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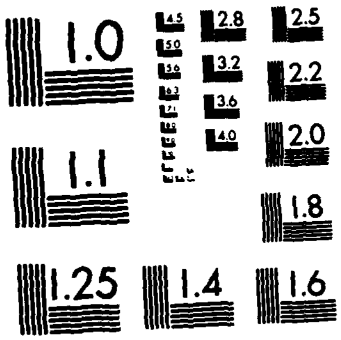

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A PLACEMENT MODEL FOR FLIGHT SIMULATORS

Edward P. Gebhard, Captain, USAF
John P. O'Neill, Captain, USAF

LSSR 23-82

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The use of flight simulators has been increasing due to the rising costs of operating and maintaining aircraft. At the same time, a drive towards increased simulator fidelity has caused a rapid increase in simulator acquisition and support costs. The rising costs of simulator acquisition and support, coupled with the fact that aircrews assigned to any one of the majority of USAF aircraft types are stationed at numerous geographic locations, provide the impetus to develop an improved methodology for comparing the costs of simulator basing strategies. The methodology includes a comprehensive analysis of the relevant and significant costs of simulator ownership. Using these costs as inputs, a computer program was developed which incorporates learning curve and present value theory into a facility location algorithm. The program determines the number and location of the simulators to satisfy aircrew training at minimum cost. A demonstration of model capabilities and a sensitivity analysis based on the acquisition of the B-52G Weapon System Trainer are included.

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A PLACEMENT MODEL
FOR FLIGHT SIMULATORS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Systems Management

By

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Captain, USAF

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September 1982

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CHAPTER I

INTRODUCTION

BACKGROUND

The use of aircraft flight simulators has greatly increased within the last ten years. A large part of this increased usage is due to the tremendous rise in the price of petroleum based resources. As the cost of flight operations began to increase, the Department of Defense (DOD) and the Air Force initiated programs to reduce costs. Since flight training consumes large amounts of fuel, Air Force and DOD planners sought means of reducing inflight training without adversely affecting the nation's defensive capabilities. Consequently, in 1977 the Air Force set as a goal a twenty-five percent reduction in flying hours by 1981 (6:8). At the same time, training in existing simulators was increased in an attempt to maintain aircrew proficiency.

A second important driving force behind the increased use of simulators is the total control and inherent safety that simulators provide. In fact, it is precisely for these reasons that Edwin Link developed his famous "Pilot Maker" (14:29-30). Simulation provides the opportunity to evaluate personnel and procedures while maintaining total control of the environment. Simulation also provides the opportunity to train personnel in certain aspects of the mission which might be unsafe or even impossible to accomplish otherwise. Probably the best known example of this capability is the training of astronauts for their missions in space. Similarly, the safety aspect of simulation is demonstrated each time aircrews practice emergency procedures or Emergency War Order training.

The words 'practice procedures' may not evoke any response from the majority of people, but they are a key phrase in any discussion of modern simulators. The original Link Trainer was based on instrumentation systems that were largely mechanical in nature. The trainer sat on a universal joint and was moved by a series of bellows and electrical motors to produce a flying effect. A small light on the nose of the machine indicated to the instructor when improper control inputs were used (14:33). Technological developments during World War II refined the use of servo systems and certain components essential to trainer realism. However, it was the introduction of analog computers in the late 1940's that made modern simulation a possibility (16:9). The analog computers provided instrument readings which corresponded directly with the pilot's control inputs.

Although simulators using analog computers represented a marked improvement over previous attempts, the devices still did not respond or "feel" like actual aircraft and thus were designated Cockpit Procedural Trainers

(CPT's). As mentioned previously, simulators (CPT's) in use at the start of the oil crisis were used in an effort to reduce flying hours. It soon became readily apparent to DOD and Air Force planners, however, that aircrew proficiency could not be maintained given the magnitude of the desired flying hour cuts (5:2). Thus, convinced that improved simulators were necessary, DOD and Air Force planning personnel examined available simulator technology and evaluated plans to improve and supplement existing simulators (5:6).

While past technology only allowed aircrews to practice procedures, present technology allows simulators to look and feel, from the aircrew's perspective, like actual aircraft. The areas having the greatest impact on realism are 1) refined motion and visual effects systems and 2) the use of digital computers. It is this improved look and feel, or fidelity, of the modern day simulators that allow them to be used in place of actual flight time with little or no impact on aircrew proficiency.

This increased or improved fidelity is not without cost, however, and in fact represents a major component of simulator cost growth. For example, the use of a three dimensional model board is an inexpensive and effective way to obtain visual cues during simulated runway approaches. On the other hand, a model board is totally ineffective for situations requiring wide fields of view or large areas of terrain (16:17). Visual cues in the form of three dimensional displays may also be synthetically generated by computer using mathematical models of the terrain. However, the problem of computer storage space becomes readily apparent when one realizes that more than 10^9 bits of information are needed to reproduce the information contained on one ten inch two-dimensional color transparency. The state-of-the-art electronics required for this improved fidelity are also currently in great demand by private industry which further adds to the cost of a modern simulator. Furthermore, attempts to update many of the older trainers would be futile. "The computers utilize hardwired mathematical models which are totally inadequate to drive either motion systems or visual devices [16:74]." Older trainers with large, heavy cockpit areas were not designed to withstand the stresses of motion. Additionally, the increasing complexity of simulators will require more extensive, and therefore expensive, maintenance test and repair capabilities.

