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THESIS

A DYNAMIC MODEL OF THE WORK FORCE AT THE NAVAL AIR WEAPONS STATION CHINA LAKE

by

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September 2008

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13. ABSTRACT (maximum 200 words)

Outsourcing entered the lexicon during the 1980s and today is a standard practice in the Department of Defense. Contractors are now filling jobs that traditionally have been held by government employees. As yearly budgets change, the decision to outsource or not outsource government jobs has placed a significant burden on project managers. This thesis focuses on the dynamic modeling of a work force labor mix consisting of civilian and contractor workers. It gives the government manager a tool to determine the optimum work force numbers for a given work load demand. It is envisioned that local managers will be able to use this study to make a more balanced and informed decision when hiring civilian and contract workers.

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A DYNAMIC MODEL OF THE WORK FORCE AT THE NAVAL AIR WEAPONS STATION CHINA LAKE

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EXECUTIVE SUMMARY

This paper presents a dynamic model and systems thinking approach to develop tools to determine the best work force labor mix to meet each fiscal year's fluctuating workload demands. As the workload changes, one must hire to meet increased workload or reduce the workforce in cases when workload decreases. Ideally, one should make work force adjustments in both a timely and cost efficient manner. The work force at the Naval Air Warfare Center Weapons Division (NAWCWD) consists of civilian and contractor workers, each of which are governed by separate policies making workforce forecasts more difficult. The objective of this thesis was to develop a computer simulation to find the most acceptable fiscal labor mix for NAWCWD that would minimize labor cost while preventing drastic management actions such as a reduction in force or serious cost overruns due to an overly large, underemployed workforce.

This study identified the parameters that management could most influence to change the work force labor mix. The parameters most important to management's ability to change the labor mix included four rates: accepting work, influencing hiring success rates, and separation rates for both civilian and contract workers. This paper presents an analytical model that outlines the interactions and feedback loops of the labor mix system. Additionally this paper presents a computer model that uses these parameters, resulting in a simulation of the NAWCWD work force that outputs the size of the workforce and government/contractor mix.

The system parameters were selected based on interviews with subject matter experts and corresponding analytical model development from the interaction of the primary parameters. Historical data was used to gauge the model. The results of the simulation are presented. Analysis of the labor mix simulations revealed that the business system was sensitive to certain parameters that potentially could be affected by management policy. The most significant parameter that influenced the best labor mix was the rate at which civilians left the work force. This provides insight to management for policy modification to effect this rate.

Senior management understands that business opportunities must be pursued. To succeed in capturing new work and maintain a healthy organization, they need a balanced work force to provide customers with desired products. Therefore, hiring civilians and contractors with the right skills and talents is mandatory, and this research helps management determine the most acceptable balance. Deciding when to hire and how many people to hire, and if they are civilian or contractor hires, can be adjusted based on the use of the analysis tool presented.

From the results of this study, it was clear the parameters such as rate of separation and rate of successful hires and acceptance of work had a significant impact on the dynamics of the work force labor mix. Manager's response to hiring and attrition could be adjusted to effect changes on the system. The contractor work force protects the civilian work force by dampening the effects of changing workload demand and changes in hiring and separation rates for civilian workers. The policies that affect the civilian and contractor labor mix can be controlled by NAWCWD management.

The ability to predict absolute system behavior was not a goal of this study. However, the ability to estimate the trends in future behavior of the labor mix system in response to current decisions was an important objective of the systems dynamic research. This model is able to predict the relative direction and magnitude of change, and NAWCWD management is now able to study the trade space effects of their decisions without having to live with unintended consequences.

ABSTRACT

Outsourcing entered the lexicon during the 1980s and today is a standard practice in the Department of Defense. Contractors are now filling jobs that traditionally have been held by government employees. As yearly budgets change, the decision to outsource or not outsource government jobs has placed a significant burden on project managers. This thesis focuses on the dynamic modeling of a work force labor mix consisting of civilian and contractor workers. It gives the government manager a tool to determine the optimum work force numbers for a given work load demand. It is envisioned that local managers will be able to use this study to make a more balanced and informed decision when hiring civilian and contract workers.

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LIST OF ACRONYMS AND ABBREVIATIONS

BRAC	Base Realignment and Closure
CL	China Lake
CLD	Causal Loop Diagram
DoD	Department of Defense
G&A	General and Administrative
KTR	Contractor
MY	Man-year
NAVAIR	Naval Air Systems Command
NAWCWD	Naval Air Warfare Center Weapons Division
NAWS	Naval Air Weapons Station
NOTS	Naval Ordnance Test Station
NWCF	Navy Working Capital Fund
RDT&E	Research, Development, Test and Evaluation
RIF	Reduction in Force
SME	Subject Matter Expert
WD	Weapons Division

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I. INTRODUCTION

A. BACKGROUND

Throughout the past several decades, the United States Department of Defense (DoD) has adapted and evolved to meet changing political and social needs. The operational tempo for our nation's military forces has never been higher than it is today. Due to continuing world conflicts and the ongoing wars in Iraq and Afghanistan, the demand for modern weaponry continues to increase. Despite the increased demand, the budgets allocated for weapons research and development continue to decrease. Weapons laboratories' have had to adapt to receiving less money, and yet remain productive, as congressional staffers question the laboratories need to exist.

In recent history, the cost of funding military forces has led to a decrease in the availability of Research, Development, Test and Evaluation (RDT&E) funds. This decrease in funding has led to a competition for resources within the military industrial complex between the government research laboratories and their industrial counterparts. Laboratories, such as the Naval Air Warfare Center Weapons Division (NAWCWD) located at Naval Air Weapons Station (NAWS) China Lake are forced to be more productive while working with diminished resources.

The normal response to reduced funding is to look for any existing inefficiency that can be corrected. In many cases the effort to increase efficiency is directed at improving the labor force. As always, it is best if there is an understanding of the current labor practices before new practices are developed. One labor solution has been to outsource the work to contract workers.

Outsourcing entered the lexicon during the 1980s and today is a standard practice in the United States. Contractors are filling an ever-increasing number of jobs, many which would traditionally have been held by government employees. However, outsourcing is still a relatively new practice at NAWCWD. For instance, NAWS China Lake is a Navy airborne weapons research and engineering test and evaluation facility in a remote geographic area. It is located in the northeast corner of California's Mojave Desert next to a small town and must bring in employees from outside the immediate community. Commonly just called "China Lake," it is the home base of several tenant commands, including the largest tenant command, NAWCWD. These jobs, once wholly staffed by government employees, are now being supplemented with contractor personnel. According to Scott O'Neil, the NAWCWD executive director, in 2007, NAWCWD had an annual budget of $1.086B and 4,059 civilian employees, 600 military personnel and 1,859 contractors.

This thesis focuses on the isolated work force environment of NAWS and NAWCWD. Given fluctuating year-to-year work demands, the parameters were identified, and the various scenarios of civilian and contractor labor mix were dynamically modeled and simulated. The result was a model that a local manager could now use to make a balanced and informed decision when hiring and outsourcing new workers.

It is necessary to understand the current NAWCWD corporate operations and the internal and external influences affecting the laboratory to best appreciate the dynamics the labor force has on business operations. NAWCWD is a DoD organization led by a military commander and a work force made up of civilians, military and contractors. The command structure consists of a Navy admiral as commanding officer and a civilian executive director. The civilian executive director maintains the corporate knowledge and continuity between the successive military commanders. It is the responsibility of the admiral and executive director to provide vision and leadership and ensure a healthy RDT&E government laboratory is supporting the goals of the military. Also, NAWCWD is a field activity under the Naval Air Systems Command (NAVAIR). The headquarters of NAVAIR is located at Patuxent River, Maryland, and is far removed from the labor problems facing the western laboratories such as China Lake. It is hoped that this study can help the managers at China Lake communicate the dynamics of the work force to their distant supervisors.

B. STATEMENT OF THE PROBLEM

The Warfare Center operates as a Navy Working Capital Fund (NWCF). Working capital funds were established under Title 10 of the United States Code 2208 and allow government organizations to operate under a commercial-like business model.

NWCF relies on sales revenue rather than direct Congressional appropriations to finance operations. The fund is intended to generate adequate revenue to cover the full costs of its operations and, at the same time, to finance the fund's continuing operations without fiscal year limitation. The fund is intended to operate on a break-even basis over time; that is, it neither makes a profit nor incurs a loss.

These rules cause NAWCWD to operate similar to a private business. Operating under this model presents unique challenges for a government laboratory whose primary purpose is weapons development. Weapons Division (WD) does not receive DoD operational funding like other DoD laboratories. Instead, external customers supply direct funds. The work force is paid with direct funds while they work for a customer and with overhead funds when they do not have a customer.

In a NWCF organization, direct funds are taxed to generate overhead funds. These overhead funds are then used as discretionary funds and reinvested into the laboratory. A problem arises with the cost of doing business when the level of direct funding falls and overhead costs are not reduced or increased. For example, if a customer cancels a program that brought in direct funds, management still has to pay the labor force, but now they are paid with overhead funding. Other customers now have to bear the burden as their direct funds are taxed to cover the increased use of overhead funds.

When this happens, government employees can be reassigned to other direct funded projects. As would be expected, a contracted worker could be laid off while the cost of a government worker must be absorbed. Yet, management does not want to have to absorb the cost of government worker, nor do they want to let the contractor go. Therefore, management wants to be able to explore the impact of the best labor mix between government and contractor work force.

C. PURPOSE OF THE STUDY

The purpose of this study was to develop an analytical model that can then be used to create a digital simulation allowing analysis of the work force labor mix. This study examined the labor dynamics of one site of the United States Navy RDT&E facility NAWS, China Lake.

The defense and weapons business is a dynamic environment with fluctuating funding and work levels that influence the local labor force. This environment can play havoc with long range planning and the perturbations in the size of the labor force, funding cycles and work accomplished. NAWCWD management would like to dampen the oscillations in the labor force caused by over- or under-reacting to available funding and expected work requirements on Center. One way to improve the business health of the organization is to study how the labor system operates, and then use that knowledge to set business policies that help minimize instabilities on the work force and resultant budget fluctuations.

Due to the complex nature of the defense business, there are many external variables management cannot anticipate or control. The intent of this research is to develop a systems thinking model that NAWCWD could use to predict trends caused by changing variables that they do have control over (e.g., hiring, separation and work acceptance). Historically, management personnel react to external inputs without informed insight into the possible long-term effects of their decisions.

Management's reflex response to outside influences is analogous to a scenario in which a non-computer controlled mechanical system is oscillating. This behavior is much like a lifting hook on an old crane. The crane operator tries to control the oscillations of the hook. However, despite the operator's best efforts, his inputs only amplify the oscillations. This amplification is due to time lags in the control system and the operator reacting to the situation, as opposed to anticipating changes. Modern cranes now use computer controls that anticipate the hooks motion and allow the operator to maintain control of the hook instead of allowing it to swing out of control.

Actions taken in a business environment have the same effect on business as the crane operator had on the hook. Using software tools, the business manager can better anticipate the effects of their decisions. In the case of this research, the goal was to develop a business tool for NAWCWD using a systems thinking model.

By including the principal parameters and associated characteristics, the systems thinking model could be used as a tool to simulate the labor system. One potential application would be for management to use the simulation to enhance understanding of the business system dynamics and conduct parametric studies to help predict the long-term effects of current labor decisions on the organization.

D. LIMITATIONS OF THE STUDY

As in any modeling and simulation project, there are many parameters that cannot, and should not, be modeled due to their chaotic behavior or complexity. We only have to look at weather models used to predict storms to appreciate the limitations of simulation models. For example, in the simulation of the weather, due to millions of complex variables, current simulations cannot include all the parameters that influence the weather. Therefore, weather forecasts are usually wrong; particularly as time passes, the perturbations build up causing unexpected results.

In every model there are many parameters found that do not improve the results of the simulation. It becomes apparent the choice of parameters and the level of detail of the model are dependent on the question being answered. As with the weather simulation model, contrails caused by passenger jets could have an imperceptible effect on the weather. It is unlikely, however, that these contrails would change the course of a storm.

Yet, we find often that these simulation models have an unnecessary level of detail. "A model is an abstraction of reality; it is not a replication of reality …adding detail to models does not make the output more credible or the result more reliable" (Grabau, 2001). It is most important to understand the system and the appropriate level of detail for the model to answer the question.

According to William McLean, Naval Ordnance Test Station (NOTS) Technical Director, 1962, "…we can accurately model only what we understand." McLean understood that the physics of the system is more important than having a computer model that attempts to simulate the real system (McLean, 1993).

The simulation model is only a tool that enhances the understanding of the system. This is true of any model or simulation, whether it is a weapon system or a model of global warming. Mark Lambert, Ph.D., observed in his doctorial thesis, "Development and Analysis of an Engineering Systems Dynamics Model of the Naval

Air Warfare Weapons Division (NAWCWD) Business Management System," in which he used dynamic modeling of NAWCWD business systems:

> The real limitation of the model and resulting simulation is that it does not generate absolute answers to potential NAWCWD business questions. The simulation was developed to a specific level of fidelity to explore a relevant subset of the business system. The simulation is more appropriately used to develop sensitivity studies where the effects of varying parameters on different scenarios can be compared (Lambert, 2002).

Unlike Lambert's doctorial dissertation, the focus of this master's thesis concentrates on finding the parameters to determine an optimum labor mix. The goal is to help the local manager make a balanced and informed decision when hiring government and contract labor and the possible long-term effects of the hiring decision. These parameters are modeled with as much detail as deemed appropriate to convey the proper level of influence on the systems dynamic model. Similar to Lambert's model, this study's simulation is that it does not generate the absolute answers for the hiring manager but is developed with the goal of exploring the relevant labor system parameters. The simulation is more appropriate as a means to develop and compare sensitivity studies using various parameter inputs.

E. SCOPE

This thesis focuses on the work force labor mix of government and outsourced workers at China Lake. Much of the analysis is dependent on interviews with subject matter expert managers, which helps to identify the model parameters. Causal loop diagrams (CLDs), which will be discussed later in detail, were developed and verified with the help of subject matter experts. These parameters, and resulting CLDs, were dynamically modeled using isee® systems thinking model software STELLA®. STELLA® was awarded the Jay Forrester Prize in 1987 when it was the first systems thinking icon-based model building and simulation tool introduced to the public. During the past decade, the management at NAWCWD has used the STELLA® program with great success. Therefore, in order to facilitate the usefulness of this study and its acceptance at NAWCWD, the STELLA® program was chosen.

Employee numbers used in this study were provided by the NAWS Physical Security Department. Civilian and contractor employee numbers include NAWCWD and all tenant commands located onboard NAWS.

