data collected.

It was difficult to determine the exact process used in deciding whether a template should be lifted using a wire or a hard template. In most cases, a decision is made by the team leader of the pipe installation group, who would assign one of the pipe fitters to lift the template. It appeared to be a decision based both on the specific case (i.e., in some cases the complexity of the system made the hard template a more reliable choice than the wire), and also on the preferences of the team leader. Although the company suggested method was to use the FARO arm, it was clear from interactions with the various team leaders that a large number of them had very strong opinions about the best method to use, and usually preferred to use that best method as much as possible.

2.1.2 Pipe Installation

In addition to observing the template process in production, the entire pipe installation process was observed in order to understand the role that templates played in the process. Additionally, since templates were used to finish the system, delays in the installation process were often reflected in the timing of the template pipes.

On both the surface ship and on the submarine under construction, pipe fitting is, in some ways, an arbitrary task with regards to timing. Although the fitters are assigned pipes to install, the number of pipes fitted in a given span of time varies greatly. At times, temporary scaffolding obstructes areas where pipes were supposed to run. In other situations, pipes do not fit into the penetrations designed for them. Other installed materials, such as cables, at times obstruct pipe fitting, in cases where the cables should have been installed around the pipes. In addition to any difficulties with actually fitting pipes, often other materials, such as brackets or flanges, are unavailable. Finding or constructing these fittings also delays installation. In general, pipes are estimated to be fit at a rate of 1.7 pipes per week per pipe fitter. Although this number seems to be drastically low, it averages the easy cases, where pipes can be fit into place and welded immediately, and the difficult cases, either due to the complexity of the pipe system, or in cases where various other problems, such as missing brackets or fittings, crop up. However, this unpredictability of the timing of pipe fitting makes it difficult to plan the appropriate amount of time for a pipe system to be finished. This, then, affects the timing of the lifting and later fitting of template pipes, since they depend on the rest of the system.

2.2 Planning

The planning departments studied were the ones which did the specific planning for each production environment; planning was examined on both the LPD and Astute projects, and compared. The role of Planning is to establish the work for the production teams, in a day-to-day breakdown. Planning for the LPD and the Astute environments is quite different. This is due to both the differences in the projects, as well as the differences in the status of the two programs; the surface ship is nearing completion, while the submarine program is still in the relatively early stages of production.

2.2.1 LPD Planning

It was difficult to determine the exact situation in planning at the LPD Production site. Since the ship is almost finished, much of the work done on it is in a stage of "tying up loose ends," and accordingly, the planning is somewhat haphazard. After a week of observation, in fact, it appeared that the Planning department was adjusting the plan to the requirements of Production, rather than production methods being dictated by the plan. Daily meetings are held in which Production informed Planning of their work for the day, and the planners accordingly procure materials and update the master plan. In addition, Planning has the role of tracking how much of the work on the ship is complete, a role which again seems a reversal of the expected role of planning the work. Clearly, planning is not a smooth operation. Specifically, with regards to pipes, nearly all the pipes requested from the pipe shop by planning are "priority" pipes, meaning they are not the scheduled pipes to be delivered, but other pipes needed in production. This disorder in Planning, combined with the unpredictability of the pipe fitting times, makes it nearly impossible to accurately predict when a system will be at a stage to need a template pipe.

2.2.2 Astute Planning

Planning on the submarine program appears to be less chaotic that at the surface ship production. In Astute planning, it is much easier to understand the progression; high level plans are received from Engineering, where the systems are designed, and the planners then break these high level plans down to day-to-day plans and order materials accordingly, so that the materials are available when they were needed in production. However, as in the LPD Planning department, it quickly became evident that there is a substantial difference between the plans developed and the work taking place in

Production. Again, planners are sometimes called upon to procure materials which had been scheduled either much earlier or later than originally planned. In one very relevant episode, a planner attempted to track the whereabouts of a certain template pipe and learned from the pipe shop that the pipe in question had been delayed for so long that the necessary material had been used for other work, and was now unavailable. Again, the discrepancy between planning and the actual production is unmistakable, and is clearly creating downstream problems. This specific example was a recurring problem, which is discussed in Chapter 4.

2.3 Logistics

With regard to pipes, the Logistics department is responsible for keeping track of the finished pipes, as well as transporting the finished pipes. The finished pipes are usually moved from the pipe shop and kept in a pipe storage facility until they are needed; once they are requested by Planning, they are moved from the pipe store to the production site where they are required.

However, casual observation of the site revealed that a large number of pipes were left at the dockside or in the production hall; those left outside were subject to corrosion, as well as often loss, since once the pipes left the Logistics transportation they were no longer tracked by the logistics team and therefore were difficult to trace. This sort of loss led to the same pipes being manufactured over and over, which affects the regular production schedule. This problem is also examined in more detail in Chapter 4.

For this study, the Logistics team provided data on the pipes currently in storage, as well as estimates of the value of the storage space itself. This information was included in later analysis. However, the Logistics team also spent a large number of manhours (a labor measure) transporting pipes. In cases where these pipes were either lost or sent back to the pipe shop for rework, this work became an additional non-value added loss on these pipes. This quantity was difficult to estimate, but was noted as additional value lost on reworked pipes.

2.4 Procurement

The procurement department is responsible for purchasing the raw stock of tube, fittings and valves used by the pipe shop in fabricating pipes. The lead times for each component varied a great deal; some of the items, which were more difficult to obtain, had lead times up to six to eight months. Procurement receives the bills of materials from the technical department, and they then order the items so that they arrive to the pipe shop in time to be made when planned. However, because the technical drawings are not always produced far enough in advance to order the materials, the length of the lead times means that the downstream effects result in shortages of materials for the pipe shop. This, in addition to delays caused by templates, as well as other factors, contributes to the need to shuffle the schedule in the pipe shop in order to have the shop continue to produce even though the pipes are then fabricated out of sequence.

Unfortunately, the delays introduced to the process in Procurement, namely material delays in the pipe shop, are not ones which can be easily fixed within the department, or in any area following Procurement in the pipe manufacturing process. The delays in the procurement process can only be alleviated by changes in either the planning or the design process; the solution is to produce the drawings needed in Production early enough to allow the materials to be ordered and to arrive on site. Alternatively, if lead times could be reduced through improved supplier relations, this could build in more flexibility to the process; however, this solution is a difficult one to address.

2.5 Pipe Production

In the pipe shop, rather than focusing on the day-to-day procedures of pipe production, most of the research was centered on understanding the scheduling procedures and how it related to the demand from the ships under construction. The pipe shop had recently been the focus of a lean manufacturing effort which had streamlined production within the shop. Since pipe production had already been analyzed using lean techniques, it was judged that changing these processes would not help with the template pipe production or the completion of pipe systems.

The data which was procured from the pipe shop, along with the conclusions drawn from this data, are discussed at length in later chapters. However, one very significant observation made in the pipe shop related the processes feeding information and materials into the pipe shop with the output of the shop. The processes preceding the pipe shop operated as much as possible on a pull system. This meant that the materials were ordered in a manner to have them arrive when they were needed, answering the demands of production. However, within the pipe shop, due to the lack of materials and other factors, and following the need to keep the pipe shop feeding work through and producing pipes, the production system was a push system. The pipes were made as soon as possible after the drawings and materials were available, and put into storage until they were needed in production. This change in production methods (from pull to push) contributed to the material shortages in the pipe shop.

2.6 Engineering

Engineering processes within the shipyard were considered through the Engineering Process Improvement Center (EPIC). This department had links into the areas where the pipe systems were designed and integrated into the larger ship design. These processes, although extremely important to pipe manufacture, seemed to be very far removed from it. Although this kind of separation was observed in many different departments, it seemed particularly marked in design.

The process by which template pipes were identified in the technical drawings was one which was touched upon within this department. However, it appeared to be a relatively sporadic and unregulated process. A number of attempts were made to learn more about this process were made, but due to its nature and especially the precise timing required to observe it (at the time of the study, most template pipes had already been identified in the designed systems), no substantive conclusions were drawn.

