NAVAL POSTGRADUATE SCHOOL
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THESIS

**AGENT-BASED SIMULATION SYSTEM:
A DEMONSTRATION OF THE ADVANTAGES OF AN ELECTRONIC EMPLOYMENT MARKET IN A LARGE MILITARY ORGANIZATION**

by

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The Navy Personnel Command assigns over 100,000 Sailors annually utilizing in excess of 200 Detailers. This process is typically done manually between Sailor and Detailer. Navy Personnel Research Studies and Technology (NPRST), together with NPS, have begun a series of studies to optimize this process through the use of an Agent-Based Employment Market System. To assist in the validation of the Agent-Based System, this thesis seeks to design a simulation program as a demonstration of the possibilities and potential advantages of an Agent-Based Electronic Employment Market. Research includes conducting a review of the current personnel detailing process in the Navy, coding a simulation program, and running various detailing scenarios. The simulation results indicated there are potential advantages of an Agent-Based Employment Market System to detailing in the Navy.

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A DEMONSTRATION OF THE ADVANTAGES OF AN ELECTRONIC EMPLOYMENT MARKET IN A LARGE MILITARY ORGANIZATION

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I. INTRODUCTION

A. BACKGROUND

In 1999, in conjunction with the Secretary of the Navy's Revolution in Business Affairs initiative, the Recruiting, Retention, Training and Assignment working group recommended that the Navy's enlisted distribution and assignment processes be reengineered. CNP directed establishing a Distribution Reengineering Action Team, chaired by PERS-4. During five two-week sessions in 1999, the team reviewed the existing (As Is) process and identified opportunity areas where near term/low cost improvements could be made. These improvements included eliminating the Enlisted Navy Career Options for Reenlistment (ENCORE) program, establishing the Guaranteed Assignment Retention Detailing (GUARD) 2000 program, enhancing enlisted placement and eliminating duplicitous and conflicting policies. Remaining recommendations were deferred for inclusion in the future process or determined to be beyond existing process capabilities. The team next developed concepts for the future distribution process. The goals for the process were to work toward a user-friendly process that would provide enhanced quality of life for sailors and significantly improve force readiness, using advanced, deliberation-capable intelligent software agents operating in a web based "market place" environment, representing the full interests of our sailors and Navy commands.

The future concepts included a sailor Production process (seeing the prospective recruit from recruiting station to first "full duty" assignment); better defined career paths (establishing reasonable career expectations, an apprentice/journeyman/master approach and potential pay banding); vacancy driven distribution based on deployment cycles; customer focused (both sailor/Command through the use of intelligent software agents); and a credit or point system (coupled with scalable incentives) that rewards those sailors who take the more arduous assignments and perform well.

Keys to the success of a new process lie in the Navy/ Marine Corps Intranet, continued research and development involving both deliberation-capable intelligent software agents (ongoing at University of Memphis) and a web-based "marketplace" environment (work being done by Naval Post Graduate School), and developing a sound change management plan. Navy Personnel Research Studies and Technology (NPRST), together with NPS, have begun a series of studies into the web-based "marketplace" environment, comprising study of the current system through both Activity Based Costing and stakeholders/process analysis and an initial development of matching algorithms for an Intelligent Agent-Based Detailing Process.

The interest of this thesis is to assist in validating the Intelligent Agent-Based Electronic Employment Market through simulations. A simulation software called Agent-Based Employment Market Simulator (ABEMS) was written using Excel Basic. ABEMS was programmed to allow the researchers to generate random profile datasets of sailors and requisition billets according to user-specified discrete distributions. ABEMS then matches the sailors to billets using the 2-sided matching algorithm. Various scenarios were explored using ABEMS, including varying the intervals between matching, and varying the length of the preference lists for the individual sailors and commands. Using a two-week interval with preference length of 5, we could emulate the "perfect" human detailer in assigning sailors to billets using ABEMS under the current detailing process to a certain degree. However, it is likely that actual human detailers may not be able to consistently match the quality and quantity of matching from ABEMS due to human errors and fatigue (especially in longer intervals with larger data pools). A related thesis study titled "Designing Economics Experiments to Demonstrate the Advantages of an Electronic Employment Market in a Large Military Organization" by MAJ Tan and MAJ Yeong covers the human experiments in detail (Reference No 3).

To ensure ABEMS will take into consideration the concerns and considerations of the sailors and commands, a study was done on the current detailing process. Measures of fit were determined between the sailors and the organization. Common modes of matching people with jobs were also analyzed for their potential benefits and possible areas of applicability to the Agent-Based System. Due to the unique nature and restrictions of a military organization, it was often found that we need to customize these modes of matching to our needs, and this presented both interesting and challenging prospects to this thesis. We also drew on economic models to predict the actions and choices of both the sailors and the organization, assuming that the parties will always choose to maximize their own benefits, thereby forming the 2-sided matching logic of ABEMS. The individual sailors and commands are modeled using the Cobb Douglas utility function, each with their own unique set of characteristics and preferences.

B. PURPOSE

This thesis will primarily deal with designing and programming a simulation software and using the software to run various scenarios to demonstrate the potential benefits of an Agent-Based Employment Market System.

C. RESEARCH QUESTIONS

1. Primary Research Question

How will an agent-based simulation model demonstrate the advantages of an electronic employment market?

2. Subsidiary Research Questions

How does the personnel detailing process work in the USN? What are the primary limitations of this process, and how do these limitations affect job assignments?

How can an agent-based electronic market help optimize job matching?

What simulation models are suitable for demonstrating the potential advantages of an agent-based employment market in a military environment?

How long are the ideal intervals between matching? How will preference lengths affect the outcome on the quality and quantity of matches made?

What are the potential benefits of implementing such a program?

Are there potential benefits from having a longer period between matching than the current 2 week process? If so, what are the required conditions?

D. SCOPE AND METHODOLOGY

The scope of the study includes:

- Review the Navy's job assignment process,
- Study the limitations, if any, for the current job assignment process,
- Conceptualize the framework for the simulation model,
- Design and program a suitable simulation software (ABEMS),
- Investigate matching scenarios,
- Analyze the simulation results from the scenarios to determine important variables that affect the quality and quantity of matching, and
- Identify potential benefits from using an Agent-Based Market System, and
- Recommend enhancements to the model.

A systemic methodology is adopted for this thesis research, comprising a literature search of books, magazine articles, CD-ROM systems, and other library information resources for related information, review of the current job matching practices in the civilian market, and augmenting our understanding of the current USN's job assignment/detailing process.

This is followed by identifying and prioritizing the limitations of the current USN's job assignment/detailing process, reviewing the information technology available now and in the foreseeable future that will facilitate implementing such a system, developing the process required for the simulation model, preparing a target proposal for the simulation model, preparing modules network diagrams, developing a programming code for the model, identifying the parameters to be used for preliminary model testing and conducting beta testing.

The finalized simulation program is then used under various scenarios to investigate the effects of having different variables such as longer intervals between matching and longer preference lengths. The results are tabulated and charted to identify possible benefits in quality and quantity of matching of an Agent-Based Employment Market System, and the conditions for such benefits to be feasible.

E. EXPECTED BENEFITS OF THE STUDY

This thesis is part of the overall framework of studies concerned with revolutionizing the detailing process from the present manual system to an Agent-Based Employment Market System. It will provide validation to the Agent-Based System by allowing us to run scenarios through ABEMS. Comparing the benefits and limitations from the simulations will provide us with a better understanding of the potential benefits of an Agent-Based System.

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II. BACKGROUND - OVERVIEW OF THE EMPLOYMENT MARKETS

A. LABOR MARKET ECONOMICS

Market-based approaches to employee/employer matching rely on the interaction of labor demand and supply, and what is now textbook understanding of labor market economics (Ehrenberg and Smith 1997). On the demand side of the labor market are employers; while on the supply side of the market are workers and potential workers. The forces of demand and supply heavily influence the wage that prevails in a particular labor market.

The demand curve is typically downward sloping. Firms typically combine various factors of production - mainly capital and labor - to produce goods or services that are sold in a product market. Their total output and the combination of capital and labor depend on three forces - product demand, the amount of labor and capital they can acquire at given prices, and the choice of technologies available to them. When the wage is high, it is likely that the potential return per dollar invested in capital is higher than labor. The firm will continue to invest more in capital than labor until the equilibrium in return per dollar invested is reached. Thus at one end, high wages typically correspond to lower labor demand. On the other hand, should the wage be cheaper, the potential return per dollar invested in labor will yield higher return than capital. The logical firm will then invest more in labor, and less in capital. Thus lower wages will usually result in higher demand for labor. The market demand curve indicates how many workers the firm will be willing to hire at each wage level, holding all other variables (such as capital costs) constant.[1]

[1] It is important to distinguish between a *shift* in a demand curve and *movement along* a curve. When the *wage* changes and other forces are held constant, one *moves along* the curve. However, when one of the *other forces* changes, the labor demand curve *shifts*. For example, if the cost of capital decreases, the substitution effect will cause the labor demand curve to shift left, i.e. overall lowered demand for labor at any given wage rate. On the other hand, lower capital costs could also result in lower product pricing,

The labor supply curve is usually upward sloping. If the wages in the other occupations are held constant, and the wages in our study market rise, we expect more people to be willing to enter this market as their opportunity costs of not joining this market becomes higher due to the relative improvement in compensation. Therefore, when the wages are low, we expect to see a low labor supply (these are the enthusiastic people who really enjoy working in this particular environment), while high wages will usually result in a high labor supply (these are the people attracted to join the market due to better compensation relative to their other choices). The market supply curve indicates how many workers would enter the market at each wage level, holding the wages in other occupations constant.

The point where the labor demand and supply curve intersect is known as the *market-clearing wage* or *market equilibrium wage*. Figure 1 illustrates labor demand and supply curves for a representative labor market. The wage rate in this market tends towards its equilibrium value denoted by W*. The quantity of labor that employers are willing to hire at this wage rate exactly equals the quantity of labor that employees willingly supply (L*). Anyone that wants to work in the industry can find sufficient work and any firm that wants to hire employees can find adequate employees.

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thereby leading to higher demand. This scaling effect could potentially shift the labor demand curve right, i.e. higher demand for labor at any given wage point. How the demand curve shifts will depend on the juxtaposition of these two market forces.

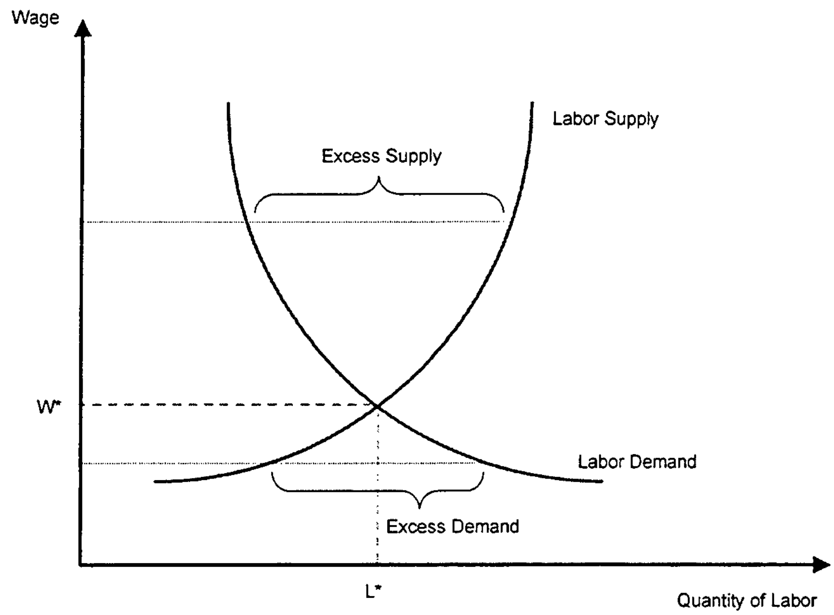


Figure 1: Market-Based Labor Markets (From: Gates and Nissen, 2001)

If the wage rate is below the equilibrium W*, the quantity of labor demanded will *exceed* the quantity supplied. At this point, employers will be competing for the few workers in the market and a shortage of workers will exist. The desire of the firms to attract more employees would lead them to increase their wage offers, thus driving up the overall level of wage offers in the market (upward pressure on wage rate towards W*).

As the wage rises, two things will happen. First, more workers will choose to enter the market and look for jobs (a movement upwards to the right along the supply curve), and second, increasing wages would induce employers to seek fewer workers (movement upwards to the left along the demand curve). If wages rise over W*, the quantity of labor supplied will exceed the quantity demanded. Employers will desire fewer workers than the numbers available. This will result in excess in supply. Employers soon realize that they can fill their positions with lower wages as eager applicants look for jobs. Some will be happy to accept the jobs at the lower wage points, while others will leave the market (thereby movement downwards along the supply curve). Again, the forces of the market will tend to drive the wage towards the equilibrium wage W*.

A subtle but important aspect of equilibrium wage rates involves job amenities, such as work environment, geographic location, commute, promotion potential, work content/challenge, job satisfaction, etc. In weighing employment benefits in one industry relative to alternative time uses (leisure and other jobs), job amenities are important considerations. If job amenities are particularly attractive in one industry, individuals will supply labor to that industry at relatively low wage rates; if job amenities are unpleasant, labor is only supplied at relatively high wage rates (Ehrenberg and Smith 1997). This is referred to as *compensating wage differentials*. For example, an engineer is likely to be paid more if he is required to perform arduous field work in third world countries versus his counterpart with the same qualifications in a comfortable office close to home. Holding other characteristics constant, individuals willing to work in an industry for relatively low wages either derive high utility from agreeable job amenities (e.g. flexible hours for a home care provider with children), or are relatively weakly deterred by objectionable job amenities (e.g. a fit young adventurous employee working as a forest ranger).

Market-based labor markets balance demand and supply, ensuring equality between the quantities of labor demanded and supplied. To operate efficiently, employees must have complete information about relevant job characteristics and opportunities, including salary, benefits and job amenities. To mimic the results of market-based labor markets, alternative labor market mechanisms must both balance demand and supply, and promote demand and supply efficiencies. To ensure demand and supply efficiency, labor assignments must reflect labor's relative value in alternative uses, employee capabilities and job preferences.

With regards to labor assignments, there are currently two modes prevailing in the matching people with jobs: 1) hierarchical planning and 2) distributed markets. Each has strengths and limitations, which will be discussed in the following sections.

1. Hierarchical Labor Market

Hierarchical labor markets assign individuals to jobs using a centralized process. Such assignments rely on administrative procedures to match individual capabilities and job requirements and to reflect both the job's relative priority and the individual's job preferences. There is no mechanism to automatically strike a balance between supply and demand efficiencies, as in market-based labor markets. At one extreme, employers can assign individuals to jobs with little regard to personal preferences. Employees can either accept the assignment or find another alternative occupation. This approach emphasizes the employer's performance (demand efficiency) at the expense of employee morale (supply efficiency). At the other extreme, employers can emphasize individual job preferences relative to job priority and the match between employee skills and job requirements. This emphasizes employee morale at the expense of employer performance. Criticisms against hierarchical labor markets concern their inability to ensure demand and supply efficiencies, inherent equilibrium conditions in market-based labor markets. This inability reflects both information requirements and asymmetric incentives (profits vs. morale).

Demand and supply efficiencies are particularly important for closed systems with a constrained labor supply. In the military, wages are uniform across jobs requiring similar skills and experience (no compensating wages). As a result, the cost of assigning labor to one use is the loss of output in the best alternative unfilled use for that labor (opportunity cost); salaries and benefits are irrelevant in measuring labor costs. If labor assignments don't maximize demand and supply efficiencies, the system wastes resources by applying them to less valuable jobs, and reduces job satisfaction, morale and retention, by assigning labor to jobs that are relatively less desirable with no compensating wage differential.

The Department of Navy (DoN) uses a centralized, hierarchical labor market to match enlisted sailors to jobs. On the demand side, Navy commands identify open positions. Job vacancies are compared to projections of available personnel. Typically, the number of positions to be filled exceeds the supply of available personnel. Therefore, the Navy develops a Navy Manning Plan (NMP) that spreads the labor shortage across all commands, on a "fair-share" basis. The Navy then prioritizes job vacancies based on each command's mission, current staffing levels, and several other relevant characteristics. This process attempts to distinguish between high and low valued demands for labor, to mimic demand efficiency in market-based economy.

On the supply side, available personnel are categorized according to their qualifications (ratings), including skills, experience, education/training, career path, etc. Similar skill groups are arranged in communities (e.g. electronics, supply, machinists). Each community has a detailer charged with matching personnel to jobs. Sailors seeking job assignments can express their personal preferences to the detailer. The detailer is responsive to job vacancy priority ratings, but there is some room for discretion in tailoring job assignments to meet the sailors' personal preferences (supply efficiency). Supply efficiency is subordinate to demand efficiency in this process.

DoN's hierarchical labor market is further complicated because enlisted sailors change jobs every two to three years. Thus, the centralized detailing process reassigns between one third and one half and one half of the enlisted force every year. This adds a time dimension to this process that is more critical than in typical civilian markets. The Navy begins identifying job vacancies and available personnel as early as nine months in advance. Time also affects the job vacancy priority rating. More imminent vacancies receive a higher priority than similar but more distant vacancies.

DoN fills billets (i.e. jobs) according to a predetermined priority ranking until the labor supply is exhausted, and demand efficiency is emphasized over supply efficiency. In market-based labor markets, equilibrium wage rates automatically performs functions; wages adjust until there is no excess supply or demand for labor, and employees voluntarily choose their preferred job, considering both relative wages (compensating wage rates) and job amenities. In DoN's hierarchical labor market, wage rates do not increase to limit the demand for labor to the available supply, so commanders are frustrated they can't fill vacant positions. Similarly, wages do not adjust across job assignments to account for job amenities, and assignments do not fully incorporate the sailor's job preferences. Predictably, both commanders and enlisted sailors voice dissatisfaction with the current hierarchical labor market.

2. Distributed Markets: Two-Sided Matching Markets

The market-based approach supports unrestricted, point-to-point matching between potential employees and outside employers. In this scenario, the potential for problematic information overload can be high, and employee turnover incessant.

Unlike fast-paced IT firms in Silicon Valley, wage rates for military personnel are set by fiat and adjust very slowly to supply- or demand-driven pressures. At least in the short term, DoN cannot rely on spot labor markets for filling its key jobs with qualified people. Indeed, without its current, hierarchical detailing system, the Navy would find it very difficult to fill many of its important jobs. Yet the Navy could also benefit from the efficiencies associated with market-based systems. A two-sided matching market assigns individuals to jobs when there are several possible employers and employees. The matching algorithm balances the employers' and employees' preferences, but it can produce assignments that give priority to either employers or employees. As such, the algorithm specifically addresses both demand and supply efficiency. Unlike hierarchical systems, matching markets balance both employers' and employees' preferences. This effectively matches job requirements and employee capabilities, and systematically helps obviate many supply side problems, including employee dissatisfaction, low morale and retention. This improves both demand and supply efficiency relative to hierarchical labor markets.

Two-sided matching markets also are responsive enough to keep pace with the extreme periodic job rotations effected routinely by the Navy. But such matching markets lack the automatic dynamic response of market-based systems, and the opportunity for side agreements that circumvent the system can be administratively cumbersome. Unlike market-based systems, two sided matching markets provide some centralized control through the clearinghouse, and periodic matching can dampen the high rates of employee turnover now experienced in high technology industries.

The balance between demand and supply preferences depend on the matching algorithm. It is important that the matching process recognize job priorities, a function performed by detailers in DoN's hierarchical process.

In our thesis, our focus will primarily be on designing a suitable simulation model that can demonstrate the differences between current systems and agent based two-sided matching systems. These results would be used for analysis and evaluation of the potential benefits and limitations of the applicability of using two-sided matching in the DoN.

B. OVERVIEW OF THE CURRENT NAVY ENLISTED DETAILING PROCESS

1. Organization Structure

The Navy's Manpower, Personnel, and Training processes include Manpower Requirements, Manpower Programming, Personnel Planning and Personnel Distribution. This thesis will concentrate on the Personnel Distribution process, specifically the Enlisted Distribution System (EDS). The EDS consists of a distribution triad: allocation, placement, and assignment, as depicted in Figure 2 below.