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II. REVIEW OF LITERATURE

In this chapter, the relevant literature is reviewed. The concept of systems dynamics, and how it relates to business systems modeling, is presented.

A. SYSTEMS DYNAMICS IN GENERAL

The study of systems dynamics is an expanding field of study. There are a multitude of case studies and academic endeavors covering systems dynamics that are available for review on the Internet. Like many universities around the world, MIT Sloan School of Management has a dedicated department just for the study of system dynamics and systems thinking. In many areas of business and economics, there has been a fundamental switch from thinking about problems in a piecewise fashion to thinking about them in terms of systems and using a global perspective. This change has led industry and academia to apply systems dynamics analysis to problems ranging from business systems to the study of animal ecology. Jay Forrester, Professor Emeritus of the Massachusetts Institute of Technology, has been at the forefront of systems thinking and systems dynamics modeling. Forrester observes in his book "Principles of Systems."

> Gradually, over the last hundred years, it has become clear that the barrier to understanding systems has been, not the absence of important general concepts, but only the difficulty in identifying and expressing the body of universal principles that explain the successes and failures of the systems of which we are a part (Forrester, 1971, p. 381).

Forrester has helped evolve the field of systems thinking from using static tools, such as spreadsheets, to using computer-based systems dynamic models.

In a study, Forrester addresses the counterintuitive behavior seen in much of society. His study includes many issues that are particularly relevant to the NAWCWD business system because there are many counterintuitive interactions in that system. In particular, he notes in his paper "Counterintuitive Behavior of Social Systems":

> The same downward spiral frequently develops in government. Judgment and debate led to programs that appear to be sound. Commitment increases to the apparent solution. If the presumed solution actually makes matters worse, the process by which this happens is not evident.

> So, when the troubles increase, the efforts are intensified such that they actually worsening the problem (Forrester, 1971, p. 73).

A good example of this downward spiral is a scenario occurring in NAWCWD's Weapons and Energetics Department. Business policy directs that incoming funds for weapons programs be taxed to pay for general and administrative (G&A) overhead costs. The overhead cost is a portion of the civilian personnel labor rate applied to all customers' funding. Upper management within the Weapons and Energetics Department has historically been resistant to hiring skilled contract labor, which would reduce the tax. As a result, according to Richard Cracraft, the NAWCWD human resource department head, the Weapons and Energetics Department has only two percent of their skilled labor work force staffed by contractors. This business practice has allowed the department to generate more tax to cover their overhead costs. However, when programs are cut back, NAWCWD incurs an increased burden to pay for the labor of civilian workers no longer working on funded taxable projects because the size of the labor force cannot adjust as quickly as the funding cut occur. This situation usually results in increasing the tax on the remaining customers. These customers may then feel they are not receiving an adequate value for their money and may reduce their funding or cancel their project completely. This further reduction in funding compounds the problem for an organization carrying a predominantly civilian work force and may result in even more overhead costs and a declining customer base.

As customers decline, and additional funding from other customers is reduced, or, worse yet, eliminated, this drives the system to increase costs, which in turn creates more problems. This situation is commonly referred to as a "death spiral," and, as is apparent, as efforts to maintain the health of the organization actually have the exact opposite effect.

One method of graphically representing the interactions of various parameters is to use Causal Loop Diagrams (CLDs). John Sterman, Director of MIT's Systems Dynamics Group, notes in his book that; '…CLDs are an important tool for representing the feedback structure of systems" (Sterman, 2000, p. 102).

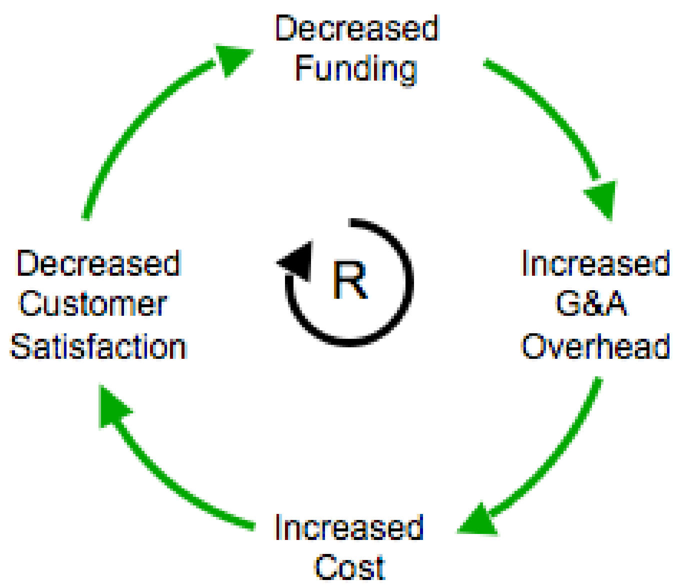


Figure 1. Causal loop diagram of potential death-spiral

Illustrated in Figure 1 is a graphical representation of a potential death spiral and the relationships between events. The central "R" and arrow indicate that the overall category of the loop is a reinforcing feedback loop. For example, as customer satisfaction decreases, the amount of funding the customer is willing to give is decreased, which will cause G&A taxes to increase to pay for the now unemployed workers. As the G&A is increased to cover the unemployed workers, the cost of the work being completed is increased and passed on to the customer, causing the customer satisfaction to decrease even more. Customer satisfaction decreases as the customer see less return on their investment. Eventually the customer goes away and all that is left is an unfunded work force.

In Figure 1, the model assumes the state of the system cannot be controlled and any corrective action results in a reinforcing increase in the state of the system. The total effect of this feedback loop is to reduce the state of the system. This simple model assumes the corrective actions are not controlled, and this would eventually increase the discrepancy. As Forrester points out, "…the efforts are intensified that are actually worsening the problem (Forrester, 1975)." By contrast, Figure 2 shows the effect of a delayed negative feedback loop. A goal is set such that corrective action is taken; each cycle causing the result to be totally different. In this example, the state of the system is compared to the goal identifying a gap and controlling a negative feedback, resulting in an under damped balancing effect.

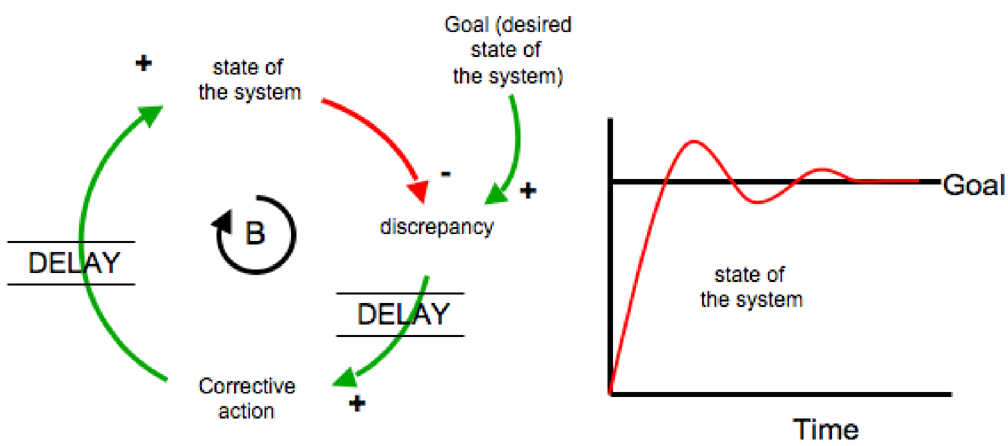


Figure 2. Causal loop diagram of delayed negative feedback

III. METHODOLOGY

The following chapter discusses the development of the NAWCWD labor mix system model and the mechanics of the utilization of the STELLA® software package to develop the digital simulation of the labor mix system.

A. OVERVIEW OF THE STUDY

Investigating the current labor system at NAWCWD in order to understand the processes and its limitations preceded the study. Numerous NAWCWD subject matter experts were interviewed to gain a better understanding of the system mechanics for both civilian and contractor hiring and to aid in the development of the analytical labor mix system model. Parameters such as hiring and separation rates affecting the labor mix were validated for their relevance and their impact on the system. It is very easy to overcomplicate the system, so only the macro level parameters are used.

The best approach is to stand back and look at the system such that the minute details merge together and one only sees the big picture. It is best to think of this as being analogous to a pilot in an aircraft flying at 30,000 feet and looking down at China Lake. Only the gross details are visible. The pilot cannot see the people, but he does see the effects of the people on the base below. The pilot can see the flow of traffic moving into and out of China Lake. Over time he can see the base is getting bigger or shrinking as areas grow and areas decay. This is a macro approach.

In this study, three research questions are answered. First, "What are the significant parameters that control the labor mix?" Second, "Can an analytical model be developed that sufficiently models the interactions of the parameters?" Third, "Can a computer simulation be developed to implement the analytical model and then be used to help the hiring decision process?"

Subsequently several analytical models were developed and refined to form an analytical model appropriate for the supporting analysis of the labor system. This analytical model was used to develop a computer simulation of the labor mix system using STELLA® systems dynamic software produced by isee systems, inc. of Lebanon, New Hampshire. Analysis of the labor mix system was then conducted using the computer simulation. A more detailed description of the model development and an overview of the STELLA® environment are discussed later in this chapter.

B. MODEL DEVELOPMENT

The modeling process used is shown in Figure 3 and the procedures are described in the Department of Army Pamphlet 5-11, Verification, Validation, and Accreditation of Army Models and Simulations.

The first step was to determine the purpose of the model, which has already been stated. Once the purpose was understood, there followed conceptualization by using mental models, which evolved into causal loop diagrams and then a STELLA® systems thinking model. The model was calibrated by comparing simulation outputs to actual historical data. Subject matter experts were used to validate the model. This was an iterative process that yielded the final simulated labor mix model.

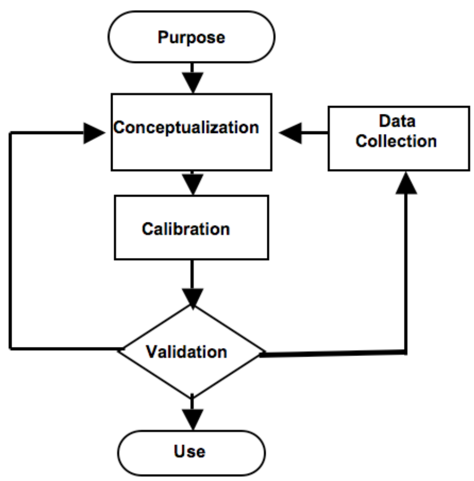


Figure 3. The modeling process flow chart

This initial model underwent several iterations as it proceeded from a notional casual loop to an engineering model. The plus and minus signs in Figure 4 represent the increase and decrease relationship of the parameters. The plus sign indicates that as the parameter located at the tail of the arrow increases, then so does the parameter at the head of the arrow. The negative sign indicates an inverse relationship. For example, it is assumed that as the amount of work available increases, the availability of workers increases as well.

Aristotle, the Greek philosopher, said in the book *Metaphysics*, that, “the sum is greater than the parts.” That is still true when looking at the dynamics of the China Lake labor pool. This is a basic principle of systems thinking and is reflected in Figure 4, a causal loop diagram of conflict between civilian and contractor workers. In this figure the conflict is the result of two competing groups - the civilian work force and the contractor work force. Both groups are motivated to take in as much work as they think they can handle, and both groups fear the other will get too much. It is the job of the manager to divide the work to the advantage of the government.

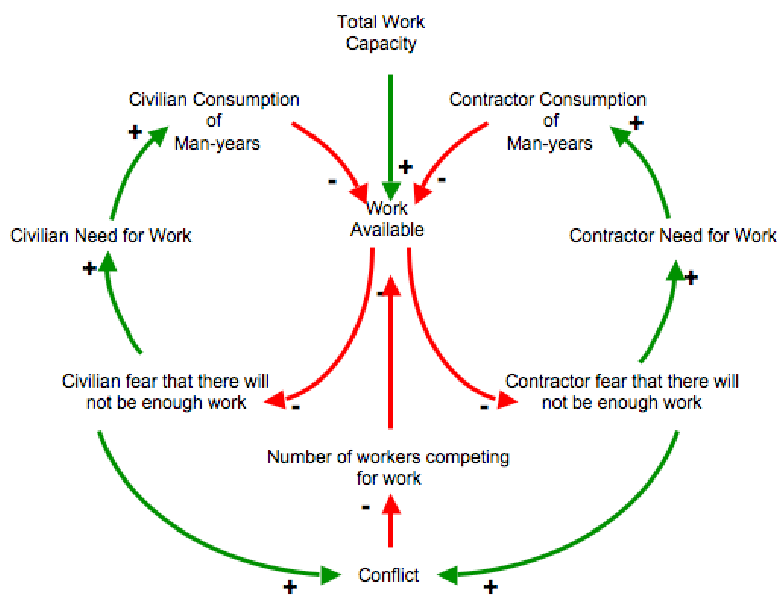


Figure 4. High-level causal loop diagram for analytical model development

An interesting aspect of the labor system described in Figure 4 is that it is an example of a homeostatic system.

> *Homeostasis: resistance to change.* A homeostatic system is a system that maintains its structure and functions by means of a multiplicity of dynamic equilibriums rigorously controlled by interdependent regulation mechanisms (Rosnay, 1979, p. 87).

This system will seek a balance by reacting to any disturbance with a corresponding opposite response.

All human social systems are homeostatic. They oppose change with every means at their disposal. The labor mix system that was modeled is an example of a homeostatic system, which naturally means that it will work to maintain its own stability. However, when a homeostatic system is threatened according to Jay Forrester, their behavior is unpredictable and counterintuitive or contravariant: "When one expects a determined reaction as a result of a precise action, a completely unexpected and often contrary action occurs instead (Forrester, 1971, p. 73)."

Based on the process shown in Figure 3, and on insight gained from interviewing the NAWCWD subject matter experts, a set of pertinent parameters was identified, and a labor mix systems analytical model was developed. A general causal loop diagram was constructed to describe at a very top level the relationship and dynamics between the two labor groups and the various parameters (e.g., man-year budgets, hiring rates and separation rates and policy). The top-level CLD displayed in Figure 5 was developed to clarify the interactions of the pertinent areas of the labor system.