The rising costs of simulator acquisition and support coupled with the fact that the aircrews assigned to any one of the majority of Air Force aircraft types are stationed at numerous geographic locations provide the impetus for modeling a cost effective solution to simulator basing. It is no longer economically feasible, as in the days of the cardboard trainers or many CPT's, to routinely place simulators such that every aircrew has on-station simulator training. Although this type of basing arrangement provided ready access to the training devices at the aircrew's home station, the costs of acquiring and supporting large numbers of modern, sophisticated simulators and accompanying facilities may no longer allow the Department of Defense this luxury. As an example, all nine B-52G bases are currently scheduled to receive the new Weapons Systems Trainers (WST's) - modern simulators incorporating computer generated visual displays. The average contract value of the one time fixed acquisition cost (purchase and placement) for the WST exceeds thirteen million dollars per copy (1:58-61). Recurring maintenance and support costs could provide further savings if even one WST can be foregone in favor of sending crews to off-station training.

JUSTIFICATION

As previously mentioned, the use of flight simulators has greatly increased throughout the last decade. The continued rising cost of flight operations coupled with the simulator's inherent safety can only serve to further this trend. A small but growing movement among the population concerning air and noise pollution is yet another reason to anticipate future increases in the use of flight simulators.

Although the military services have employed flight simulators for almost half a century, the services, faced with ever more expensive simulators, have only recently begun to explore various simulator basing modes. Most of the past and much of the current research has been directed at determining the cost effectiveness of a given simulator with respect to the actual aircraft (4; 19; 22). Other research is concerned with quantifying the learning transfer rates among the various instructional tools - classroom, CPT simulator, or actual aircraft flights (16; 17; 23). It appears that while efforts are being made to efficiently acquire new simulator systems, few if any efforts have been directed toward determining an objective and efficient method of analyzing the costs associated with alternative basing strategies. In fact, documentation exists showing that the simulator locations for at least one regional simulator network was accomplished by visually approximating the locations on a map (30:10).

An extensive literature review did not disclose any acceptable solutions to the problem of analyzing alternative simulator basing strategies. Captains David R. VanDenburg and Jon D. Veith developed a mathematical model to assist in the placement analysis of A-7 simulators. The variables considered were:

1) fixed costs (F_j) - the one time costs associated with installing a simulator to include the costs of hardware, building construction, and freight.

2) transportation costs (C_{ij}) - costs to transport

crews from their assigned base i to the simulator location j and back to include meals and incidentals such as parking fees or taxi fares. This cost was found to be a function of the distance between the bases and the mode of transportation used.

3) availability (S_j) - number of crews per month that could be trained at a given simulator at base j.

4) demand (d_i) - number of crews per month from base i that required simulator training.

5) decision variable (X_{ij}) - number of crews from base i sent to base j for simulator training each month. This variable was model output rather than input.

6) number of simulators available (N) - the maximum number of simulators available or to be purchased.

A mixed integer linear programming model with the following form was chosen:

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} Y_j + \sum_{j=1}^{m} F_j Y_j$$

where Y_j was a dummy variable equal to one if base j is chosen as a simulator site and zero otherwise (30:19-25). Although a model was developed, it did not include any recurring fixed costs, discounting, or learning curve effects on acquisition costs. Additionally, no suitable computer algorithm could be discovered to solve the resulting equations. Furthermore, the data required to determine the fixed cost variable F_j was not available for

A-7 simulators.

Research regarding simulator placement analysis was continued by Captain Franklin E. Hoke, Jr. Using VanDenburg and Veith's model, Hoke developed a suitable computer algorithm and applied it to analyze B-52G WST basing strategies. Transportation costs in the model were computed as the fuel cost per hour for the B-52 multiplied by the flight time between bases i and j. Demand constraints were expressed in hours per year and based on the needs of the crew position having the maximum training requirement (13).

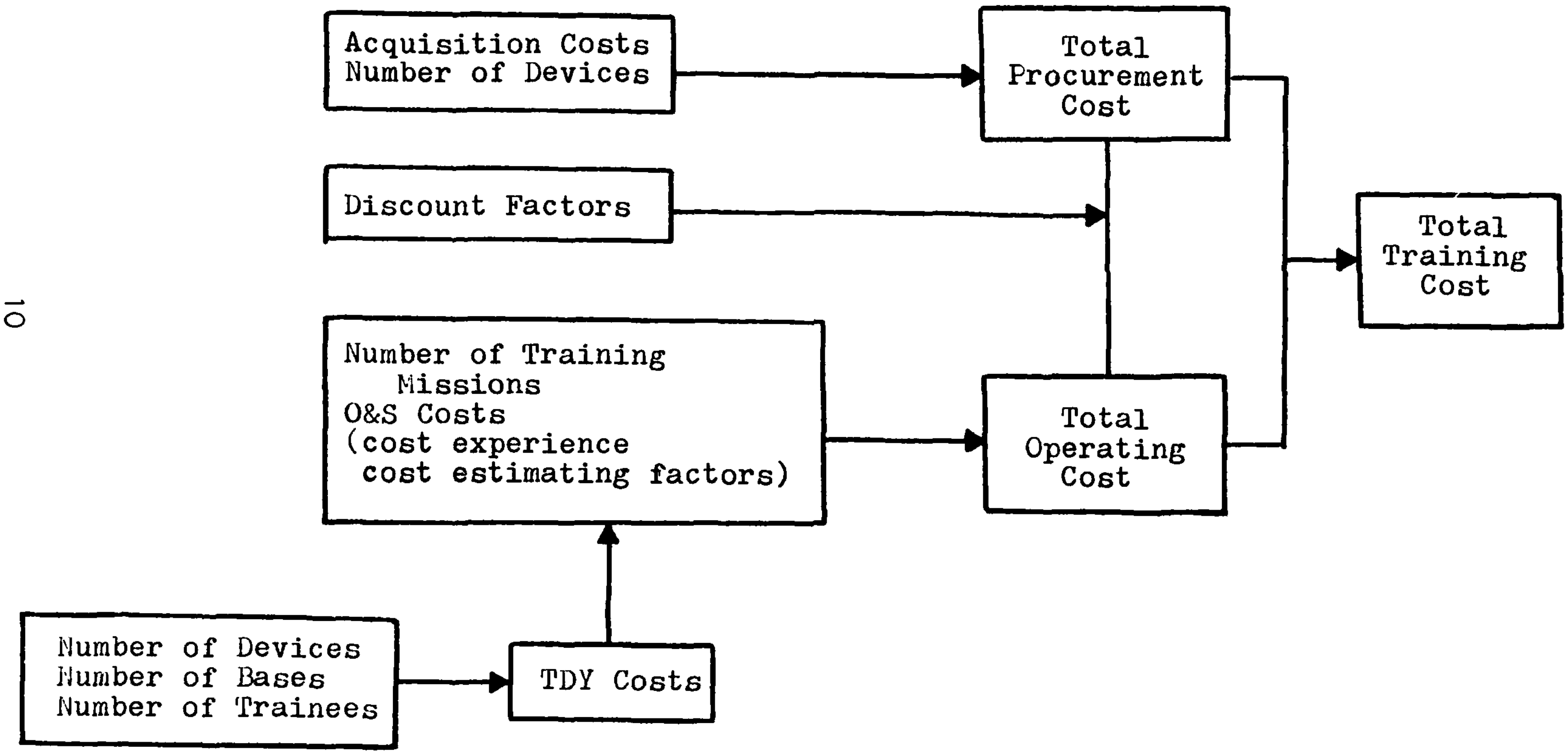
Hoke applied a Multi Purpose Optimization System algorithm (MPOS - available on CYBER) to solve the WST location problem. Specifically, the Branch and Bound Mixed Integer Program (BBMIP) was selected. BBMIP first solves the minimization problem without regard to the integer constraints and then "proceeds as if to enumerate the set of all possible mixed integer solutions by sequentially constraining each integer variable and in turn to an integer value within its range [10:48]." Optimality for the given constraints was established by BBMIP, and Hoke performed sensitivity analysis by varying the number of crews per base.