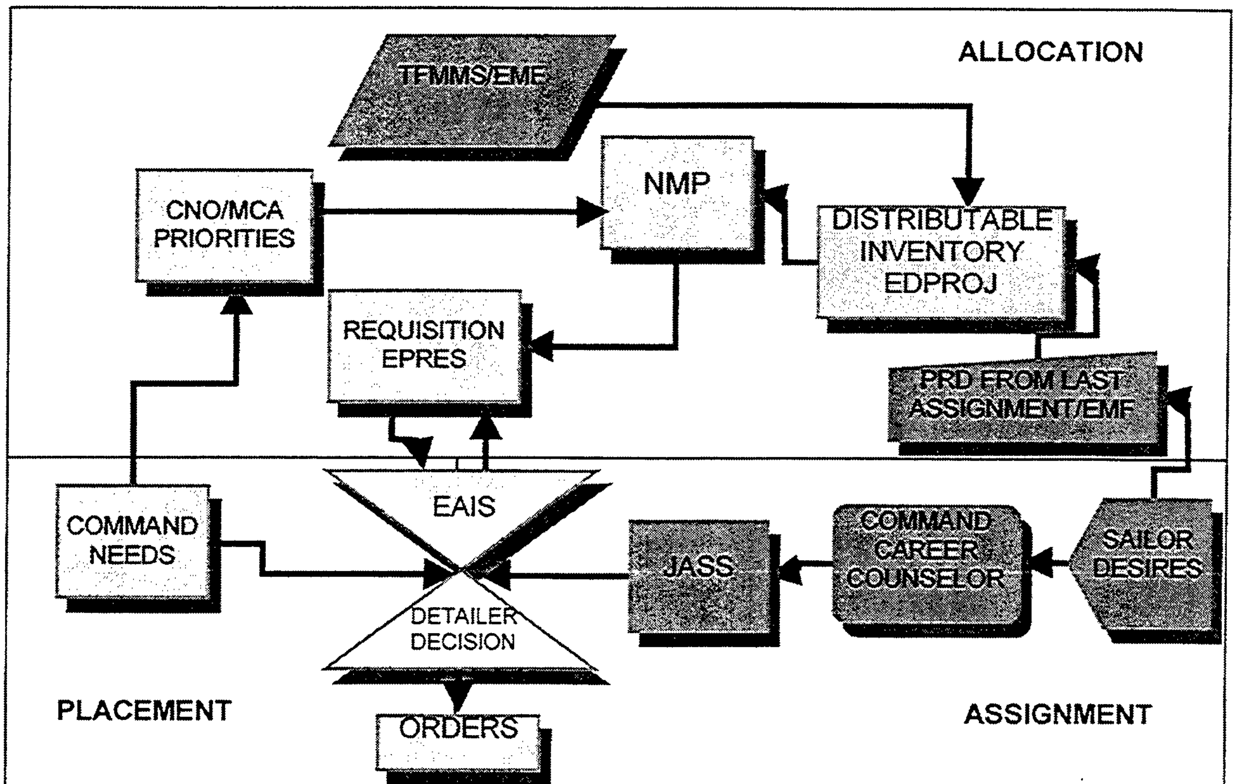


Figure 2: Manpower, Personnel, & Training PowerPoint Brief (From CDR Bill Hatch, 16 May 2000)

The overall distribution goal is to ensure what is commonly referred to as the "four rights" or "R^4:" the right Sailor with the right training occupying the right billet at the right time. The focus in this thesis will be on the assignment process within the distribution triad, which is commonly called "detailing," for active duty enlisted Sailors.

The allocation process initially separates distributable and non-distributable personnel inventory. Distributable inventory includes everyone who is not a student or in a Transient, Patient, Prisoner, or Holdee (TPPH) status. Students also referred to as Awaiting Instruction (AI) and TPPH personnel are non-distributable and are included in the Individuals Account (IA). This process is depicted as Figure 3 below.

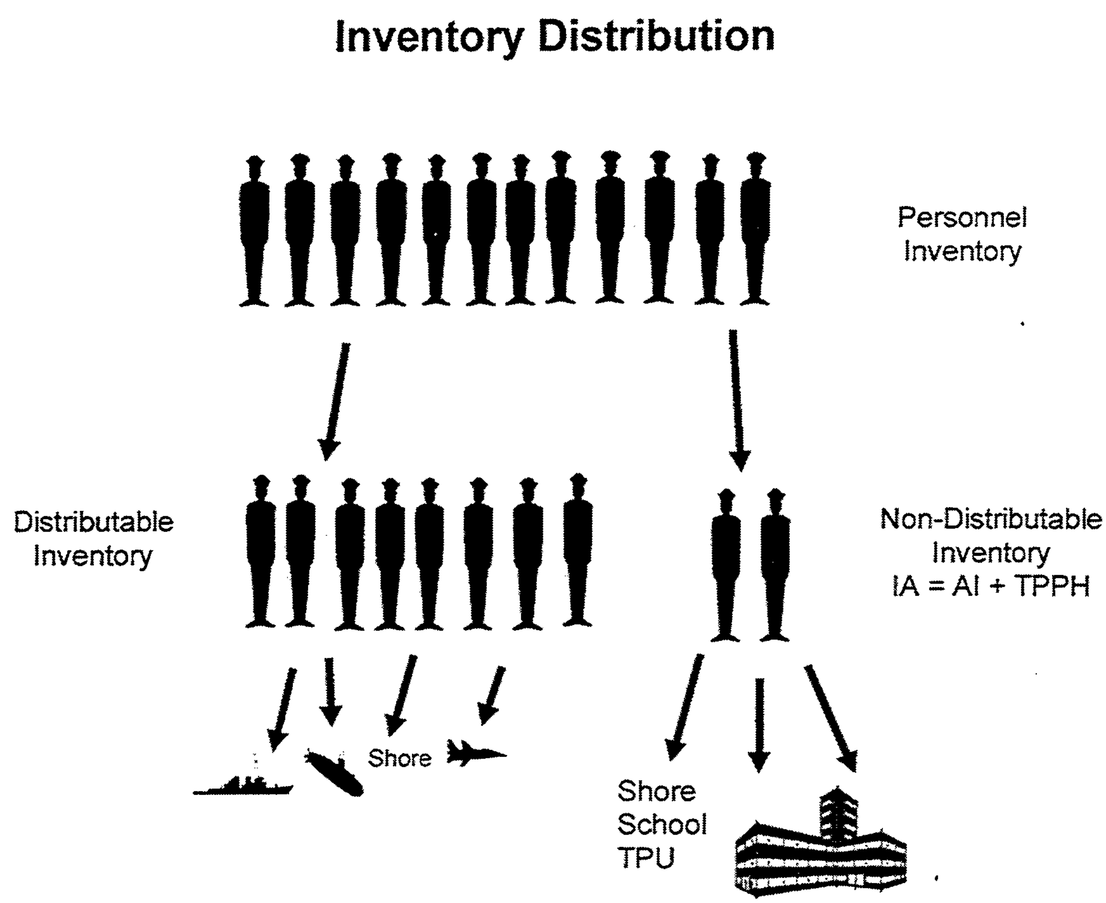


Figure 3: Manpower, Personnel, & Training PowerPoint Brief (From CDR Bill Hatch, 16 May 2000)

The four Manning Control Authorities (MCAs) are then apportioned distributable inventory in accordance with Chief of Naval Operations (CNO) priorities. The four

MCAs include Commander in Chief, U.S. Pacific Fleet (CPF); Commander in Chief, U.S. Atlantic Fleet (CLF); Commander, Navy Personnel Command (CNPC); and Commander, Naval Reserve Forces (CNRF). The CNO and MCAs establish priority manning for distributable inventory. Allocation, placement, and assignment of distributable inventory are depicted in Figure 4 below. Each level of distribution is discussed in further detail following the chart.

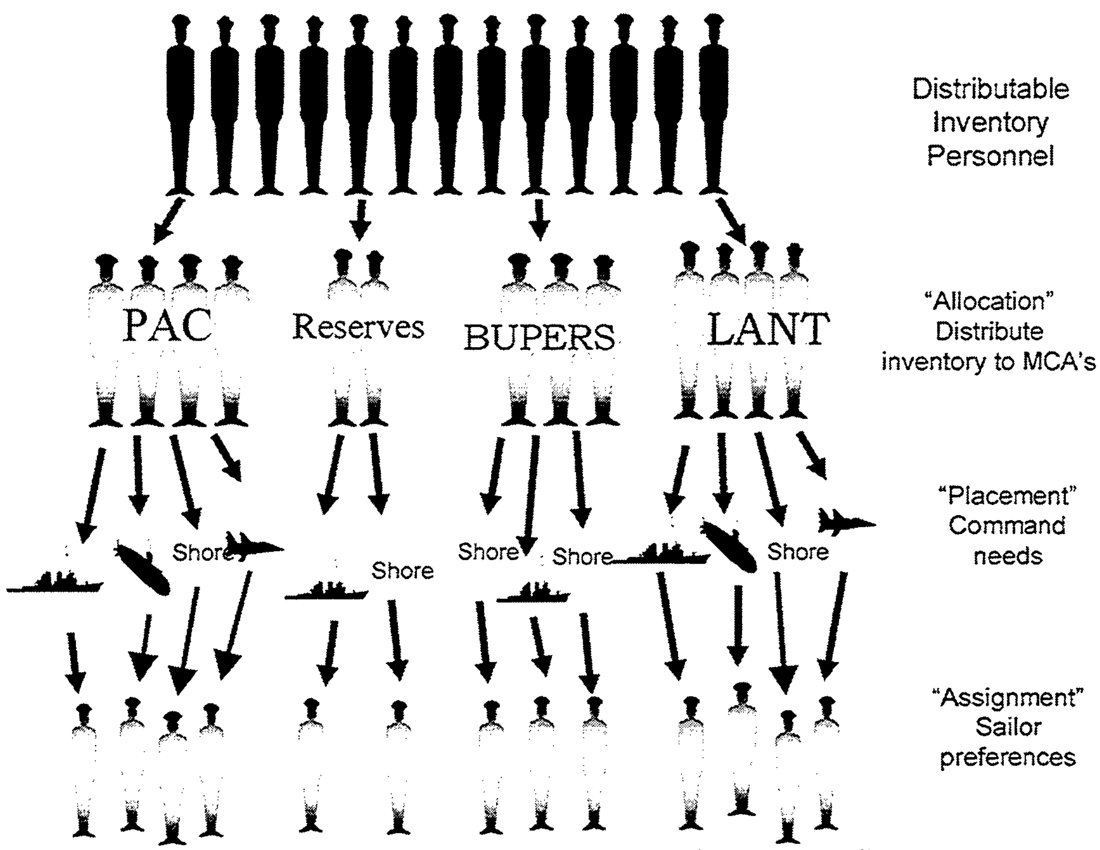


Figure 4: Manpower, Personnel, & Training PowerPoint Brief (From CDR Bill Hatch, 16 May 2000)

From Figure 4 above, the three distribution levels for distributable inventory are clear. The allocation process apportions distributable inventory to the four MCAs based on CNO priorities. Then, the placement process ensures that command needs are addressed. Finally, the assignment process considers the Sailors' preferences. These processes are further explained.

CNPC is involved with the allocation process. It is organized into different branches or departments, commonly referred to as Personnel or "Pers" codes. The Distribution Management, Allocation, Resources and Procedures Department (Pers 45) is responsible for allocation supervision and ensures a prioritized balance of distributable personnel to both sea and shore activities. Pers 45 personnel use the Enlisted Distributable Projections System (EDPROJ), a computer program which measures current strength against current billets for statistical purposes, and measures the projected strength nine months in the future against the projected billet time frame. EDPROJ receives data from two information systems, the Total Force Manpower Management System (TFFMS) and the Enlisted Master File (EMF), to determine where available personnel should be assigned to ensure equitable allocation among CNO priorities and the four MCAs.

Pers 45 uses EDPROJ to measure current strength versus current billets and projected strength versus projected billets in the next nine months. The CNO determines CNO priority manning (Pri 1/2), which is transferred to EDPROJ to ensure that these priorities are accounted for before any other allocations are made. This resulting information is transferred from Pers 45 to the Enlisted Placement Management Center (EPMAC). (Hatch, 2000).

EPMAC uses the projected personnel from EDPROJ, coupled with MCA's prioritization manning algorithms and billet information from TFMMS to establish Navy Manning Planning (NMP) levels. NMP equitably distributes the projected personnel by rate (i.e. E3, E6, E9); rating (i.e. ABF, PN, EN); and Navy Enlisted Classification (NEC) code across all activities to ensure each command receives its "fair share" of distributable personnel. Distributing the projected enlisted inventory equitably across the four MCAs, EPMAC's goal as the command advocate is to ensure the right person with the proper occupational skills occupies the right billet on time.

The MCAs communicate with EPMAC to ensure that activities have the personnel they need to accomplish their missions. Depending on the command's operational schedule, special circumstances, or additional considerations, MCAs can adjust requisition priorities to meet individual command personnel needs. When activities need to increase manning above their NMP level for specific mission accomplishment, MCAs may designate Priority 3 requisitions within their areas of responsibility. Priority 3 requisitions are valid for up to one year, and they are automatically cancelled on 30 September, unless another specific date is authorized. Designating a requisition as Priority 3 indicates that the billet has a higher priority than other requisitions, but Priority 3 requisitions are not as high priority as the CNO Priority 1 and 2 requisitions. Requisition priorities are an important consideration during the assignment process. During the assignment process, Sailors are selected and assigned, commonly called "detailing," into high priority billets based on NMP. In other words, the assignment process matches "faces" with "spaces." "Faces" result from scheduled rotation or availability whereas "spaces" occur when the command has fewer projected assigned personnel than the NMP, producing a "requisition."

Requisitions are generated in the Enlisted Personnel Requisition System (EPRES) information system when a command's projected manning in a particular rating (skill) and rate (pay grade) falls below the projected NMP levels. The requisitions are then downloaded into the computer-based Enlisted Assignment Information System (EAIS), where the assignment officer, referred to as the detailer, can review them. Requisitions appear in priority order with the number one requisition being the highest priority billet to fill. CNO Priority 1 and 2 requisitions will appear at the top of the list immediately followed by the MCA Priority 3 requisitions.

The detailer represents the Sailors, or faces, in the Enlisted Distribution System. The detailer's goal is to cost effectively match Sailors with the necessary skill sets to the prioritized requisitions. Detailers employ EAIS to accomplish their difficult task of assigning available personnel to priority requisitions. Detailers view distributable inventory Sailors in EAIS nine months before completing their current tour of duty, i.e., their Projected Rotation Date (PRD). Non-distributable Sailors in the IA (students and TPPH) also appear in EAIS nine months prior to their PRD.

Once detailers have selected a Sailor for a particular requisition, they access the Orders Writing Screen (OM) to begin the order writing process. Once orders are electronically assigned, before actual orders are written, EPMAC reviews those orders for personnel E6 and above for quality of fit. EPMAC has the authority to veto preliminary assignments between detailers and petty officers first class and above. This ensures that the detailers' assignment best matches Sailors to jobs. EPMAC placement specialists can veto orders that fail to meet fleet readiness manning and balance, even if the orders are exactly what the E6 or above Sailor requested. EPMAC provides a sanity check on orders to ensure the fleet receives the Sailor it needs. Once approved by EPMAC, if applicable, the Sailor receives written orders. Essentially, the allocation, placement, and assignment processes work in concert to meet the Navy's readiness priorities.

2. Navy Assignment From A Micro Perspective

The Navy's centralized system to reassign personnel among different duty types has two objectives. First, the assignment system must optimize readiness and stability for both afloat and ashore activities. Secondly, the assignment system must provide equal opportunity for personnel to serve in their desired duty. In theory, the task appears rather simple; in practice, balancing the Navy's needs with the Sailor's desires involves complex, time-consuming tradeoffs often requiring the Sailor to either accommodate or acquiesce one or more facets of their desired job assignment. Sailors may have to accept a different type duty, location, billet, or ship than they originally preferred.

Detailers rely on myriad information systems as well as personal rating knowledge to direct personnel into prioritized, available billets. EAIS, which displays requisitions by priority, is their primary information system. If personnel require training en route to their new command, detailers use the Navy Training Reservation System (NTRS) database to obtain class quotas and ensure requisite training is accomplished. (Hatch, 2000)

Currently, there is no single tool to help the detailers "mentally juggle" diverse policies, procedures, and information to ensure that the right Sailor with the necessary occupational skills is assigned to the right job on time. Detailer decisions, primarily subjective, may not always result in the best match for the Navy and/or the Sailor. Detailers must consider numerous, often changing, policies and procedures promulgated by the DoD, CNO, MCA, and CNPC when matching personnel to billets. (Hatch, 2000) Furthermore, Sailors have their own unique preferences, goals, and personal needs that detailers must consider. Detailers continually struggle to manage the Navy's requirements and the Sailor's wishes.

The detailer's primary consideration is whether the Sailor possesses the occupational skill set the billet requires. This consideration must be balanced with the detailer's next concern: conserving Permanent Change of Station (PCS), or transfer, funds. Detailers must minimize monetary expenditures yet maximize the effective use of personnel abilities and qualifications. To assist with this tasking, detailers can review Sailor's qualifications in EAIS. EAIS will give the detailers pertinent information for reassignment decisions such as number of dependents, NECs, End of Active Obligated Service (EAOS) date, Projected Rotation Date (PRD), current duty station and assignment history or Armed Forces Qualification Test (AFQT) scores, which are used to determine reassignments.

Detailers also take into account spreadsheets containing the average PCS expenditures based on the Sailor's pay grade, location, and number of dependents. Detailers tenaciously match Sailors to jobs to the best of their ability. Their job is made more difficult because EAIS is only about 80 percent correct in characterizing service members' skills and the average PCS expenditures are only updated biennially. (Short, 2000)

If the Sailor does not possess the billet's required skill level, detailers may consider training alternatives. Depending on class quota availability and training expenditure levels, the detailer can offer the constituent training en route. Using NTRS, the detailer immediately reserves the Sailor's quota; ensuring required training is accomplished prior to the member's arrival at the new command.

Detailers must also maintain fleet balance by ensuring that enlisted personnel are equitably distributed to all activities among the MCAs by rate, rating, and NEC in proportion to the Enlisted Master File (EMF) delineated by the NMP. The requisition's priority require detailer's focus to ensure that priority-designated jobs are filled first and that face-to-face turnover occurs whenever possible.

Acting as career counselors, detailers must advocate various duty assignments for service members. Detailers must ensure that personnel have the opportunity for advancement experience and rating excellence, and that they equitably share any existing hardship duty. Other factors requiring the detailer's attention are the member's Projected Rotation Date (PRD) and sea/shore rotation cycle. When considering personnel for overseas assignments, detailers must also follow Congressional policy which states that active duty members may not be assigned on land outside the United States or its territories and possessions, until they have had twelve weeks of basic training or its equivalent. Therefore, detailers can assign new enlistees overseas only after their initial basic training.

For personnel who have family members in primary or secondary school, detailers attempt to schedule transfers during school breaks, to minimize school schedule disruption as practicable. Additionally, military couples must be co-located if at all possible. Gender is another factor requiring the detailer's careful attention; females must be near adequate medical treatment facilities during pregnancy and females have fewer potential duty assignments (e.g. no female billets are available on submarines or Navy Sea, Air, Land (SEAL) units and certain ships are not configured for female Sailors).