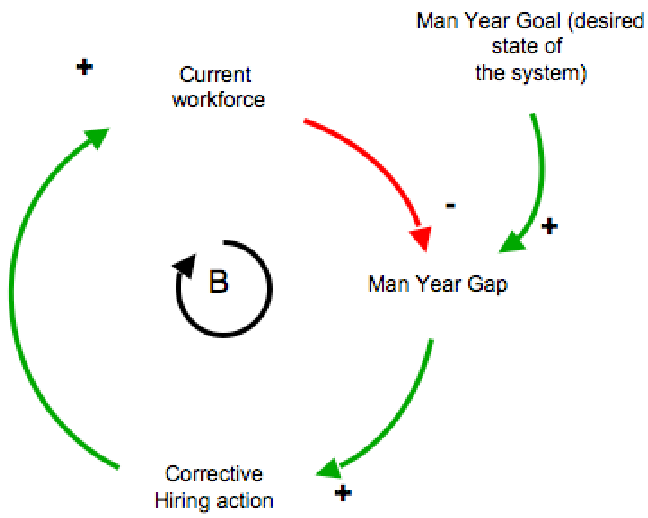


Figure 5. Refined causal loop diagram in evolution of analytical model

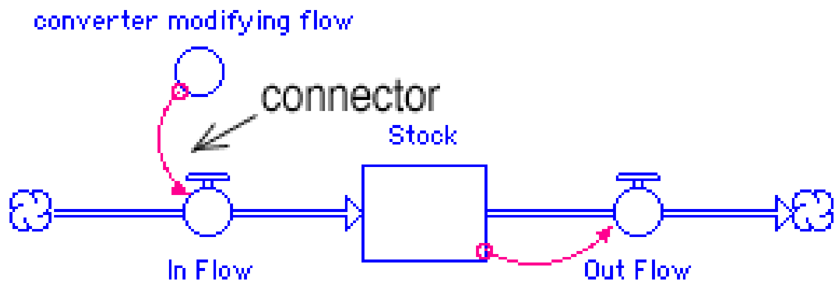
NAWCWD management is concerned with meeting the work goals set by the customer who is providing the funding. The manager must determine the gap created between the work to be accomplished and the ability to complete that work. Depending on the gap that results, the manager must adjust the work force accordingly.

After the analytical model was refined into its final form shown later in this paper, the STELLA® software package was used to convert the model from an analytical model to a computer simulation. STELLA® software is well suited for this task of this nature, and the task is similar to applications the software package has been used for in the past. Modeling the China Lake labor mix system using the computer simulation provided the principal data for the analysis and results. Finally, the simulation and analysis results are discussed in more detail in Chapter IV.

C. STELLA® BUILDING BLOCKS

The STELLA® programming environment is an intuitive graphical programming interface. An element can only affect the other elements it is connected to directly. This programming environment ensures there are no hidden connections between elements from what is graphically displayed.

STELLA® software automatically generates the computer program that represents the graphical model developed by the user. The user need not work directly with the computer program because the graphical representation contains all the information needed to understand and simulate a model.



STELLA® generated source code

Stock(t) = Stock(t - dt) + (In_Flow - Out_Flow) * dt

INIT Stock = 0

INFLOWS:

In_Flow = converter_modifying_flow*1

OUTFLOWS:

Out_Flow = Stock*1

converter_modifying_flow = 1

Figure 6. Basic STELLA® building blocks with source code

Referring to Figure 6, system dynamic STELLA® models are made using stocks, flows, converters and connectors. Stocks are drawn as boxes and are used to represent items that can accumulate (e.g., population, money in a bank account, water in a bathtub, etc.). Flows are drawn as valves and represent the rate of change of things going into and out of the stocks. The flow represents those actions or activities that cause the stock value to increase or decline over time. If the flow points into the stock, it causes the stock value to increase, and if the flow points away from the stock, it causes the stock value to decrease. Converters are drawn as circles and allow the modification of other elements. A converter is used to represent additional logic important to the model. Unlike stocks, converters do not accumulate, but merely modify the relationship between different items. The connector serves as an information wire (dashed), or as an action wire (solid). As the name implies, connectors represent the association between the connected elements. Connectors are drawn as arrows, which defines the direction of information flow.

The cloud shapes at either side of Figure 6 represent the model boundaries, which define the area of interest of the simulation. Beyond the boundaries, the modeler does not care where the inflow is coming from or where the outflow is going.

An application of Figure 6 could be the hiring and firing in an organization. The staff in the company is represented by the stock, the in-flow is hiring, and the out-flow represents firing or laying off employees. In this case, the analyst developing the model is assuming that there are an infinite number of people to hire, and it is not relevant to this model where they come from or where they go after they have been fired. Obviously, if there were a limited number of candidates in the hiring pool, the model would need to be modified to represent that situation. This simple example outlines the basic mechanics and hints at the complexities that can be quickly introduced into a simulation.

The final STELLA® software model of the labor mix system shown later in this study was constructed using the building blocks in Figure 6 and connecting them according to their relationships to the graphical user interface model. For a more detailed description of the software, consult the STELLA® user manual or the isee systems, Inc. (http://www.iseesystems.com).

The front end of the graphical model is the control page. Figure 7 is a STELLA® control page developed specifically for the NAWCWD labor mix model within the STELLA® modeling environment. The control page allows the user to customize and manipulate the parameters and simulation environment. Arrayed along the left side of Figure 7 are the control buttons. These buttons allow the user to modify the run specifications, run the simulation, stop the simulation and restore the parameters.

Along the bottom of Figure 7 are graphical parameter control inputs for controlling man-year budgeted, and control dials inputs for civilian hiring success rate, civilian separation rate, contractor hiring success rate, and contractor separation rate.

The graph shows the results of a simulation run. In this case the graph is showing the changes in the contract work force, lost work, man-year down time and the civilian work force numbers over a period of ten years.

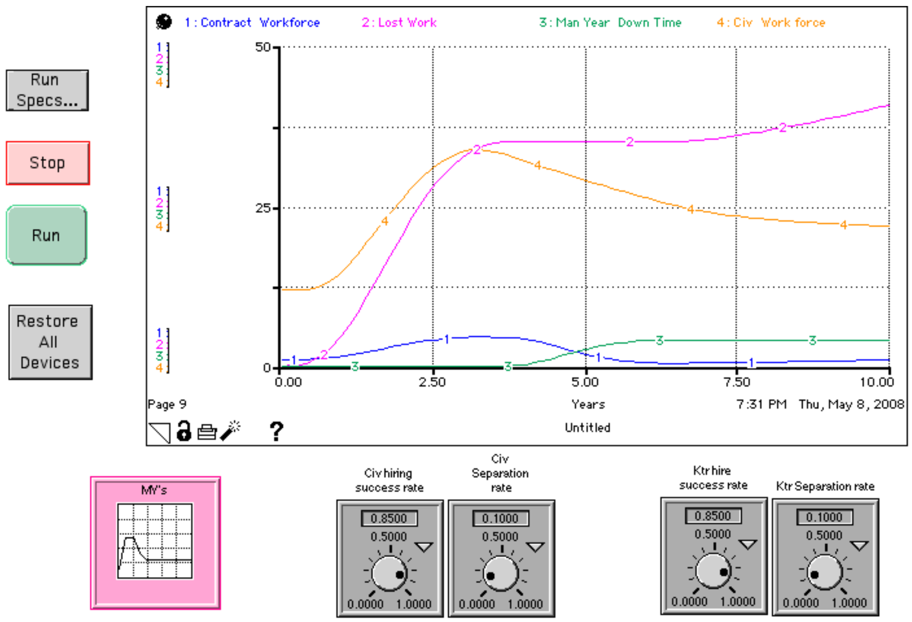


Figure 7. Example of model control page with sample graph

In summary, an investigation of the NAWCWD labor mix system was conducted by interviewing subject matter experts to identify the pertinent parameters and the mental model. Subsequent conceptual model of the system and the corresponding algorithms were developed to model the interactions of the pertinent parameters. The algorithms developed to model the labor mix system were incorporated into the STELLA® software package to build a digital simulation allowing sensitivity studies. The various parameters modeled in the simulation were then varied in a series of simulation runs to explore the sensitivity of perturbations on the labor mix system. The limitations, constraints, assumptions and results of these analyses are discussed in the next chapter.

IV. RESULTS

The results of the study are presented as findings answering each of the research questions. The results presented here are the outcome of many interactions and refinements to initial investigations.

Regarding research question one, the parameters selected for use in this research were chosen based on their significant influence on the labor mix system model and the resulting simulation. For example, it is well within control of management to decide to reorganize the command staff, but that decision would have a minor effect on the labor mix model, other than subtle effects it might have on corporate productivity.

Choosing the most significant parameters in research question one set the bounds for the analytical model developed in research question two and the resulting simulation developed for research question three. While answering question one and two provided the groundwork of the model and simulation development, the preponderance of the discussion focuses on the system dynamics in the section on research question three. The answers to question three were really the ultimate goal of this research.

A. RESEARCH QUESTION ONE

The purpose of this research question was to identify the significant parameters by investigating and understanding the labor system. There are many parameters that can be directly or indirectly controlled by the senior management team at NAWCWD. This is an important aspect of the problem because, "in systems that can be easily quantified, it is possible to design specific control strategies and to provide accurate predictions of behavior (Wolstenholme, 1990, p. 238)."

Additionally, there are many parameters that cannot be controlled by Navy management, such as the health of the national economy. The economy also drives the labor situation. Nonetheless, some organizations still manage to meet their labor demands even during economics swings.

So, the important question is simply not what can or cannot be controlled. The question is what should be done with the parameters that can be controlled to better position the organization to exploit the external environment. With regard to a work force made up of civilians and contractors, it obviously requires an understanding of the NAWCWD business operations as well as its interaction with the external environment. Describing and modeling this relationship can be very challenging.

The primary parameters relevant to this analysis of the organization are listed in Table 1, along with the default values. The default values are used in calibration and validation phase of the analysis.

Category	Parameter	Starting Default Value
Funding	Man-year Goal	8,541 man-years
	New Man-year Goal	variable (Historical Data)
Work Force	Civilian Work Force	6,053 workers
	Civilian Hiring Success Rate	variable (0 – 100%)
	Civilian Separation Rate	variable (0 – 100%)
	KTR Work Force	2,488 workers
	KTR Hiring Success Rate	variable (0 – 100%)
	KTR Separation Rate	variable (0 – 100%)

Table 1. Model parameters and default values

A description of each parameter follows. The descriptions are broken out as they are grouped in Table 1 by the following areas: funding and work force.

1. Funding Parameters

The first category of parameters relate to funding. Funding is represented in man-years funded and is the work currently available. This parameter represents the demand from the customer and can fluctuate each year. If the demand is greater or less than the current work force, an imbalance will occur. When the man-year goal increases there is more work coming in than can be completed by the current work force. This would cause an increased demand in hiring. Likewise, if the man-year goal were decreased, a resulting demand to decrease the work force would result.

The difficulty of equating funding to the work force would seem trivial at first, until one actually tries to derive the head count or number of civilian and contract workers in any given year based on fiscal data. In practice, it is very difficult to break down a billion dollar budget. Getting good, usable data on work demand and the work force proved to be insurmountable due to the multitude of variables. These variables included various pay scales, hours worked, multiple fees, material cost, travel, and several types of funding that make up the budget. Organizational changes, switching accounting programs, and introducing new procedures also compound the difficulty of this task over the past decade.

The most reliable source of information that reflected the size of the work force and type of workers, proved not to be the financial data from the comptroller, but the head count data maintained by the Pass and Identification office at China Lake. Therefore, this dynamic model is based on the actual number of workers that stepped onto NAWS to work as reflected by the data presented in Table 2.

The initial man-year work goal is based on the actual head count of the work force of 8,541 workers, 6,053 civilians and 2,488 contractors, in the year 1997 listed in Table 2. The follow on man-year work goals can be varied in the model based on the head count data collected over a decade of work performed from 1997 to 2007 at China Lake. This gives the manager the ability to use the actual data for the decade or to run simulations based on variable scenarios of man-year goals.

Year	Civilian	Contractor	Total
1997	6,053	2,488	8,541
1998	6,038	2,488	8,526
1999	5,019	2,464	7,483
2000	4,771	2,443	7,214
2001	4,739	2,438	7,177
2002	4,871	2,430	7,301
2003	4,808	2,224	7,032
2004	4,221	1,935	6,156
2005	4,152	2,009	6,161
2006	3,961	1,929	5,890
2007	4,059	1,851	5,910

Table 2. Civilian and contractor head count at China Lake

2. Work Force

The second category of parameters is related to the work force. The work force parameters represent the number of civilian and contractor workers available to management and the rate at which new workers are added or current workers are removed. This work force is controlled by the demand for work and the success and separation rates for civilian and contract workers. The rates are the actual rates experience between 1998 and 2007 with the 1997 data used as a starting point. However, the model can be varied so various scenarios can be run to simulate changes to those rates, as will be demonstrated later in this chapter. For example, using this study, the manager has the ability to simulate the effect of an increased civilian separation rate on the work being completed. This could also be used to study the fallout effect of increased retirements caused by baby boomers leaving the work force.

Details on how each group of parameters were varied in the model are provided in the section on research question three.

B. RESEARCH QUESTION TWO

As stated earlier, research question two was, "Can an analytical model be developed that sufficiently models the interactions of the parameters discovered in question one?" The goal of this question was to develop a model that could then be turned into a simulation that would be useful in analyzing the China Lake labor mix. Given there are a large number of parameters that can affect a labor force; the goal was to understand the system sufficiently so the simulation would respond in a realistic manner. The model had to adequately represent the system interactions. Based on this criterion, interviews were conducted with both contractor and government managers. This information was used to develop and later to validate the model.

The challenge of modeling a complex and dynamic system is to create a model that captures the characteristics of the system without being any more complicated than it needs to be. The final CLD shown in Figure 8 contained the relevant system components to model the behavior of the system.

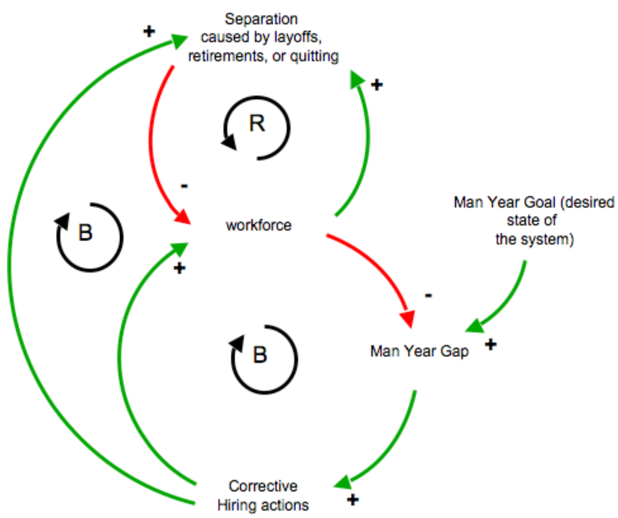


Figure 8. Final CLD of Labor Mix Model

C. RESEARCH QUESTION THREE

Answering the previous two research questions provided the groundwork to address the third question. “Can a computer simulation be developed to implement the analytical model developed in question two and then be used to help the hiring decision process?” The investigation of the labor system parameters and the development of an analytical model of the labor system were necessary steps to develop a simulation suitable for studying the system.