Although the algorithm selected does solve the model as presented the model possesses an inherent weakness. The model as presently formulated considers only two costs of simulator training. The one time fixed acquisition costs are compared with variable crew transportation costs. No consideration is given to recurring fixed costs or other variable costs. Furthermore, no consideration is given to the discounting of cost flows, or the learning effect on acquisition costs. As such, any "optimal" strategy determined by the above model would eventually become nonoptimal as the expected life of the system is increased. In other words, by only considering the one time fixed acquisition costs and not the recurring fixed costs it is only a matter of time before the nondiscounted variable transportation costs would eventually exceed any savings in fixed costs.

The following figure presents one view of the cost process associated with a regional simulator network (17:19). The cost of a single simulator is composed of both fixed and variable costs. Fixed costs may be further subdivided into recurring and nonrecurring costs. Nonrecurring fixed costs include the initial purchase price and the transportation expense incurred in shipping the simulator from the factory to its desired location. Recurring fixed costs will be incurred for operations and maintenance support. For example, a recurring fixed cost will be incurred for merely maintaining a maintenance detachment at a simulator location regardless of the number of hours the simulator is used. Variable costs are those costs which vary as a function of usage. Among these

Figure 1.1

Cost Process



variable costs are the temporary duty (TDY) costs experienced in transporting aircrews between their home base and the simulator location. Additionally, a maintenance cost will also be incurred which is variable in nature and dependent on simulator usage.

Several cost models have been developed to help in the analysis of life cycle costs. Although it appears that no Air Force life cycle cost model has been developed specifically for simulators, several models could be adopted for use.

AFR 173-13 provides a Cost Oriented Resource Estimating (CORE) Model designed to provide an estimate of an aircraft squadron's annual operating and support (O & S) costs. The cost structure is hierarchical and provides great flexibility with regard to the desired level of analysis. In the initial phases of acquisition it is probable that only estimates for major program elements would be possible. As the program develops however, each major element's estimate would be further refined through the use of subelement estimates. Examples of typical life cycle annual operating and support costs are provided for selected aircraft. Unfortunately, no mention is made concerning the costs associated with a squadron's simulator training program.

As stated in AFR 173-13 an important concept to remember is that

> Complexity is not a desirable trait in an O&S cost model. Often the cost, labor hours, and schedule required to set up and provide data for a complex model prohibits its effective and timely use in the decisionprocess. The model should be structured so that it is useful in the early phases of the acquisition program and can evolve to accommodate more information as the program continues through the acquisition phases [29:7-1].

The CORE model provides a theoretical basis for many cost estimating models. A hierarchical model is intuitively appealing in that it is flexible and provides for continued estimate refinements. Unfortunately, however, the model is only designed to estimate the O&S costs for a given number of aircraft squadrons based on linear cost behaviors. The model is not concerned with any type of optimization but merely estimates average annual O&S costs for a given basing decision. Furthermore, acquisition costs are excluded in the model.

A cost model which specifically addresses simulator training costs and overcomes some of the shortcomings in the CORE model was recently developed by Analytic Services, Inc. Although the primary purpose of the research was to identify the cost-effective mix of training devices (including aircraft, simulators, part task trainers, etc.) for aircrew training for a given weapon system at a single base, the model provides an in-depth analysis of simulator costs. In fact, the level of analysis caused difficulties in validating the model. In the authors' own words, the primary problem encountered in testing the model was that much of the cost input data did not exist nor was the Air Force in the process of acquiring it (17:128).