Given these considerations, balancing the Sailor's desires with the Navy's priorities requires the detailer's meticulous attention and genuine concern. Sailors' personal concerns include such items as home ownership, spouses' careers, children's stability, and location preference. Each is a valid concern that detailers should address. Furthermore, an entire detailing division is dedicated to handling service members' special assignments, such as Humanitarian Assignments (HUMS) or Exceptional Family Member (EFM) personnel. Currently, approximately 294 enlisted detailers manage nearly 330,000 Sailors' careers. (Cunningham, 2000)

To improve decision-making efficiency and effectiveness, the Job Advertising and Selection System (JASS) was developed. JASS is an on-line information and decision support system for Sailors, Command Career Counselors (CCCs), and detailers. At their convenience, Sailors around the world view and apply for the posted prioritized billets. Prior to JASS, Sailors had to negotiate with detailers via the telephone. This first-come, first-serve process forced Sailors to make hasty decisions over the phone and compelled detailers to assign personnel to billets when they were not the "best qualified" or least costly move. Furthermore, Sailors assigned to ships, remote locations, or night shifts often did not have the opportunity to contact their detailers for jobs upon initial opening. (Short, 2000) As a result, they often got "stuck" with less desirable billets. These Sailors were frustrated by their disadvantaged position. In short, the Navy's priorities and Sailor's desires were not optimized before JASS was introduced in 1995.

JASS permits Sailors to view jobs available in their pay grade and rating or Navy Enlisted Classification (NEC) code. Inconvenient phone calls to the detailers and snap decisions without family involvement are minimized. View-only JASS, available via Bureau of Personnel (BUPERS) Access, allows Sailors to see, but not apply for, all available jobs in the current requisition. Any service member, enlisted or officer, can use view-only JASS to see the available jobs by rate, rating, and NEC. (Short, 2000) With this initiative, Sailors can go on-line through the internet in the comfort of their homes or workstations to explore available jobs. Sailors can see available positions, research alternatives, and discuss options with family. Ultimately, this information system allows Sailors to make informed, sagacious decisions regarding their next duty assignment. Only Command Career Counselors, or those designated by their Commanding Officer as career counselors, have the access to make job applications. Command Career Counselors are involved for two reasons. First, they ensure that the Sailors are eligible and qualified for the positions to which they are applying. Secondly, Command Career Counselors are fully engaged in the advisory role for Sailors' careers. View-only JASS offers Sailors flexibility and convenience.

Command Career Counselors aboard naval vessels use JASS Client. They download bi-monthly data for the latest information cycle and jobs available. Using the ship's Standard Automated Logistics Tool Set (SALTS) or International Maritime Satellite (INMARSAT) communication capabilities, the CCC can download the most recent JASS information, including the latest requisitions, via File Transfer Protocol (FTP) program. The Command Career Counselor then works off-line with JASS Client, assisting Sailors with their job applications. Before the end of the application cycle, usually five days, the Command Career Counselor uploads all Sailors' billet applications for their detailers' review. Currently, WEB JASS is being introduced as an improved tool for Command Career Counselors. (Short, 2000) This simplifies their access to JASS information by allowing downloads and uploads directly from the Internet, to ships or stations with Internet access.

Using JASS Client or WEB JASS, the Command Career Counselor helps Sailors apply for up to five different jobs in preference order during a two-week requisition cycle. Because Sailors only have approximately five days to submit applications to the detailer before requisitions close, Sailors at sea, in remote locations, or working odd shifts have the opportunity to apply for the same jobs to which shore Sailors conveniently apply. No longer is the detailing process a first-come, first-serve assignment process. Detailing involves batch processing, thereby leveling the playing field for all Sailors. (Short 2000; Hatch, 2000)

When requisitions close, detailers spend approximately four days reviewing constituents' desires and matching the best-qualified person to the available positions based on the Navy's needs and the Sailor's desires and/or qualifications. Allowing batch-process detailing, JASS ensures a greater probability of efficient, effective Sailor-to-job pairing. Once a Sailor is assigned to an available position and new requisitions are uploaded from NMP, the detailer releases new billets on JASS, restarting the two-week cycle.

One drawback to JASS is that Sailors expect to be assigned to their number one billet application, even though they apply for up to five different jobs. Frequently Sailors are not selected for their most preferred job, so detailers receive numerous phone calls or emails from disgruntled constituents requesting explanations and/or recommendations. (Short, 2000) At the beginning of every two-week requisition cycle, the detailers can expect to answer these phone calls or emails. Detailers can give Sailors career advice on steps to make them more marketable for their desired positions.

Despite some disadvantages, JASS is generally advantageous for detailers as well. Detailers have the highest level of JASS access. They can view jobs, apply for jobs, and select Sailors to fill jobs. Since JASS in not compatible with EAIS, detailers must laboriously hand-transfer information from JASS into EAIS, and vice versa. On the other hand, JASS allows detailers to concentrate on actual assignments because it eliminates initial phone calls requesting available billet information. In addition, detailers can now select the "best qualified" Sailor for the job from several applicants rather than the first person who is able to contact the detailer, benefiting both the Navy and the Sailor. Helping detailers optimize the Navy's priorities and grant Sailor's desires, JASS is a step toward connecting detailers, Command Career Counselors, and Sailors in this ever increasingly automated world.

3. The Need For Alternative Approach

The Navy must ameliorate the cumbersome, random detailing process to create incentives for junior and senior Sailors to remain in the Navy. In recent years, the civilian unemployment rate has declined to four percent, a 30-year low. First-term Navy attrition approached 40 percent in 1998-1999, the highest in history. (Moniz, 2000) Considering the booming economy and the potentially disruptive military life, we must take steps to ensure that people are not leaving the military in search of alternative occupations. The Navy's centralized, labor-intensive detailing process often disappoints its Navy customers, including both commands and Sailors. In addition, the detailing process is such a significant factor in Sailors' careers, that it may potentially reduce Sailor morale and retention. If left unchecked, a deficient detailing process could lead to Sailors' substandard performance and poor fleet readiness. (Gates and Nissen, 2001) Sailors today expect fast answers and quick explanations for why they were not selected for the first-choice job or what their next career-enhancing move should be.

The Navy-wide Personnel Survey found that approximately 78% of enlisted Sailors have full-time employed spouses, a significant increase from previous years. (Kantor 1997; Olmsted, 2000) In many instances, the spouse's career provides a larger family income than the Sailor's career. Thus, the Navy must allow and, indeed, encourage continued spousal employment by assisting Sailors to accommodate their spouse's career. Otherwise, assignment may have a direct bearing on whether Sailors decide to continue their Navy career. (McGrath, 2000)

A common complaint among Sailors using JASS is that their Command Career Counselor is not readily available to assist them with career advice or job applications. Very often Sailors resort to the former method of telephoning their detailer to get the perceived "inside scoop." Furthermore, despite being able to view available jobs on JASS, Sailors believe they will receive better or different job options by directly contacting the detailer. (Short, 2000)

The Enlisted Distribution System may wish to examine lessons learned from the Commander, Navy Recruiting Command (CNRC), which now employs online recruiting to enlist new troops. CNRC is meeting Generation Y on their own turf, the Internet, and the military's recruiting targets are being met. Vice Admiral Ryan, Chief of Naval Personnel, recently commented that cyber-recruiting could be more effective than the old method of stalking malls and high schools for enlistees. (Moniz, 2000) The detailing process must follow suit and start offering job searches and selections via the Internet. Although not problem free, JASS is an excellent first step, but needs to go further to balance the Navy's needs and the Sailor's desires.

Two-sided matching labor markets offer the potential to address the concerns experienced by the commanders and the sailors. This thesis will focus on first order simulation models that would be used to demonstrate the potential benefits and limitations of applying agent-based two-sided matching to DoN's hierarchical labor market. The models would form the foundation for enhancement to be made.

C. 2-SIDED MATCHING ALGORITHM

1. A Classical Algorithm For Stable Marriage

2-sided matching algorithm can be employed to achieve stable marriage matching of sample size n. A stable matching is a complete matching of men and women such that no man and woman who are not partners both prefer each other to their actual partners under the matching. (Irving, Leather & Gusfield, 1987)

In an instance of the stable marriage problem, each n men and n women lists the members of the opposite sex in order of preference. This classical algorithm normally yields what is called the male optimal solution, with the property that every man has the best partner that he can have in any stable marriage. If applied with the roles of men and women interchanged, the algorithm will yield the female optimal solution, which similarly favors the women. The achievement of best possible partners by the members of one sex results in the members of the opposite sex having their worst possible partners.

MATCHING ALGOTHM MEN BIAS

MEN	PREFERENCE							
1	3	1	5	7	4	2	8	6
2	6	1	3	4	8	7	5	2
3	7	4	3	6	5	1	2	8
4	5	3	8	2	6	1	4	7
5	4	1	2	8	7	3	6	5
6	6	2	5	7	8	4	3	1
7	7	8	1	6	2	3	4	5
8	2	6	7	1	8	3	4	5

WOMEN	PREFERENCE							
1	4	3	8	1	2	5	7	6
2	3	7	5	8	6	4	1	2
3	7	5	8	3	6	2	1	4
4	6	4	2	7	3	1	5	8
5	8	7	1	5	6	4	3	2
6	5	4	7	6	2	8	3	1
7	1	4	5	6	2	8	3	7
8	2	5	4	3	7	8	1	6

MEN	PREFERENCE							
1	3	1	5	7	4	2	8	6
2	6	1	3	4	8	7	5	2
3	7	4	3	6	5	1	2	8
4	5	3	8	2	6	1	4	7
5	4	1	2	8	7	3	6	5
6	6	2	5	7	8	4	3	1
7	7	8	1	6	2	3	4	5
8	2	6	7	1	8	3	4	5

WOMEN	PREFERENCE							
1	4	3	8	1	2	5	7	6
2	3	7	5	8	6	4	1	2
3	7	5	8	3	6	2	1	4
4	6	4	2	7	3	1	5	8
5	8	7	1	5	6	4	3	2
6	5	4	7	6	2	8	3	1
7	1	4	5	6	2	8	3	7
8	2	5	4	3	7	8	1	6

MEN	PREFERENCE							
1	3	1	5	7	4	2	8	6
2	6	1	3	4	8	7	5	2
3	7	4	3	6	5	1	2	8
4	5	3	8	2	6	1	4	7
5	4	1	2	8	7	3	6	5
6	6	2	5	7	8	4	3	1
7	7	8	1	6	2	3	4	5
8	2	6	7	1	8	3	4	5

WOMEN	PREFERENCE							
1	4	3	8	1	2	5	7	6
2	3	7	5	8	6	4	1	2
3	7	5	8	3	6	2	1	4
4	6	4	2	7	3	1	5	8
5	8	7	1	5	6	4	3	2
6	5	4	7	6	2	8	3	1
7	1	4	5	6	2	8	3	7
8	2	5	4	3	7	8	1	6

MEN	PREFERENCE						
1	3	1	5	7	4		
2	1	3	4	8	7		
3	7	4	3	1	2	8	
4	5	8	6	1	4	7	
5	4	2	8	7	3	6	5
6	6	5	7	4	3		
7	8	6	2	3	4	5	
8	2	7	1	3	5		

WOMEN	PREFERENCE						
1	4	3	8	1	2		
2	3	7	5	8			
3	7	5	8	3	6	2	1
4	6	4	2	7	3	1	5
5	8	7	1	5	6	4	
6	5	4	7	6			
7	1	4	5	6	2	8	3
8	2	5	4	3	7		

Figure 5: Male And Female Preference Lists

The classical algorithm for a solution to a stable marriage instance is based on a sequence of "proposals" from the men to the women. Each man proposes, in order, to the women on his preference list, pausing when a woman agrees to consider his proposal, but continuing if a proposal is either immediately or subsequently rejected. When a woman receives a proposal, she rejects it if she already holds a better proposal, but otherwise agrees to hold it for consideration, simultaneously rejecting any poorer proposal that she may currently hold. (A "better" proposal means a proposal from some man higher in the woman's preference list.)

Hence after first round, it can seen from the example in Fig 5, men [2] and [7] would have received the rejection from the woman first on their preference list. The match [2,6] and [7,7] are considered unstable matches and shaded gray. Men [2] and [7] will now propose to the women second on their preference list, highlighted in white. 3 scenarios can happen:

- **Women accepts proposal, rejecting proposal they held earlier from other men**. The other man would have to "move on" and propose to the woman of their second choice. The process of proposal is repeated again for the rejected men.
- **Women rejecting the proposal by men [2] & [7]**. The unstable matches would be shaded gray and the men moved on to propose to the women next on their list.
- **Women accepting the proposal, with no prior proposal from other men**. The process represents a stable match and nobody gets rejected.

The process is repeated until all matches are stable. In this example, the stable match scenario occurs when men [2] & [7] proposed to their second choice women.

It can thus be shown that, the sequence of proposals will result in every woman holding a unique proposal, and that the proposals held constitute a stable matching. (A similar outcome results if the roles of males and females are reversed, in which case the resulting stable matching may or may not be the same as that obtained from the male proposal sequence). Two fundamental implications of this initial proposal sequence are

- If a man, *m,* proposes to woman, *w*, then there is no stable matching in which *m* has a better partner than *w*;
- If *w* receives a proposal from *m*, then there is no stable matching in which *w* has a worse partner than *m*.

These observations suggest that we should explicitly remove m from *w*'s list, and *w* from *m*'s, if *w* receives a proposal from someone she likes better than *m*. These are shaded in gray in the example in Fig.5 and the resulting list is called the shortlist (male-oriented) for the given problem instance, with the following properties:

- If *w* does not appear on *m*'s shortlist, then there is no stable matching in which *m* and *w* are partners.
- *w* appears on *m*'s shortlist if and only if *m* appears on *w*'s, and is first on *m*'s shortlist if and only if *m* is last on *w*'s.
- If every man is paired with the first woman on his shortlist, then the resulting match is stable; it is called the male optimal solution, for no man can have a better partner than he does in this matching, and indeed no woman can have a worse one.
- If the roles of males and females are interchanged, and if every woman is paired with the first man on her (female-oriented) shortlist, then the resulting matching is stable; this would be a female optimal solution, for no woman can have a better partner than she does in this matching, and indeed no man can have a worse one.

2. Relevance To This Thesis

This classical algorithm will be the matching algorithm used in coding the simulation model for matching between the sailors and different command. As demonstrated in the illustration above, it can be seen that the current system of assignment can be mimicked by replacing the males with commands and females with sailors becoming available for assignment. This will result in a command biased match, reflecting the current detailing process where detailers tries to assign sailors to prioritized jobs while trying to take into account the sailor's preferences. Our thesis will attempt to demonstrate the potential difference in utilities between a sailor and command biased match; the possibility of a minimum critical mass required for efficient matching to occur while using an agent-based matching algorithm thus drawing implications it has on the time frame required for detailing and assignment process.

III. EMPIRICAL STUDY/ THE MODEL

A. INTRODUCTION

1. Overview of the Simulation Process

The simulation models will be coded and run in a Microsoft Excel environment. In this thesis, the factors used for the simulation process are what the authors considered to be fundamentally important to the detailing process. In our coding, we are acutely aware that we have not exhaustively characterized the detailing process in the US Navy. Thus, our model allows future additions/enhancements to the factors used for simulation. The model will be primarily used to answer the following questions:

- How will an agent-based simulation model demonstrate the advantages of an electronic employment market?
- How can an agent-based electronic market help optimize job matching?
- What are the potential benefits of implementing such a program?
- Is there a critical mass required for benefits to be derived from such a matching process?
- Is there any impact on the time frame (2 weeks) used for the detailing and assignment cycle in the current process?
- What is the effect of preference list lengths on the two-sided logic matching algorithm?

B. THE SIMULATION MODEL - AGENT-BASED EMPLOYMENT MARKET SIMULATOR (ABEMS)

The Agent-based Employment Market Simulator, or ABEMS, is a simulation software written using Excel Basic. It comprises two major components: 1) profile generator, and 2) the preference generation and matching logic.

ABEMS will allow the user to generate their sample of sailors, priority 1 requisition billets and priority 2/3 requisition billets. After the profile generation, the user can then activate the main simulation module to generate preference lists for both sailors and commands. The agent then matches the sailors to billets according to the logic chosen. The logic can be either sailor or command biased.

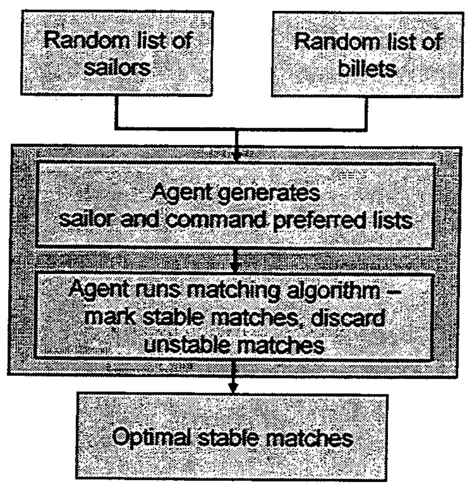


Figure 6: ABEMS Process

1. The Profile Generator

The profile generator requires the Excel analysis toolpak for it to work. If the analysis toolpak is not listed in the *Add-Ins* dialog box, click *Browse* and locate the drive, folder name and file name for the analysis toolpak add-in, Analys32.xll (usually located in the Microsoft Office\Office\Library\Analysis folder. Alternatively, the user may run the Setup program to install the toolpak.

To use the profile generator, the user may enter the discrete distributions of the characteristics of sailors, priority 1 and priority 2/3 billets in their respective worksheets, namely SProfiler, P1Profiler and P2Profiler, respectively. The sum of each discrete distribution for each characteristic must sum to 1. The random number generator is activated by clicking *Tools*, and then *Data Analysis*. From the dialog box, select *Random Number Generation.*

From the Random Number Generation dialog box, enter the number of random numbers you want to generate (e.g. 2000), select the probability and input range from the profile worksheet (e.g. for SR, select B4 to C8), and then select the output range by clicking the first cell in the Sailor worksheet you want the profiler to start generating from (e.g. for SR, select Sailor!B4). Click *enter* and the new profile for those characteristics will be generated according to the specified discrete distributions. Repeat the process for the rest of the characteristics. The process should be repeated for priority 1 and priority 2/3 billets as well.

PRIORITY 1 BILLETS

BILLET ID BI	RATE BR	PREFERRED TRNG LVL BTL	PROMOTION INDEX BPI	BILLET LOCATION BL	SHORE BILLET BS
	BILLET'S CHARACTRERISTICS				
1	2	2	4	1	1
2	1	3	3	1	1
3	2	4	3	2	1
4	5	3	5	2	5
5	1	2	2	2	5
6	3	2	2	4	5
7	2	3	4	5	1
8	3	2	3	1	1
9	1	1	5	4	5
10	1	1	4	4	1
11	2	2	2	2	1
12	2	2	2	2	1
13	1	5	2	4	1
14	3	3	2	3	1
15	2	4	4	5	1
16	5	2	4	4	1
17	2	4	2	1	1

Figure 7: Snapshot of 17 Billets' Characteristics

The preference weights of the sailors and commands uses the Cobb Douglas utility function (which will be described in detail in the following sections). They are randomly generated by the profilers and copied to their respective database worksheet when you click *regenerate alphas/betas* command button. Each sailor will have his/her own unique characteristics, and his/her own weights to their billet preference, randomly generated in the simulated environment. For example, the more ambitious sailors will have a heavier weight placed on the promotion index weight of the job (a demanding high profile billet is likely to boost the sailor's chance for promotion and career advancement if the sailor excels in it), than if the job is a shore billet. Similarly, the billets themselves have their individual characteristics. For example, some commands will be more concerned on PCS costs due to budget constraints, while others will put more weight to getting sailors of the correct training and experience.