An analytical model developed to represent the labor mix process and related parameters was converted to a digital simulation with STELLA® software. This provided the capability to facilitate the analysis of hiring decisions and long-term impacts on the organization. This was done by simulating the dynamics of the interrelations of all the labor mix components within the simulation.

With relatively simple building blocks in the STELLA® software, a complex model was developed. However, one must be cautious in developing overly simple or overly complex models because, according to Albert Einstein, “An explanation should be as simple as possible, but not simpler (Forrester, 1975).”

The causal loop in Figure 8 was further developed to structure the major parameters that drive the labor mix system. From this, the STELLA® simulation of the systems dynamics in Figure 9 was developed.

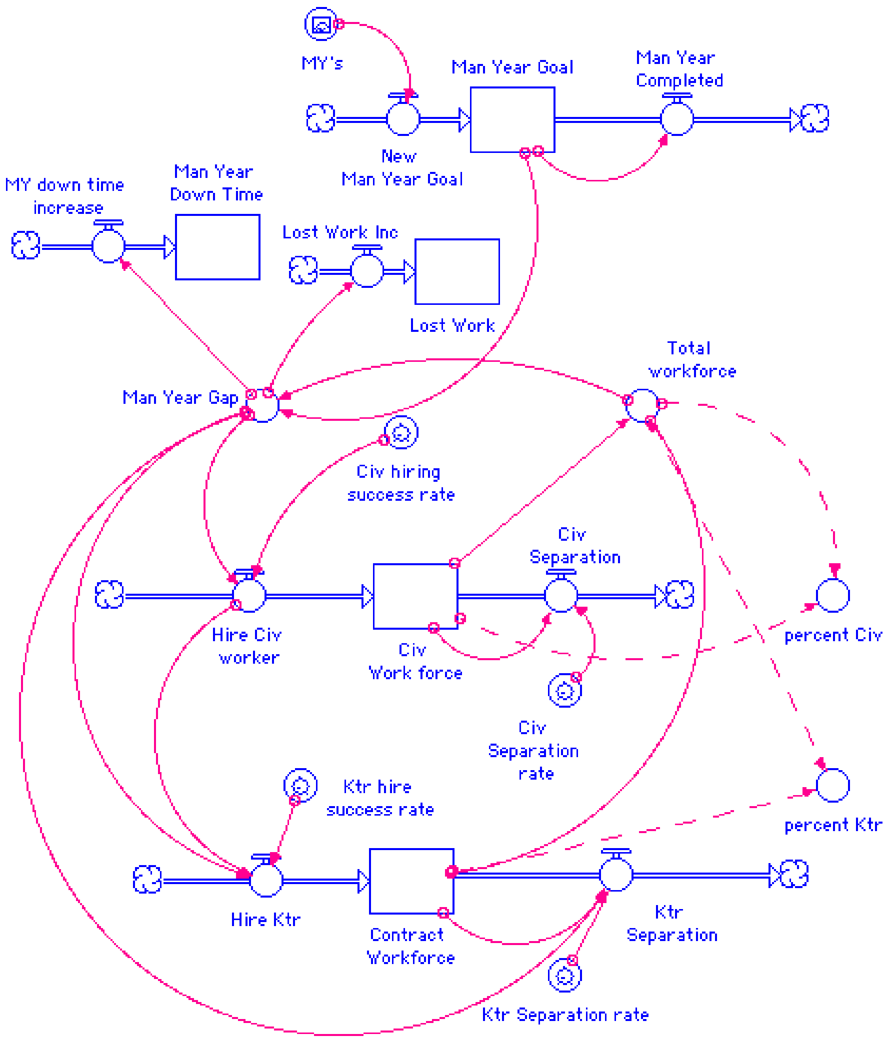


Figure 9. Graphical display of digital model

1. Model Calibration and Validation

To calibrate the model, a steady state scenario with no system perturbations was run to ensure the simulation was operating as expected. The initial values were chosen from the year 1997. I n the scenario, the man-year goal was set at a constant 8,541. Hiring success rates were set at one (equivalent to 100%) and separation rates set to zero (equivalent to zero percent). The initial labor force was started with 6,053 civilians and 2,488 contract workers. The result was a steady state response as displayed in Figure 10.

As would be expected in the calibration test, the sum of the civilian work force and the contract workforce equaled the man-year goal.

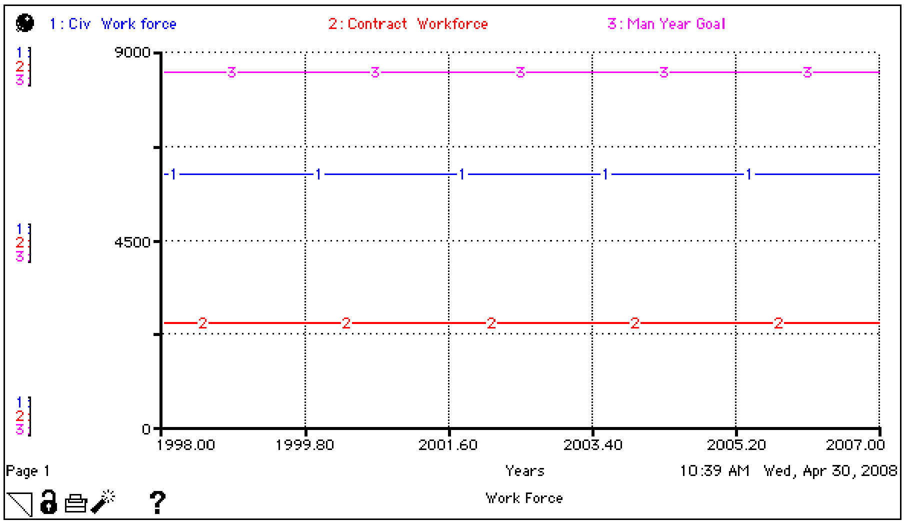


Figure 10. Steady state system

In the second scenario, that further tested the response of the simulation, the results were compared to historical data of the number of civilian and contract workers at China Lake from 1998 to 2007. The simulation was initialized with the historical data and a run was made.

Table 3 and Figure 11 compare the historical labor data from 1998 to 2007 and the corresponding simulation run. In Figure 11, the historical data is plotted out in blue while the simulated data is plotted in purple. The data gathered from the simulation appears to track nicely with the historical data. As will be shown the simulation data is also compared to a moving average of the historical data.

	Historical Data			Simulated Results		
Year	**Civilian**	**KTR**	**Total**	**Civilian**	**KTR**	**Total**
1998	6,038	2,488	8,526	6,053	2,488	8,541
1999	5,019	2,464	7,483	5,563	2,476	8,039
2000	4,771	2,443	7,214	4,988	2,453	7,441
2001	4,739	2,438	7,177	4,850	2,440	7,290
2002	4,871	2,430	7,301	4,834	2,434	7,267
2003	4,808	2,224	7,032	4,803	2,329	7,132
2004	4,221	1,935	6,156	4,489	2,091	6,581
2005	4,152	2,009	6,161	4,190	1,964	6,154
2006	3,961	1,929	5,890	4,062	1,929	5,991
2007	4,059	1,851	5,910	3,920	1,853	5,774

Table 3. History and simulation of data of labor mix for China Lake

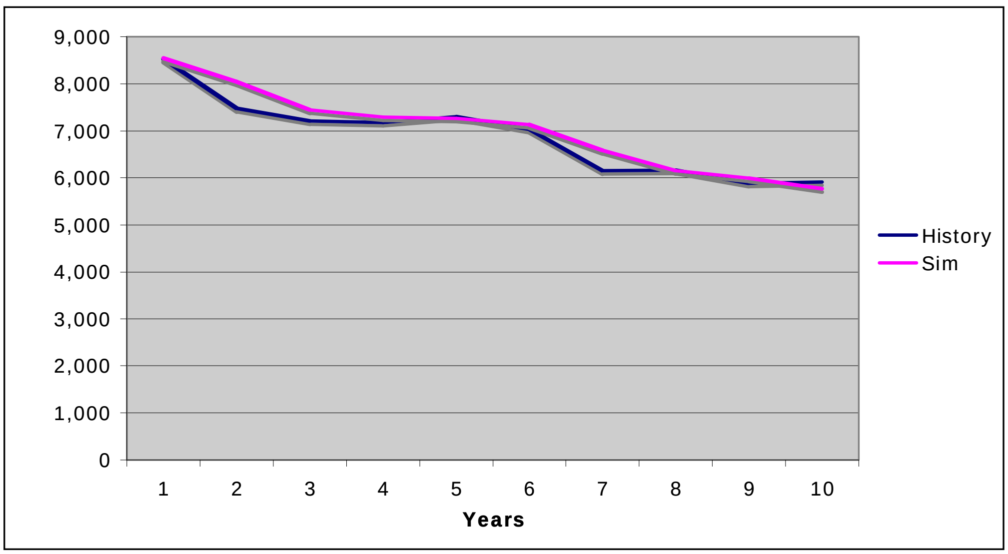


Figure 11. History and simulation of data of Labor Mix for China Lake

Figure 12 shows the same data as Figure 11, but has the additional graph of the forecast of the history data using the moving average method. The moving average is shown in green while the simulation data is shown in red and the historical data is shown in blue. It is note worthy that the simulation data and moving average data are almost identical.

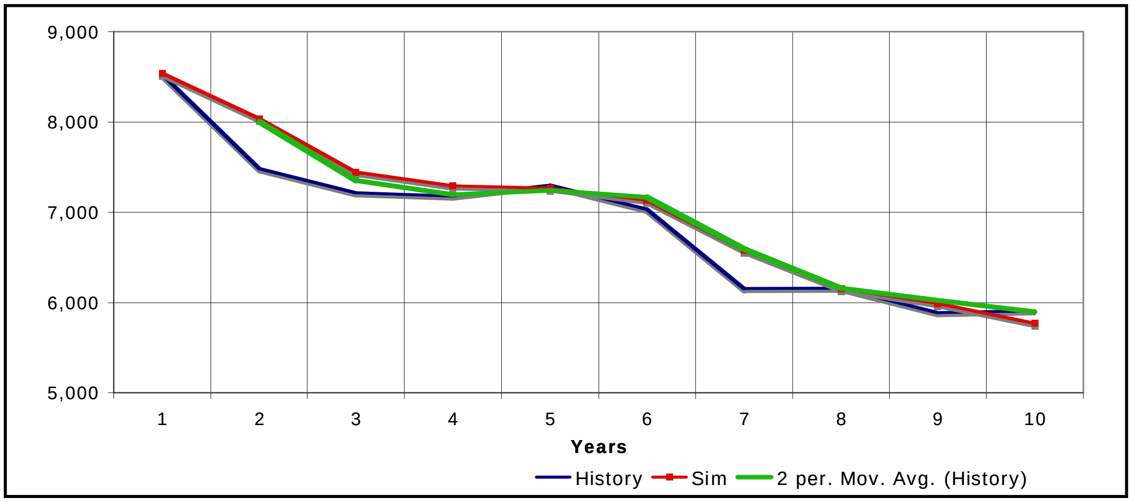


Figure 12. History and simulation of data with moving average of history data

The fact that the forecast of the historical data using a moving average method appears to support the simulation cannot be the only proof of the models validity. In fact, it is believed that it is impossible to truly validate any model (Sterman, 2000 p. 846). The best that can be achieved is faith that the model is acceptable.

> Any model-validation procedure rest eventually at some lower level on a judgment or faith that either the procedure or its goals are acceptable without objective proof (Forrester, 1961, p. 123).

Additional faith in the validation was achieved by demonstrating the model to subject matter experts. The SMEs compared the model and simulation to their own real world experience. This method of face validation is discussed in the Department of Army, Pamphlet 5-11. The conclusion was that the Labor Mix simulation model was valid and reasonable.

2. Sensitivity Analysis

The primary objective of this paper is to determine the optimum labor mix given what we know about the model parameters. One-way to do this is by conducting a series of sensitivity tests. The STELLA® program has the ability to perform sensitivity and comparison testing on input parameters. Sensitivity analysis is a good tool for predicting the behavior of the model with changing parameter inputs.

In the following sensitivity simulations one will see the effect that changes in hiring success rates and separation rates has on the required percentage of contract workers. These relationships are shown in Table 4.

Contractor Separation Rate ↑	Percentage of Contractors ↓
Contractor Hiring Success Rate ↓	Percentage of Contractors ↓
Civilian Hiring Success Rate ↑	Percentage of Contractors ↓
Civilian Separation Rate ↑	Percentage of Contractors ↑

Table 4. Relationship of parameters to the percentage of contractors

The sensitivity testing shows, in Figures 13, 14, 15, and 16, that there is an inverse effect from changes in contractor hiring success and civilian hiring success rates to the percentage of contractors in the workforce. Additionally the contractor hiring success rate inversely affects the percentage of contractors. The worse case scenario was found to be the effect the civilian separation rate has on the percentage of contractors in the work force. As will be shown later in this chapter the civilian separation rate is the most troublesome parameter facing managers at China Lake.