2.7 Integrated Business Systems

The Integrated Business Systems (IBS) team is in the process of developing a software system by which the entire manufacturing process of building ships and submarines would be improved. It involves linking the various separate databases in a manner which would propagate information throughout the system, so that each department would have greater visibility of the actions occurring in other departments. However, overall, the IBS process does not appear to bring significant change to the business. Specifically, it does not seem that the IBS process changes and software developments will have much effect on the template manufacturing process, or even on the general pipe manufacturing process. Although there are indirect effects, through design and ordering, which would impact the pipe shop, there is no component which would directly influence pipe production. This kind of global improvement was targeted at improving the business overall, but would not impact the changes needed in pipe production.

2.8 Summary

This chapter's summary of the processes involved in pipe production encompasses the areas of the shipyard which were considered in making evaluations of the template pipe manufacturing process. Perhaps the most important information gleaned through this study was the lack of continuity between the various departments, and the lack of regard for the impact on downstream processes which each department had. Although a number of areas which affected pipes were observed to have large areas in which change would benefit the template process, the conclusion of the background study was that specific recommendations should apply to the manufacturing processes within the pipe shop. This method had a number of limitations, as the most serious problems in the pipe shop had their roots outside the shop itself. However, given the environment in the shipyard, it was concluded that specific recommendations outside the pipe shop would be difficult or impossible to implement. This situation is considered in greater detail in the next chapter. Although specific recommendations for change were limited to the pipe shop, later chapters provide more general suggestions for the rest of the business which were described in this chapter. These are considered to be important areas, which, although outside the scope of this study, merit further consideration.

3 ORGANIZATIONAL PROCESSES WITHIN THE SHIPYARD

The following chapter deals primarily with the organizational processes which directly influenced this project, as well as the overall processes throughout the shipyard. While these issues are not part of the data analysis of the project, they have a large influence on the implementation of any recommendations. Therefore, they are presented here; this analysis will direct the course of the research undertaken and the recommendations made in later chapters.

This project was placed in a somewhat unique position in the shipyard. This is due to the fact that the project spanned a large number of departments. The original project, the improvement of template pipe production, was centered on the pipe shop. However, as the project progressed, it became clear that it would involve a number of other departments. This was unusual; most projects remained within a specific department.

The ultimate goal of the project was to improve the production and delivery of template pipes in order to streamline the completion of pipe systems. As the project progressed, however, it became clear that significantly improving the production of template pipes would involve changes to the entire pipe manufacture process. As stated above, this caused the project to involve a number of departments which were involved in pipe manufacture, even if they were not direct participants.

This project was chosen to address a need which had been noticed but not addressed for some time. As the delays with template pipes were not easily identified or fixed, the problem had been ignored for the most part. Although template pipes had not been examined in detail, the larger issues had been identified in an internal report published approximately 6 months preceding the start of the project. However, this report simply listed a number of issues but did not address them; this research project offered an opportunity to examine the problem in more detail and to recommend solutions. Excerpts from the report are included with the analysis of the pipe process. Many of the issues identified by this project were also identified in this report.

The first three sections of this chapter deal successively with three different perspectives of the business. The first takes a strategic view, dealing with the organizational structures within the business. The second describes the political structures and their effect on the project. The final view is the cultural one, which, although the hardest to quantify, is in some ways the most significant. Finally, the chapter describes the change process within the business and as implemented in this project.

3.1 Strategic Design View

The Submarine division of BAE SYSTEMS is a small part of the overall business, making up just 3% of the company. The shipyard was acquired by BAE SYSTEMS for strategic reasons; it was considered an important addition to the company's portfolio in the defense industry. However, manufacturing and production processes in the yard have not changed significantly since it became part of BAE SYSTEMS; the change has been most visible in departments such as Human Resources and Finance.

Within the yard, the business is broken up into a number of different departments, such as Planning, Engineering, Procurement, and Production. Each of these departments is an independent entity, and is evaluated on their own progress, with no connection to any of the other areas. For example, the design department might be evaluated on the number of drawings produced in total, regardless if they are the drawings planned by the Planning department, or the drawing needed by Production. Similarly, the pipe shop is evaluated on the number of pipes produced, whether or not they are the pipes planned or installed on board the ship. These criteria are measured by a Performance Index (PI) which corresponds to the amount of work done which is paid for by the customer.

At a lower level, the departments are divided into Integrated Work Teams (IWT). These teams allow for a great deal of autonomy in day-to-day work, as they are independent of each other. Each team includes representatives from other departments; however, these liaisons are not utilized to improve communication between various departments. For the most part, each team and each department acts on its own.

Due to this large degree of autonomy for both work teams and different departments, implementing a change process which spans them is a challenge. Changes which save money for the business as a whole can detrimentally affect a particular department based on the measurements used (specifically, the PI.) This makes it extremely difficult to convince departments to change. This requires change to come from the top of the organization, since it must include a change in the evaluation methods as well as process changes.

3.2 Political View

The structure of the project included rotations through different departments; these were to be supervised within each area by a manager identified as a "stakeholder" in the project. Since each area in which the study was conducted had a connection to pipe manufacture, these managers would all be affected by changes to the pipe production process; therefore, they were considered stakeholders in the project.

However, given the manner in which they would be affected, these stakeholders ranged from supportive, to unresponsive, to discouraging. By far, the most common reaction to the improvement project was indifference. Although the managers were not disapproving of the project, it was too far from their day-to-day work to make much of an impression on them; although the recommendations of the project did relate to a number of different departments, not only the pipe shop and areas directly associated with pipe manufacture.

The stakeholders downstream from the pipe shop, the managers of pipe installation, stood to gain from the project, as it would mean an improved, timely pipe supply. However, wrapped up in their own work, they did not have strong feelings about the project, although they would be affected. Likewise, those upstream from the project, the managers in planning, did not attach much importance to the project, although in some cases it was their work which would have to be changed in order to supply the pipe shop with better information.

3.3 Cultural View

The cultural aspects of the company will have, in an indirect way, an immense effect on the implementation of any of the recommendations from this project. In some ways, this seems inevitable. Shipbuilding is an extremely old profession, and this shipyard has been in existence over a hundred years. In many ways, there are a large number of ingrained methods and mentalities which are difficult or nearly impossible to change. In addition, the downsizing of the yard in the recent past has created a new sort of job-defending culture, which can be another barrier to efficiency.

One of the largest challenges to accomplishing the goals of this project is the move of the customer to fixed price contracts. Formerly, contracts were paid on a cost-plus basis; whatever was spent on constructing a submarine was reimbursed by the customer, and the profit was a set percentage of the costs. Under this system, obviously, the higher the costs, the more profit made by the company. Therefore, high levels of rework were, from a profitability standpoint, a good thing. They did still delay production, which was undesirable, but from a cost perspective, there was no incentive to keep costs low and to keep rework levels down. Likewise, with an essentially unlimited budget, high inventory levels are far less important, as there is never a shortage of cash for operating expenses, capital expenditures, and other production costs.

The current Astute contracts are, however, like the LPD contracts before them, fixed-price contracts. This means that the customer will pay a set amount for the boat, and so in order to make a profit, production costs need to be as low as possible. This new method of payments makes the reduction of rework and the limitation of inventory levels far more important, as there is no longer a limitless stream of cash coming into the business. Currently, cost reductions and process improvements have a much higher priority than formerly.

According to Taiichi Ohno, in reference to the development of the Toyota Production System, one of the foundations of lean production, a "revolution in consciousness" is indispensable to this sort of production shift. On this topic, he states:

> There is no waste in business more terrible than overproduction. Why does it occur? We naturally feel more secure with a considerable amount of inventory...Modern industry also seems stuck in this way of thinking. A person in business may feel uneasy about survival in this competitive society without keeping some inventories of raw materials, work-in-progress, and products.
>
> This type of hoarding, however, is no longer practical. Industrial society must develop the courage, or rather the common sense, to procure only what is needed when it is needed and in the amount needed.