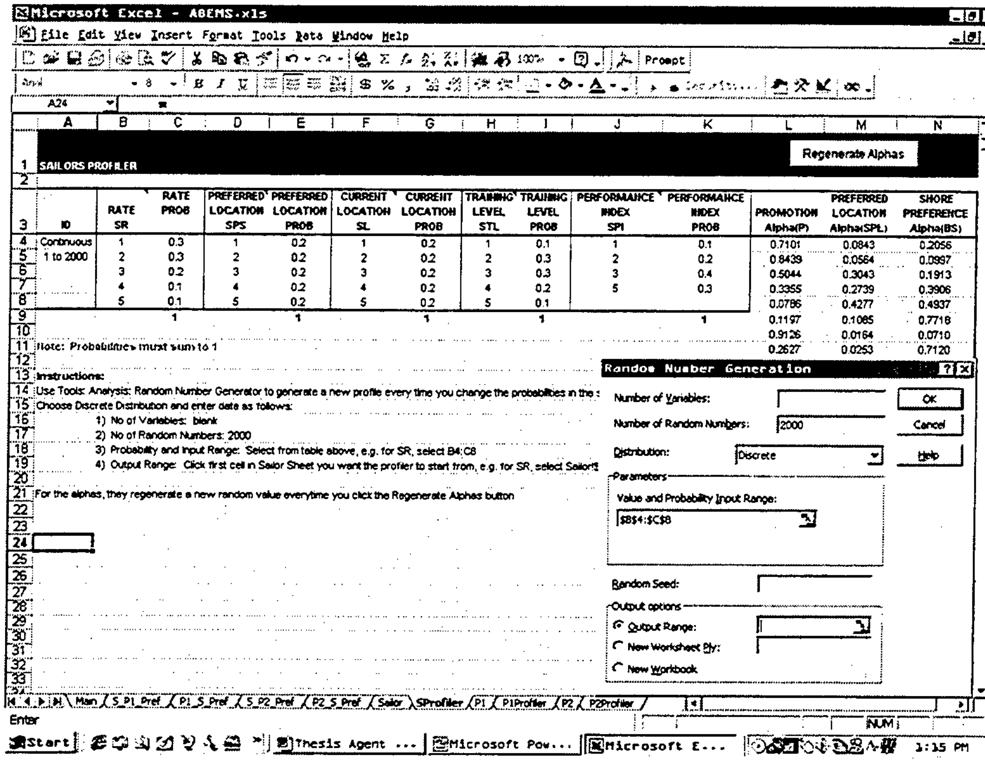


Figure 8: ABEMS Profile Generator

2. Preference Generation and Matching Logic

ABEMS will activate the simulator specifications dialog box when you click the *start simulation* command button on the main worksheet. The dialog box will allow you to specify various parameters for the simulation, including number of sailors to be matched, number of priority 1 requisition billets, number of priority 2/3 requisition billets, and the preference length list.

You may choose to run through the simulation process step by step, or simply click the *auto sailor biased logic* or the *auto command biased logic* command button to run the whole simulation process (the preference lists generation logic and the sailor/command biased matching logic is explained in detail in the following sections). The advantage of stepping through is that it will allow you to view the simulation process step by step (e.g. examination of the sailors preference list), while the auto runs will be faster in total execution time.

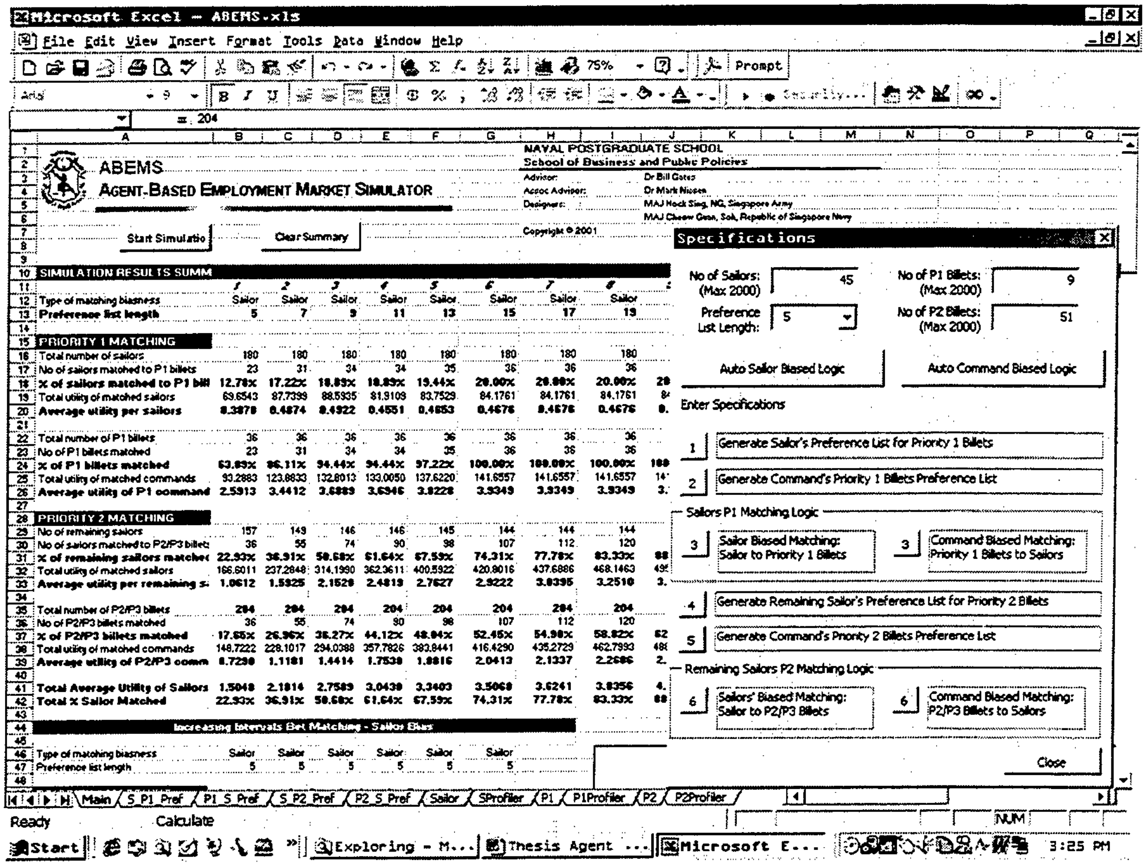


Figure 9: ABEMS Simulation Specifications

In the preference list generation, the agent will prioritize the sailors' and commands' preference lists according to the returned sailor utility U_S and command utility U_C. The preference lists are kept in worksheets *S_P1_Pref* (Sailors to P1 billets), *P1_S_Pref* (P1 billets to sailors), *S_P2_Pref* (Remaining unmatched sailors to P2/P3 billets), and *P2_S_Pref* (P2/P3 billets to remaining sailors). Figure 10 shows that billet 9 offers the highest utility to sailor 1 (highest possible value of 5), followed by billet 10 with a value of 3.9. Similarly, priority 1 commands have their preference list of sailors. The agent then uses the chosen matching logic (sailor or command biased) to find the best stable matches, while discarding the unstable matches. The matched sailors and billets are shown in blue. Thus in the sample shown below, sailor 11 is matched to billet 36. There are no stable matches found for sailor 1, hence he is unmatched. The unmatched sailors will then be consolidated by the agent for a second round generation of preference lists and matching logic with priority 2/3 requisition billets. The whole process is shown in Figure 11.

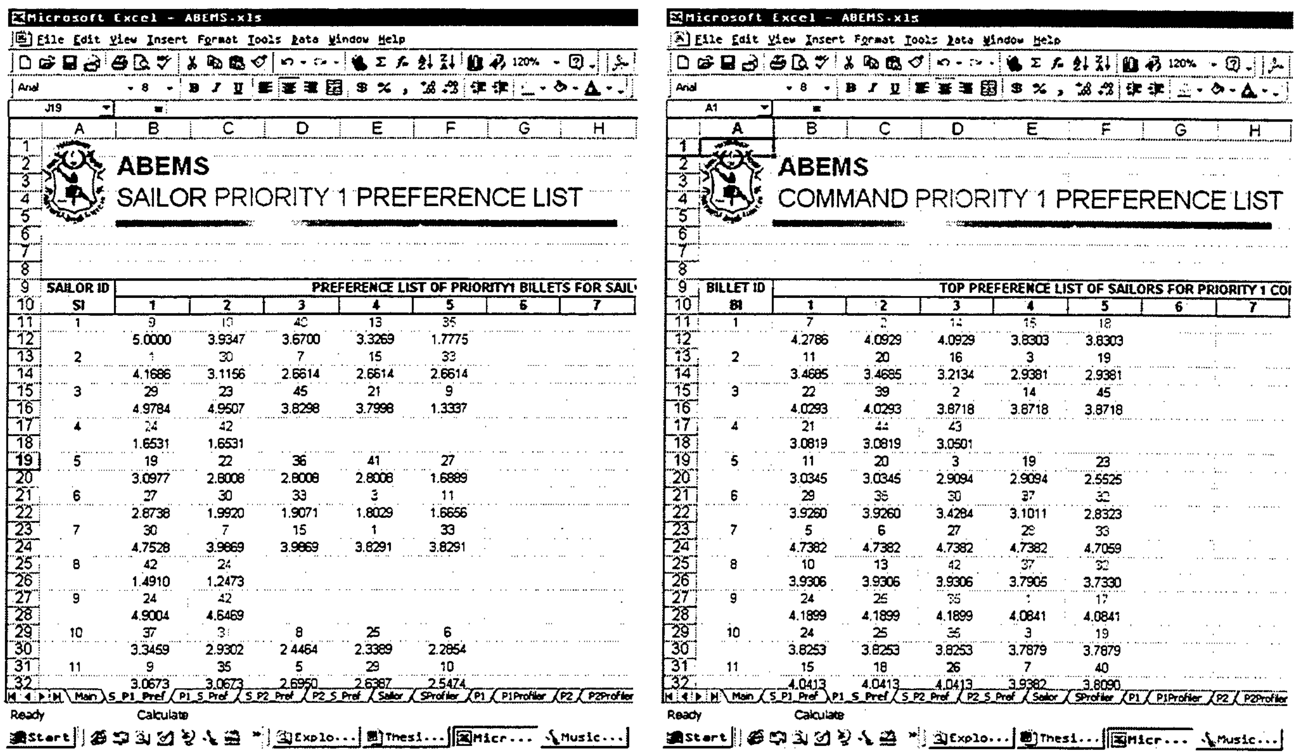


Figure 10: Sailor Preference List for Priority 1 Billets and the Corresponding Command Priority 1 Preference List after Matching Logic

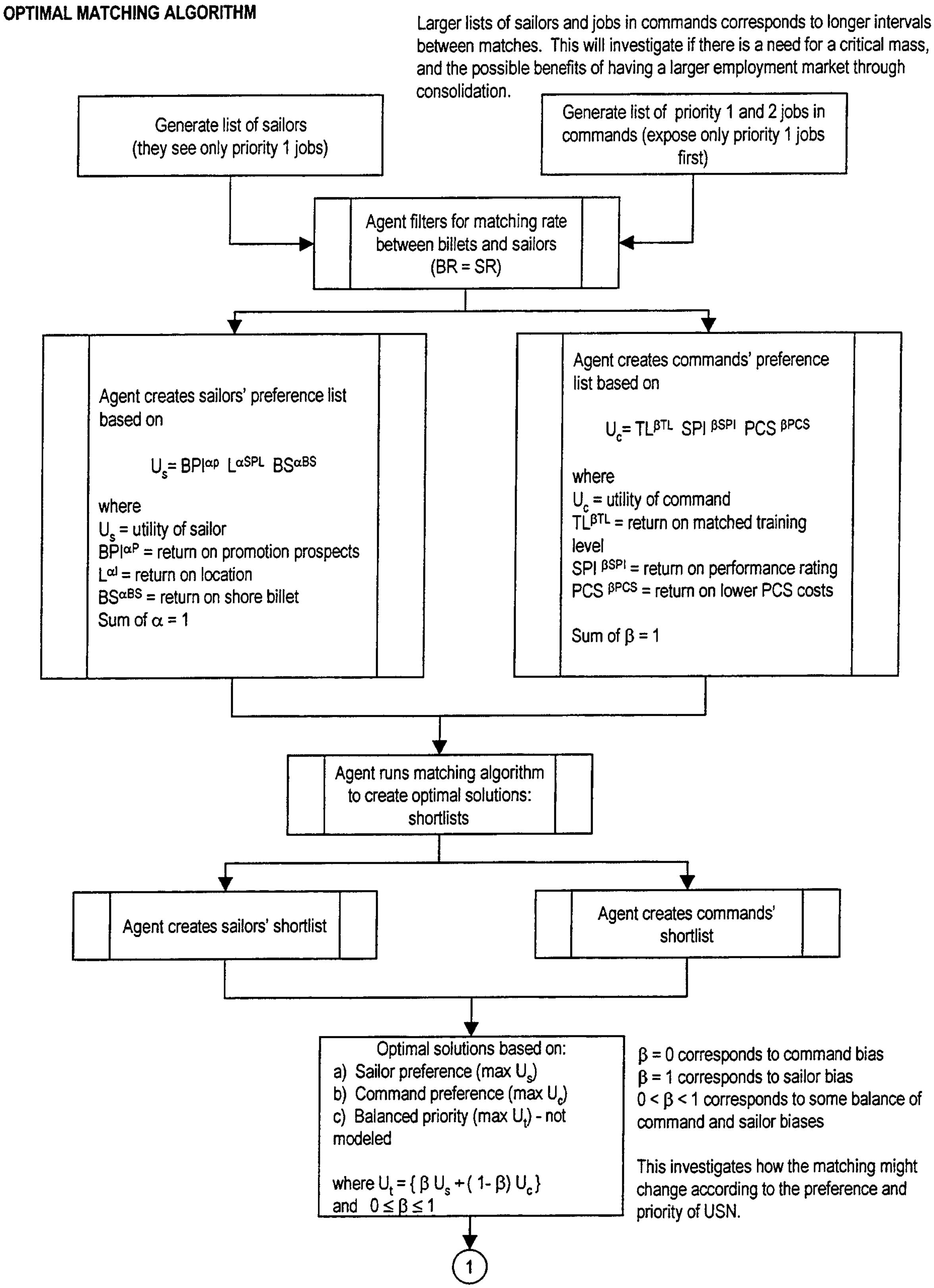
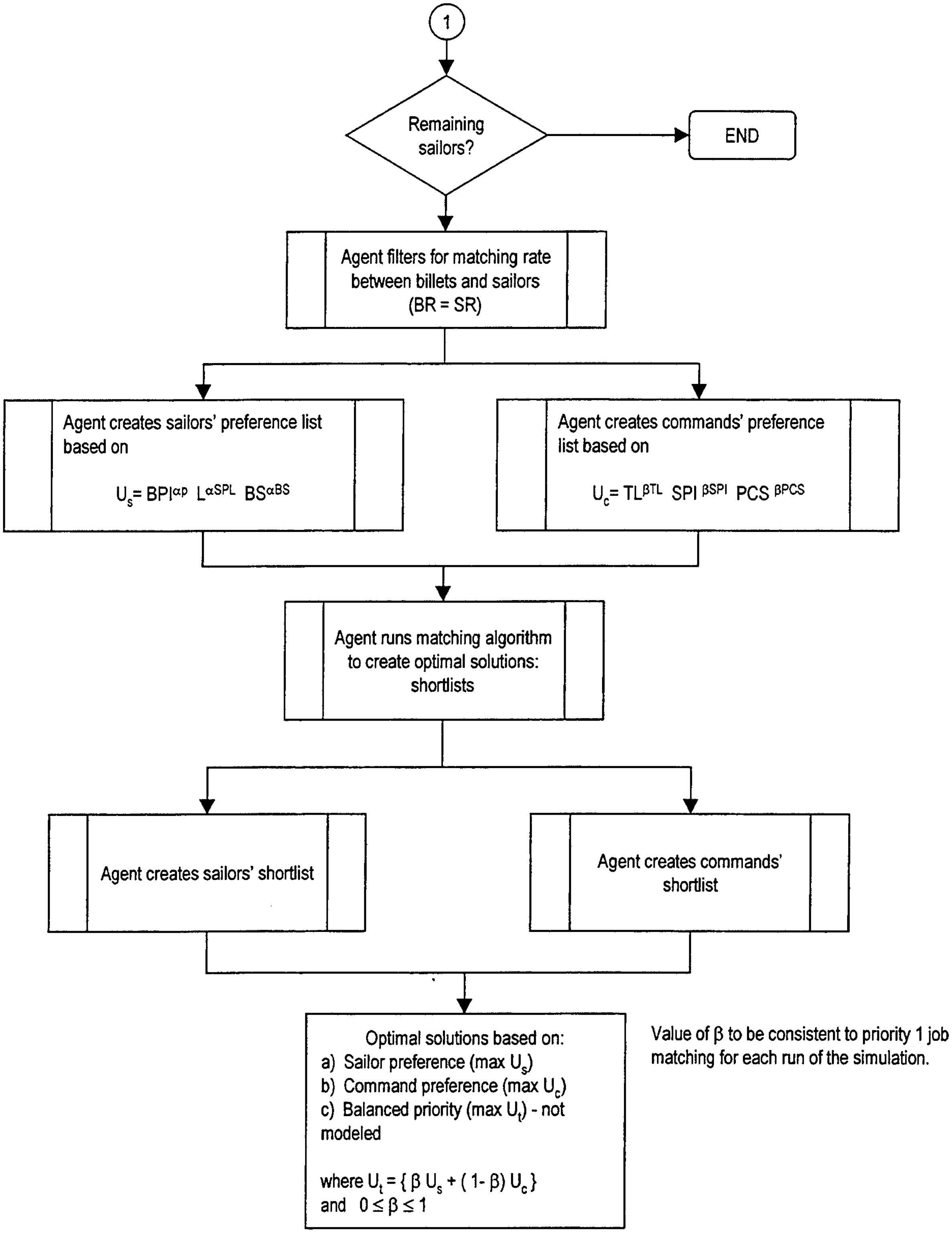
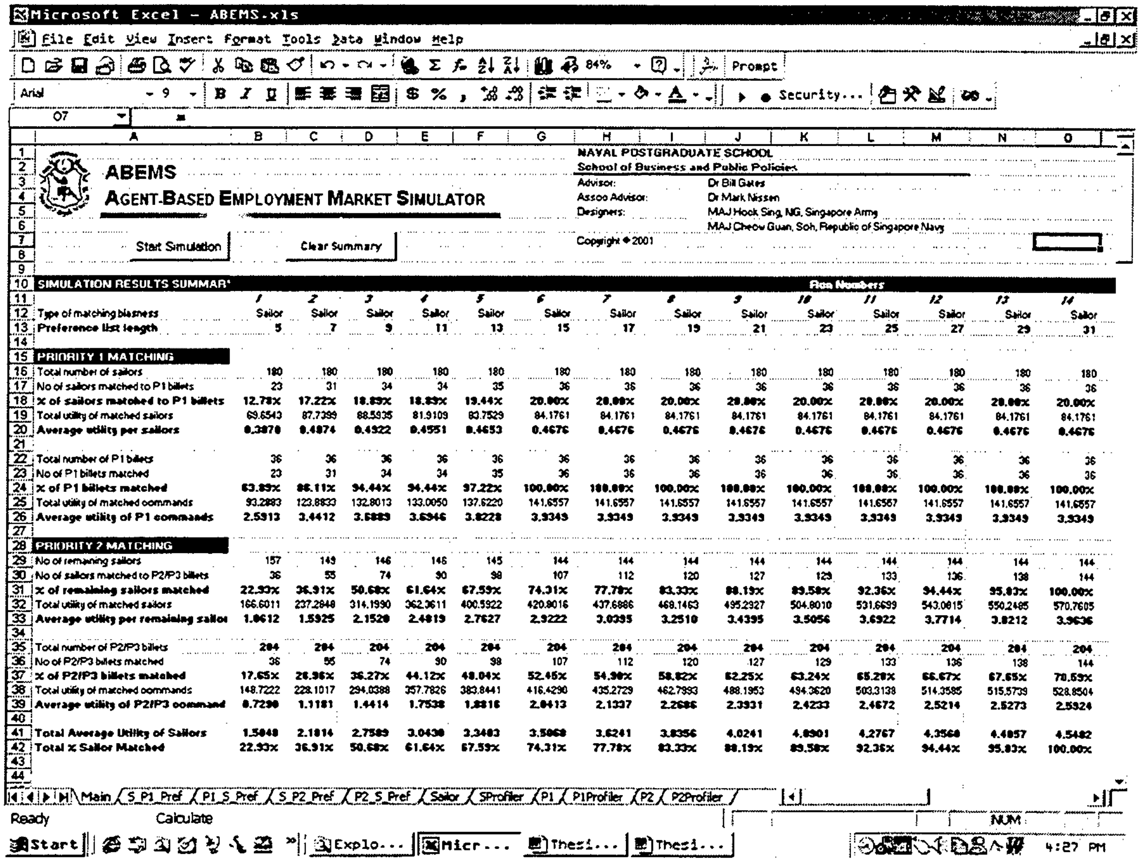


Figure 11: Flow Diagram of Simulation Model


1
Remaining sailors?
END
Agent filters for matching rate between billets and sailors (BR = SR)
Agent creates sailors' preference list based on
$U_s = BPI^{\alpha P}\ L^{\alpha SPL}\ BS^{\alpha BS}$
Agent creates commands' preference list based on
$U_c = TL^{\beta TL}\ SPI^{\beta SPI}\ PCS^{\beta PCS}$
Agent runs matching algorithm to create optimal solutions: shortlists
Agent creates sailors' shortlist
Agent creates commands' shortlist
Optimal solutions based on:
a) Sailor preference (max U_s)
b) Command preference (max U_c)
c) Balanced priority (max U_t) - not modeled
where $U_t = \{ \beta U_s + (1-\beta) U_c \}$
and $0 \leq \beta \leq 1$
Value of β to be consistent to priority 1 job matching for each run of the simulation.