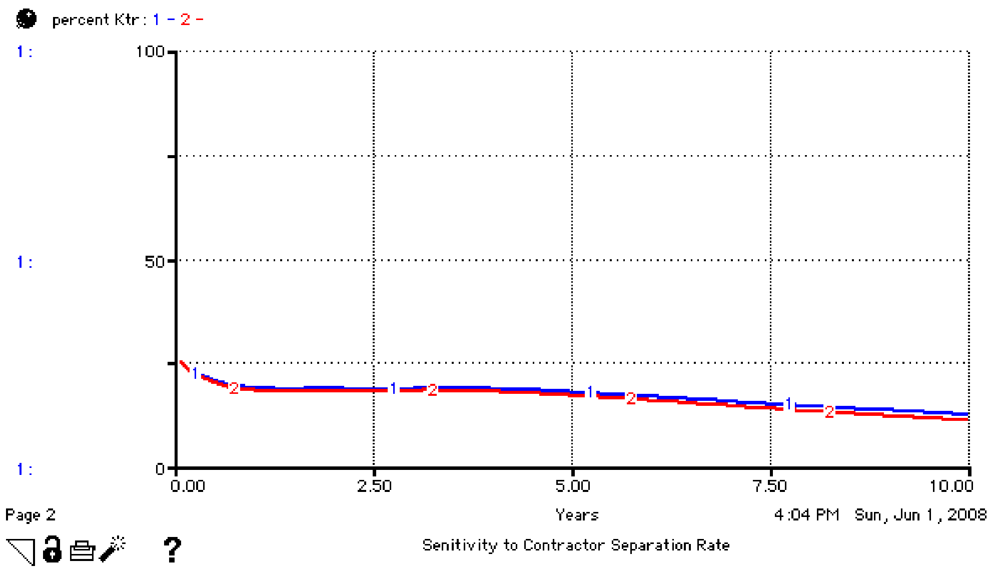


Figure 13. Sensitivity of percentage of contractors to contractor separation rate of 5% (line 1) and 20% (line 2)

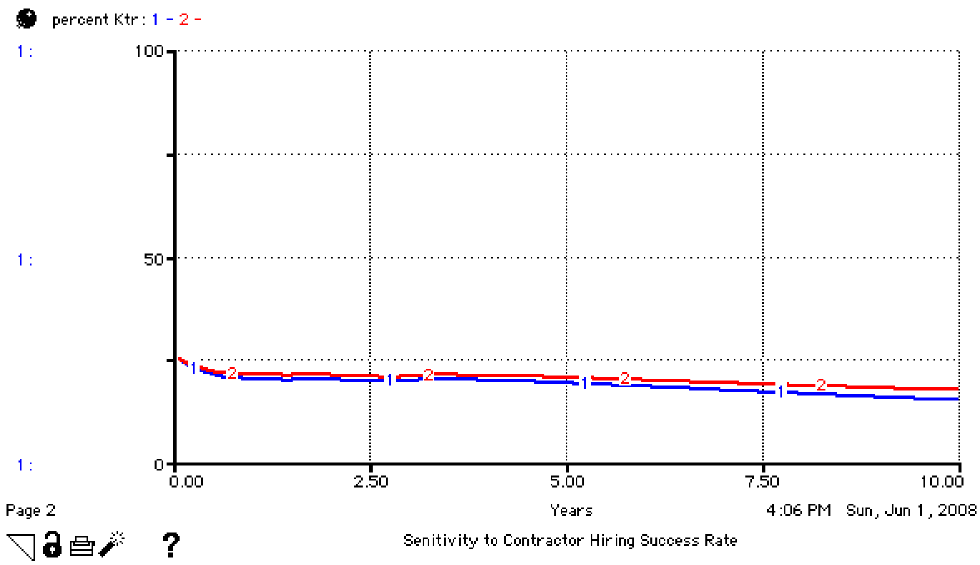


Figure 14. Sensitivity of percentage of contractors to contractor hiring success rate of 50% (line 1) and 80% (line 2)

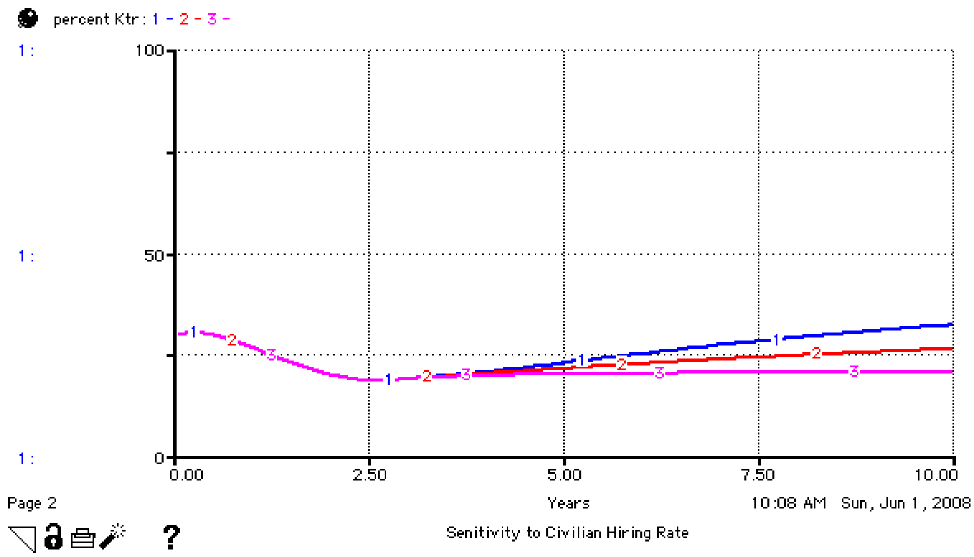


Figure 15. Sensitivity of percentage of contractors to civilian hiring success rates of 65% (line 1), 75% (line 2), and 80% (line 3)

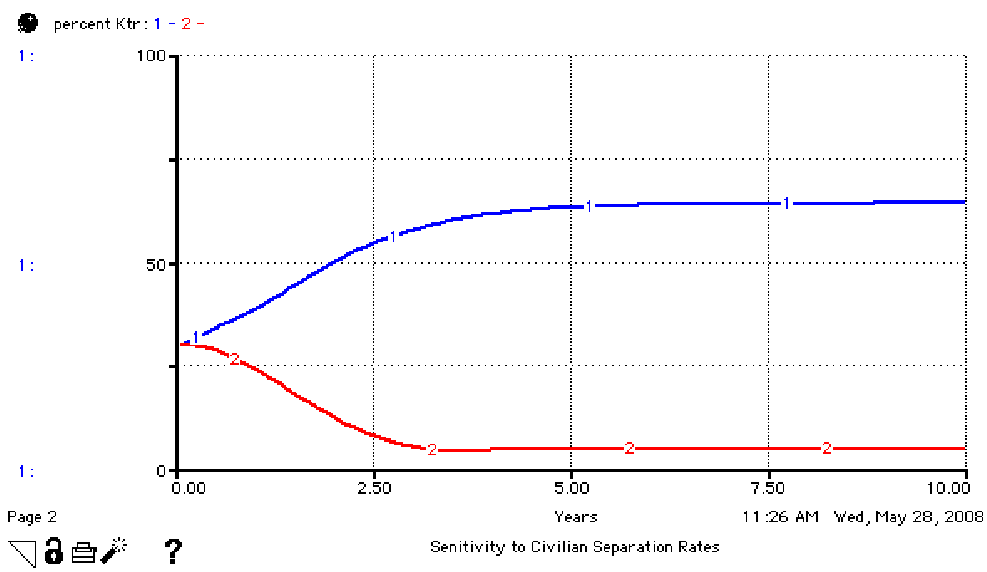


Figure 16. Sensitivity of percentage of contractors to civilian separation rates of 50% (line 1), and 10% (line 2)

As Figure 16 shows the percentage of contractors is most sensitive to variability of civilian separation rate. All the parameters influence the optimum labor mix, but the civilian separation rate has the greatest long-term influence. As will be shown the best indicator of what the labor mix should be, is the rate at which civilians depart the work force.

In the sensitivity test shown in Figure 17, the work force started with twenty-five percent contractors. The hiring success rate for both civilians and contractors was set to 85%. The contractor separation rate was assumed to be ten percent. The sensitivity test of the percentage of contractors in the work force was testing against a change in civilian separation rates of 5%, 13.3%, 21.7% and 30%. As is shown in the graph, the percentage of contractors is very sensitive to the rate at which civilians depart the work force. If the civilian separation rate is 13.3%, the percentage of contract workers will converge to 17%.

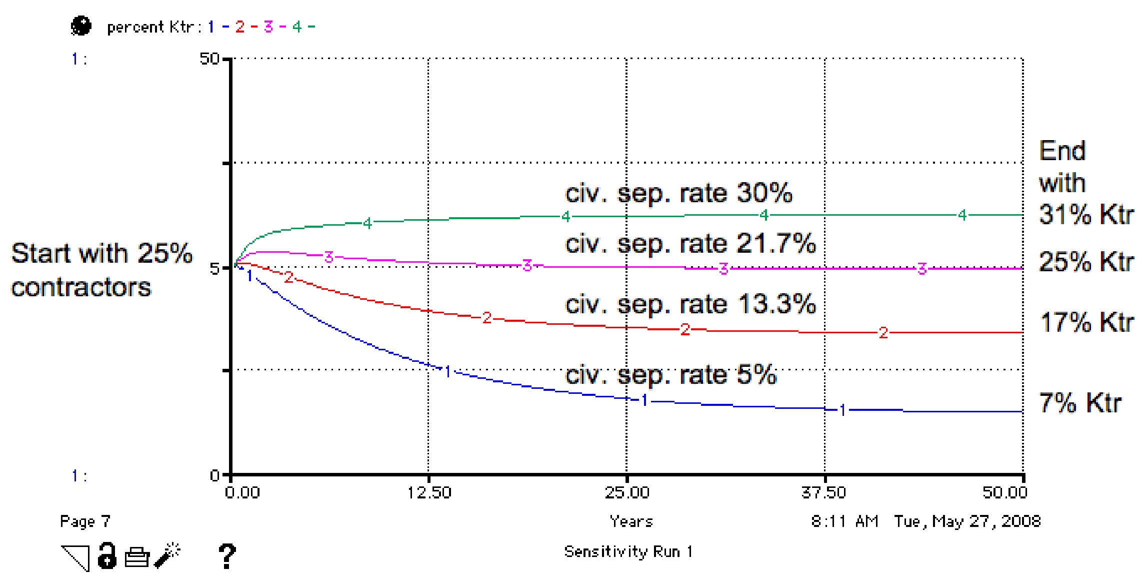


Figure 17. Sensitivity of Contractor Workforce to Civilian Separation

From the information presented in the figure above, one can assume that if the civilian separation rate is 13.3%, the corresponding optimum percentage of contractors should be 17%. This assumes that the civilian hiring success rate and contractors hiring success rate is 85% and the contractor separation rate is 10%. In real life all these parameters will change and so the optimum number of contractors would have to be recalculated and adjusted.

The following simulation run, displayed in Figure 18 shows the result of a 10% change in work demand. It was assumed that the civilian separation rate was 13.3% and the contractor work force started at 17%.

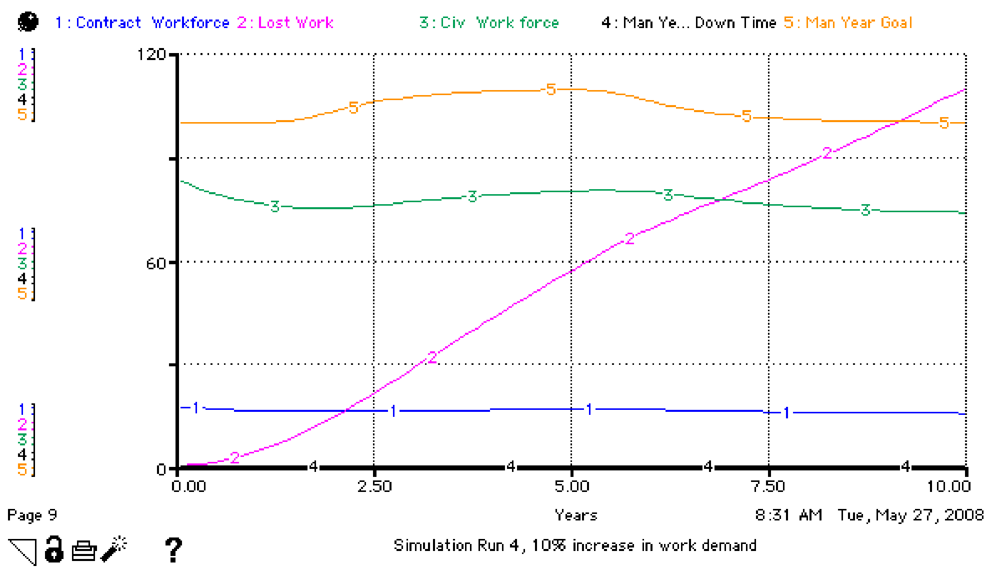


Figure 18. Simulation Run with 10% change in work demand, civilian separation rate at 13.3%, contractor work force is 17%.

The next graph shown in Figure 19 shows the results of the same simulation but with a work force of only five percent contractors. Notice that the contractor work force is growing and the civilian work force is decreasing and is more volatile, otherwise the amount of lost work and down time is the same.

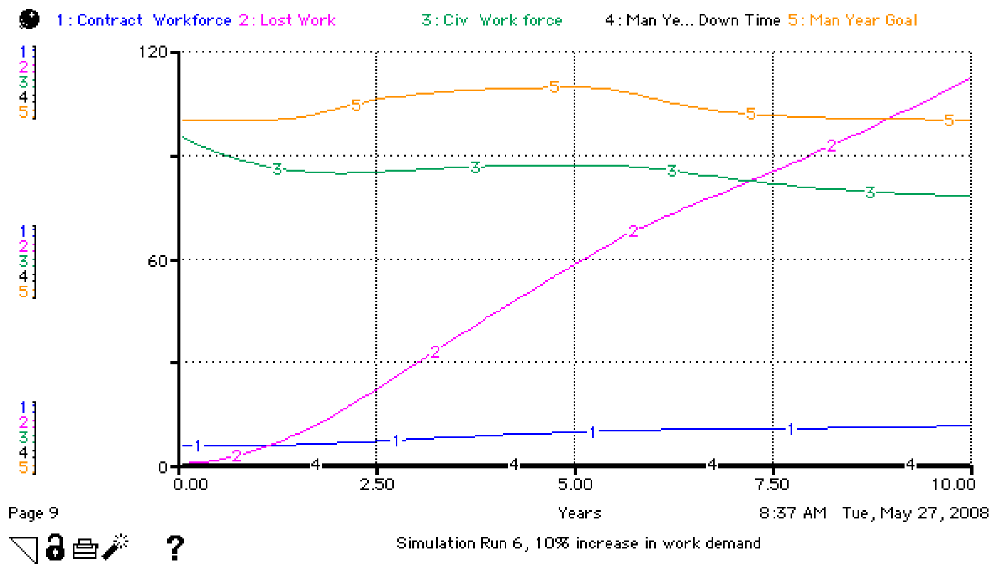


Figure 19. Simulation Run with 10% change in work demand, civilian separation rate at 13.3%, contractor work force is 5%.

The benefit of an optimum labor force mix is best demonstrated by the next few figures. Figure 20 shows the results of a drastic change in work demand when starting with an optimum percentage of contractors.