> This requires what I call a revolution in consciousness, a change of attitude and viewpoint by business people. In a period of slow growth, holding a large inventory causes the waste of overproduction. It also leads to an inventory of defectives, which is a serious business loss. We must understand these situations in-depth before we can achieve a revolution in consciousness. (14)

Clearly, this is not a unique problem for the shipyard; it is one which is being faced all over the U.K, as well as in manufacturing across the world. In a study on the health and prospects of the U.K. economy, Michael Porter asserts, "The UK currently faces a transition to a new phase of economic development. The old approach to economic development is reaching the limits of its effectiveness, and government, companies, and other institutions need to rethink their policy priorities." (5)

With these changes, a problem arises because many of the working methods date to the days when it was acceptable to produce at high cost, as long as the finished product was acceptable to the customer. Therefore, it becomes far more difficult to change these methods when there is not an awareness of the importance of cost savings. Although this awareness is paramount at higher levels of the business, it is difficult to communicate it effectively at the level of the person doing every day tasks. Yet this is the level at which a great deal of waste occurs, and this waste is often not tracked or recognized. This project addresses this kind of waste, but the changes suggested represent a paradigm shift.

Another cultural aspect of the business which will impair the implementation of the recommendations of this project is the lack of communication between different departments. Since the different departments are evaluated on their individual performance, there is little incentive to save costs to the business in ways which do not directly affect the department making the changes. This is also impacted by the lack of communication between departments, so that often these opportunities are missed or not taken advantage of, even when they are recognized. Again, there is no incentive to help another department, especially at a cost to one's own, even if the business as a whole would benefit.

These are cultural issues which relate to the entrenched attitudes within the business. However, a much more recent development will also have a profound effect on the project. In the past two decades, the yard has reduced employment by nearly 80%. Layoffs of this magnitude create a culture where everyone is anxious to hold onto their jobs. This leads to two problems with the specific issues addressed by this project. First, people become extremely reluctant to make any change that has an element of risk, as they are frightened of losing their jobs or the jobs of others, and the safest course often seems to be to continue on as before, even when the business continues to lose money in the process. Money saving measures are often seen as opportunities to reduce headcount. Specifically, this project makes recommendations to slow over-production (these recommendations are described in detail in the following chapters) and this involves idle time for the workers in the pipe shop. Although the suggestion is to eliminate non-value added work time, being idle is still a frightening prospect for a work force concerned about their jobs. The recommendation is not to reduce headcount; in fact, the capacity of the pipe shop should not be reduced in order to make the recommendations effective. However, there are many in the business who see idle time as an unnecessary expense, both among the shop floor workers and among management. In the case of the pipe shop, working at 100% capacity is actually creating more waste within the business, but there are a large number of people in the yard who see anything less than 100% productivity is a waste, regardless of the downstream effects on the rest of the business.

One more cultural issue is an underlying worry for many in the business which will impact the project. The issue is the future of the shipyard. The shipyard under study is currently the only nuclear submarine facility in the United Kingdom. If the shipyard were to close, the country would be forced to either buy nuclear submarines abroad or to do without them in the Royal Navy. This is an issue which is not commonly discussed, but one engendering many strong opinions within the yard. Some are convinced that the Ministry of Defense will keep the yard in business, no matter the cost, so that the capability is not lost. Some feel that as more and more collaboration takes place with the American shipyards, it will only be a small step to shut down the yard and buy submarines from the Americans. And some feel that by the end of the lifetime of the current nuclear submarines, the defense industry will have changed enough that nuclear facilities will no longer be necessary.

Again, this is a problem which is typical of the present economy. In the same study mentioned previously, Porter states, "Pessimism and the lack of an overall strategic perspective characterize much of the current public discussion about UK competitiveness. Attention is focused on the prosperity and productivity gap that remains with the United States and primary European rivals Germany and France." (5) Clearly, this pessimism is visible within the shipyard.

The implications of these underlying assumptions of the future role of the shipyard are clear. If the customer will continue to buy the product no matter what the cost, in order to keep the yard afloat, then the incentive to cut costs is not as strong.

There is still incentive, but it is less pressing. In the case either that the Ministry will buy submarines abroad or do without, the shipyard is in dire straits. If they cannot produce the submarines profitably, the business has no future, and the ships produced under fixed contract thus far have not been profitable enough to keep a struggling business alive without government subsidies. This argument goes beyond the simple level of whether or not the shipyard should stay open, as there are factors of national security, economic support, taxpayer money leaving the British economy, in addition to other issues. However, the question which impacts the shipyard is whether or not the government will guarantee contracts and payments no matter what the state of the business. In the short term, producing submarines at lower cost may help to sway the balance.

Clearly, any and all recommendations will have to take into account the cultural impacts of the changes. Implementation strategy will need to involve the underlying assumptions and behaviors, or no change plan will be successful.

3.4 The Change Process

The change process within the yard is one which is difficult to implement. Although there are avenues through which new ideas are given recognition, implementing the actual changes is often a different story.

The changes suggested in this project are a combination of changes within various departments (specifically, changes within the pipe shop) and changes across departments (see the final chapter for more details on the actual recommendations.) However, all of these changes will be difficult to put into place, due to the high levels of resistance to change in general, and specifically to changes which increase idle time, as discussed in the previous section.

The most effective way to make change within the business appears to be to use a top-down approach. In order to make change, it needs to come from the director level and move down the chain. Although the specific recommendations were made to be within the pipe shop, the manager of the pipe shop will not implement them unless they are approved by his manager, the head of manufacturing in the shops. And this manager will not approve the changes unless they are approved by his manager, the Director of Manufacturing and Construction. Essentially, the most effective way to drive change will be though the Managing Director of the shipyard.

This, therefore, is the method which is being employed in this project. The recommendations are being presented at all levels, but they are directed most of all at the Director level, and from there the change will trickle down the chain.

3.5 Summary

The harsh reality is that the business is losing money, and the future of the shipyard is in question. Although it may be supported by the government to a certain extent, it seems unlikely that this support will continue forever. Of the changes discussed in this chapter, it seems that the cultural ones will be the most difficult to accomplish. The strategic processes are already evolving, and the political ones will follow suit; it is the cultural issues which are most embedded. Yet they must change, if the business is to have a future. The recommendations of this project are only a small step in that direction.

4 Template Pipes and Pipe Manufacturing: Analysis

As discussed previously, a large number of the problems involved in pipe manufacture stem from outside the pipe shop. Most notable are delays in technical drawings leading to delays in material ordering, and issues with the accuracy of production planning. Yet, after a thorough examination of a number of different areas in the business involved in pipe manufacture, the conclusion was reached that changes made within the pipe shop were the most likely to be accepted. This was due to two main factors. One was the fact that the pipe shop was considered to be a "showcase" for lean manufacturing within the business, so that suggestions to further improve lean production within the pipe shop were more likely to be met with enthusiasm. Additionally, since the original research project was designed to be an improvement in pipe manufacturing methods, the project had the most support within the pipe shop.

4.1 Template Lifting Methods

In the data analysis, the first area examined was the methods of lifting template pipes. This was the original basis of the project, and was determined to be an important issue to consider. There seems to be no consensus about the effectiveness of the various methods; different people in different sections of the business have very different ideas about this problem, as described in the background section regarding template pipes.

In order to consider the effectiveness of the different methods of template lifting, data was obtained directly from the pipe shop regarding the number of times template pipes needed to be remade (thereby giving an effectiveness rate), the number of manhours required to manufacture the pipe, and the number of days in manufacture. This data is summarized below.

Template Type	Rework Level	Average Days in Manufacture	Average Manhours Required
FARO	7.07%	22.6	18.2
Wire	8.23%	12.9	6.3
Hard	8.37%	19.5	10.5

Rework Level: The percentage of template pipes which need to be made more than once
Average Days in Manufacture: The number of days between the start of work on the pipe and the day the pipe is finished.
Average Manhours required: A measure of the actual labor required to produce the pipe.

Figure 4.1 Template Method Comparison

In this table, the rework level indicates the percentage of the time that a template pipe needed to be remade. The average days in manufacture indicates the number of days elapsed between when the template arrived at the pipe shop and the completed pipe was delivered to production. The average manhours required is a measure of the amount of labor required for each kind of pipe.

As can be seen from the listings above, there is no obvious difference between the different methods in rework levels. All three have extremely close effectiveness rates (contrary to the belief of many of the workers actually lifting templates, as described in Section 2.1.1). These values only range over a difference of 1.3%. None of these differences are statistically significant.