Bearing in mind the general guidance contained in AFR 173-13 concerning complexity and cost models, it is felt that a model could be developed to combine VanDenburg and Veith's model and the Analytical Services model into a more powerful analytical tool. Whereas the Analytical Services model attempts to include all costs associated with simulator training the proposed model will attempt to determine all relevant simulator costs associated with the analysis of various basing strategies in a regional simulator network. Once the relevant cost elements have been identified each cost's behavior will be determined (fixed, variable, recurring, nonrecurring). Discounting of the cost flows will then be accomplished to determine net present values of the various alternative basing strategies.

STATEMENT OF THE PROBLEM

An objective and efficient method is needed to examine and analyze the costs of alternative simulator basing strategies (variable number and location).

OBJECTIVES OF THE RESEARCH

The purpose of this study is to develop and validate a mathematical model that can be used to examine and analyze the costs associated with the various simulator basing strategies for a given aircraft type.

The model will be used to determine the costs associated with alternative simulator networks which meet a given training capacity. Such a model might also be used to estimate the amount of excess training capacity for a given simulator network.

As such, the specific objectives of this research are to:

1) determine the relevant costs of alternative simulator training basing strategies;
2) develop a model which estimates the cost of a simulator network and compares alternative networks; and
3) gather data concerning a specific simulator system, the B-52G Weapon System Trainer (WST), and demonstrate the model's capabilities.

SCOPE AND LIMITATIONS

It must be realized that the model will be based solely on economic costs and as such cannot include subjective inputs. Nonetheless, these subjective inputs are many times quite important and should not be ignored. Both decision makers and modelers alike should remember that the objective of modeling is to aid in decision making (8:23). Subjective inputs will be considered following model results. Additionally, the research deals only with the questions concerning alternative basing strategies. Questions concerning the cost effectiveness of the various types of training, applicable transfer rates, or optimal fidelity levels are beyond the scope of this research.

SUMMARY

The ever increasing costs of modern simulators provides fertile ground for cost analysis. A quantitative model capable of objectively and efficiently analyzing alternative basing strategies could provide a firm foundation on which to base management decisions.

Chapter II traces the development of the model and analyzes the various costs of a simulator network.

CHAPTER II

THE BASING MODEL

This chapter describes the methodology used to develop the model for examining the cost of simulator basing alternatives. Model development is discussed by first restating the objectives of the research and then stating the assumptions which are basic to the model. Next, the subject of costs and benefits is addressed with primary emphasis on the costs of simulator ownership. Discounting of cost streams and learning curve theory are also discussed. The chapter also outlines the general format of the facility location problem and defines the variables required for the mixed integer programming formulation chosen for this model. The mathematical derivation of each variable is listed. An alphabetical listing of the input variables along with a short description and data source follows. The computer program formulated to build the data tape and the logic incorporated by the Branch and Bound Mixed Integer Program (BBMIP) to solve the facility location problem are also discussed. Finally, the questions of model validation and sensitivity analysis are addressed.

RESEARCH DIRECTION

As stated previously in Chapter I the primary purpose of this study is to develop and validate a mathematical model that can be used to examine and analyze the costs associated with the various simulator basing strategies for a given aircraft type. Economic analysis, which has been defined as a systematic cost estimating approach to problems of choice which identifies the alternative yielding the required level of benefits at the lowest cost (26:4), is the logical choice as a conceptual framework for the research.

The key elements of economic analysis are 1) establishing and defining the "goals or objectives" desired, 2) formulating appropriate assumptions, 3) searching out alternatives for accomplishing the objective, 4) determining the costs and benefits of each alternative, 5) comparing the costs and benefits of the alternatives and ranking alternatives, and 6) testing the sensitivity of major uncertainties on the outcome of the analysis (21:2.1).

Establishing Objectives

The most important step in any analysis is, of course, the first step, the definition of the objectives. The objectives of this research as put forth in Chapter I are to:

1) determine the relevant costs of alternative simulator training basing strategies;
2) develop a model which estimates the cost of a simulator network and compares alternative networks;

3) gather data concerning a specific simulator system, the B-52G Weapon System Trainer (WST), and demonstrate the model's capabilities.

Economic analysis is the framework for fulfilling the first two objectives.

Formulating Assumptions

Assumptions are made to reasonably limit the scope of a study. One of the primary assumptions in this study is that the simulator training system in question will actually be instituted. Much research and analysis has and is continuing to be conducted concerning the cost effectiveness of the various alternatives to flight training, such as simulator training or classroom instruction, as well as the required or most cost effective level of simulation, such as Cockpit Procedural Trainers (CPT's), motion systems, or visual systems (4; 22; 16; 17; 23). By assuming that the simulator in question will be implemented the research effort is free to focus on analyzing alternative basing strategies with regards to the number of training devices and their location.

A second important assumption concerns the period of time during which the costs will be compared. The comparison period in this analysis will equal the economic life of the simulator or the aircraft, whichever is less. Using the guidance provided in AFR 173-1 concerning the lifespan of electronic equipment the model will assume an economic life of ten years for a simulator (25:1-1). Provisions will be made for incorporating the actual projected life of the simulator and this data should be used if it is available. Similar guidance pertains to the projected life of the aircraft.

Choosing Alternatives

Conceptually speaking, the problem is one of satisfying training requirements (demand) at minimum cost. Total demand (D) may be defined as follows:

$$D = \sum_{j=1}^{n} NAIRC_j \times NMAIRC$$

where

D = Demand

$NAIRC_j$ = Number of aircrews at base j

$NMAIRC$ = Number of simulator missions required per person per period (in multiplace aircraft select crew position with highest simulator training requirement per period)

n = Number of bases for the weapon system crews

Simulator training capabilities, expressed in missions available per period, form the supply constraints for a given type of simulator. Availability (S_j) is the number of missions per period that may be provided and represents the maximum training capability that can be supported by base j.