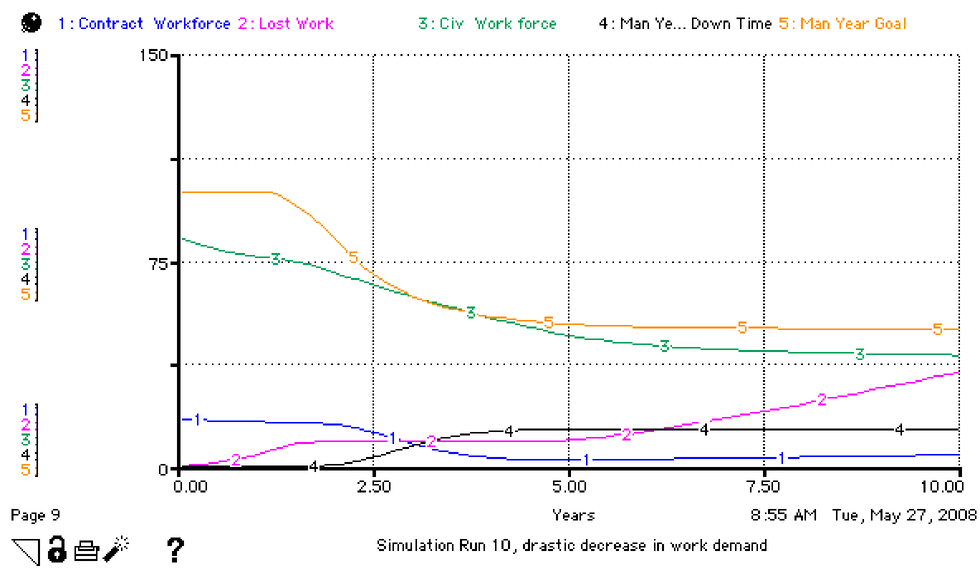


Figure 20. Simulation Run of a drastic change in work demand with a 13.3% civilian separation rate and 17% contractor work force

Referring to Figure 20, the size of the contractor work force is plotted by line one, the civilian work force is line three, and the work demand is shown as man-year goal, line five. The important data for the manager is the amount of lost work and the amount of down time. Lost work can be managed by paying out more overtime or turning away work. The real problem for the manager is the amount of down time.

Down time represents a burden, which can eventually lead to downsizing and firing employees. The goal of finding an optimum labor mix is to have a labor force that will give the management the minimum regret for their hiring decisions. In the case of down time this would equate to minimum cost. As will be shown the worst time to have to worry about labor cost is during a down turn in work demand. The actions that management must take can have a long term consequences, which can take decades to correct.

Now consider the same scenario, shown in Figure 21, but now with only a work force consisting of five percent contractors. Notice line four, the plot of down time. The down time has increased. In year three the contract work force is zero. This is a bad situation, which could be compounded if work demand is fluctuating.

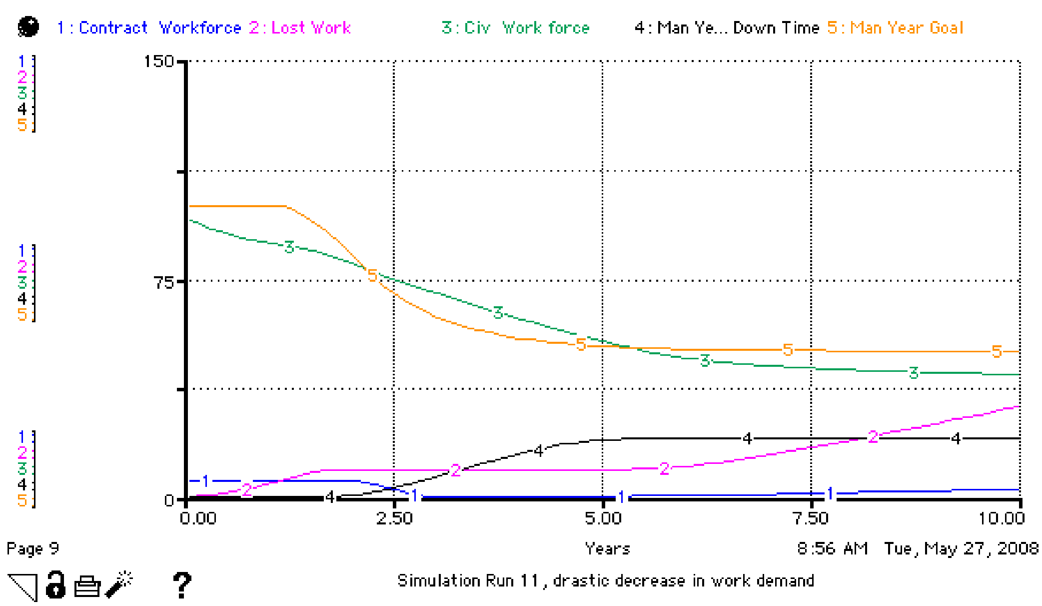


Figure 21. Simulation Run of a drastic change in work demand with a 13.3% civilian separation rate and 5% contractor work force

Comparing Figure 21 to Figure 20, one will see that the change in the size of the contractor work force from 17% to five percent has a profound effect. First, notice that the graph in Figure 21, the simulation takes longer to reach a steady state. The contractor work force has dropped to zero. The civilian work force is too large and the amount of down time is greater. Figure 20 shows that if the civilian separation rate is 13.3% the best position going into a recession is to have a contractor work force of 17%.

The results of an optimum work force mix are best shown by Figure 22, in which a comparison of down time is plotted for various work force mixes given a drastic decrease in work demand. Line one, a work force consisting of five percent contractors, shows the greatest amount of down time. Line two is the optimum work force with 17% contractors. Line three is the result of a work force with 30% contractors. The optimum work force mix of 17% with a civilian separation rate of 13.3% fared the best and would present the minimum cost to the organization that is facing a recession.

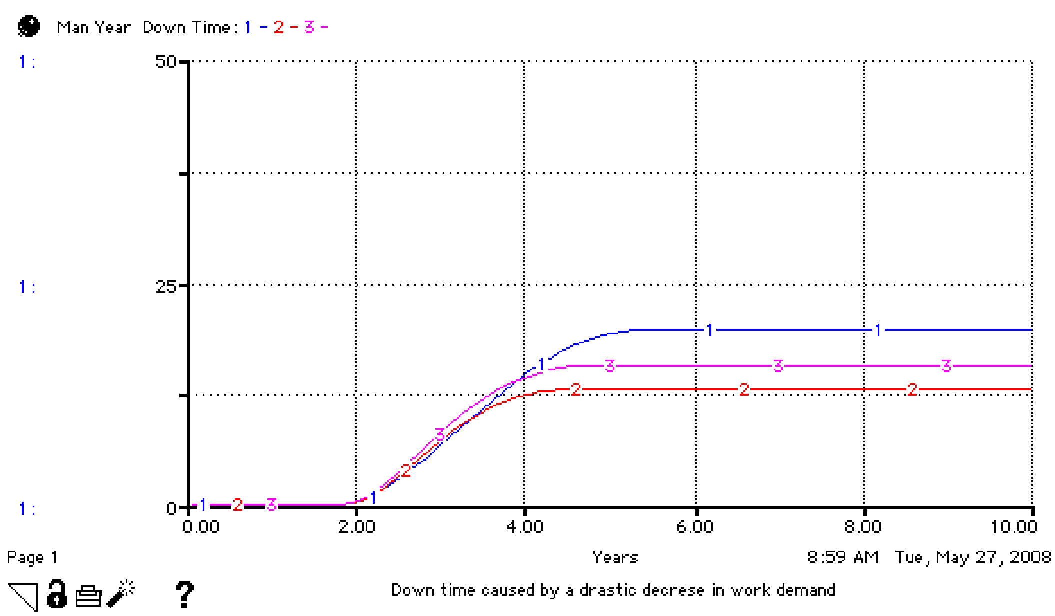


Figure 22. Simulation comparison of down time for various force mixes

These simulations help illustrate a real event that occurred at China Lake. After the Reagan presidency there was a dramatic decrease in work. The result was traumatic as the work force was down sized. Management had no choice but to do a Reduction in

Force (RIF) and to stop hiring for several years. Figure 23 shows the fallout effect of this period on the work force demographics.

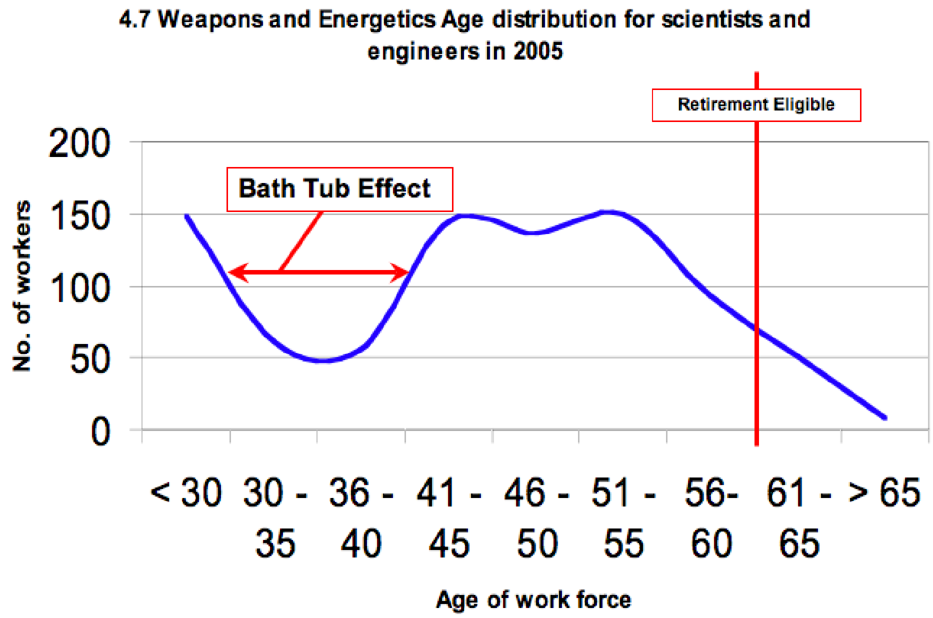


Figure 23. Work force demographics by age

As Figure 23 shows, the current work force is lacking in a sufficient number of scientist and engineers between the ages of 30 and 40. The true significance of the problem is highlighted when one considers the effect that civilian separation rate will have as more employees retire from the work force over the next few years. As has been shown, the civilian separation rate is an important parameter that determines the optimum percentage of contractors at China Lake.

3. Simulation Runs and Data Analysis

In the following simulations one can see the effect that changes in man-year work requirements has on the amount of lost work or overhead levels and the head count of civilian and contractor workers.

Table 5 shows the matrices of simulation parameters examined and varied in the analysis runs. The values for each parameter in the table represent the initial value of the parameter for that simulation run. Simulation run one simulates a drastic reduction in work by starting from 100 and dropping to fifty man-years per year. Simulation run two simulates an increase in work by starting at 50 man-years and jumping up to 100 man-years. Finally, simulation run three simulates a pulse response with a two-year increase in work from 50 to 100 man-years followed by a return to 50 man-years of work per year.

		Simulation Runs		
Category	**Parameter**	**No.1**	**No.2**	**No. 3**
Funding	Man-year Goal	100	50	50
	New Man-year Goal	50	100	100 for 2 yrs
Work Force	Civilian Work Force	70	35	35
	Civilian Hiring Success Rate	85%	85%	85%
	Civilian Separation Rate	10%	10%	10%
	KTR Work Force	30	15	15
	KTR Hiring Success Rate	85%	85%	85%
	KTR Separation Rate	10%	10%	10%

Table 5. Initial values for simulation runs

Figure 24 shows the results of simulation run one, which simulates a drastic reduction in work. The purple line traces the MY demand which starts at 100 man-years in year zero and drops to 50 man-years after year two. The yellow line tracks the down time associated with workers that are charging to overhead and not to direct funded projects. The pink line shows the lost work due to not having enough workers to meet all the work demand. The blue line tracks the number of contractor workers, while the green line tracks the number of civilian workers.

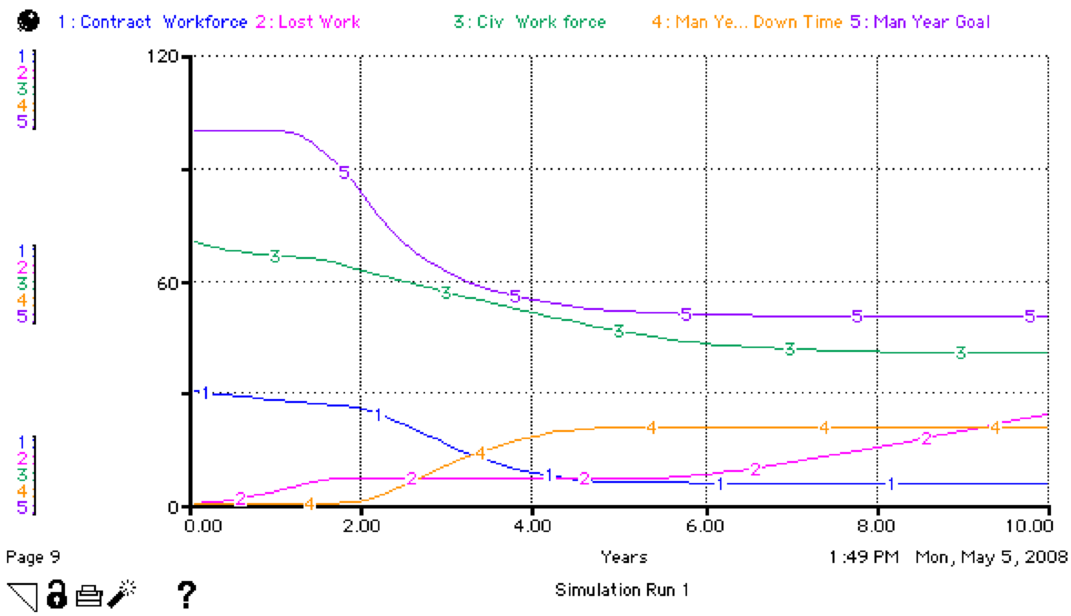


Figure 24. Simulation Run One Results

In this simulation run, as in all the simulations, the hiring success rate was set to 85 percent for both contractors and civilian hires. This is consistent with the rates experienced at China Lake in the past. Additionally, the separation rates for both contactors and civilian workers were set to 10 percent each year. By slowing down the simulation speed, and varying the separation, hiring success rates each year, and man-year goals, one can run any number of simulation scenarios.

Figure 25 shows the percentage of civilian and contract workers for simulation run one. Line one shows the man-year gap which when positive reflects the work force is undersized and when the gap is negative the work force is too large. Line two tracks the percentage of civilian works and line three tracks the percentage of contract workers. As one would expect the percentages change as the demand for work is reduced from 100 man-years to 50 man-years. As in real life, the contract work force is reduced to make up for the reduction in man-year demand.