There are larger differences in the amount of time required to manufacture the templates. Statistically, these times are all significantly different (at a 95% confidence level), except for the number of days in manufacture of the wire templates and FARO templates, which are not significantly different. Details of this calculation appear in Appendix 1.

However, although these differences are statistically significant, the differences in the averages perhaps could be explained by an implicit bias in the original data. Since the data used was actual ship installation data, it was not obtained in a controlled environment. That is to say, for simpler templates, a wire template was often used, while more complicated templates would require either a hard template or a FARO template. Therefore, it is impossible to tell from the data whether the methods are significantly different in manufacture times, or if the specific template pipes selected required more time due to their complexity. However, from the author's observation of the various template pipes, the latter conclusion seems the more likely. It was concluded that the method of lifting templates was not the best area in which to make significant changes, as it would not yield substantial improvement to the process overall. If the different methods had yielded average times which differed by an order of magnitude, it might have been more worthy of change; given the large number of uncontrolled factors in the data, and the other areas available for change, other areas were considered more important.

Due to this conclusion, other ways to improve pipe manufacture, specifically template pipe manufacture, were considered. These included an examination of the materials used in pipe manufacture, the scheduling of pipe manufacture. These were extended to include an examination of pipe manufacture as a whole and the data collection regarding it. These investigations are detailed in the rest of the chapter.

4.2 Delay in Template Pipes

The next area of pipe manufacture considered were the delays involved in producing template pipes. Before examining this problem, data was collected and analysis was performed to verify that this was a problem worth pursuing. The data collected consisted of information about the length of time involved in manufacturing the template pipes (discussed previously), and the component of that time which was delay due to material shortages. A summary of the data follows:

Delay (at least)	Percentage
3 days	53.4%
1 week	26.4%
2 weeks	12.3%
1 month	4.7%

Figure 4.2 Template Delays

The most significant threshold was considered to be one week's delay, which occurs approximately a quarter of the time. Although it was impossible to estimate the cost of this delay of a template pipe to the project, for the overall Astute project, a delay of a week corresponds to a cost of on the order of one million pounds in overhead. Although one template pipe does not hold up the entire project, this comparison does demonstrate that delays are extremely costly, and therefore the delays in template pipes are significant. The next several sections describe the ways template delays were examined.

4.21 Pipe Materials

One of the first areas considered in the overall process was the use of materials in pipe manufacture. If the numbers of different kinds of materials could be reduced, fewer types of tube would be required in stock, and this could reduce the amount of shortages for specific pipes, especially template pipes. If different kinds of tube were used on the basis of cost, the savings from having fewer kinds might outweigh the cost increase in stocking fewer different, but potentially more expensive, tubes. The different kinds of material used, as well as their application on board a submarine, were discussed at length (see

Appendix 2 for a summary of these). However, two things quickly became apparent; first, that the different kinds of tube were selected due not just to cost reasons, but also due to differences in properties important for submarine design; density, strength, and magnetic behavior, in particular. Additionally, even if these could be changed, it was something to consider well upstream in the process; another issue which was out of the pipe shop and back in the design process. Due to the reasons described previously, this approach was not pursued.

4.22 Scheduling in the Pipe Shop

The next area considered was the production scheduling in the pipe shop. This was due to a simple line of reasoning. Delays in template pipes were caused by material shortages. However, the templates were usually late, not early; this means that the materials used in their production should have been ordered and received well in advance of the delivery of the template from the ship. Where were the materials?

The answer was deceptively simple; the materials were being used to produce other pipes while the templates were delayed. Pipes in the pipe shop were produced earlier than needed in order to maintain the production cycle of the facility whilst the templates were delayed. This, in turn, used up the materials intended for the template pipes. The next area to examine was therefore the issues surrounding these pipes which were produced early.

Pipes produced "early" were a difficult group to address. A number of different issues made these pipes hard to classify. The main problem with categorizing pipes by date was that the dates were set by a plan made by the groups who designed the pipework. The dates corresponded to the installation plans of the pipes. However, these plans often bore little resemblance to what was actually going on in ship production, and therefore the ship would produce lists of "priority pipes" which were requested when they were needed, but often either ahead or behind their planned schedule. Producing these pipes could disrupt the rest of the production schedule in the pipe shop. Additionally, due to the long lead times for materials, pipes designed too close to when they were needed were often scheduled in the past; a technical impossibility for the pipe shop to produce on time. These pipes, automatically late due to this scheduling twist, were usually then even later due to actual wait times for the needed materials. Finally, template pipes, the original focus of the project, were scheduled according to the same plan, and therefore were often requested of the pipe shop months before the system was installed; so the template pipes were "late", even though there was no way they could have been manufactured.

However, all of these scheduling problems occurred *outside* the pipe shop. Although they were clearly important parts of the template pipe problem, as well as problems with pipe production overall, it was also clear that direct change recommendations in these areas were outside the scope of this project. As discussed earlier, specific recommendations stemming from this project were aimed at the pipe shop, as this is where they were most likely to be implemented. However, these other areas will be addressed in the conclusions.

Therefore, the dates received by the pipe shop were the ones used to classify pipes as "early" or "on-time/late". Although these dates were known not to be fully accurate, they were the only ones available to the pipe shop, and therefore they were the ones used.

A threshold of two weeks in advance was set as a limit between the early pipes and the on-time pipes. The two weeks applied to the difference between the date the pipe was requested to be available, and the day it was completed and delivered to the pipe store.

Several arguments favored slowing down the production of early pipes, in addition to the original goal of keeping material available for the template pipes. One of these was the amount of finished pipe inventory in the pipe store. At the time of this report, this consisted of pipes totaling £494,000 in value, based on material costs. However, the amount of pipes in the pipe store was recently reduced; the average inventory amount for 2002 was £735,000, with a peak of 5,800 pipes valued well over £1,000,000. This inventory represents cash which is unavailable to the business. Although the cash is not, for the most part, lost, it is still cash which cannot be used to pay operating expenses for the business.

The other major cost of producing pipes earlier than they were needed was hypothesized to be a higher level of rework for these early pipes. This was because pipes made early were subject to a large number of issues which pipes made on time and installed were not. These, as discussed previously, included the potential for corrosion, loss, or becoming obsolete due to design changes. Pipes which were produced when they were needed and delivered to production for installation immediately, could not be lost, corroded, or subject to design change (as by the time of installation the design should be mature.) Therefore, it was assumed that this would lead to higher levels of rework for pipes made early.

Although the reduction in inventory, along with the material availability for template pipes, were both important improvements, it was the change in rework levels which would result in the most obvious savings for the business. Therefore, an effort was made to produce a realistic estimate for the savings which would result from lowered rework levels if the pipes were produced closer to their installation date.

To this end, a great deal of data was gathered about pipe production. Three data sets were analyzed in isolation. The first was a selection of the pipes which had been made in the previous year (2002). Next, a sample of all the pipes made on each of the two recent surface ships (LPD01 and LPD02) was examined. A summary of the data collected is available in Appendix 3. The main conclusion drawn, however, was that, in fact, the rework levels were approximately the same for pipes made early and pipes made late. This made the case for slowing down production in the pipe shop much weaker. Additionally, it was contrary to the expectations of nearly everyone who tracked the work in the pipe shop. Therefore, an effort was made to examine more closely reasons why the data analysis had produced these results.

4.3 Data Collection and Hidden Costs

An examination of the data collection methods revealed a number of areas in which the data might have possibly been skewed in such a way to make the early pipes appear to have the same rework levels as the pipes made on time. The easiest breakdown to spot was in the area of the dates used in the analysis. As mentioned before, these dates were often set artificially to account for lead times or other fluctuations. Therefore, it was difficult to pin down an accurate classification for pipes which were "early" or "on-time." This was clearly a problem for the pipe shop, both in their own processes and in their ability to handle demand as they received it from outside the shop. However, the dates as received by the pipe shop were the only data available. Actual installation data was constantly changing, as was the model of the pipework; neither the upstream nor downstream processes from the pipe shop could provide an accurate method of tracking demand. Therefore, although this was identified as a potential area for improvement, other areas were examined for more specific recommendations.