Theoretically, the minimum number of simulators required to satisfy a given level of demand equals total demand divided by the training capability of one simulator, assuming that all simulators have equal availability. In view of the fact that partial simulators are not allowed, the resulting figure must be rounded up to the next integer value. Possible alternatives are therefore constrained by the minimum number of simulators needed. No such constraint exists for the maximum number of simulators although past practice tended toward placing simulators at each demand location. Thus, any basing strategy which provides the required training capacity is considered as a possible alternative.

Determining Costs and Benefits

The determination of the benefits derived from a simulator network is normally a difficult undertaking. One measure of benefit is the training capability provided by the basing strategy. A problem in the measurement process occurs however in the area of scaling. Does doubling the training capability double the benefit? One possible solution would be the use of a decision maker utility function. Another solution to the problem, and the solution chosen for this analysis is to select a minimum benefit. The minimum benefit is defined as the capability to meet the required training demand. Any alternatives which do not provide the minimum training capacity are excluded from further consideration. Alternatives which provide excess training capacity are viewed as providing equal benefit.

The cost of a single simulator is composed of both fixed and variable costs. Fixed costs may be further subdivided into recurring and nonrecurring costs. An example of nonrecurring fixed costs are the initial purchase price and the transportation expense incurred in shipping the simulator from the factory to its desired location. Recurring fixed costs will be incurred for such things as operations and maintenance support. For example, a recurring fixed cost will be incurred for merely maintaining a maintenance detachment at a simulator location regardless of the number of hours the simulator is used. Variable costs are those costs which vary as a function of usage, i.e. missions provided per year. Foremost among these variable costs are the temporary duty (TDY) costs experienced in transporting aircrews between their home base and the simulator location.

MODEL DEVELOPMENT

The problem of ranking the alternative basing strategies which satisfy the training requirements can be solved by determining the basing strategy which will experience the lowest total fixed and variable costs. The various cost elements of simulator training must be examined to determine their behavior, relevance, and significance. Costs which do not vary in response to changes in the number and or location of the simulators are not relevant to the analysis. Because this research effort is concerned with determining the costs of alternative basing strategies for a given level of demand any variable costs which are purely a function of usage will not be relevant. As an example, if the cost of providing spare parts for the simulators is purely a function of total usage, and total usage is by definition constant, the cost of spare parts will be the same regardless of the number or location of the simulators. Furthermore, costs which are relevant but which are of minor consequence will not be included.

Cost Element Analysis

The major cost elements initially considered for inclusion in the model were:

1. Acquisition costs
   a. Research Development Test and Evaluation (RDT&E)
   b. Engineering development
   c. Procurement
2. Operation costs
   a. Operations manpower
   b. Base system maintenance manpower
   c. Base maintenance materiel
   d. Miscellaneous personnel support
   e. Utilities/fuel
   f. Temporary duty
3. Base operating support costs
   a. Base services manpower
   b. Miscellaneous personnel support

4. Logistics support costs
    a. Depot maintenance manpower and materiel
    b. Supply depot manpower and materiel
    c. Second destination transportation
    d. Technical order maintenance
5. Personnel support costs
    a. Recruit technical training manpower
    b. Technical training cost
    c. Medical manpower
    d. Medical materiel
    e. Permanent change of station
    f. Miscellaneous personnel support of medical and other personnel
6. Recurring investment costs
    a. Replenishment spares
    b. Recurring modifications (Class IV)
    c. Common support equipment

(2:4-3,4-4; 17:18-20)

1) Acquisition Costs

a) Research Development Test and Evaluation (RDT&E) - RDT&E costs are composed of the initial costs for producing a given type of simulator (F-15, B-52, etc.) including all (a) direct research and development and (b) test and evaluation. As stated previously, one of the primary assumption of this research is that the type of simulator being studied will be built. Additionally, it is logical to conclude that RDT&E costs are independent of the number of simulators being built. As such, all RDT&E costs are sunk costs from a basing strategy perspective. Although these costs may be quite large the costs are independent of the number of simulators of a given type purchased. Therefore, RDT&E costs will not be considered in the model.

b) Engineering Development - This category includes the costs of initial design efforts associated with system development. This element also includes the cost of fabricating and assembling prototype models (7:321). Engineering development costs appear to exhibit the same cost behavior as RDT&E costs and are not included in the model.

c) Procurement - Procurement cost is composed of the acquisition costs of a simulator to include the cost of the actual simulator device, the costs of transporting it to the selected location, and the construction and outfitting of the simulator building. Procurement costs are the one time fixed costs associated with positioning a simulator at a given location. Procurement cost estimates are normally available from the SPO or contractor. Due to the small number of simulators of a given type that are usually acquired procurement costs can vary substantially with quantity purchased. The model will therefore incorporate a "learning curve" to better estimate these costs.

2) Operations Costs

a) Operations manpower - This cost element represents the annual cost of the full number of instructors and other personnel, such as technicians and console operators, required for the operation of the simulator. Base maintenance and support personnel are not included and are considered elsewhere. The cost of crews is not included because the crews will be trained regardless of the basing decision. Provisions will be made in the model to include the cost of instructors if the instructors' primary duties are as operators of the simulator facility. On the other hand, if crews provide their own instructors only the TDY costs incurred by the instructors will be considered, and these TDY costs will appear in the TDY cost category. The operations manpower cost element will be set equal to the sum of the annual salaries for the average projected simulator manning and is considered a recurring fixed cost.

b) Base system maintenance manpower - This cost category is composed of the cost for personnel needed to fulfill base level maintenance requirements. Base maintenance personnel maintain and repair equipment at the organizational and intermediate levels. The element cost is equal to sum of the annual salaries for the assigned maintenance team and is considered a recurring fixed cost.