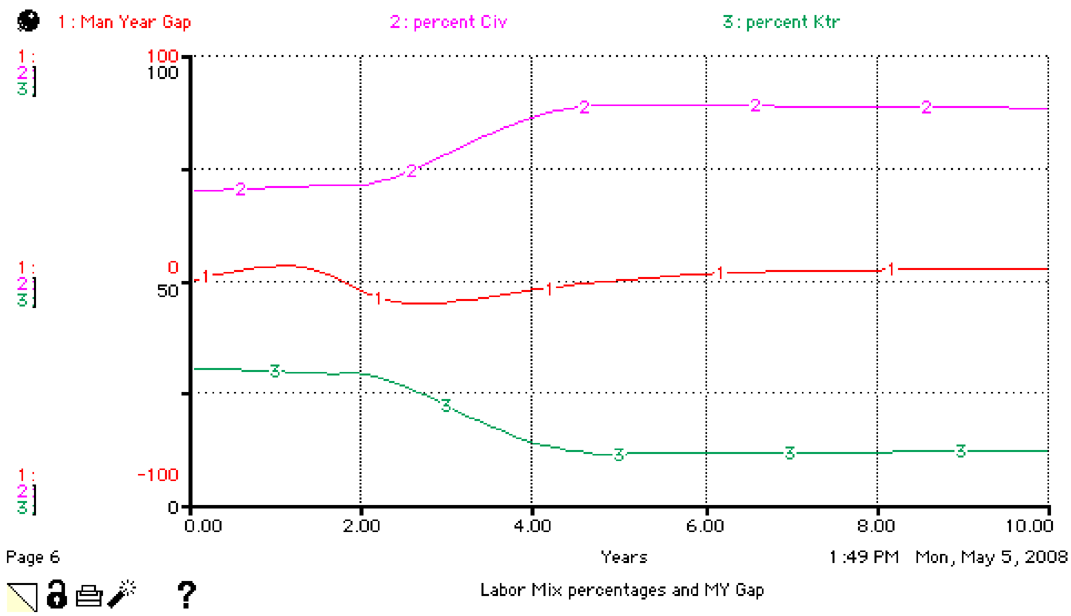


Figure 25. Simulation Run One Civilian and Contractor Percentage Results

An interesting observation of the man-year gap is that in year six, the gap is positive and stays positive to year 10, indicating the work force is undersized. The reason for this gap is the constant loss of employees separating from the work force. Like in real life, the simulation takes into account that a percentage of the work force will always be departing. At China Lake, the rate is typically 10 percent.

Simulation two, shown in Figure 26, simulated a drastic increase in work demand from 50 man-years to 100 man-years. In this simulation the notable difference is the constant increase in lost work due to a work force that cannot meet the work demand. The reason for this lost work, despite an increasing work force, is the constant turnover of workers caused by worker separations and the fact that the hiring rate cannot exceed 85 percent efficiency. Even if the hiring rate were 100 percent successful to meet the work demand, the separations rate would cause an increase in lost work. Fortunately, as shown in line four, the down time is zero.

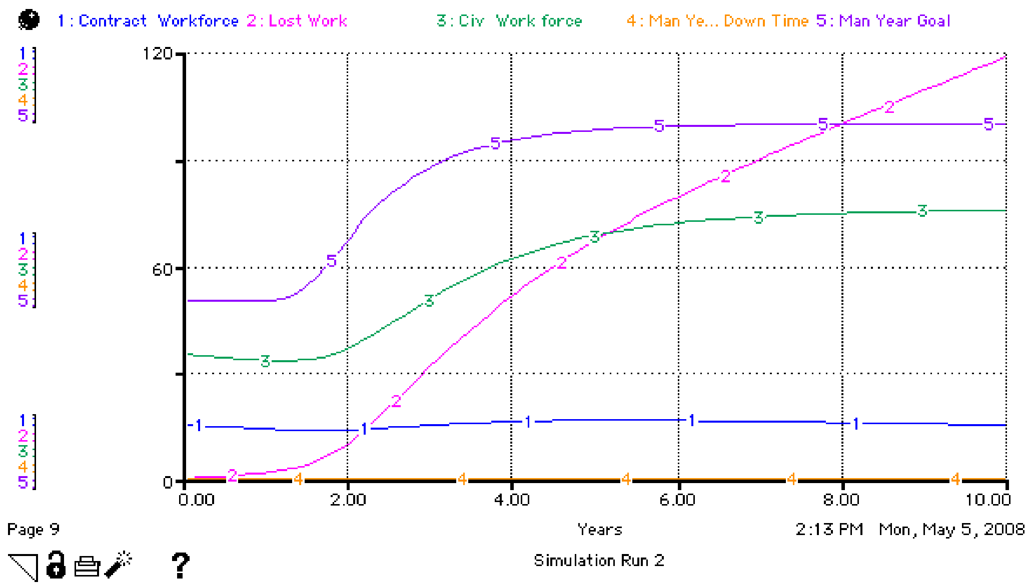


Figure 26. Simulation Run Two Results

In Figure 27 the simulation run two percentages for civilian and contractor workers are displayed. Even though the size of the work force is larger, and there are more contract workers, the simulation shows that the trend is for the percentage of contract workers to decrease. Additionally, the man-year gap stays positive due to the rate of separations and the hiring success rate.

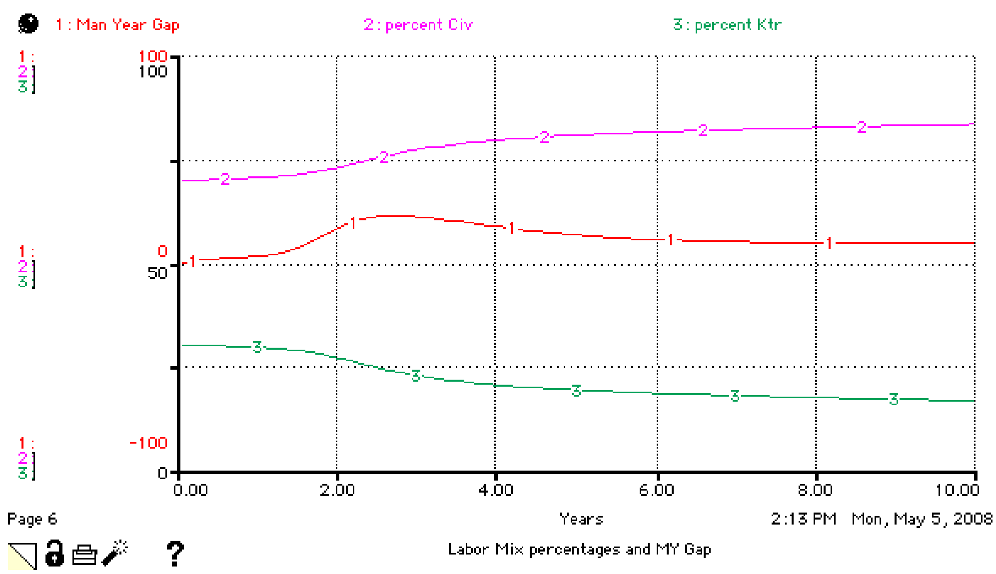


Figure 27. Simulation Run Two Civilian and Contractor Percentage Results

Figure 28 shows the results of simulation three, in which a temporary increase in work demand of 100 man-years for two years is followed by a return to a sustained work demand of 50 man-years.

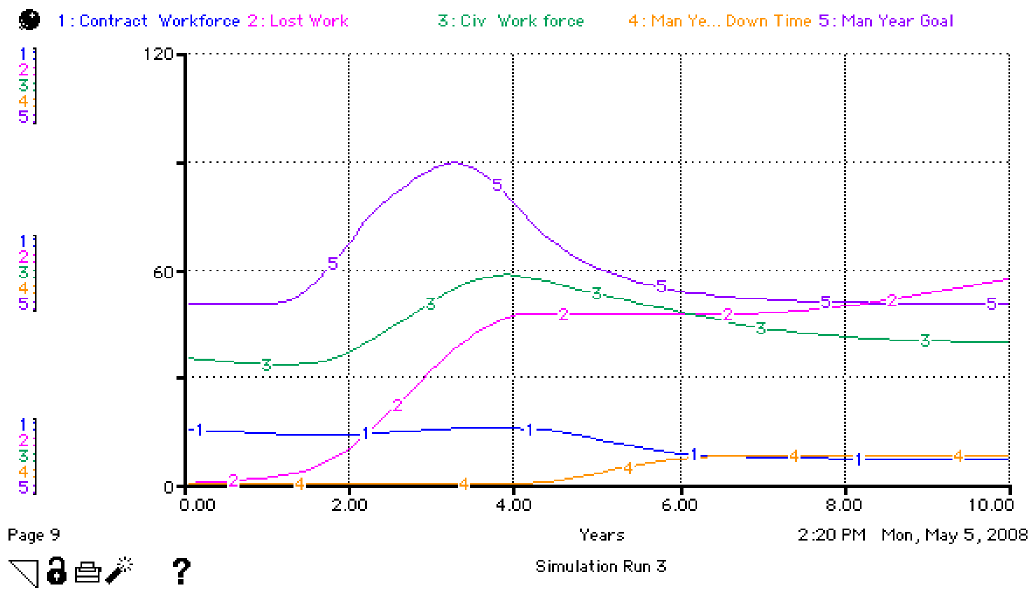


Figure 28. Simulation Run Three Results

Simulation three shows that a temporary increase in work can have a dramatic change in the work force. The size of the civilian work force has grown while the contractor work force has decreased. Additionally, there is an increase in down time due to the increased civilian work force. To compound matters, the amount of lost work continues to increase.

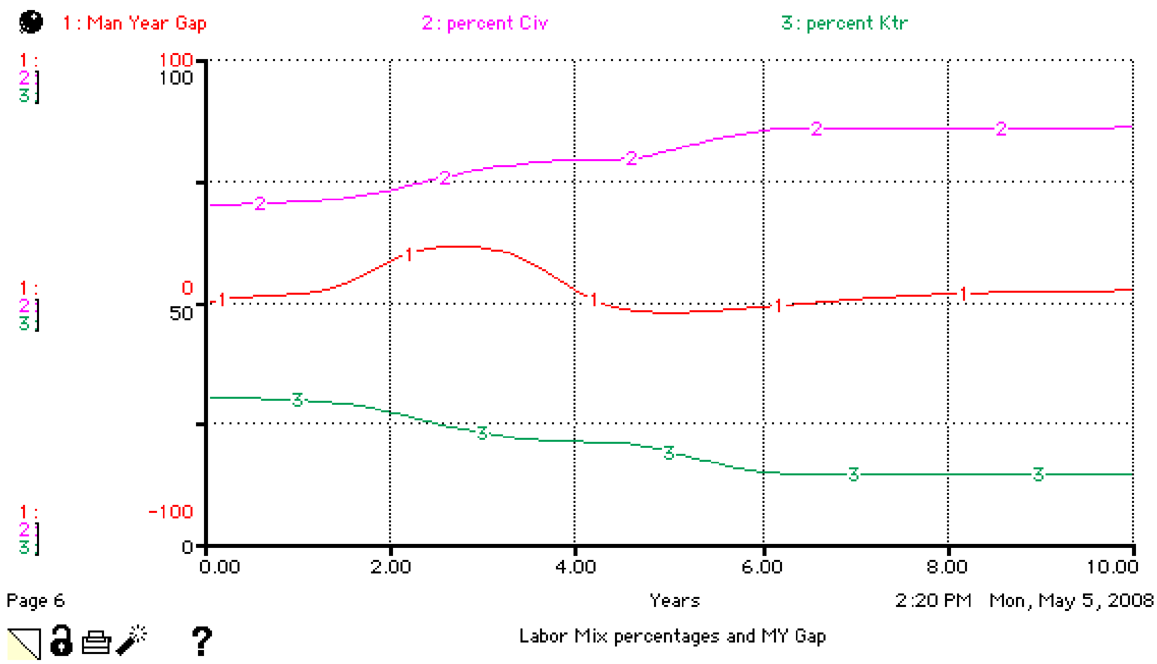


Figure 29. Simulation Run Three Civilian and Contractor Percentage Results

As shown in Figure 29, the percentage of civilian workers increases while the percentage of contractors decreases. This temporary work demand has had a profound impact on the work force and may not be the result management wants. This simulation shows that without management intervention, by manipulating hiring rates and separation rates, a potentially undesirable event can play out. As shown repeatedly, the contractor work force adversely absorbs the fluctuations.

The optimum labor mix is not a static value and will change as the scenario changes. Just as in real life, today's best solutions may not be tomorrows. The best one can expect, is an optimum solution for the present state that minimizes adverse effects in a future state. If one knew with some certainty the future work demands, the best action may be one that contradicts the conventional wisdom.

In summary, each of the research questions has been successfully answered. The system parameters most relevant to controlling the NAWCWD labor mix system were found and presented. An analytical model that captured the essence of the system dynamics was developed. Lastly, a digital simulation based on the parameters of interest and derived from the analytical model was developed. The digital simulation was first calibrated and validated and then exercised in a series of simulation runs. The data from the simulations demonstrated the usefulness of this simulation tool.

The next chapter discusses the implications of these results and the significance of the findings on potential policy changes at NAWCWD.

V. SUMMARY, CONCLUSION AND RECOMMENDATIONS

The discussion for this chapter is presented as follows: summary of the labor mix model development and analysis, conclusions, and implications and recommendations for future research.

A. SUMMARY OF SYSTEMS MODEL DEVELOPMENT

The utility of creating a labor mix model and simulation is to allow management to gain insight into the long-term effects of current work force decisions.

The analysis was conducted to aid a NAWCWD manager in their hiring decision. Obviously, the work force dynamics of an organization as large as China Lake and NAWCWD can be quite complex. This analysis has attempted to capture the essence of those dynamics by modeling, and then simulating the work force demand and the civilian and contractor labor mix.

These system components were selected based on interviews with subject matter experts and corresponding analytical model development from the interaction of the primary parameters. Historical data was used to baseline the ability of the model and simulation to help predict the future labor mix. The results of the simulating of the labor mix model were shown in the preceding chapter. Analysis of the labor mix simulation revealed that the business system was sensitive to certain scenarios that potentially could be affected by management policy.

The following sections discuss the implications and conclusions from the labor mix investigation and simulation run data shown previously.

1. Research Question One

The purpose of this research question was to identify the significant parameters by investigating and understanding the labor system. There are many parameters that can be directly or indirectly controlled by the senior management team at NAWCWD.

This investigation revealed the major parameters management has for affecting the work force and labor mix as were listed in Table 1. Those parameters include accepting work and influencing hiring success rates and separation rates for both civilian and contract workers. Developing a model of the relationship between these parameters would give management insight into the effect of their hiring decisions on the optimum labor mix between civilian and contract workers and the possible outcome of those decisions. Understanding the relationship between the work demand and the available work force proved to be an important aspect of assessing the system. Predicting future workloads continues to be a challenge in shaping the size and composition of the work force.