In order to better understand how many pipes were being made and for what purpose, a summary of all the pipes made for each of the surface ships was obtained. A full description of the analysis of this data is available in Appendix 4. The following table provides a summary.

	LPD01	**LPD02**	**Total**
Difference Between Design and Pipes Made	33.5%	32.6%	33.0%
Tracked Rework	17.4%	18.6%	18.0%
Unaccounted Pipes	16.0%	13.9%	15.0%

Figure 4.3 Summary of LPD Rework Rates

To produce the numbers above, all the pipes made for the two ships were considered. Approximately 15,000 pipes were originally needed per ship, according to the design (this figure included a 10% addition for rework). Approximately 20,000 pipes were made for each ship. Of these pipes, about 2,500 were marked as "rework" pipes (~15% of the number needed.) However, another 2,500 were made over the number needed – but these pipes were not marked as rework. Again, this was approximately 15% of the total of pipes needed. This leads to two main questions. First, what were the extra pipes which were made, if they were not rework pipes? These are assumed to be rework pipes which were not tracked as such. The other question which arises is that of the overall level of rework. Why are a third of the pipes needed made twice? Although some rework is to be expected, a rework level of 10% is included in the original estimate. So the pipes made over the original 15,000 are all rework for which there was no budget. A projection of costs to the Astute project, using these same rework percentages, is listed below; this data gives an idea of the future costs to the business if these levels of rework are not reduced. The data is broken up into two separate projections. First, the cost of the rework pipes is listed, broken out into the rework which is tracked (17.4% of the number of pipes actually needed), the pipes which are not tracked as rework (16.0% of the pipes needed in the design) and a total of both of these numbers; for all three boats, this cost exceeds £10 million. In the estimates of these costs, an overhead rate of £20 per hour of labor was used to calculate the total. This figure was used to demonstrate the potential value lost to the business, and can in no way be used as an accurate figure; it is mainly used to give a perspective of the magnitude of the losses.

	Percent used in Estimate	**Nuclear Pipework**	**Non nuclear Pipework**	**Total**	**Total for Three Boats**
Tracked Rework	17.4%	£266,526	£1,551,691	£1,818,217	£5,454,650
Unaccounted Pipes	16.0%	£245,081	£1,426,842	£1,671,923	£5,015,770
Total Rework	33.4%	£511,607	£2,978,533	£3,490,140	£10,470,420

Figure 4.4 Astute Estimated Loss due to Rework

Next, the percentage of pipes actually thrown away on the LPD project was applied to the Astute project. Unlike the rework, some of which is justified, these pipes are indisputably a cost to the business which cannot be recovered. These pipes, if discarded on Astute at the same rate that they were discarded on LPD, could cost £6.5 million (again, using the estimated rate of £20/hr). Additionally, a projection is provided of the costs due to pipes which were discarded after being made more than two weeks early; it is these pipes which are targeted for improvement in the recommendations. From the numbers shown below, simply reducing the rework on these pipes by 50% will lead to a savings of approximately £1.3 million over the three Astute boats.

	Percent used in Estimate	Nuclear Pipework	Non nuclear Pipework	Total	Total for Three Boats
Pipes Scrapped	20.8%	£318,605	£1,854,895	£2,173,500	£6,520,501
Pipes Made Early and then Scrapped	8.6%	£131,731	£766,928	£898,659	£2,695,976

Figure 4.5 Astute Estimated Loss due to Discarded Pipes

As is evident from the projections above, if change is not made to the pipe manufacture process to reduce the amount of rework, the cost to the Astute project will be substantial. These numbers show that although pipes are not usually given a great deal of prominence in cost saving measures, they are in fact creating a great deal of hidden cost, and without change, this cost will continue to be extremely high.

4.4 Summary

As can be seen from the previous discussion, the original, very specific analysis went to a much broader overview of the pipe manufacturing process and incorporated the overall process in an attempt to improve the production of template pipes. This leads to the conclusion that although small improvements can be made to the template process, such as standardizing the method of lifting templates, larger measures will be required to bring significant improvement. Likewise, although the specific recommendations from this project address the pipe shop, this will only bring incremental change. Real improvement will only come through changing processes throughout the entire manufacturing change. These conclusions and recommendations, both specific and more general, are discussed in greater detail in the final chapter.

5 CONCLUSIONS AND RECOMMENDATIONS

This section covers both the conclusions reached regarding the pipe manufacturing process as well as recommendations for change. The suggested changes fall into two categories: specific changes to be implemented within the pipe shop, and more general recommendations for various areas across the business. The specific recommendations can be implemented relatively easily, while most of the more general recommendations will require further investigation and significant change, as they would impact a much wider scope than the changes within the pipe shop. However, the changes within the pipe shop can only lead to incremental improvement. In order to substantially improve the pipe manufacturing processes, the entire process, from design to installation, must be streamlined and more closely interlinked.

As discussed previously, many of the issues identified in this project had been previously summarized in an internal report published in February 2003. This report stated the following (taken from Document BA324A-0001-A, as listed in the References):

- Of the work packages being issued to the Pipeshop, a significant proportion of them could not be progressed by the shop because pipe materials and/or flanges and fittings were not available.
- Where materials were missing there was no information supplied with the work package from planning concerning the present availability or planned delivery of these materials.
- Generally the Planning Department does not appear to check or have available to it the status of materials for a particular work package when it issues that package to the Pipeshop for manufacture.
- There were a significant number of instances where pipes, required earlier than others, had no materials available, and the other later pipes had and could be progressed, albeit out of sequence.

All of these issues are nearly identical to the ones studied throughout this project. However, this internal report merely identified these problems; this research project intends to provide suggestions for change, in the following sections. The sections are divided into two areas; first, the changes to be applied to scheduling within the pipe shop are described, followed by the wider recommendations for change throughout the business.

5.1 Suggested Changes in the Pipe Shop

As discussed in previous chapters, the pipe shop makes a large fraction (approximately half) of the pipes more than two weeks in advance of the date for which they are requested (specific data on early vs. on time pipes is contained in Appendix 3) . The specific change recommended in the pipe shop is to slow down production so that fewer pipes are made early, which is a final goal of making pipes to match demand rather than making them in advance at all.

This would have several benefits. The most obvious of these it to reduce the amount of finished pipe inventory held in the pipe store. This inventory ties up a significant amount of free cash for the business, as discussed in the previous chapter (see Section 4.2). Although it is desirable to have a small amount of inventory to keep production supplied in any situation, this amount of inventory could be reduced significantly. The pipe shop has a capacity of up to 900 pipes a week; production workers estimate a maximum of 100 installed pipes per week per ship. Although the planned production demand may exceed 100 pipes a week, this is the maximum number of finished pipes that could actually be used by production in a specific week. Therefore, reducing the amount of inventory should not lead to pipe shortages on board the ship, irrespective of the stage of production and even in the case where three boats are under construction. The benefit will be a greater amount of free cash, as well as a greater degree of flexibility.

The next benefit of slowing pipe production to meet actual demand would be to make available the materials needed for template pipes (and other pipes) which are needed immediately for installation. As discussed in the previous chapter, template pipes are often delayed due to a lack of material. Slowing down production of pipes produced ahead of demand would result in the template materials being available a greater proportion of the time, as well as materials for other priority pipes. Given the long lead times on many of the materials used in pipe production, especially pipes for submarines, this change is essential in order to have these materials available for the pipes in demand for installation on board. Slowing production will smooth the manufacture of pipes which are actually needed while cutting down the pipes which are produced to stock.

Finally, perhaps the most important improvement resulting from producing pipes to match demand will be a reduction in the amount of rework. Although this cannot be conclusively proved, due to the lack of accurate data, it is an extremely likely outcome of reduced production. This is in agreement with the opinions of those involved directly in pipe manufacture, as well as making logical sense; pipes which are made early are subject to higher risk of corrosion, loss and becoming obsolete than pipes made when they are needed. Since the pipe shop has a greater capacity than demand, it will not slow down ship production, and it will serve to reduce inventory and improve pipe material availability. Therefore, this recommendation is still valid, although there is not a proven lower rate of rework in pipes made closer to demand. It is expected that this lower rate would be evident if the pipe data were better tracked; the unidentified rework discussed in the last chapter is a likely candidate for this rework.