3. ABEMS Output

After a successful simulation run, ABEMS will output the results of the simulation in the main worksheet. The output primarily comprises the *quality* and *quantity* of the matching. Quality is captured by the average utility of the sailors, priority 1 and priority 2/3 commands. Quantity is captured by the percentage matched for the sailors, priority 1 and priority 2/3 commands. The detailed matching of individual sailors to individual billets are captured in their respective preference worksheets (denoted by blue). By varying the number of sailors, priority 1 and 2/3 billets, we can examine the effect of having longer intervals between matching. By varying the preference lengths, we can examine the effect of having a longer preference to the matching logic. We can even vary both at the same time to examine their combined effects and to find various optimal conditions for the two-sided matching logic. These scenarios and their outcomes are discussed in detail in Chapter IV.



SIMULATION RESULTS SUMMARY	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	5	7	9	11	13	15	17	19	21	23	25	27	29	31
PRIORITY 1 MATCHING														
Total number of sailors	180	180	180	180	180	180	180	180	180	180	180	180	180	180
No of sailors matched to P1 billets	23	31	34	34	35	36	36	36	36	36	36	36	36	36
% of sailors matched to P1 billets	12.78%	17.22%	18.89%	18.89%	19.44%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
Total utility of matched sailors	69.6543	87.7399	88.5935	81.9109	83.7529	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761
Average utility per sailors	0.3870	0.4874	0.4922	0.4551	0.4653	0.4676	0.4676	0.4676	0.4676	0.4676	0.4676	0.4676	0.4676	0.4676
Total number of P1 billets	36	36	36	36	36	36	36	36	36	36	36	36	36	36
No of P1 billets matched	23	31	34	34	35	36	36	36	36	36	36	36	36	36
% of P1 billets matched	63.89%	86.11%	94.44%	94.44%	97.22%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total utility of matched commands	93.2883	123.8833	132.8013	133.0050	137.6220	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557
Average utility of P1 commands	2.5913	3.4412	3.6889	3.6946	3.8228	3.9349	3.9349	3.9349	3.9349	3.9349	3.9349	3.9349	3.9349	3.9349
PRIORITY 2 MATCHING														
No of remaining sailors	157	149	146	146	145	144	144	144	144	144	144	144	144	144
No of sailors matched to P2/P3 billets	36	55	74	90	98	107	112	120	127	129	133	136	138	144
% of remaining sailors matched	22.93%	36.91%	50.68%	61.64%	67.59%	74.31%	77.78%	83.33%	88.19%	89.58%	92.36%	94.44%	95.83%	100.00%
Total utility of matched sailors	166.6011	237.2848	314.1990	362.3611	400.5922	420.8016	437.6886	468.1463	495.2927	504.8010	531.6699	543.0815	550.2485	570.7605
Average utility per remaining sailor	1.0612	1.5925	2.1520	2.4819	2.7627	2.9222	3.0395	3.2510	3.4395	3.5056	3.6922	3.7714	3.8212	3.9636
Total number of P2/P3 billets	204	204	204	204	204	204	204	204	204	204	204	204	204	204
No of P2/P3 billets matched	36	55	74	90	98	107	112	120	127	129	133	136	138	144
% of P2/P3 billets matched	17.65%	26.96%	36.27%	44.12%	48.04%	52.45%	54.90%	58.82%	62.25%	63.24%	65.20%	66.67%	67.65%	70.59%
Total utility of matched commands	148.7222	228.1017	294.0388	357.7826	383.8441	416.4290	435.2729	462.7993	488.1953	494.3620	503.3138	514.3585	515.5739	528.8504
Average utility of P2/P3 command	0.7290	1.1181	1.4414	1.7538	1.8816	2.0413	2.1337	2.2686	2.3931	2.4233	2.4672	2.5214	2.5273	2.5924
Total Average Utility of Sailors	1.5048	2.1814	2.7589	3.0430	3.3483	3.5068	3.6241	3.8356	4.0241	4.8901	4.2767	4.3560	4.4057	4.5482
Total % Sailor Matched	22.93%	36.91%	50.68%	61.64%	67.59%	74.31%	77.78%	83.33%	88.19%	89.58%	92.36%	94.44%	95.83%	100.00%

Figure 12: ABEMS summary output of Quality and Quantity of Matching

C. PREFERENCE LIST ALGORITHM

The sailor's individual utility is given by the Cobb Douglas utility function:

$$U_S = BPI^{\alpha_P} * L^{\alpha_{SPL}} * BS^{\alpha_{BS}}$$

Where:

U_S = Utility of sailor

$BPI^{\alpha p}$ = Sailor's derived utility from promotion prospects of billet

$L^{\alpha SPL}$ = Sailor's derived utility from fit between sailor's preferred location and Billet location SPL and BL

$BS^{\alpha BS}$ = Sailor's derived utility from getting a shore billet

$\alpha_P + \alpha_{SPL} + \alpha_{BS} = 1$

Sailor's derived utility from promotion prospects of billet. More demanding and high profile billets are likely to be more challenging to the sailors, and competent sailors who pass the test are likely to be noticed and ranked higher. This elevates their chances for promotion and career advancement. This index is captured by the Billet Promotion Index (BPI) of each requisition billet, ranging from 1 to 5 (see table). How much utility a sailor derives from a billet that is likely to boost his career advancement and promotion prospects will depend on his weight α_P.

Sailor's derived utility from fit between sailor's preferred location and billet location. Sailors specify their preferred location by the index SPL. The billets specify their location by the index BL. If there is a match between SPL and BL, the Location Index L will be assigned the value of 5, otherwise, L will be assigned the value of 1. The sailor will thus derive a higher level of utility for a successful location match. How much utility he derives on the match will depend on how much weight he assigned to location fit, specified by α_{SPL}.

Sailor's derived utility from getting a shore billet.[2] A shore billet will have a BS value of 5, while a sea billet a BS value of 1. How much utility a sailor derives from a shore billet will depend on his weight α_{BS}.

The agent will first filter out the billets that specify a different rate than the sailor's, i.e. the index BR and SR must match. Of the remaining billets, the agent will calculate the U_S each billet can provide to each sailor, and rank profile the billets for each sailor based on decreasing U_C. This is the Sailor's Preference List.

[2] In the current process, it is recognized that the Navy has a policy of fixed sea-shore rotation. Hence, it will be unrealistic to let the sailor have a choice between sea-shore billets. However, in our model for agent-based matching algorithm, we are proposing that if indeed an efficient matching algorithm can be established, then the assignment process may not need a fixed policy of sea-shore rotation in order for it to work effectively.

Table 1: Data Characteristics for Sailors

Sailor ID SI	Preferred Location SPL For sailor $U_{s)}$	Rate SR for Command to filter	Characteristics of Sailor (used for calculating Command Utility Uc)			Preference Weight (used in Cobb Douglas utility function for individual sailors Us - to sum to 1)		
			Location SL PCS cost	Training Level STL	Performance Index SPI	Promotion Index Weight α_P	Preferred Location Weight α_{SPL}	Shore Preference Weight α_{BS}
1 to 2000	1: W 2: MW 3: S 4: NE	1: E04 2: E05 3: E06 4: E07 5: E08 & E09	1: W 2: MW 3: S 4: NE	1: Not trained 2: Moderately trained 3: Trained 4: Well trained 5: Well trained with experience	1: Not promote 2: Promote 3: Must promote 5: Early promote	Sailor's affinity to high profile, challenging jobs that may boost his promotability and career advancement	Sailor's affinity to his preferred station's location, i.e. fit between **SPL** and **BL**	Sailor's affinity for shore preference

The command's individual utility is given by the Cobb Douglas utility function:

$$U_C = TL^{\beta_{TL}} * SPI^{\beta_{SPI}} * PCS^{\beta_{PCS}}$$

Where:

U_C = Utility of command

$TL^{\beta TL}$ = Command's derived utility on getting sailor of the desired trained level.

$SPI^{\beta SPI}$ = Command's derived utility on getting a sailor of a higher performance rating.

$PCS^{\beta PCS}$ = Command's derived utility on getting a lower PCS cost

$\beta_{TL} + \beta_{SPI} + \beta_{PCS} = 1$

Command's derived utility on getting sailor of the desired trained level. Commands want to be assigned a sailor whose training level (STL) matches the requirement of its billet (BTL). If there is a perfect match between STL and BTL, the matched TL will be assigned a value of 5. Further deviations between STL and BTL will yield lower values of TL as given by the formula

$$TL = 5 - | BTL - STL |$$

Billet's Desired Training Level BTL	Sailor's Training Level STL	Matching Training Level TL
3: Trained	3: Trained	$TL = 5 - \| BTL - STL \|$ $= 5 - \| 3 - 3 \|$ $= 5$
3: Trained	2: Moderately trained	$TL = 5 - \| 3 - 2 \|$ $= 4$

Having determined the value of TL for every eligible sailor for a particular billet, the agent then calculates the utility derived from a training level match. How much utility a command derived from training level matching will depend on the command's weight to training level matching β_{TL}

Command's derived utility on getting a sailor of a higher performance rating. Some commands will derive a higher utility from being assigned a sailor with a higher performance rating than others. The sailor's performance rating ranges from 1 (not promote) to 5 (early promote). The command's derived utility will depend on how much weight the command has assigned to β_{SPI}.

Command's derived utility on getting a lower PCS cost. Budget strapped commands will desire being assigned a sailor with lower PCS cost than those commands whose chief concerns are getting sailors of the right training level and high performance rating.[3] To calculate PCS cost, the agent will use a lookup table comparing the sailor's current location SL and the billet's location BL. The lookup table will return a value of 1 for highest PCS cost to 5 for lowest PCS cost. How much utility a command derives from the PCS index will depend on its weight to PCS cost, or β_{PCS}. The lookup table is found on the worksheet *P1Profiler*.

Table 2: Data Characteristics for Command Billets

Billet ID **BI**	Rate **BR** (for Command to filter)	Desired Trained Level **BTL**	Characteristics of Billet (used for calculating Sailor Utility U_S)			Preference Weight (used in Cobb Douglas utility function for Commands to calculate their U_C - to sum to 1)		
			Promotion Index **BPI**	Billet Location **BL**	Billet Sea or Shore **BS**	Training Level Weight β_{TL}	Performance Index Weight β_{SPI}	PCS Cost β_{PCS}
1 to 2000	1: E04 2: E05 3: E06 4: E07 5: E08 & E09	1: Not trained 2: Moderately trained 3: Trained 4: Well trained 5: Well trained with experience	Billet's boost to promotion prospects 1: Low 2: Moderate 3: Average 4: High 5: Excellent	1: W 2: MW 3: S 4: NE	1: Sea 5: Shore	Commands' affinity to getting sailors to their desired training level, i.e. fit between **STL** and **BTL**	Commands' affinity to getting a high performance sailor. Linked to **STL**	Commands' affinity to PCS costs PCS cost is determined through a lookup table between **SL** and **BL**

D. SAILOR BIASED MATCHING ALGORITHM

The matching algorithm for both sailor biased or command biased followed in essence, the basic principle for that discussed in Chapter II. The classical algorithm will be the matching algorithm used in coding the simulation model for matching between the

[3] The use of PCS costs in the simulation model creates the opportunity for commands to be issued "virtual" dollars in the future. Recognizing that commands will always want the best trained and performing sailors to join them, the consumption of these desirable traits, in economic terms, will involve the concept of opportunity cost, and hence the theory of PPF will be appropriate in the analysis of the utility function here.

sailors and different commands. The matching logic is achieved by replacing the males with sailors becoming available for job assignments and females with billets that are available in different commands, requisitions. This will result in a sailor biased match, which indicates that each sailor who was matched cannot possibly find another stable match with a billet ranked higher in his preference list. The commands however, will only be matched to a sailor that is ranked lowest in its preference list that resulted in a stable match. In this matching algorithm, the utility of the sailors are maximized while utility of the commands are minimized, while still ensuring a stable match. The match will be optimal for the sailors.

E. COMMAND BIASED MATCHING ALGORITHM

In the command biased matching algorithm, the system of assignment is achieved by replacing the males with billets at different commands and females with sailors becoming available for assignment. This will result in a command biased match, reflecting the current detailing process where detailers try to assign sailors to prioritized jobs while trying to take into account the sailor's preferences. Similar to the sailor biased matching algorithm, the commands' utilities are maximized while still ensuring a stable match occurs. The match will be an optimal match for the commands. This thesis will design simulation models that reflect these two biases, analyzing the results from the two algorithms and studying the possible implications they have on the current detailing process.

F. BALANCED COMMAND AND SAILOR MATCHING ALGORITHM

The classical algorithm yields a sailor or command optimal solution, with the property that every sailor or command has the best billet or sailor that they can have in any stable matching. In reality, however, it is rare to achieve the best match for one interested party (biased party or the proposar) while the other party achieves its worst match. The matches are likely to be a compromise between both interested parties. There are articles proposing the idea of "optimal" matching. In this thesis, the focus is on showing the effects that a sailor or command biased logic has on the utility of the interested parties. This utility is used as a pseudo representative for the general morale and happiness of the enlisted personnel in the US Navy, hence directly affecting the retention of the enlisted corps. Using a "balanced" matching algorithm to better reflect reality will require further studies and coding, which is not covered in the scope of this thesis.

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IV. FINDINGS

A. AGENT-BASED EMPLOYMENT MARKET SIMULATOR (ABEMS) SCENARIOS

Using the algorithm logic discussed in Chapter III, different scenarios were explored to evaluate the usefulness of an algorithm-based logic matching system. The evaluation is broadly categorized into qualitative (utility) and quantitative (% matched) analysis. Qualitative analysis is referenced to show how the average utility per sailor or command varies as different parameters vary and their possible implications/applications (whenever relevant) for the detailing system in the USN. Quantitative analysis is evaluated based on the percentage matched for the sailors, the priority 1 jobs (P1) and priority 2/3 (P2/3) jobs. While the focus of the thesis is to study the usefulness of an agent-based matching system in detailing the sailors, the team has, as far as possible, used terms that are consistent with their usage within the detailing community. The variables chosen for the simulation were chosen due to their perceived importance in a matching process between sailors and commands.

Under the current norms, empirically, about 4600 sailors are available for job assignment at any one-requisition cycle, within a 9-month time frame (Short, 2000). This is based on a constant job rotation rate and current 2-week requisition cycle. From the literature study of NMP and the manning levels, the team found that there are only enough sailors primed for posting to fill 85 to 90% of the total billets tendered for requisition at each matching cycle (Hatch, 2000). This ratio is used for generation in the different scenarios.

In the design of the model, 2000 random sailor and command profiles were generated to reflect the differences in weightage an individual sailor or command might place on the different factors/variables which would affect their utility derived from a proposed match. The team noted that 45 sailors and 60 billets are the norm for one detailer in the current 2-week process, and of the total billets, approximately 15% are priority 1 requisition billets (or approximately 9). This sample batch size will form the staring point for the simulation, with the team increasing or decreasing the sample sizes proportionately to reflect longer or shorter intervals between matching. It is noted here that the simulated results obtained for a 2-week requisition cycle would mimic the current process of detailing in the USN, provided the detailers have perfect information of all the billets and sailors available during the cycle, and that their matching logic is flawless, i.e. no human error.

The different scenarios evaluated are:

- **Scenario 1:** Find the optimal intervals between matching, given conditions that mimic current detailing process. The number of sailors, priority 1 and priority 2/3 requisition billets are proportionately increased to reflect longer intervals between matching. The preference list lengths are kept constant at 5, which is the current practiced norm.

- **Scenario 2:** Find the optimal preference list length (required to be stated by the sailor and command) in the matching process. The number of sailors, priority 1 and 2/3 billets are kept constant, while the preference list lengths are varied.

- **Scenario 3:** Find the optimal preference length for increasing intervals in the requisition cycles. By varying the number of sailors, priority 1 and 2/3 billets, as well as preference list lengths, the team sought to demonstrate the delicate relationship between these parameters on the final matching output.

- **Scenario 4:** Find the effect of increasing proportions of P1 billets in the matching process. All other parameters are kept constant for this simulation.

- **Scenario 5:** Study the effects of sailor biased and command biased matching.

- **Scenario 6:** Compare and contrast the optimal possible matching outcome for a 2-week and 8-week sample by varying the preference lengths.

B. SCENARIO 1 : FIND THE OPTIMAL INTERVALS BETWEEN MATCHING, GIVEN CONDITIONS THAT MIMIC CURRENT DETAILING PROCESS (SAILOR BIASED ALGORITHM)

The current detailing process was mimicked by setting the preference length to 5, number of sailors available and number of requisitions available to 45 and 60, respectively, for a 2-week requisition cycle. The proportion of P1 requisitions to P2/P3 requisitions are set to 15%:85%. The simulated results were obtained to determine the quality and quantity of fit between sailors and requisitions. This process was repeated for different intervals between matching, from 1 week to 6 weeks. The simulated results are reflected in Figures 13 and 14.