c) Base maintenance materiel - This is the cost of purchasing materiel from the general and system support division of the stock fund to include the cost of expendable items such as electronic repair parts. This cost element is normally calculated on a cost/hour basis (29:7-2; 17:72) and would thus be a function of usage and not basing strategy. As such this cost will not be included in the model.

d) Miscellaneous Personnel Support for Simulator Operations - This cost element represents the cost of supplies, services, and equipment needed to support military and civilian personnel associated with the operation and maintenance of the simulator at the base level. This includes administrative supply items, expendable equipment, custodial services, and other personnel oriented support items (desks, chairs, etc.). This cost is viewed as a recurring fixed cost in that it represents the funds expended for (a) maintaining existing stocks of supplies and support items and (b) custodial services. This recurring fixed cost will be included in the Base Operating Support (BOS) cost estimate. The initial stocking and purchasing costs are included in Procurement Costs.

e) Utilities/Fuel - This is the cost of electricity, gas, oil, and water used to operate and support the simulator. Although a slight fixed cost is undoubtedly present, the majority of the cost is dependent on simulator usage. As such the cost of utilities/fuel is not considered relevant with regard to a basing decision and will not be included in the model.

f) Temporary Duty (TDY) Cost - This is the cost of travel and per diem for the crew members from their home station to the simulator location, to include similar costs for any instructors that accompany the crewmembers to provide instructional training at the simulator location. If military aircraft on a normal (routine) training mission are used for transportation to and from the simulator location the travel cost can be assumed to be zero since these costs would be part of the flight training budget and not relevant to the decision process being considered. TDY costs are viewed as variable costs that are dependent upon the number of simulators in the system, the distance from home station to the simulators, and the length of time away from home station.

3) Base Operating Support Costs

a) Base Services Manpower - The cost of personnel necessary to directly support simulator personnel. These support activities include such things as food services, supply, motor pool, and CBPO services. This cost is viewed as a recurring fixed cost.

b) Miscellaneous Personnel Support Costs - The cost of supplies and equipment needed to support base services personnel who directly support the simulator personnel. This includes such things as administrative supply items, expendable equipment and office machines, custodial services, and other personnel-oriented support items. This cost element is viewed as a recurring fixed cost.

4) Logistic Support Costs

a) Depot Maintenance Manpower and Materiel Costs - The cost of the manpower and materiel required to perform major overhaul of the simulator components, including completely rebuilding or manufacturing parts. This type of maintenance involves greater technical capability and more extensive facilities than are available at base level.

The total cost of depot maintenance has two components. One component is based on the fact that depot maintenance must be provided no matter how many simulators are in the system utilizing the service. The other component is a function of the utilization rate of the simulators (17:78). The more the simulator is used the more breakdowns and maintenance can be expected.

The first cost component is only dependent on whether or not a given simulator type is built. This cost is independent of the number of simulators and is therefore not relevant to the problem. With regards to the second cost component, while the actual number of failures will rise as the use of a given simulator increases the failure rate should remain relatively constant.

Since the simulator system will be used to satisfy the training demand requirement independent of the number of simulators in the system, the second component (depot maintenance cost per utilization hour) is also not relevant and will therefore not be considered in the model.

b) Supply Depot Manpower and Materiel Costs - The cost of the materiel and personnel needed to perform the distribution of simulator parts and supplies to and from the supply depot and the simulator location. This represents the cost of managing the inventory of maintenance spare parts needed to support the simulator system. Experience has shown that this cost is normally quite small (17:80). As such this cost does not have a significant impact on the problem and will not be considered in the model.

c) Second Destination Transportation Costs - The cost of shipping supplies and materiel needed to support simulators and their support personnel. These costs include shipment of spares and repair parts between the centralized repair depot and the simulator location. These costs may be calculated by multiplying a command input value by the number of devices being shipped to (29:7-5,7-8).

Although this cost is viewed as a recurring fixed cost which would impact the total cost of any solution, experience indicates that this cost is usually quite small and that it will not have a significant enough impact to warrant consideration in this model (17:82).

d) Technical Order Maintenance Cost - This is the cost of maintaining the technical orders to reflect revised policies, concepts, and data for the simulator operation. This cost element is a recurring cost. It is dependent upon the number of pages revised per year and is calculated by multiplying the number of pages by the estimated average cost of producing a page. Normally, the value of this cost element will be small and can be ignored or assumed to be zero (17:82). Any impact on basing decision is thus insignificant, and the cost element is therefore not included in the model.

5) Personnel Support Costs

a) Recruit/Technical Training Manpower Costs - This is the cost of replacing personnel who annually attrite from squadron and base services functions. The cost can be calculated by multiplying the average or estimated turnover rate by the pay rates for the personnel being replaced. This cost is viewed as a recurring fixed cost. This cost element is normally quite small (17:83-85) and will usually be included in the Base Operating Support (BOS) costs.

b) Technical Training Cost - Technical training costs are the costs of training and providing qualified personnel to operate, maintain, and instruct in the simulator. To determine this cost an estimate of the type and rate of turnover must be made. The cost per simulator is then equal to the estimated turnover times the cost of providing replacements for the lost personnel. This element is viewed as a recurring fixed cost.

c) Medical Manpower Costs - The cost of medical personnel needed to provide medical support for the simulator personnel. The total cost for the decision should also include the cost of the medical personnel to support the training activities that provide qualified replacements. The number of medical people needed is based on manpower engineering standards that prescribe the ratio of medical to support personnel. The cost per location is equal to the number of additional medical personnel needed times their pay rate. The cost for the decision option is then dependent on the number of locations in the solution.