Currently in the pipe shop, pipes are batched; if a pipe of a certain size is needed, all pipes needed in the near future for which materials are available are made at the same time. This is to reduce the amount of setup time; once a setup is performed for a particular pipe, batching eliminates the need to do the same setup again for any of the pipes in the batch. However, this method, while improving the efficiency with which each single pipe is manufactured (by reducing the proportion of setup time which is allotted to each pipe), leads to the overproduction of the pipes. In order to slow production, it is suggested batching be reduced. This could be accomplished by setting a threshold on the amount of time in advance a pipe is made; for example, pipes more than two weeks in advance of their requested date will not be included in batches. Although this will raise the amount of setup time on each pipe, it will lead to the benefits discussed above, as well as keeping the labor loads sufficient to prevent layoffs.

This idea is documented exactly in Ohno's description of the development of the Toyota Production System. In his words:

> Generally in a business, *what*, *when*, and *how many* are generated by the work planning section in the form of a work start plan, transfer plan, production order, or delivery order passed through the plant. When this system is used, "when" is set arbitrarily and people think it will be all right whether parts arrive on time or early. Managing parts made too early, however, means carrying a lot of intermediate workers. The word "just" in "just-in-time" means exactly that. If parts arrive anytime prior to their need – not at the precise time needed – waste cannot be eliminated. (29)

5.2 Suggested Areas of Improvement Outside of the Pipe Shop

As discussed in earlier chapters, the specific recommendations were limited to the pipe shop; these recommendations can be summarized as a reduction in early pipe production, to be implemented by decreasing batch sizes. However, this will result only in an incremental improvement. Throughout the study of the business, a number of issues in various departments were identified as more crucial areas for improvement. These span a large number of different parts of the pipe manufacture process, and range from relatively small modifications to major changes which would impact the business dramatically. All of these require additional investigation as to methods and ramifications. They are presented here mainly as future directions for this project.

5.2.1 Causes of Rework

The most obvious area of change resulting from this work is an improvement in the amount of pipe rework. There are a number of issues which have been identified through this study. Most clear is the amount of rework which has been passing through the system unidentified. This rework is between 15 and 20 percent of the total amount of pipes originally forecasted for each ship (where the forecast already includes a 10% rework rate); this is in addition to the 15 to 20 percent of rework which is traced. This unidentified rework makes improvement difficult, as these pipes are disappearing without notice, yet they represent a significant expense to the business.

Of equal importance as the unidentified rework are the overall levels of rework, both traced and untraced. Approximately a third of the total pipes needed for each ship are made twice. This is an incredibly high number; yet it is not clear why the levels of rework are so high. Further investigation to reduce the overall amount of pipe rework is suggested.

5.2.2 Planning Methods

It is well known throughout the business that the planning system does not accurately reflect the ongoing work. This ranges from drawing production, to the demand placed on the shops around the yard, to the installation on board the ship. Specifically, the demand placed on the pipe shop bears little resemblance to the pipes needed on board the ship, giving rise to priority lists and rushed pipes. This is part of the reason pipes are manufactured in advance; it is impossible to tell which pipes are the ones which will be needed.

In regard to template pipes, it has been suggested that template pipes be placed on separate work orders from pipes which are manufactured to isometric drawings. Although this could improve the scheduling of template pipes in particular, the overall demand for pipes placed in the pipe shop still needs to more accurately reflect the pipes needed in production. This could dramatically improve the pipe shop's ability to meet that demand without overproducing pipes and building up excessive amounts of finished pipe inventory.

Clearly, improved planning would streamline the entire process, but with regards to this project, it is the demand on the pipe shop which is more directly relevant.

5.2.3 Supply Chain

One of the major problems identified in the template pipe manufacture process was the lack of materials in the pipe shop. This applies to materials for all pipes made in the shop as well. An estimated 25% of the pipes in current demand at any given time on the shop cannot be made due to a lack of materials. Improved relationships with suppliers could possibly reduce lead times on these materials. The most effective way to improve these relationships would be to have a more accurate demand for these suppliers; this relates to the improvements in planning, specifically in drawing production, discussed in the previous section. Although vertical integration is not feasible, a more streamlined supply chain could lead to dramatic changes in material availability.

5.2.4 Design Freeze

A frequent cause of pipe rework was identified as engineering change requests (ECR). This is due to the constant revision and update of the ship design. This allows for the incorporation of design as well as technological improvements. However, although it may improve the model used to build the submarine and may result in a more technologically advanced ship, the cost and delays incurred by this process may not balance this improvement. Both the costs and delays are distributed all along the manufacturing process, impacting large numbers of different departments throughout the yard. An accurate estimate of either is correspondingly difficult to make. It may be worthwhile to estimate these costs to the business and to consider freezing the design at a predetermined stage. Although it may make it impossible to incorporate everything into the ship, it may save enough time and money to balance this lack. Clearly, although first an evaluation of the current situation is crucial, any decisions in this matter would have to include the Ministry of Defense, in order to reflect the priorities of the customer.

5.2.6 Performance Index (PI)

The Performance Index (PI) is a measure used throughout production to examine the effectiveness of a given department. However, in the case of the pipe shop, it appears that the use of the PI does not always provide incentive to the pipe shop to produce pipes which will then be installed on the ship correctly and in a timely manner. This is because the pipe shop is measured on the number of pipes made per time period, rather than the number of pipes made accurately or for use. This causes the pipe shop planners to pull work forward in order to keep the pipe shop busy; idleness would cause the PI to fall. However, this has several downsides. First, the pipe shop will keep making pipes far in advance of demand, in order to stay occupied. This causes overproduction and the growth of excess inventory. Additionally, the pipe shop will choose to make pipes which require less work over pipes which take more work, so that in that period, more pipes are made. This will then result in the pipe fitters having a great deal of straight lengths of pipe available, but not the curved branched pipes required to complete a system. By altering the PI to measure installed pipes, or completed systems, or some other measure which takes into account the use of the pipes, the pipe shop would have more incentive to produce effectively.

5.2.7 Integration across the business

In general, it appears that different areas of the business have little awareness or communication with other departments which do not directly affect their work. For example, the planning department which places demand on the pipe shop does not consult with the pipe shop to check the feasibility of the schedule they are providing. The integration drawing team does not have any awareness of how delays in their output affect the procurement department's ability to order materials in time for production. More communication between departments and more awareness of the impact of each teams' effect on processes upstream and downstream from them could lead to a more effective use of the resources available.

5.3 Evaluation of the Project

Evaluation of the project is not a straightforward process. At the project's inception, it involved the then-manager of the pipe shop and a BAE SYSTEMS corporate representative who did not work in the Barrow shipyard. Although both were interested in putting together an appropriate project, they did not have a clear idea of the results of the project. By the time of the project's completion, neither of these stakeholders had a direct connection to the results. As discussed in the organizational chapter, there were a number of other stakeholders in the project who would be affected by it; yet the majority of these did not have a strong interest in the project. Therefore, the objectives remained ambiguous.

However, the project did have some objectives which were met, even though they were not clearly defined. The project was intended to provide concrete recommendations to the pipe shop, which it did. It also was an evaluation of the entire pipe manufacture process, which was also accomplished. Perhaps the most specific requirement was a comparison of template lifting methods, which was one of the first tasks accomplished. From this perspective, the project was successful.

As a change process, the project may not be as successful. Although the findings have been presented in the channels most able to instigate change, it remains to be seen whether these changes will actually take place. A university-sponsored project is not the way to make change in this business; it must come from within. Although the wheels have been set in motion, only time will tell if the changes suggested are implemented. Additionally, many of the changes recommended will take a long time to examine and improve, and results cannot be expected immediately. Even if the results of the study are approved, change will be slow in coming.

Finally, the project has opened a number of new channels for investigation. Many of these are potentially high cost problems within the business, but will require a large degree of commitment to change. Yet merely the identification of these issues is a step in the right direction.