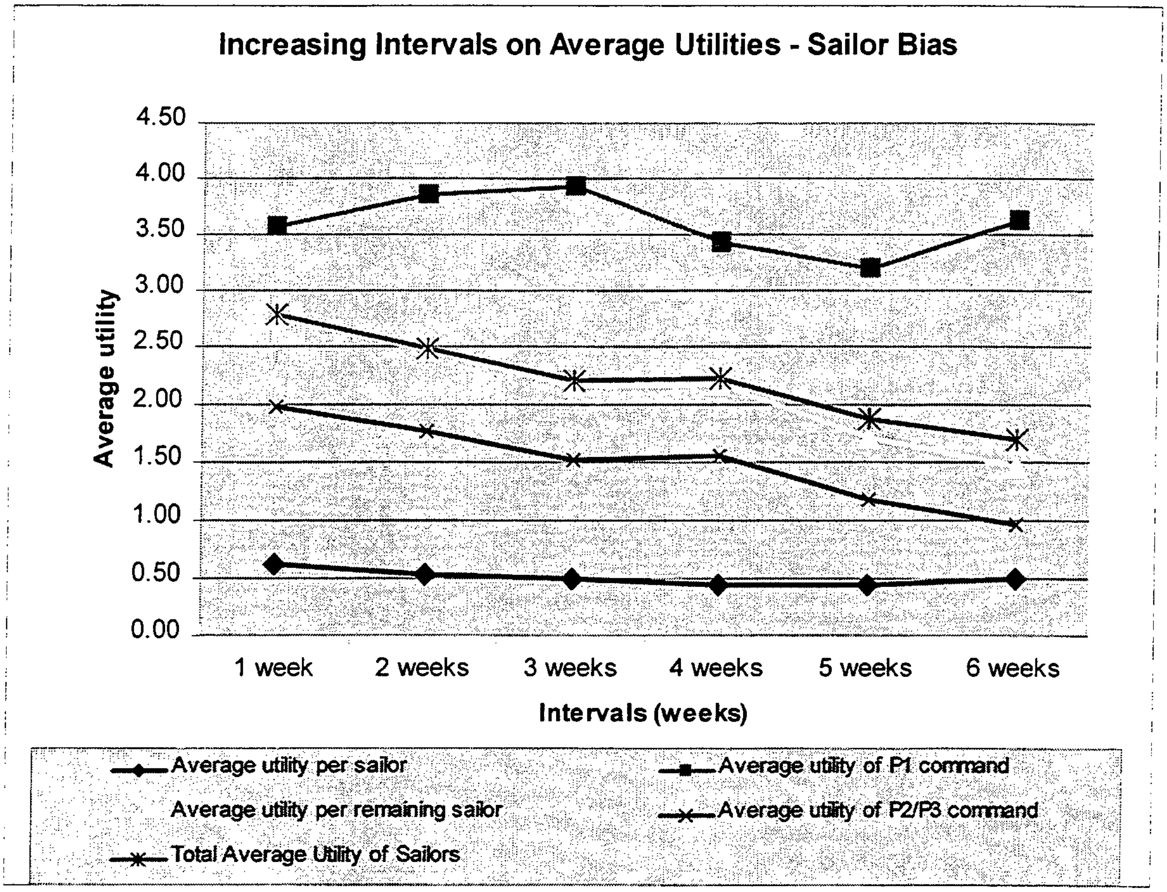

Figure 13: Increasing Interval on Average Utilities

From the charts, it was observed that the average quality of matches for all sailors and P1/P2 requisitions decreases as the interval (requisition cycle) was increased. The quality of match for P1 increases at first, before it started to decrease and seemed to bottom out before increasing again. This seemed to contradict the general belief of the team, that there could exist a critical mass for an agent-based matching system that would allow better rates of return (in utility), suggesting a need for longer requisition interval. If this belief was consistent in the simulation, the results expected would be a graph that would have shown an increasing average utility as the intervals were increased, before tapering off, reaching a somewhat plateau, and perhaps declining average utility to reflect the effects of diminishing returns. It should be noted that the graphs showed the average utilities over all sailors/billets. The overall decline in the utilities level reflects the decrease in percentage matched (Figure 14). If we only take utilities of those matched into consideration (discarding the unmatched sailors/billets), the average utilities of those matched would increase.

It should be noted that subsequent simulations (Scenario 2 and 6) showed that while the quality and match depends on the interval (requisition cycle), it was equally dependent on the preference list length given. Comparing between Scenario 1 and 6 would showed that average utilities were higher for a 8-week cycle, suggesting that there indeed could be a critical mass to realize maximum average utility. A full study to determine the optimal interval would require firstly, determining the optimal preference length for each unique interval through simulation; followed by running the simulations for the different intervals at their optimal length to determine the optimal period. It was beyond the scope of this thesis to perform these simulations, given the limitations of software availability and time constraints. However, the team understands that commercial simulation software, such as Arena would be able to incorporate the logic programmed for this thesis and performs the desired simulations. This presented the opportunity for future study.

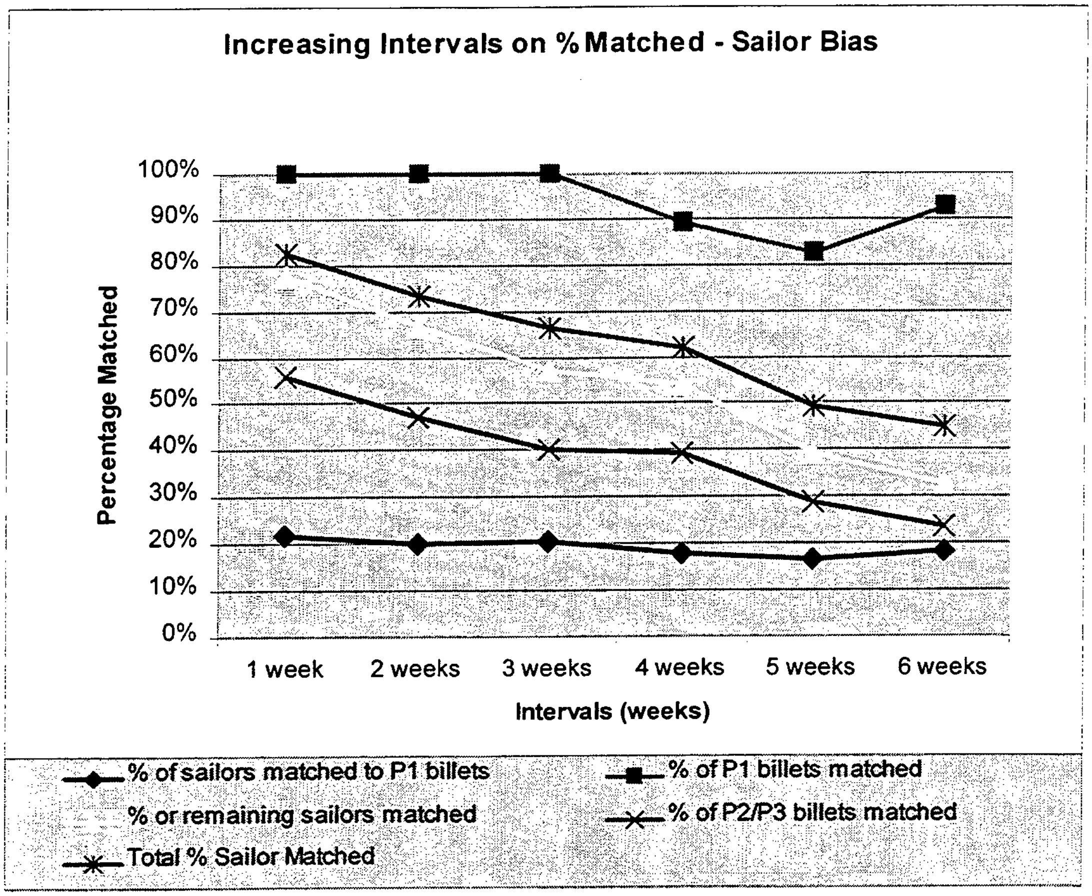

Figure 14: Increasing Interval on Percentage Matched (Sailor Biased Algorithm)

The percentage of P1 and P2/P3 requisitions matched to a sailor followed the same general decline as the interval between matches increased. A similar observation was made for the total percentage of sailors matched as for average utility. Given a preference length of 5, this trend is expected since it would become increasingly difficult for the algorithm to match sailors to requisitions. The number of preferences stated are the limiting factor, as the same perceived favorable jobs are popular amongst most of the sailors and the same perceived good sailors become the favorite choice for most of the commands, resulting in more "unwanted" jobs and sailors who were not even rated in the preference list for the algorithm to consider.

Based on Figures 13 & 14 alone, a general observation could be made. Given that the conditions for the simulation mimicked the current detailing process, 2 weeks requisition cycle seemed reasonable for quality and quantity matches. A big assumption here, of course, is that the preference list length is set to 5. As the pool of participants get larger, maintaining the preference list length at 5 will severely increase the chance of a "no match" where Sailor X prefers billet A but finds that billet A does not even list Sailor X in its preference list. The presence of such a scenario actually validates the simulation package, as it is highly likely that many sailors will be competing for the best billets, while the commands will be competing for the best sailors. A short preference list means that almost every sailor is choosing a narrow range of good billets, to the exclusion of all others - hence the poorer matching for longer intervals with preference lengths fixed at 5.

C. SCENARIO 2: FIND THE OPTIMAL PREFERENCE LENGTH IN THE MATCHING PROCESS (SAILOR BIASED ALGORITHM)

Scenario 1 demonstrated that the quality of match depends on both the interval and preference list length specified for the simulation. In Scenario 2, the focus was to determine if there was any optimal preference length for the matching algorithm in a 2 week interval. In this scenario, the conditions that mimicked the current matching process were set to constant, varying only the preference list length. The graphical results are depicted in Figures 15 & 16.

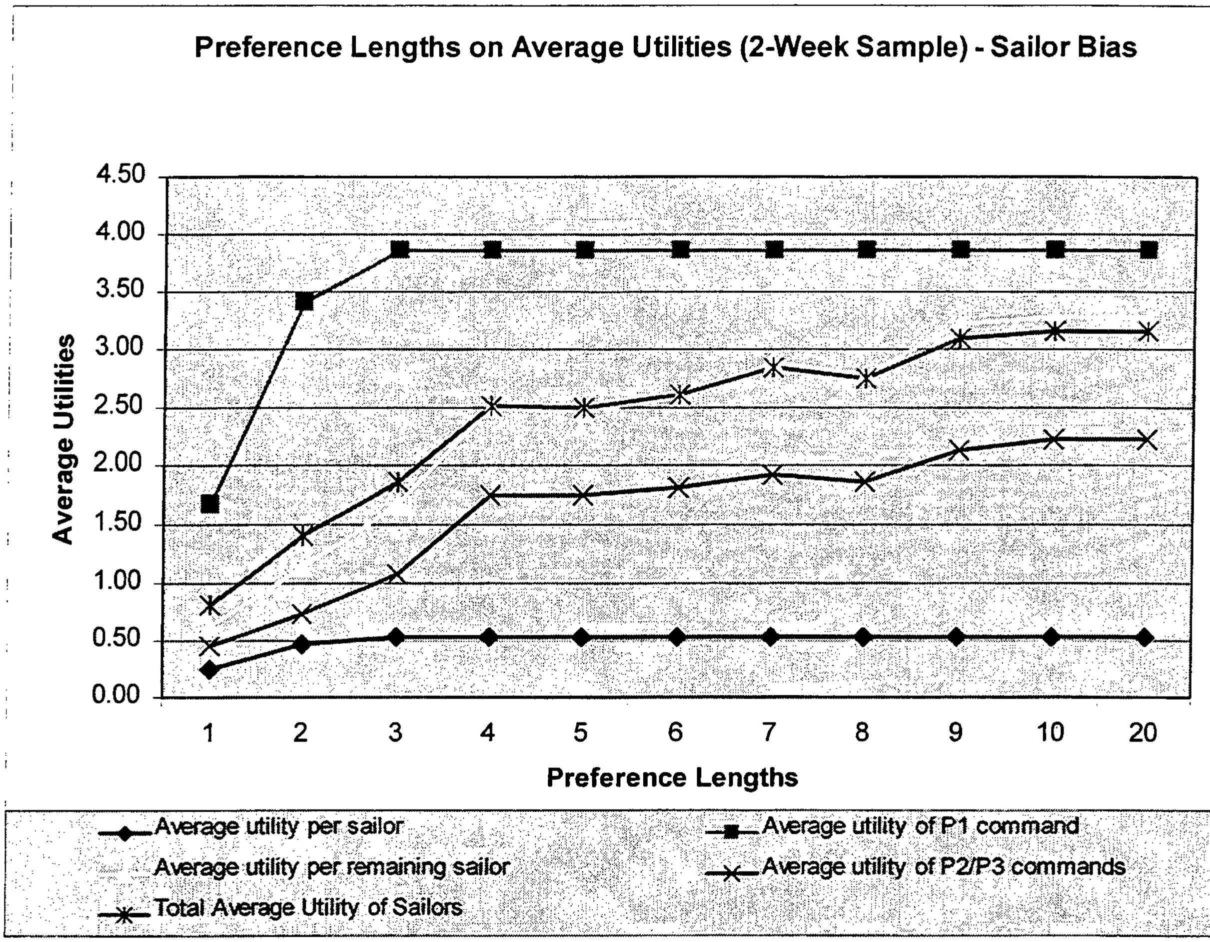

Figure 15: Increasing Preference Length on Average Utilities (Sailor Biased Algorithm)

The results showed that the preference lengths had a significant influence on the quality of the match. For P1 requisitions, the average utilities for the command and sailors matched in this category rose to a maximum as the preference length was increased from 1 to 3, remaining constant thereafter for other increases in the preference length. Similar observations for average utilities were made for the sailors and commands in P2/P3 categories, reaching a maximum when the preference length was increased to 9.

From more re-runs of the simulated scenario, it was noted that the smallest number of requisitions or sailors in each category drive the minimum preference length required before diminishing returns set in. For example, in the category for P1, the minimum number of preference length required before diminishing returns varied in tandem with the number requisitions, as long as the number of requisitions were smaller than the number of sailors available for matching in this category.

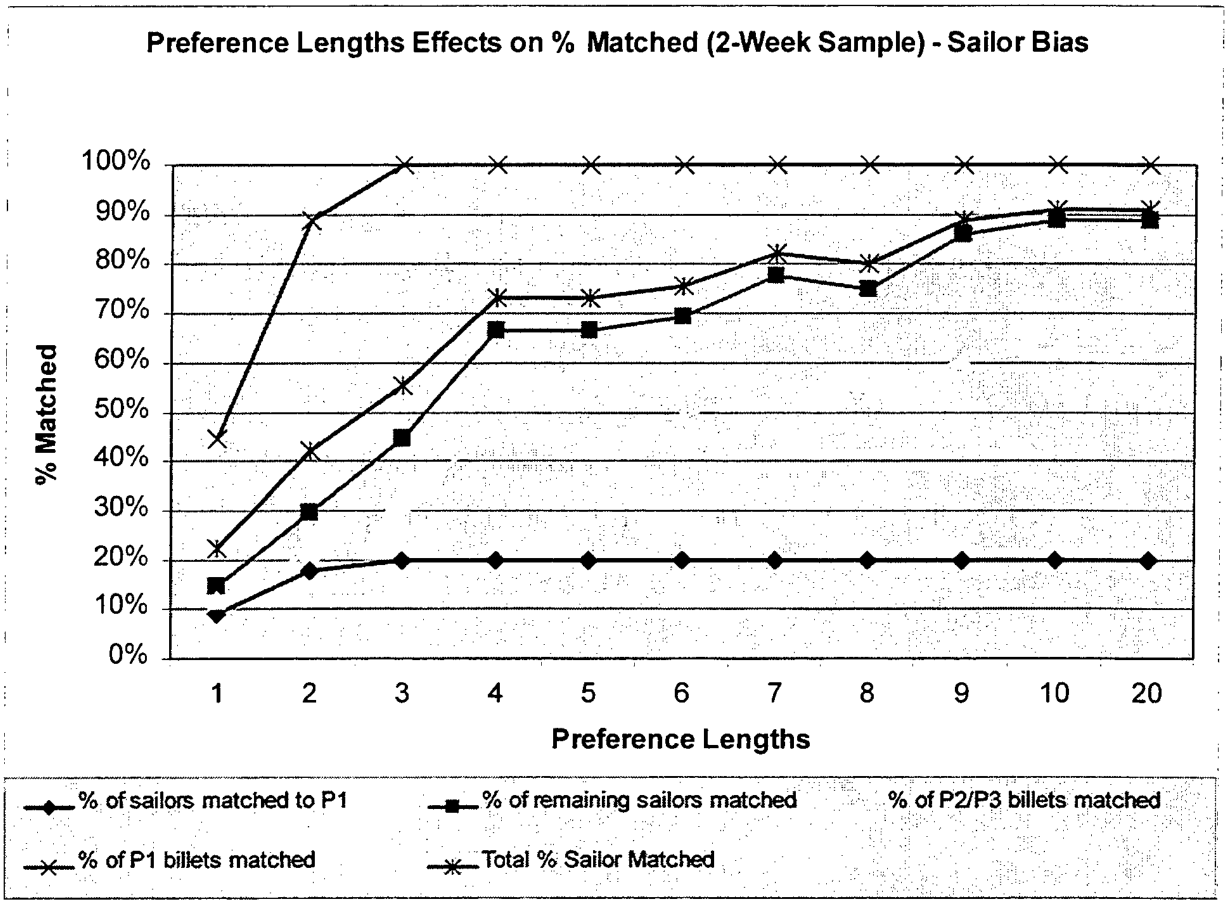

Figure 16: Increasing Preference Lengths on Percentage Matched (Sailor Biased Algorithm)

Similar observations were made when the quantity of matches in each category were plotted against increasing preference length. For sailors and P1 commands, the minimum preference list length appears to be 3, and 9 for P2 commands.

D. SCENARIO 3: DEMONSTRATE THE EFFECT ON MATCHING WITH INCREASING INTERVALS AND PREFERNCE LENGHTS (SAILOR BIASED ALGORITHM)

In scenario 3, the focus was to demonstrate the effect of changing both the matching intervals and preference list length, on the resulting match. From scenario 1, it was noted that the average utilities and percentage matched decreased as the interval was increased, while keeping the preference length at 5. As the interval increases, keeping preference length fixed at 5 means that more sailors and requisitions became "unwanted" as the same favorite jobs/sailors became the predominant feature in most preference lists. Undesirable jobs and sailors are left out from the lists. Total average utilities and percentage matched therefore, showed a general decline. From scenario 2, it was observed that for a given batch size (interval), there exists a minimum length for the preference list, below which many sailors and billets remain unmatched but beyond which the utilities and percentage matched do not increase significantly. This minimum is driven by the smallest number of sailors or requisitions in each category.

In this scenario, both intervals and preference lengths were increased simultaneously to see the combined effects on matching. The preference list length was chosen to keep percentage matched relatively constant. The preference list length are shown in parenthesis in Figure 17. The charted results are shown.

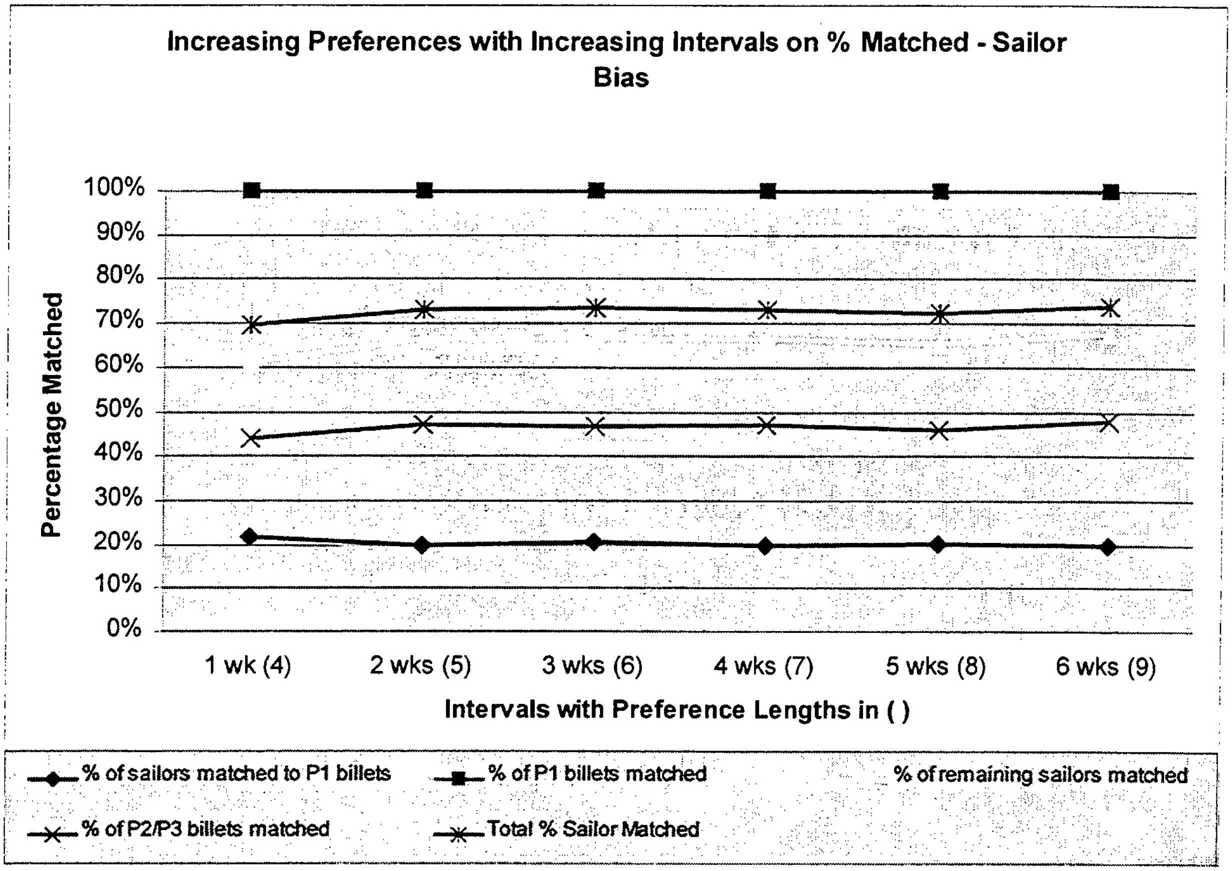

Figure 17: Increasing Interval on Average Utilities

From these results, it appears that the percentage matched can be maintained at about the same level as the matching interval increases, by increasing the preference list lengths correspondingly. This meant that requisition cycle can be increased with no detrimental effect on the quantity matched. The only constraint is the need for longer preference lengths and it may be impracticable for the sailor or the command to specify a list longer than 5. Further work is needed to design a preprocess which would assist the sailor and command in shortlisting their preferences, based on their input of pertinent characteristics for the jobs/sailors they desire. Similar in concept to search engines on the web, such as Yahoo! Search, this preprocess would search out and rank order the preference list for the sailor or command after they key in their relative importance for different characteristics. The sailor and command would then only be required to change the order of the list if they had any disagreement. This is also a task well suited for performance by intelligent agents (Gates and Nissen, 2001). This will make implementing a longer requisition cycle feasible.