2. Research Question Two

Can an analytical model be developed that sufficiently models the interactions of the parameters discovered in question one?

The development of an analytical model proceeded from the overview approach shown in Figure 4 and was refined to the more focused model, which attempted to capture the fundamental dynamics of the labor mix system while maintaining an appropriate level of detail. The development of the analytical model was discussed previously and illustrated in Figure 5.

An important benefit of this causal loop diagram was that it modeled, and made clear, the feedback loops resulting from the interaction of the system parameters. The benefit of the approach of creating this causal loop diagram to model the labor mix was based on a relatively simple and intuitive investigation of the feedback loops and the structure of the interactions.

While the analytical model provided the basic and mandatory understanding of the interactions and feedback loops of the labor mix system, it did not provide the quantitative results needed to understand the labor mix dynamics. A digital simulation was required to exercise the system dynamics. Therefore, the need for question three was clear as the analytical model was transformed to a simulation that could be used to conduct numerical analysis. The following section discusses the analysis conducted by using the simulation.

3. Research Question Three

Can a computer simulation be developed to implement the analytical model developed in question two and then be used to help decision making about the labor mix?

The task of translating an analytical model that makes intuitive sense into a computer simulation that maintains that same level of intuitive appeal can be challenging. The analytical model of Figure 5 was used to develop the simulation that was shown in Figure 9. The apparent simplicity of the simulation belies its ability to model complex system dynamics. The development of the simulation and the resulting dynamics were discussed in the previous chapter.

The simulation was calibrated based on two types of runs. The first was a steady state scenario in which the initial conditions were in balance and there were no perturbations during the run. As expected, the response in Figure 10 showed no changes in the systems behavior. The simulation was also exercised with China Lake historical data shown in Figure 12 to demonstrate the simulation's capability to replicate the dynamics in the number of civilian and contract workers over the last 10 years. Additionally, the simulation was demonstrated and validated by subject matter experts.

The final task was to exercise the simulation with a series of studies. These were broken into three scenarios: a drastic increase in work demand, a drastic decrease in work demand, and a one-time spike in work demand.

From the results of the studies, it was clear the parameters such as rate of separation and rate of successful hires and acceptance of work had a significant impact on the dynamics of the work force labor mix. Manager's response to hiring and attrition could be adjusted to effect changes on the system. Understanding how the system responds to these adjustments could help management define future hiring policies.

In summary, these studies yielded further understanding of the work force labor mix responses to differing initial conditions and perturbations.

B. CONCLUSIONS

Understanding and changing a complex and dynamic system is challenging. Internal and external environmental influences, as well as corporate culture drive the business system in preferred directions based on the structure of the system. These cultural directions are often difficult to change. To make things even more complicated, the direction taken by any business system in response to actions by managers may be counterintuitive to the managers who intend to drive the system in a different direction. Further management actions, and the resulting consequences, may be far separated by events and time, which can make it difficult to understand the relationships between the two.

Senior management understands that business opportunities must be pursued. An important way they can succeed in capturing new work and maintain a healthy organization is by having a balanced work force provide customers with desired products. Therefore, hiring civilian and contractors with the right skills and talents is mandatory, and this decision is not going to be changed by this research. However, deciding when to hire and how many people to hire, and if they are civilian or contractor hires, may well be adjusted based on the outcomes of the analysis.

One notable conclusion was the often-adverse effect on the contractor work force due to changes in work demand. The contractor work force protects the civilian work force by dampening the effects of changing work demand and changes in hiring and separation rates for civilian workers. The policies that affect the civilian and contractor labor mix can be controlled by NAWCWD and should be more closely examined.

The ability to predict absolute system behavior was not a goal of this study. However, the ability to estimate the trends in future behavior of the labor mix system in response to current decisions was an important objective of the systems dynamic research. By developing confidence that the model is able to predict the relative direction and magnitude of change, it is hoped that management will be able to study the effects of their decisions without having to live with unintended consequences.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

As any analyst knows, a modeling and simulation task is never really completed. There are always refinements that could be implemented given time and money. In the case of this analysis, there are many arguments that could be made for future research. One particular area that this study did not investigate was the labor mix for skilled workers. This study did not distinguish between skilled and unskilled workers and if they were civilian or contractors. The model assumed that the skilled work force was made up of both civilian and contractors. The truth is that at NAWCWD most unskilled work is contracted out while skilled work is given to civilians. This puts the skilled civilian work force at risk of becoming a burden when work demand decreases. This is preventable and deserves further study.

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APPENDIX A. MODEL EQUATIONS

Civ__Work_force(t) = Civ__Work_force(t - dt) + (Hire_Civ__worker - Civ__Separation) * dt

INIT Civ__Work_force = 12

INFLOWS:

Hire_Civ__worker = if (Man_Year_Gap<0) then 0 else Man_Year_Gap*Civ_hiring__success_rate

OUTFLOWS:

Civ__Separation = Civ__Work_force*Civ__Separation__rate

Contract__Workforce(t) = Contract__Workforce(t - dt) + (Hire_Ktr - Ktr__Separation) * dt

INIT Contract__Workforce = 1

INFLOWS:

Hire_Ktr = (Man_Year_Gap-Hire_Civ__worker)*Ktr_hire__success_rate

OUTFLOWS:

Ktr__Separation = IF(Man_Year_Gap<0) THEN ABS(Man_Year_Gap) ELSE (Contract__Workforce*Ktr_Separation_rate)

Lost_Work(t) = Lost_Work(t - dt) + (Lost_Work_Inc) * dt

INIT Lost_Work = 0

INFLOWS:

Lost_Work_Inc = if(Man_Year_Gap>0) then Man_Year_Gap else 0

Man_Year_Goal(t) = Man_Year_Goal(t - dt) + (New__Man_Year_Goal - Man_Year__Completed) * dt

INIT Man_Year_Goal = 13

INFLOWS:

New__Man_Year_Goal = MY's

OUTFLOWS:

Man_Year__Completed = Man_Year_Goal

Man_Year__Down_Time(t) = Man_Year__Down_Time(t - dt) + (MY_down_time__increase) * dt

INIT Man_Year__Down_Time = 0

INFLOWS:

MY_down_time__increase = if (Man_Year_Gap<0) then abs(Man_Year_Gap) else 0

Civ_hiring__success_rate = .85

Civ__Separation__rate = .1

Ktr_hire__success_rate = .85

Ktr_Separation_rate = .1

Man_Year_Gap = Man_Year_Goal-Total__workforce

percent_Civ = (Civ__Work_force/Total__workforce)*100

percent_Ktr = (Contract__Workforce/Total__workforce)*100

Total__workforce = Civ__Work_force+Contract__Workforce

MY's = GRAPH(TIME)

(0.00, 13.0), (1.00, 56.0), (2.00, 56.0), (3.00, 35.0), (4.00, 25.0), (5.00, 25.0), (6.00, 25.0), (7.00, 25.0), (8.00, 25.0), (9.00, 25.0), (10.0, 25.0)

APPENDIX B. COMPTROLLER DATA

```
Fiscal Year New Orders DBC 9800     NZ 9800     Civilian   Labor   Total
      NZ Civ Labor      Contracts Total   Civ + KTR   Materials    Total
      Travel DBC 21P0   TOA ($M)                      Fiscal Year Civ
ES DBC 9010 NZ 9010     KTRs  NZ KTR      Year Total  % Civ % KTR
1997  "$873,198,392.96 "      0.088       "$400,060,786.01 "      0.086
      "$1,273,261,175.97 "    "$1,673,321,962.07 "    "$77,225,351.95  "
      "$16,990,392.54 " "$1,458"                      1997  "6,053"
      0.115 No Info
1998  "$877,252,383.29 "      0.088       "$452,312,445.45 "      0.097
      "$1,329,566,826.74 "    "$1,781,879,272.29 "    "$94,663,384.55  "
      "$18,708,227.71 " "$1,448"                      1998  "6,038"
      0.115 "2,488"     0.112 "8,526"     0.708 0.292
1999  "$835,181,582.52 "      0.084       "$399,647,123.64 "      0.086
      "$1,234,830,705.16 "    "$1,634,477,828.89 "    "$78,625,980.25  "
      "$21,252,047.80 " "$1,354"                      1999  "5,019"
      0.095 "2,464"     0.111 "7,483"     0.671 0.329
2000  "$804,228,082.47 "      0.081       "$389,218,482.12 "      0.084
      "$1,193,448,564.59 "    "$1,582,667,046.79 "    "$77,825,212.47  "
      "$14,897,945.97 " "$1,367"                      2000  "4,771"
      0.091 "2,443"     0.110 "7,214"     0.661 0.339
2001  "$826,526,887.65 "      0.083       "$396,015,027.67 "      0.085
      "$1,222,543,916.32 "    "$1,618,558,944.08 "    "$53,935,484.06  "
      "$20,788,624.11 " "$1,403"                      2001  "4,739"
      0.090 "2,438"     0.110 "7,177"     0.660 0.340
2002  "$897,248,005.85 "      0.090       "$413,860,384.25 "      0.089
      "$1,311,110,392.10 "    "$1,724,970,776.44 "    "$51,517,620.41  "
      "$21,228,142.00 " "$1,559"                      2002  "4,871"
      0.092 "2,430"     0.109 "7,301"     0.667 0.333
2003  "$957,797,910.78 "      0.096       "$455,026,314.76 "      0.098
      "$1,412,826,228.54 "    "$1,867,852,543.40 "    "$65,619,616.94  "
      "$21,761,145.37 " "$1,486"                      2003  "4,808"
      0.091 "2,224"     0.100 "7,032"     0.684 0.316
2004  "$925,549,412.18 "      0.093       "$434,487,238.00 "      0.093
      "$1,360,038,654.18 "    "$1,794,525,892.27 "    "$67,641,072.68  "
      "$24,917,837.24 " "$1,554"                      2004  "4,221"
      0.080 "1,935"     0.087 "6,156"     0.686 0.314
2005  "$897,987,600.47 "      0.090       "$436,327,698.84 "      0.094
      "$1,334,317,304.31 "    "$1,770,645,003.24 "    "$66,301,202.39  "
      "$15,728,084.36 " "$1,435"                      2005  "4,152"
      0.079 "2,009"     0.090 "6,161"     0.674 0.326
2006  "$964,520,918.68 "      0.097       "$440,577,259.30 "      0.095
      "$1,405,100,183.98 "    "$1,845,677,443.37 "    "$56,055,664.51  "
      "$23,240,347.65 " "$1,487"                      2006  "3,961"
      0.075 "1,929"     0.087 "5,890"     0.672 0.328
2007  "$1,086,052,012.24 "    0.109       "$441,035,987.94 "      0.095
      "$1,527,090,007.18 "    "$1,968,125,995.21 "    "$74,860,038.03  "
      "$25,157,088.65 " "$1,637"                      2007  "4,059"
      0.077 "1,851"     0.083 "5,910"     0.687 0.313
Total "$9,945,543,189.09 "          "$4,658,568,747.98 "
                                  total "52,692"
      "22,211"          "68,850"
```

Notes: Contracts include much more than just labor. The integrity of all FY03 data is questionable. KTRs data represents On-Site Badges.

FY 2007 Data is cumulative from month-to-month

FY 2007 New Orders DBC 9800 NZ 9800 Civilian Labor Total
NZ Civ Labor Contracts Total Materials Total
Travel DBC 21P0

October-06 "$376,724,901.53 " 0.038 "$29,254,770.68 " 0.011
"$10,574,192.11 " "$3,992,510.67 " "$2,971,266.36 "

November-06 "$505,665,737.88 " 0.052 "$68,343,056.83 " 0.025
"$34,425,463.47 " "$9,703,527.74 " "$4,895,658.96 "

December-06 "$634,089,699.86 " 0.065 "$100,704,270.99 "
0.037 "$64,223,298.34 " "$13,387,936.31 "
"$5,836,918.50 "

January-07 "$721,069,441.93 " 0.074 "$131,332,471.66 "
0.048 "$91,726,340.22 " "$18,655,995.61 "
"$7,472,264.35 " Historical Data
Simulated Results
February-07 "$792,266,492.09 " 0.081 "$165,249,551.87 "
0.060 "$128,690,823.23 " "$23,554,926.84 "
"$9,292,675.38 " Year Civilian KTR
Total Civilian KTR Total
March-07 "$853,303,543.01 " 0.087 "$204,213,693.24 "
0.075 "$181,388,017.06 " "$30,754,439.94 "
"$11,439,130.28 " 1998 "6,038"
"2,488" "8,526" "6,053" "2,488" "8,541"
April-07 "$853,303,543.01 " 0.087 "$239,574,451.68 "
0.087 "$217,240,509.19 " "$37,205,317.43 "
"$14,058,758.05 " 1999 "5,019"
"2,464" "7,483" "5,563" "2,476" "8,039"
May-07 "$944,354,637.18 " 0.096 "$286,094,843.47 "
0.104 "$255,423,827.13 " "$44,872,305.73 "
"$16,209,873.54 " 2000 "4,771"
"2,443" "7,214" "4,988" "2,453" "7,441"
June-07 "$965,919,378.02 " 0.099 "$326,579,234.03 "
0.119 "$303,917,785.35 " "$47,880,597.55 "
"$18,529,732.52 " 2001 "4,739"
"2,438" "7,177" "4,850" "2,440" "7,290"
July-07 "$1,017,531,051.96 " 0.104 "$351,634,359.07 "
0.128 "$346,894,886.27 " "$53,234,810.54 "
"$20,853,808.76 " 2002 "4,871"
"2,430" "7,301" "4,834" "2,434" "7,267"
August-07 "$1,046,943,213.02 " 0.107 "$394,746,156.55 "
0.144 "$400,260,365.13 " "$60,912,564.66 "
"$22,780,177.23 " 2003 "4,808"
"2,224" "7,032" "4,803" "2,329" "7,132"

September-07 "$1,086,052,012.24 " 0.111 "$441,035,987.94
" 0.161 "$1,527,090,007.18 " "$74,860,038.03 "
"$25,157,088.65 " 2004 "4,221"
"1,935" "6,156" "4,489" "2,091" "6,581"

2005 "4,152" "2,009" "6,161" "4,190" "1,964"
"6,154"
total "$9,797,223,651.73 " "$2,738,762,848.01 "
"$3,561,855,514.68 "
2006 "3,961" "1,929" "5,890" "4,062" "1,929"
"5,991"

2007 "4,059" "1,851" "5,910" "3,920" "1,853"
"5,774"

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