5.4 Conclusions

The submarine division of BAE SYSTEMS is a business which has faced a great deal of change in the past few years. The transition from a cost-plus method of payment, in which no expense was spared in the production of world class vessels, to the need to keep costs down in order to make the business profitable under fixed price development, is not an easy one. A great deal of change has already been put into place, but in order to make the business profitable, more change is required. Pipe production is often overlooked as an area in which transformations can improve the business dramatically. However, pipes are crucial to the production of any ship, and the conclusion of this study is that there is a great deal of unnecessary cost incurred in the manufacture of pipes. Delays in template pipe manufacture are a symptom of the breakdown of the pipe manufacture process. Although specific changes can be made to improve the production of template pipes, real change can only come by taking a broader view of the importance of pipes in the construction of submarines. By improving this area of the production process, significant savings can be made for the entire business. This will lead to improved profitability and a more stable future for the Barrow shipyard.

REFERENCES

ASM Handbook, Tenth Edition. Volume 1: Properties and Selection: Irons, Steels, and High Performance Alloys. Materials Park, OH: ASM International, 1990.

ASM Handbook, Tenth Edition. Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials. Materials Park, OH: ASM International, 1990.

Dul, Paul. "Application of Cellular Manufacturing to Low Volume Industries." Masters thesis, Leaders for Manufacturing, MIT, 1994.

Goldratt, Eliyahu M. and Cox, Jeff. *The Goal.* Croton-on-Hudson, NY: North River Press, 1984.

Mendenhall, William, Beaver, Robert J., Beaver, Barbara M. *Introduction to Probability and Statistics.* Pacific Grove: Duxbury Press, 1999.

Ohno, Taiichi. *Toyota Production System: Beyond Large-Scale Production.* Cambridge: Productivity Press, 1988.

Porter, Michael E. and Ketels, Christian H.M. "U.K. Competitiveness: Moving to the Next Stage." DTI Economics Paper No.3. Economic and Social Research Council: May 2003.

Shipbuilders and Shiprepairers Association. "BAE Systems Marine Ltd, Barrow SSA Masterclass – Pipework Assessment Report (BA324A-0001-A)". Newcastle upon Tyne, England: Appledore International Limited, February 2003.

Verne, Jules. *20,000 Leagues Under the Sea.* Trans. Walter James Miller and Fredrick Paul Walter. Annapolis, Maryland: Naval Institute Press, 1993.

Womack, James P., Jones, Daniel T. *Lean Thinking.* New York: Simon and Schuster, 1996.

Informational Interview:
John Gullotti, Electric Boat

APPENDIX 1: TEMPLATE DATA

In order to compare the rework levels, the days in manufacture, and the number of manhours required for each type of template pipe (hard templates, wire templates, and FARO templates), statistical tests were used to compare the types in pairs. All of the template data available for the two LPD ships were used to calculate these values, so large sample (normal) approximations were used. This is due to the fact that each population used was well over thirty (the smallest was over 200 pipes). The data from this sample was assumed to be representative of the entire population of template pipes (across projects). Therefore, the test results were interpreted to be predictive for the entire population.

The test used to compare the rework levels of the template pipes was the test for difference in proportions. This test uses the following formula to calculate the z-value used:

$$z = \frac{(p_1 - p_2)}{\sqrt{[(p(1-p)/(n_1-1)) + (p(1-p)/(n_2-1))]}}$$

where z is the test statistic, p_1 and p_2 are the population proportions, n_1 and n_2 are the population sizes, and p is a weighted average of the two proportions, calculated according to the following formula:

$$p = \frac{(p_1 n_1 + p_2 n_2)}{(n_1 + n_2)}$$

The test used to compare the average days in manufacture and the average manhours required was the large scale sample test of hypothesis for the difference between two population means (see Mendenhall 355). The formula used to calculate the z-value in this test was the following:

$$z = \frac{(x_1 - x_2) - D_0}{\sqrt{((\sigma_1^2/n_1) + (\sigma_2^2/n_2))}}$$

where z is the test statistic, x_1 and x_2 are the population means, σ_1^2 and σ_2^2 are the population variances, D_0 is the hypothetical difference between the two populations, and n_1 and n_2 are the population sizes. The null hypothesis in each test was that there was no difference between the two populations; therefore D_0 was set to zero in each case. The significance level used was 95%; this led to a z-value for comparison of 1.96.

The z-values were calculated from the following data:

	Rework Percentage	Days in Manufacture			Manhours Required			Sample Size
		Mean	Std. Dev.	Variance	Mean	Std. Dev.	Variance	
Hard Template	7.07%	22.6	34.2	1172.0	18.2	16.5	273.6	239
Wire Template	8.23%	12.9	19.9	395.5	6.3	14.8	219.7	571
FARO Template	8.37%	19.5	31.6	996.7	10.5	13.6	185.3	934

The z- values for each combination were as follows:

Hard vs. Wire	Rework	0.56
	Days in Manufacture	4.09
	Manhours	9.60
Hard vs. FARO	Rework	0.66
	Days in Manufacture	1.26
	Manhours	6.61
Wire vs. FARO	Rework	0.10
	Days in Manufacture	4.97
	Manhours	3.97

As discussed in the text, none of the rework z-values are significant. However, all of the values for the days in manufacture and the manhours are significant, except the difference in days in manufacture between hard templates and FARO templates. These significant values indicate that in these cases the null hypothesis is not accurate and there is a statistically significant difference in the template types; the only exception is the test for the difference in the days in manufacture between hard templates and FARO templates. These results are examined in detail in Chapter 4.

APPENDIX 2: MATERIALS USED IN PIPE MANUFACTURE

This appendix lists some information, properties and uses of the primary metals used in pipe fabrication. These metals are steel, stainless steel, and two different copper nickel alloys. As mentioned in the text, all of these materials are extremely different, and dues to their weights, magnetic properties, and costs, it would be unrealistic to combine or substitute them for each other, even though it could potentially lead to smoother supply chain management and material flow through the pipe shop. All of the data in this appendix was taken from the ASM Metals Handbook, Volumes 1 and 2, listed in the References.

Steel: The primary steel used in pipe fabrication is BS (British Standard) 3601, low carbon steel. This steel is closest in composition to SAE grade 1013. The composition of this steel is as follows; by percent weight, C: .17, Si: .35, Mn: .40-.80, P: .045. S: .045. The tube used in the pipe shop is formed using electric resistance welding (ERW), which means the pipes have a seam, but are less expensive than pipes made using seamless methods. Steel pipes are used throughout the boat, in many of the auxiliary systems, for sea water, and in the steam generator.

Copper-Nickel Alloys: Both kinds of CuNi tube are typically used in applications such as condensers, condenser plates, distiller tubes, evaporator and hear exchanger tubes, and saltwater piping. The details of each alloy are listed below.

> **70Cu-30Ni:** The composition of this alloy is as follows: in percent weight: 0.05 Pb max, 0.4-0.7 Fe max, 1.0 Zn max, 29-33 Ni, 1.0 Mn max, 0.5 max other, balance Cu. Pipes made from this alloy are used primarily for high pressure pipes.
>
> **90Cu-10Ni:** The composition of this alloy is as follows: in percent weight: .05 Pb max, 1-1.8 Fe max, 1.0 Zn max, 9-11 Ni, 1.0Mn max, 0.5 max other, balance Cu. Pipes made from this alloy are used for primarily for pumping hydraulic fluid and for cooling systems.

APPENDIX 3: LPD PIPE DATA: COMPARISON OF EARLY AND ON-TIME PIPE REWORK LEVELS

As discussed in the text, the initial assumption made about pipe manufacture and scheduling was that pipes manufactured early would have higher levels of rework, due to a greater likelihood of design changes, loss, corrosion, and other factors affecting early pipes differently than on-line pipes. In order to investigate this hypothesis, data was collected in order to compare the pipes made early to the pipes made on time. This data was taken from the two LPD ships; both the individual data for the two ships and the totals are shown below.