E. SCENARIO 4: FIND THE EFFECTS ON MATCHING OF INCREASING PROPORTIONS OF P1 REQUISITIONS (SAILOR BIASED ALGORITHM)

In scenario 4, the proportion of P1 billets was increased. This is to demonstrate what might happen should we fall into the tendency of wanting to please commands by placing too many billets as priority 1 instead of maintaining the current 10 to 15% of the total requisition billets as priority 1. The results are charted in Figure 18.

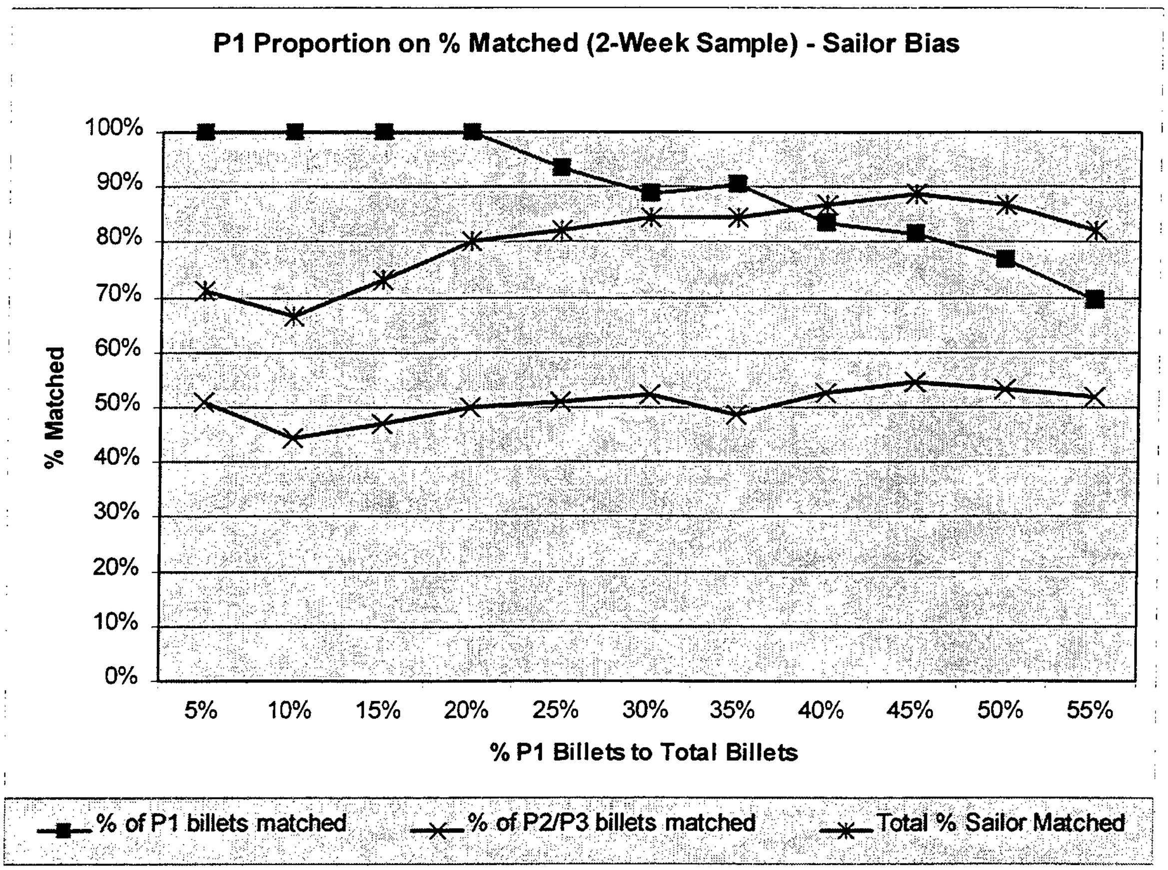

Figure 18: Increasing Proportion of P1 Requisition Billets on Percentage Matched

From the chart, it was noted that the percentage matched for P1 requisitions remained at 100% percent matched until the proportion of P1 requisitions grew beyond 20%. Beyond 20%, the quantity matched began to decline. Similar observations were noted for several other scenarios with different matching intervals, but at constant preference length of 5. The implication of this simulated results showed that an overzealous classification of billets into the P1 category is counterproductive. It will work against the very reason why different priority requisitions were created originally.

It was also observed that in general, the total percentage matched for the sailor population increased to a maximum as the proportion of P1 increases to about 50% before declining. This is consistent with general expectations since at 50% P1 proportion, there would be no differentiation between P1 and P2/P3 in the requisitions available for matching, hence the algorithm is expected to deliver the best match it can delivers by quantity (percentage matched). This observation was consistent with trial runs using different intervals.

The results above were obtained by setting the preference length at 5. Noting the potential influence of preference list length on the quality and quantity of matches, it was hypothesized that if the optimal preference length were used for each desired interval, the maximum proportion of P1 requisitions before deviation from 100% matched could be obtained. In this scenario, the preference length was close to the optimal preference length of 5 for a 2-week matching interval, thus 20%:80% ratio (or less) seemed to be the reasonable cut-off point for 100% matching for P1 requisitions.

F. SCENARIO 5: STUDY THE DIFFERENT EFFECTS ON MATCHING BETWEEN SAILOR AND COMMAND BIASED ALGORITHM

In scenario 5, the sailors and requisitions were matched in similar manner as scenario 1, replacing the sailor-biased algorithm with the command based algorithm.

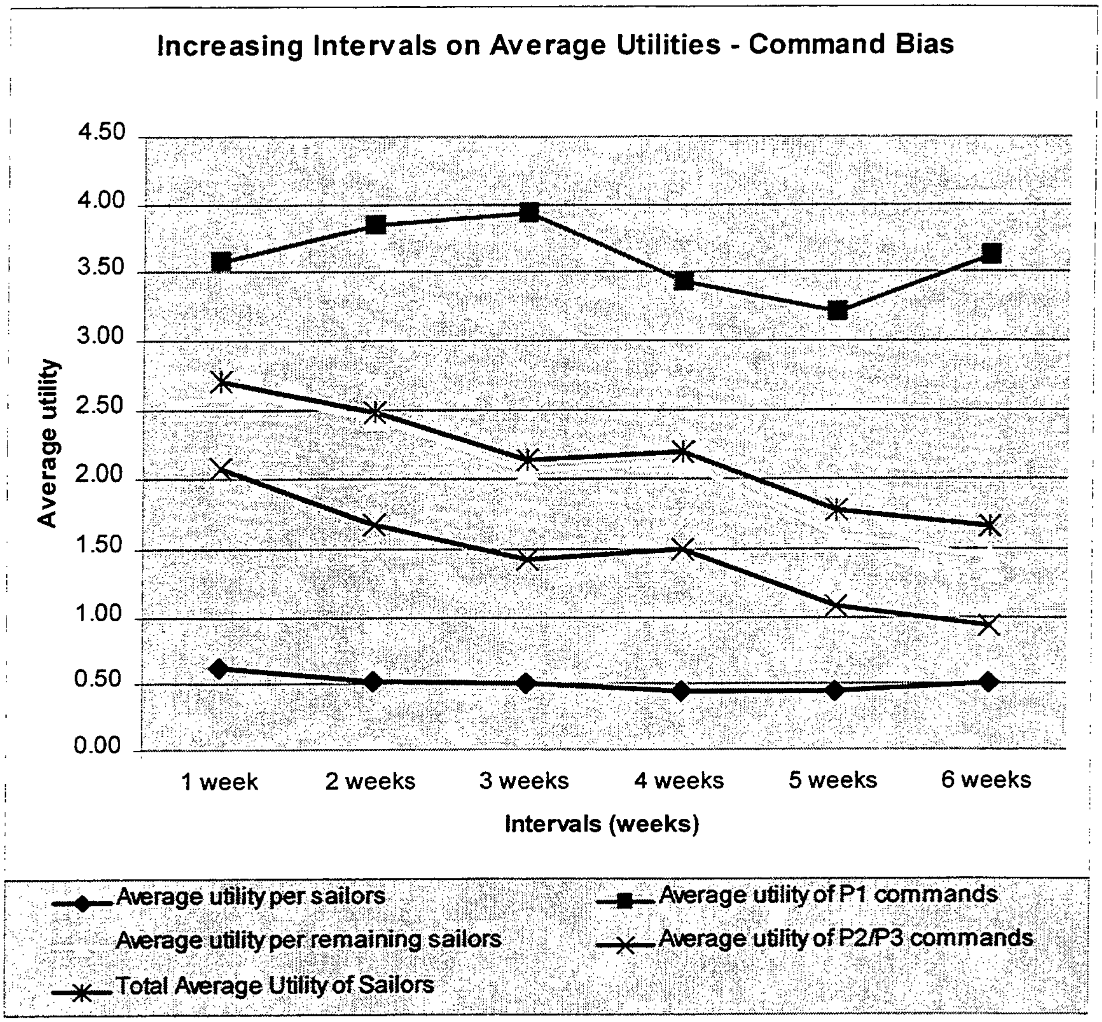

Figure 19: Increasing Intervals on Average Utilities (Command Biased Algorithm)

The results obtained showed that the average utility for the P1 commands were similar to the results in scenario 1. This result was expected since the P1 requisitions were matched hundred percent in both scenarios and the P1 billets were able to choose between all available sailors, so the utility is expected to be about the same. A slight but noticeable overall increase in utility is observed for commands in the P2/P3 category. This difference was probably due to the command-biased algorithm. The matching algorithm probably had more choices in deciding which sailors to fill the requisitions, and matched with the aim so that the commands got the highest sailors on their preference list. This result is consistent with the observed overall decline in total average utility for the sailor when the command-biased algorithm was used to produce the match.

The percentage of match, however, was only affected minimally. There was no significant trend to be observed between the two scenarios. The utility function used for the simulation was based on a Cobb-Douglas model, and hence differences in utility were not expected to be large. This could explain the small differences in results observed. The use of a utility function that resembles the wide ranging tastes in sailors and commands might result in more pronounced differences.

G. SCENARIO 6: COMPARE AND CONTRAST THE OPTIMAL MATCHING OUTCOME POSSIBLE BETWEEN 2-WEEK AND 8-WEEK REQUISITION CYCLE, BY INCREASING THE PREFERENCE LENGTH (SAILOR BIASED ALGORITHM)

Scenario 1 and 2 demonstrated that both the intervals and preference lengths influenced the quality and quantity of matches from the algorithm. In this scenario, the focus was to determine the optimal preference list length for a 8-week interval, making comparisons with the results obtained for a 2-week interval. The results are shown in Figure 20.

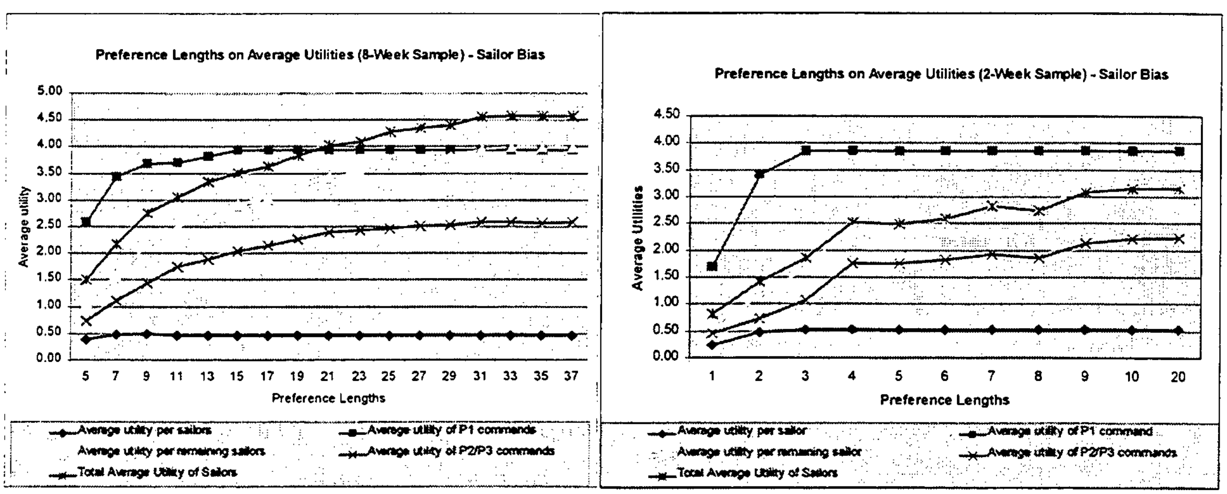

Figure 20: Comparison of Optimal Matching Quality Achievable for 8-week & 2-week Sample

From the graphs, it was noted that the utility for commands in the P1 category tapered off at about preference list length of 14/15. In the 2-week interval, the preference list length was three. The utility for the commands in P2/P3 category and the average utility for every sailor tapered off at around 33. In the 2-week interval, the tapering off occurred at about nine. It was observed that the optimal preference list length for a given interval seemed to vary proportionately. When the interval was increased by a multiple of 4, the preference list length was observed to increase by a multiple of 4 correspondingly.

Comparing the graphs in Figure 20, it was noted that generally, the *optimal average utilities* for the sailors and commands were *higher* for the 8-week interval, compared to the 2-week interval. However, a correspondingly higher preference list number is required for the 8-week sample to attain the higher returns compared to the 2-week sample. Similarly, the team observed a higher percentage matching for the 8-week sample at their optimal point compared to the 2-week sample. Again, this only occurs if preference list lengths are higher for the 8-week sample.

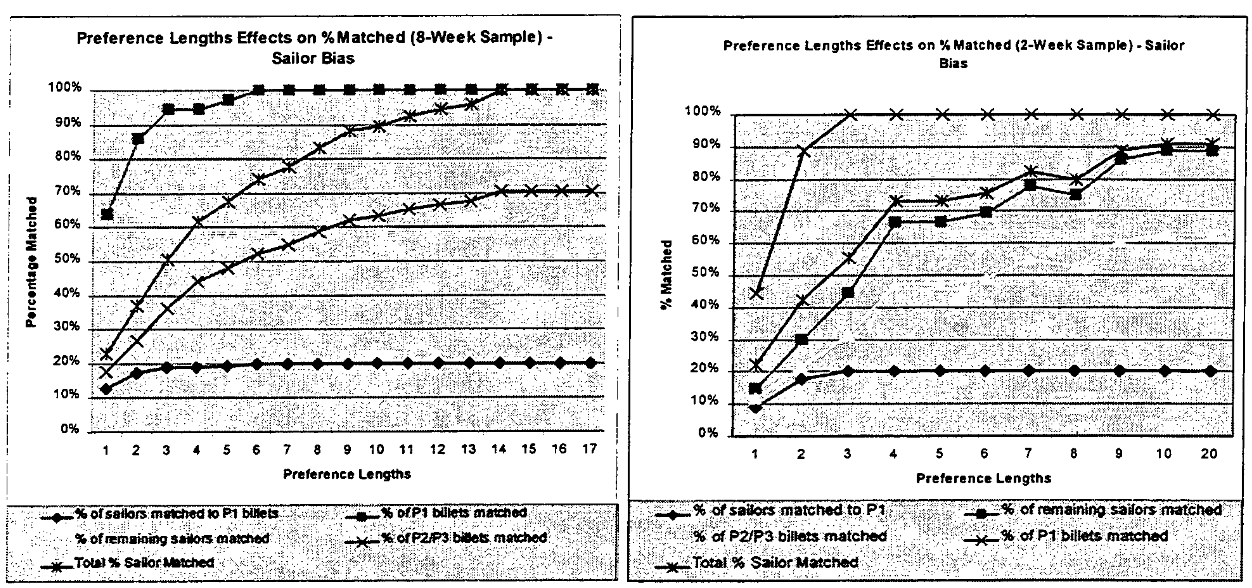

Figure 21: Comparison of Optimal Matching Quantity Between 8-week and 2-week Sample

This observation has significant implication since it means economies of scale can be reaped for larger intervals, provided the optimal preference list length is used. The caveat, however, is the need for the commands and sailors to specify the lengthy preference list which might prove impractical. Furthermore, each sailor would need to weigh their preferences for 240 or more billets, compared to just 60 for a normal 2-week cycle. The commands/detailers would also need to sift through many more sailors than for a 2-week sample. Therefore, some sort of a decision support preprocess (such as that mentioned in scenario 3), using an intelligent web-based agent would be required to reap the benefits of scale. As suggested by the simulation runs, the potential benefits, in both quality and quantity of matching by using longer intervals could be rather significant, thus justifying the need for more studies.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

A web-based detailing system is an essential tool for the future. The explosion of technology and the arrival of generation Y sailors who are technology savvy means that the current way of detailing would have to be improved to maintain an efficient and effective detailing system for the Navy. Otherwise, in the face of technology, the current system would be left behind and risk being labeled obsolete.

This thesis is an important building block of a bigger initiative aimed at serving the Navy with a relevant, efficient and effective detailing system for the future. Through the use of simulations, the team has demonstrated that USN could potentially reap higher quality and quantity of matching by having longer intervals between matching. This is logical; when the pool gets larger, it should be possible to find better matches among the participants using the two-sided matching logic. However, the larger pool must also have longer preference lists to reap the economies of scale. Otherwise, many sailors may list only a narrow selection of the same choice billets, and many commands will only list a narrow selection of the few choice sailors. This will result in a "low match" scenario, and the quality and quantity of the matches will degrade with increasing intervals.

Along with longer intervals and preference lengths, the team found that the information individual sailors and commands/detailers must process is tremendous. Thus, there is strong justification for a web-based intelligent agent. Individual sailors could specify their characteristics and preferences to the agent, and the agent could process, filter and rank order the choice list of billets for that individual sailor. The sailor could then further refine his list or play with different scenarios. Commands and detailers could similarly benefit from such an agent system.

B. RECOMMENDATIONS TO DOD / SUGGESTED FURTHER STUDIES

While ABEMS has demonstrated potential areas from which USN could reap benefits in their detailing process, further research is required. Most significant would be the using actual sailor and billet data in the process to better predict matching outcomes. The use of possible "incentives" in the form of bonus dollars should also be examined to make the more onerous billets more desirable to sailors. This could even expand to the use of gaming theory where bonus dollars attached to billets could be bided upon and dynamically adjusted according to market forces.

In Chapter III, it was mentioned that this thesis focused on the effects on interested parties' utilities resulting from a sailor or command biased logic. In reality, it is very likely that the match occurs between these two biases. Hence a "balanced" matching algorithm to better reflect reality will require further studies and possibly extra coding to improve this simulation model.