This element is viewed as a recurring fixed cost. Assuming that the most complex simulator would be supported by less than 50 people, any average or large size base should be able to support these few additional people with little impact on their medical manpower requirement. This recurring fixed cost element will be included in the Base Operation Support (BOS) cost estimate.

d) Medical Materiel Cost - The cost of medical materiel required to provide medical services to simulator personnel and base personnel who provide direct support to the simulator and its staff. The cost is calculated by multiplying the medical materiel cost for personnel supported, derived from past experience, times the additional personnel to be supported caused by the simulator being located at the base. Total cost for the solution option is then dependent on the number of simulators in the system.

This recurring fixed cost will be included in the BOS cost estimate.

e) Permanent Change of Station (PCS) Costs - This cost element represents the cost of rotating personnel into and out of simulator operations and maintenance.

Methods have been developed to estimate the annual number and cost of PCS moves on the basis of past experience. The methodology takes into account personnel turnover rates and produces both an average PCS cost estimate per move and an average annual PCS cost per man. This cost element is a recurring fixed cost and will be estimated using an average annual PCS per man value.

f) Miscellaneous Support of Medical and Other Personnel - This element represents the cost of providing basic operating supplies, equipment, and support to each recruit, trainee, medical, and other personnel who support the simulator personnel. The cost per simulator location is equal to the number of additional medical and support personnel needed to handle the additional worker load caused by the simulator, personnel time, the cost of the additional supplies and equipment needed by these support people. The total cost for the decision option equals the cost per location times the number of locations plus the cost incurred through depot maintenance and recruiting and training activities. This element is viewed as a recurring fixed cost. In many cases these costs are quite small and so will be included in the BCS cost estimate (17:89-90).

6) Recurring Investment Costs

a) Replenishment Spares - This cost element includes the cost of procurring and stocking expendable and repairable system subassemblies, spares, and repair parts.

This does not include the cost of the basic spare parts inventory that was purchased as a part of the initial simulator acquisition. This recurring fixed cost is calculated by estimating a replenishment spares cost per operating hour and multiplying it times the number of total operating hours to meet the training demand requirements (29:7-7). This cost is therefore not relevant to a basing decision.

b) Recurring Modification Cost - The cost of modifying the simulators in the operating inventory to make them safe for continued operation, enabling them to perform mission essential tasks (not new capability), and to improve reliability or reduce maintenance costs. A modification factor cost per unit is available for the type of aircraft being simulated (29:7-3). Since similar modifications may be required for the simulator, unless better information is available from the SPO, this cost will be assumed to be the same as for the aircraft.

c) Common Support Equipment Costs - The cost of procuring maintenance and repair shop equipment, instruments and laboratory test equipment, and other miscellaneous items including spares for this equipment. The cost of replacing this equipment is estimated as a percentage of the buy cost of the aircraft. This procedure has been developed from replacement cost experience of currently operating aircraft systems. Although this element is viewed as a recurring fixed cost, experience has shown that the common support equipment costs of simulators are not significant and this cost element is therefore eliminated from consideration in this model (17:92).

The following table summarizes the cost elements which are to be included in the model.

Present Value

After analyzing the major cost elements the relevant and significant costs must be collected into fixed and variable cost accounts. The applicable cost flows in each account must be discounted and totaled over the lesser of the simulator's or the aircraft's projected life time to arrive at the present value of the fixed and variable costs.

Conceptually, the cost of a basing alternative is equal to the sum of the discounted cost streams for the selected locations. These cost streams may be considered as annuities, and the annuity factor, which when multiplied by the recurring fixed cost results in the present value cost, is computed as follows (12:192-199):

$$A = \frac{(1 - (1+r)^{-n})}{r}$$

where

A = Annuity factor
n = Number of periods
r = Rate per period

Current economic analysis guidance (26) specifies the use of

Table 2.1

COST ELEMENTS

COST ELEMENT	COST TYPE: FIXED RECUR	COST TYPE: FIXED NONREC	COST TYPE: VARIABLE	IN MODEL
ACQUISITION COSTS				
RDT&E		X		
Engineering development		X		
Procurement		X		X
OPERATION COSTS				
Operations manpower	X			X
Base system maint. manpower	X			X
Base maintenance material			X	
Misc. personnel support	X			X
Utilities/fuel			X	
Temporary duty			X	X
BASE OPERATING SUPPORT COSTS				
Base services manpower	X			X
Misc. personnel support	X			X
LOGISTICS SUPPORT COSTS				
Depot maint. manpower and material		X	X	
Supply depot manpower and material	X			
Second destination transportation	X			
Technical order maintenance	X			
PERSONNEL SUPPORT COSTS				
Recruit technical training manpower	X			X
Technical training cost	X			X
Medical manpower	X			X
Medical material	X			X
Permanent change of station	X			X
Misc. personnel support of medical and other personnel	X			X
RECURRING INVESTMENT COSTS				
Replenishment spares	X			
Recurring modifications(Class IV)	X			X
Common support equipment	X			

a 10 percent discount rate, and this will be the rate incorporated in the model. Again, procurement costs will not be discounted but will be added to the discounted recurring fixed costs to arrive at a single fixed cost value. Temporary duty mileage and per diem costs will be discounted to obtain the cost of transporting a crew between any two locations.

Fixed Costs

As stated earlier, the fixed cost (F_i) associated with positioning a simulator at location i is composed of both the one time fixed costs of procurement ($OTFIXC_i$) and the present value of any recurring fixed costs ($PVRCFIXC_i$).

$$F_i = OTFIXC_i + PVRCFIXC_i$$

$$OTFIXC_i = TRANSC_i + BLCONT_i + COSTHD$$

where

$OTFIXC_i$ = Acquisition costs to locate simulator at location i.

$TRANSC_i$ = Cost of transporting simulator from production site to location i.

$BLCONT_i$ = Cost of constructing building to house simulator at location i.

COSTHD = Cost of actual simulator hardware.