	LPD 01	LPD02	Total
All Pipes Made	20777	20847	41624
Pipes Made more than Two Weeks Early	9469	10105	19574
Percentage of All Pipes Made Early	45.6%	48.5%	47.0%

Pipes Made on First Demand (Not Rework)	16826	16619	33445
Pipes Made Early on First Demand	7472	8088	15560
Percentage of Early First Demand Pipes	44.4%	48.7%	46.5%

Rework on First Demand Pipes (Tracked)	5053	2340	7393
Percentage of First Demand Pipes Reworked	30.0%	14.1%	22.1%
Early Pipes	2195	1031	3226
Percentage of Early Pipes Reworked	29.4%	12.7%	20.7%
On-Time Pipes	2858	1390	4248
Percentage of On Time Pipes Reworked	30.6%	16.3%	23.8%
Total Rework Level (Tracked):	24.32%	11.22%	17.8%

As can be seen from this data, approximately half of all pipes made were made at least two weeks earlier than scheduled. The first conclusion drawn from these calculations was that the hypothesis had not been proved: on LPD01, the rework levels on early and on-time pipes are nearly identical, while on LPD02, the rework levels of early pipes are actually substantially lower than the rework levels of on time pipes.

However, this data, which was pulled directly from the database of the pipe shop, shows a great deal of inconsistency, which was the first inkling that pipe rework levels were not being tracked accurately. The totals of first demand pipes and rework pipes do not add up to the total pipes made. In the case of LPD01, the sum of the first demand pipes and the rework pipes is over a thousand pipes more than the total number of pipes declared to be made for the project! And in the case of LPD02, the sum of the two kinds of pipes is nearly two thousand pipes less than the total number tracked to that ship. Overall, for both ships, there is a discrepancy of approximately 1,000 pipes between the "total" made, and the sum of the rework and the first demand pipes.

The next step was to investigate the reporting of the pipe data; the results of this search are presented in the next appendix.

APPENDIX 4: LPD OVERALL REWORK CALCULATIONS

Once it became apparent how much of the pipe data was missing, inaccurate, or inconsistent, an investigation was begun to examine the total number of pipes made as compared to the total needed in the design. Additionally, the number of pipes tracked as rework in the database, as compared with the number of pipes made above the designed number (which was the actual number of rework pipes) was calculated.

The following table compares the number of pipes designed and included in the contract budget, the total pipes actually made, and the discrepancies between the two. Additionally, the difference between the rework which was tracked and the rework which was not is shown. The data was collected for each LPD ship, and is aggregated into a total number.

	LPD01	LPD02	Total
Number of Pipes in Design	15890	15890	31780
Original Budget of Manhours	74924	74924	149848
Hours per Pipe allocated	4.7	4.7	4.7
Total Pipes Made	21208	21065	42273
Total Manhours Used	110994.5	89168.2	200162.7
Hours per Pipe Averaged	5.2	4.2	4.7
Total Pipes Tracked as Rework	2768	2959	5727
Difference between Design and Actual	5318	5175	10493
Extra Pipes not Tracked as Rework	2550	2216	4766
Percentage of Rework (Percentage of Pipes made over designed number)	33.5%	32.6%	33.0%
Percentage of Rework Tracked	17.4%	18.6%	18.0%
Percentage of Rework Untracked	16.0%	13.9%	15.0%

As can be seen from the percentages, on average, a third of the pipes are remade on each ship. Additionally, just under half of these rework pipes are untracked. These untracked pipes could substantially change the analysis in the last Appendix; however, since they were unrecorded, this data is not available. These missing pipes also lead to large expenses which are unidentified on the contract. These percentages are applied to the Astute design and budget to project the expected expense to the Astute contract if these levels of rework are maintained. This calculation appears in the next Appendix.

In addition to the pipes which are reworked, the number of pipes which were fabricated and then discarded for the LPD ships was examined. This route was chosen because, unlike the rework pipes, which were not properly tracked, these pipes were thrown away. A summary of this data appears below:

	LPD01	LPD02	Total	Early LPD01	Early LPD02	Early Total
Total Pipes Discarded	3312	3350	6662	1361	1350	2711
Manhours used on Discarded Pipes	15873.91	15989.7	31863.61	2271.05	4253.84	6524.89
Materials Cost of Discarded Pipes	£207,591	£189,149	396739.907	£21,785	£56,353	£78,138
Manhours Cost on Discarded Pipes (at £20/hour)	£317,478	£319,794	637272.2	£45,421	£85,077	£130,498
Total of Materials and Manhour Cost	£525,069	£508,943	1034012.11	£67,206	£141,430	£208,636

For these pipes, the material cost and the amount of labor used was available and is included here. This gives an idea of the cost of the pipes which were thrown away on each boat. The labor rate of £20/hour is an estimate of the actual rate; it is not the actual rate, but is used to demonstrate the magnitude of the costs. The early totals refer to a subgroup of the pipes which were made more than two weeks early and then thrown away; this is provided to give an idea of the number of pipes which could be potentially saved by delaying production of early pipes.

As with the rework pipes, the percentage of pipes discarded out of the total pipes in the design is calculated and is used to project costs to the Astute contract if the levels of discarded pipes remain the same. This information is included in the next Appendix.

APPENDIX 5: ASTUTE DATA PROJECTIONS

In order to project the cost of current levels of rework and discarded pipes on the Astute contract, a certain number of base numbers were used. The number of nuclear and non-nuclear pipes were taken from the Astute budget allocations. The average material costs and manhours per pipe were calculated from the average values on pipes made for the contract thus far. These values are summarized below:

Total Nuclear Pipes per Boat	1142
Total Non-Nuclear Pipes Per Boat	18021
Average Hours per Nuclear Pipe	52.14
Average Hours per Non-Nuclear Pipe	11.68
Average Material Value for Nuclear Pipes	£298.02
Average Material Value for Non-Nuclear Pipes	£261.24
Manhour Rate	£20/hr

These values were combined with the percentages calculated from the historical LPD data to project numbers of pipes reworked and discarded, as well as associated costs for the Astute project. The manhour rate of £20/hr is an estimate, used to project the costs to the business; a more accurate estimate would require the actual manhour overhead rate. The following summarizes the rework levels, discarded pipes, and costs:

Nuclear Pipework

	Percentage used in Estimate	Pipes	Hours	Cost of Materials	Labor Cost (£20/hr)	Total	Total for Three Boats
Rework	17.4%	199	10364.26	£59,240	£207,285	£266,526	£799,577
Unaccounted Pipes	16.0%	183	9530.36	£54,474	£190,607	£245,081	£735,243
Total Rework	33.4%	382	19895	£113,714	£397,892	£511,607	£1,534,820
Pipes Scrapped	20.8%	238	12389.47	£70,816	£247,789	£318,605	£955,816
Pipes Made Early and then Scrapped	8.6%	98	5122.57	£29,280	£102,451	£131,731	£395,193

Non-Nuclear Pipework

	Percentage used in Estimate	Pipes	Hours	Cost of Materials	Labor Cost (£20/hr)	Total	Total for Three Boats
Rework	17.4%	3136	36626	£819,178	£732,513	£1,551,691	£4,655,073
Unaccounted Pipes	16.0%	2883	33679	£753,267	£673,575	£1,426,842	£4,280,527
Total Rework	33.4%	6019	70304	£1,572,445	£1,406,088	£2,978,533	£8,935,599
Pipes Scrapped	20.8%	3748	43782	£979,247	£875,648	£1,854,895	£5,564,685
Pipes Made Early and then Scrapped	8.6%	1550	18102	£404,881	£362,047	£766,928	£2,300,783

Total Astute Pipework

	Percentage used in Estimate	Pipes	Hours	Cost of Materials	Cost at £20/hr	Total	Total for Three Boats
Rework	17.4%	3335	46990	£878,418	£939,798	£1,818,217	£5,454,650
Unaccounted Pipes	16.0%	3066	43209	£807,741	£864,182	£1,671,923	£5,015,770
Total Rework	33.4%	6401	90199	£1,686,159	£1,803,981	£3,490,140	£10,470,420
Pipes Scrapped	20.8%	3986	56172	£1,050,063	£1,123,437	£2,173,500	£6,520,501
Pipes Made Early and then Scrapped	8.6%	1648	23225	£434,161	£464,498	£898,659	£2,695,976