In Scenario 1 findings, we noted that that the determination of the optimal interval required obtaining the optimal preference list length for each unique interval through simulations before running more simulations to finally obtain the optimal interval. The use of commercial simulation software allows future study to be conducted for this purpose.

This thesis demonstrated the potential benefits that can be reaped from a agent-based matching system for the Navy. The results revealed the tip of the ice-berg: the quality and quantity of matches can improve with electronic matching. Further in depth studies however, should be conducted to determine scientifically, the variables that should be included in the simulation program and the relative weight each factor contributes to the sailor's and commands' utility. This will add realism and credibility to the simulation program for comparison with real data input from today's process.

APPENDIX A. TABLES OF RESULTS FROM SCENARIO 1-6

Scenario 1

[redacted]

Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	5	5	5	5	5	5
[redacted]	**1 week**	**2 weeks**	**3 weeks**	**4 weeks**	**5 weeks**	**6 weeks**
Total number of sailors	23	45	68	90	113	135
No of sailors matched	5	9	14	16	19	25
% of sailors matched to P1 billets	**21.74%**	**20.00%**	**20.59%**	**17.78%**	**16.81%**	**18.52%**
Total utility of matched sailors	14.4054	23.6423	33.8930	40.4706	49.7271	67.3856
Average utility per sailor	**0.6263**	**0.5254**	**0.4984**	**0.4497**	**0.4401**	**0.4992**
Total number of P1 billets	5	9	14	18	23	27
No of P1 billets matched	5	9	14	16	19	25
% of P1 billets matched	**100.00%**	**100.00%**	**100.00%**	**88.89%**	**82.61%**	**92.59%**
Total utility of matched commands	17.8928	34.6774	55.0437	61.7142	73.6243	98.0313
Average utility of P1 command	**3.5786**	**3.8530**	**3.9317**	**3.4286**	**3.2011**	**3.6308**
[redacted]						
No of remaining sailors	18	36	54	74	94	110
No of sailors matched to P2 billets	14	24	31	40	37	36
% or remaining sailors matched	**77.78%**	**66.67%**	**57.41%**	**54.05%**	**39.36%**	**32.73%**
Total utility of matched sailors	49.6272	88.7141	116.4915	160.1194	160.4167	160.0499
Average utility per remaining sailor	**2.7571**	**2.4643**	**2.1573**	**2.1638**	**1.7066**	**1.4550**
Total number of P2/P3 billets	25	51	77	102	128	153
No of P2 billets matched	14	24	31	40	37	36
% of P2/P3 billets matched	**56.00%**	**47.06%**	**40.26%**	**39.22%**	**28.91%**	**23.53%**
Total utility of matched commands	49.5167	89.8517	115.9128	157.2701	150.1207	148.1747
Average utility of P2/P3 command	**1.9807**	**1.7618**	**1.5054**	**1.5419**	**1.1728**	**0.9685**
Total Average Utility of Sailors	**2.7840**	**2.4968**	**2.2115**	**2.2288**	**1.8597**	**1.6847**
Total % Sailor Matched	**82.61%**	**73.33%**	**66.18%**	**62.22%**	**49.56%**	**45.19%**

Scenario 2

[redacted]

Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**20**
[redacted]											
Total number of sailors	45	45	45	45	45	45	45	45	45	45	45
No of sailors matched	4	8	9	9	9	9	9	9	9	9	9
% of sailors matched to P1	**8.89%**	**17.78%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**
Total utility of matched sailors	11.0163	21.3065	23.6423	23.6423	23.6423	23.6423	23.6423	23.6423	23.6423	23.6423	23.6423
Average utility per sailor	**0.2448**	**0.4735**	**0.5254**	**0.5254**	**0.5254**	**0.5254**	**0.5254**	**0.5254**	**0.5254**	**0.5254**	**0.5254**
Total number of P1 billets	9	9	9	9	9	9	9	9	9	9	9
No of P1 billets matched	4	8	9	9	9	9	9	9	9	9	9
% of P1 billets matched	**44.44%**	**88.89%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Total utility of matched commands	15.1284	30.6482	34.6774	34.6774	34.6774	34.6774	34.6774	34.6774	34.6774	34.6774	34.6774
Average utility of P1 command	**1.6809**	**3.4054**	**3.8530**	**3.8530**	**3.8530**	**3.8530**	**3.8530**	**3.8530**	**3.8530**	**3.8530**	**3.8530**
[redacted]											
No of remaining sailors	41	37	36	36	36	36	36	36	36	36	36
No of sailors matched to P2 billets	6	11	16	24	24	25	28	27	31	32	32
% of remaining sailors matched	**14.63%**	**29.73%**	**44.44%**	**66.67%**	**66.67%**	**69.44%**	**77.78%**	**75.00%**	**86.11%**	**88.89%**	**88.89%**
Total utility of matched sailors	25.9638	42.2442	60.1982	89.5577	88.7141	93.2451	103.7262	99.9243	115.4895	118.1076	118.1076
Average utility per remaining sailor	**0.6333**	**1.1417**	**1.6722**	**2.4877**	**2.4643**	**2.5901**	**2.8813**	**2.7757**	**3.2080**	**3.2808**	**3.2808**
Total number of P2/P3 billets	51	51	51	51	51	51	51	51	51	51	51
No of P2/P3 billets matched	6	11	16	24	24	25	28	27	31	32	32
% of P2/P3 billets matched	**11.76%**	**21.57%**	**31.37%**	**47.06%**	**47.06%**	**49.02%**	**54.90%**	**52.94%**	**60.78%**	**62.75%**	**62.75%**
Total utility of matched commands	23.2075	37.2387	54.9174	89.2330	89.8517	92.6996	98.0389	94.9038	108.5811	113.3851	113.4981
Average utility of P2/P3 commands	**0.4550**	**0.7302**	**1.0768**	**1.7497**	**1.7618**	**1.8176**	**1.9223**	**1.8609**	**2.1290**	**2.2232**	**2.2255**
Total Average Utility of Sailors	**0.8218**	**1.4122**	**1.8631**	**2.5156**	**2.4968**	**2.5975**	**2.8304**	**2.7459**	**3.0918**	**3.1500**	**3.1500**
Total % Sailor Matched	**22.22%**	**42.22%**	**55.56%**	**73.33%**	**73.33%**	**75.56%**	**82.22%**	**80.00%**	**88.89%**	**91.11%**	**91.11%**

Scenario 3

[redacted]

Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	**4**	**5**	**6**	**7**	**8**	**9**
[redacted]	**1 wk (4)**	**2 wks (5)**	**3 wks (6)**	**4 wks (7)**	**5 wks (8)**	**6 wks (9)**
Total number of sailors	23	45	68	90	113	135
No of sailors matched to P1 billets	5	9	14	18	23	27
% of sailors matched to P1 billets	**21.74%**	**20.00%**	**20.59%**	**20.00%**	**20.35%**	**20.00%**
Total utility of matched sailors	14.4054	23.6423	33.8930	41.4386	53.3657	63.5438
Average utility per sailors	**0.6263**	**0.5254**	**0.4984**	**0.4604**	**0.4723**	**0.4707**
Total number of P1 billets	5	9	14	18	23	27
No of P1 billets matched	5	9	14	18	23	27
% of P1 billets matched	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Total utility of matched commands	17.8928	34.6774	55.0437	67.7779	86.3295	104.6727
Average utility of P1 commands	**3.5786**	**3.8530**	**3.9317**	**3.7654**	**3.7535**	**3.8768**
[redacted]						
No of remaining sailors	18	36	54	72	90	108
No of sailors matched to P2/P3 billets	11	24	36	48	59	73
% of remaining sailors matched	**61.11%**	**66.67%**	**66.67%**	**66.67%**	**65.56%**	**67.59%**
Total utility of matched sailors	39.2482	88.7141	136.4093	187.4535	238.6823	295.5469
Average utility per remaining sailors	**2.1805**	**2.4643**	**2.5261**	**2.6035**	**2.6520**	**2.7365**
Total number of P2/P3 billets	**25**	**51**	**77**	**102**	**128**	**153**
No of P2/P3 billets matched	11	24	36	48	59	73
% of P2/P3 billets matched	**44.00%**	**47.06%**	**46.75%**	**47.06%**	**46.09%**	**47.71%**
Total utility of matched commands	42.2819	89.8517	133.6207	187.7974	232.2339	287.0601
Average utility of P2/P3 commands	**1.6913**	**1.7618**	**1.7353**	**1.8412**	**1.8143**	**1.8762**
Total Average Utility of Sailors	**2.3328**	**2.4968**	**2.5044**	**2.5432**	**2.5845**	**2.6599**
Total % Sailor Matched	**69.57%**	**73.33%**	**73.53%**	**73.33%**	**72.57%**	**74.07%**

Scenario 4

[redacted]

Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	5	5	5	5	5	5	5	5	5	5	5
% P1 billets to Total Billets	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**
[redacted]											
Total number of sailors	45	45	45	45	45	45	45	45	45	45	45
No of sailors matched to P1 billets	3	6	9	12	14	16	19	20	22	23	23
% of sailors matched to P1 billets	**6.67%**	**13.33%**	**20.00%**	**26.67%**	**31.11%**	**35.56%**	**42.22%**	**44.44%**	**48.89%**	**51.11%**	**51.11%**
Total utility of matched sailors	8.2629	16.2110	23.6423	31.3302	36.0866	41.2227	48.0668	54.4637	63.1475	72.8372	74.4348
Average utility per sailors	**0.1836**	**0.3602**	**0.5254**	**0.6962**	**0.8019**	**0.9161**	**1.0682**	**1.2103**	**1.4033**	**1.6186**	**1.6541**
Total number of P1 billets	3	6	9	12	15	18	21	24	27	30	33
No of P1 billets matched	3	6	9	12	14	16	19	20	22	23	23
% of P1 billets matched	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**93.33%**	**88.89%**	**90.48%**	**83.33%**	**81.48%**	**76.67%**	**69.70%**
Total utility of matched commands	11.7764	21.8188	34.6774	46.2593	53.9435	59.9274	70.6086	76.2567	83.7639	86.1148	87.3899
Average utility of P1 commands	**3.9255**	**3.6365**	**3.8530**	**3.8549**	**3.5962**	**3.3293**	**3.3623**	**3.1774**	**3.1024**	**2.8705**	**2.6482**
[redacted]											
No of remaining sailors	42	39	36	33	31	29	26	25	23	22	22
No of sailors matched to P2/P3 billets	29	24	24	24	23	22	19	19	18	16	14
% of remaining sailors matched	**69.05%**	**61.54%**	**66.67%**	**72.73%**	**74.19%**	**75.86%**	**73.08%**	**76.00%**	**78.26%**	**72.73%**	**63.64%**
Total utility of matched sailors	98.1536	88.9177	88.7141	86.5873	83.1835	79.1540	68.0172	63.2174	61.8455	56.6733	48.8274
Average utility per remaining sailor	**2.3370**	**2.2799**	**2.4643**	**2.6239**	**2.6833**	**2.7294**	**2.6160**	**2.5287**	**2.6889**	**2.5761**	**2.2194**
Total number of P2/P3 billets	**57**	**54**	**51**	**48**	**45**	**42**	**39**	**36**	**33**	**30**	**27**
No of P2/P3 billets matched	29	24	24	24	23	22	19	19	18	16	14
% of P2/P3 billets matched	**50.88%**	**44.44%**	**47.06%**	**50.00%**	**51.11%**	**52.38%**	**48.72%**	**52.78%**	**54.55%**	**53.33%**	**51.85%**
Total utility of matched commands	110.4233	89.1729	89.8517	90.7015	81.2993	81.4050	66.8496	65.9981	63.5824	54.0751	48.9870
Average utility of P2/P3 commands	**1.9373**	**1.6513**	**1.7618**	**1.8896**	**1.8067**	**1.9382**	**1.7141**	**1.8333**	**1.9267**	**1.8025**	**1.8143**
Total Average Utility of Sailors	**2.3648**	**2.3362**	**2.4968**	**2.6204**	**2.6504**	**2.6750**	**2.5796**	**2.6151**	**2.7776**	**2.8780**	**2.7392**
Total % Sailor Matched	**71.11%**	**66.67%**	**73.33%**	**80.00%**	**82.22%**	**84.44%**	**84.44%**	**86.67%**	**88.89%**	**86.67%**	**82.22%**

Scenario 5

[redacted]						
Type of matching biasness	Comd	Comd	Comd	Comd	Comd	Comd
Preference list length	**5**	**5**	**5**	**5**	**5**	**5**
[redacted]	**1 week**	**2 weeks**	**3 weeks**	**4 weeks**	**5 weeks**	**6 weeks**
Total number of sailors	23	45	68	90	113	135
No of sailors matched to P1 billets	5	9	14	16	19	25
% of sailors matched to P1 billets	**21.74%**	**20.00%**	**20.59%**	**17.78%**	**16.81%**	**18.52%**
Total utility of matched sailors	14.4054	23.6423	33.8930	40.4706	49.7271	67.3856
Average utility per sailors	**0.6263**	**0.5254**	**0.4984**	**0.4497**	**0.4401**	**0.4992**
Total number of P1 billets	5	9	14	18	23	27
No of P1 billets matched	5	9	14	16	19	25
% of P1 billets matched	**100.00%**	**100.00%**	**100.00%**	**88.89%**	**82.61%**	**92.59%**
Total utility of matched commands	17.8928	34.6774	55.0437	61.7142	73.6243	98.0313
Average utility of P1 commands	**3.5786**	**3.8530**	**3.9317**	**3.4286**	**3.2011**	**3.6308**
[redacted]						
No of remaining sailors	18	36	54	74	94	110
No of sailors matched to P2/P3 billets	14	23	29	39	34	35
% of remaining sailors matched	**77.78%**	**63.89%**	**53.70%**	**52.70%**	**36.17%**	**31.82%**
Total utility of matched sailors	47.6515	87.7141	111.7284	157.0926	151.0198	158.1175
Average utility per remaining sailors	**2.6473**	**2.4365**	**2.0690**	**2.1229**	**1.6066**	**1.4374**
Total number of P2/P3 billets	**25**	**51**	**77**	**102**	**128**	**153**
No of P2/P3 billets matched	14	23	29	39	34	35
% of P2/P3 billets matched	**56.00%**	**45.10%**	**37.66%**	**38.24%**	**26.56%**	**22.88%**
Total utility of matched commands	52.1438	85.9343	109.6569	152.9523	138.5339	143.2279
Average utility of P2/P3 commands	**2.0858**	**1.6850**	**1.4241**	**1.4995**	**1.0823**	**0.9361**
Total Average Utility of Sailors	**2.6981**	**2.4746**	**2.1415**	**2.1951**	**1.7765**	**1.6704**
Total % Sailor Matched	**82.61%**	**71.11%**	**63.24%**	**61.11%**	**46.90%**	**44.44%**

Scenario 6

[redacted]	1	2	3	4	5	6	7	8
Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**
[redacted]								
Total number of sailors	180	180	180	180	180	180	180	180
No of sailors matched to P1 billets	23	31	34	34	35	36	36	36
% of sailors matched to P1 billets	**12.78%**	**17.22%**	**18.89%**	**18.89%**	**19.44%**	**20.00%**	**20.00%**	**20.00%**
Total utility of matched sailors	69.6543	87.7399	88.5935	81.9109	83.7529	84.1761	84.1761	84.1761
Average utility per sailors	**0.3870**	**0.4874**	**0.4922**	**0.4551**	**0.4653**	**0.4676**	**0.4676**	**0.4676**
Total number of P1 billets	36	36	36	36	36	36	36	36
No of P1 billets matched	23	31	34	34	35	36	36	36
% of P1 billets matched	**63.89%**	**86.11%**	**94.44%**	**94.44%**	**97.22%**	**100.00%**	**100.00%**	**100.00%**
Total utility of matched commands	93.2883	123.8833	132.8013	133.0050	137.6220	141.6557	141.6557	141.6557
Average utility of P1 commands	**2.5913**	**3.4412**	**3.6889**	**3.6946**	**3.8228**	**3.9349**	**3.9349**	**3.9349**
[redacted]								
No of remaining sailors	157	149	146	146	145	144	144	144
No of sailors matched to P2/P3 billets	36	55	74	90	98	107	112	120
% of remaining sailors matched	**22.93%**	**36.91%**	**50.68%**	**61.64%**	**67.59%**	**74.31%**	**77.78%**	**83.33%**
Total utility of matched sailors	166.6011	237.2848	314.1990	362.3611	400.5922	420.8016	437.6886	468.1463
Average utility per remaining sailors	**1.0612**	**1.5925**	**2.1520**	**2.4819**	**2.7627**	**2.9222**	**3.0395**	**3.2510**
Total number of P2/P3 billets	**204**	**204**	**204**	**204**	**204**	**204**	**204**	**204**
No of P2/P3 billets matched	36	55	74	90	98	107	112	120
% of P2/P3 billets matched	**17.65%**	**26.96%**	**36.27%**	**44.12%**	**48.04%**	**52.45%**	**54.90%**	**58.82%**
Total utility of matched commands	148.7222	228.1017	294.0388	357.7826	383.8441	416.4290	435.2729	462.7993
Average utility of P2/P3 commands	**0.7290**	**1.1181**	**1.4414**	**1.7538**	**1.8816**	**2.0413**	**2.1337**	**2.2686**
Total Average Utility of Sailors	**1.5048**	**2.1814**	**2.7589**	**3.0430**	**3.3403**	**3.5068**	**3.6241**	**3.8356**
Total % Sailor Matched	**22.93%**	**36.91%**	**50.68%**	**61.64%**	**67.59%**	**74.31%**	**77.78%**	**83.33%**

[redacted]	9	10	11	12	13	14	15	16
Type of matching biasness	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor	Sailor
Preference list length	**21**	**23**	**25**	**27**	**29**	**31**	**33**	**35**
[redacted]								
Total number of sailors	180	180	180	180	180	180	180	180
No of sailors matched to P1 billets	36	36	36	36	36	36	36	36
% of sailors matched to P1 billets	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**	**20.00%**
Total utility of matched sailors	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761	84.1761
Average utility per sailors	**0.4676**	**0.4676**	**0.4676**	**0.4676**	**0.4676**	**0.4676**	**0.4676**	**0.4676**
Total number of P1 billets	36	36	36	36	36	36	36	36
No of P1 billets matched	36	36	36	36	36	36	36	36
% of P1 billets matched	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Total utility of matched commands	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557	141.6557
Average utility of P1 commands	**3.9349**	**3.9349**	**3.9349**	**3.9349**	**3.9349**	**3.9349**	**3.9349**	**3.9349**
[redacted]								
No of remaining sailors	144	144	144	144	144	144	144	144
No of sailors matched to P2/P3 billets	127	129	133	136	138	144	144	144
% of remaining sailors matched	**88.19%**	**89.58%**	**92.36%**	**94.44%**	**95.83%**	**100.00%**	**100.00%**	**100.00%**
Total utility of matched sailors	495.2927	504.8010	531.6699	543.0815	550.2485	570.7605	574.3064	574.7457
Average utility per remaining sailors	**3.4395**	**3.5054**	**3.6922**	**3.7714**	**3.8212**	**3.9636**	**3.9882**	**3.9913**
Total number of P2/P3 billets	**204**	**204**	**204**	**204**	**204**	**204**	**204**	**204**
No of P2/P3 billets matched	127	129	133	136	138	144	144	144
% of P2/P3 billets matched	**62.25%**	**63.24%**	**65.20%**	**66.67%**	**67.65%**	**70.59%**	**70.59%**	**70.59%**
Total utility of matched commands	488.1953	494.3620	503.3138	514.3585	515.5739	528.8504	525.7994	525.4729
Average utility of P2/P3 commands	**2.3931**	**2.4233**	**2.4672**	**2.5214**	**2.5273**	**2.5924**	**2.5774**	**2.5758**
Total Average Utility of Sailors	**4.0241**	**4.0901**	**4.2787**	**4.3560**	**4.4057**	**4.5482**	**4.5728**	**4.5758**
Total % Sailor Matched	**88.19%**	**89.58%**	**92.36%**	**94.44%**	**95.83%**	**100.00%**	**100.00%**	**100.00%**

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