Since the one time fixed costs are experienced at the beginning of the cost stream they need not be discounted.

However, the recurring fixed costs will, by definition, be experienced during every year of simulator operation and the annual recurring costs must be multiplied by an annuity factor to reduce the cost stream to its present value.

$PVRCFIXC_i$ is the remaining portion of the fixed cost (F_i) associated with placing a simulator at location i and is equal to the present value of the annual recurring fixed costs ($RCFIXC_i$). The relevant and significant recurring fixed costs were determined earlier in this chapter. Thus

$$PVRCFIXC = RCFIXC \times ANNFAC$$

where

PVRCFIXC = Present value of the recurring cost stream

ANNFAC = Annuity factor

$$ANNFAC = \frac{1 - (1+DR)^{-YRS}}{DR}$$

DR = Discount rate

YRS = Lesser of number of years of projected simulator or aircraft lifetime

$$RCFIXC_i = OPSMAN_i + BSMMC_i + SUPNEL_i + TTRAIN_i + PCSCST + RECMOD$$

The six individual terms comprising $RCFIXC_i$, the annual recurring fixed at location i, are defined and computed as follows:

1) OPERATIONS MANPOWER

$$OPSMAN_i = AMN1_i \times ABPF1 + OFF1_i \times OBPF1$$

where

$OPSMAN_i$ = Annual cost in current year dollars for manpower to operate a simulator at location i

$AMN1_i$ = Number of airmen (or civilians of similar pay grade) assigned to direct operational duty at the simulator at location i

ABPF1 = Airmen basic pay factor (non-rated)

$OFF1_i$ = Number of officers (or civilians of similar pay grade) assigned to direct operational duty at the simulator at location i

OBPF1 = Officer basic pay factor (non-rated)

2) BASE MAINTENANCE MANPOWER

$$BSMMC_i = AMN2_i \times ABPF_1 + OFF2_i \times OBPF1$$

where

$BSMMC_i$ = Annual cost in current year dollars for manpower to maintain a simulator at the base level

$AMN2_i$ = Number of airmen (or civilians of similar grade) needed to fulfill base level maintenance requirements of simulator at location i

ABPF1 = Airmen basic pay factor (non-rated)

$OFF2_i$ = Number of officers (or civilians of similar grade) needed to fulfill base level maintenance requirements of simulator at location i

OBPF1 = Officer basic pay factor (non-rated)

3) PERSONNEL SUPPORT COSTS

where

SUPNEL = Annual personnel support costs

This cost element is composed of the combined costs of:

1) Miscellaneous Personnel Support for Simulator Operations
2) Base Services Manpower
3) Miscellaneous Personnel Support
4) Recruit/Technical Training Manpower
5) Medical Manpower
6) Medical Materiel

The above costs are termed General and Administrative (G&A) costs and may be estimated in several ways. Air Force Logistics Command (AFLC) estimates these costs as a percentage of direct personnel pay (15). As an example, assume the pay of the operations and maintenance manpower required to place a simulator at a given location totaled $200,000 annually. Assuming a G&A factor of 10% the yearly estimated personnel support costs equals $20,000. Another method of estimation involves the determination of a support cost per person factor. Annual support costs are thus set equal to the number of direct personnel times the support cost factor. The most important point is to insure that regardless of the method chosen the resulting estimate must be reliable and valid.

4) TECHNICAL TRAINING

$$TTRAIN_i = AMN4_i \times TRFA + OFF4_i \times TRFO$$

where

$TTRAIN_i$ = Annual cost of training and providing qualified replacement personnel to operate, maintain, and instruct in the simulator at location i

$AMN4_i = (AMN1_i + AMN2_i) \times TOVFA$

$AMN4_i$ = Average or expected number of enlisted personnel (or civilians of similar pay grade) attriting annually from one simulator at location i

TOVFA = Annual turnover rate factor for airmen

TRFA = Cost of acquiring and training an airman

$OFF4_i = (OFF1_i + OFF2_i) \times TOVFO$

$OFF4_i$ = Average or expected number of officers (or civilians of similar pay grade) attriting annually from one simulator at location i

TOVFO = Annual turnover rate factor for officers

TRFO = Cost of acquiring and training an officer

5) PERMANENT CHANGE OF STATION

$$PCSCST_i = AMN4_i \times APCS + OFF4_i \times OPCS$$

where

$PCSCST_i$ = Annual PCS cost per simulator location i in current year dollars

APCS = Permanent change of station cost (dollars/airmen/year)

OPCS = Permanent change of station cost (dollars/officer/year)

6) RECURRING MODIFICATION

$$RECMOD = 9220 \times (FAC)^{.74116}$$

where

RECMOD = Recurring annual modification costs (Class IV) of one simulator. The equation is taken from AFR 173-13 and is used to estimate the cost of modifying one aircraft. Unless more accurate information is available the cost of modifying a simulator will be set equal to the cost of modifying an aircraft.

FAC = Aircraft fly away cost in millions

When summed, the above six cost elements will equal the expected annual recurring fixed costs associated with locating a simulator at location i. Multiplying the expected annual recurring fixed cost by the annuity factor and adding it to the one time fixed cost results in a total fixed cost for location i. Thus

$$F_i = OTFIXC_i + PVRCFIXC_i$$

and represents the present value of all of the relevant and significant fixed costs associated with building and maintaining a simulator at location i.

Variable Costs

As stated previously, the cost of any basing strategy is equal to the sum of the relevant and significant fixed and variable costs. From Table 2.1 it can be seen that the only relevant and significant variable cost is the TDY cost experienced when transporting a crew between locations.

The transportation cost incurred in shipping one crew to an off base simulator is equal to the sum of the crew's per diem and travel expenses. There is no transportation cost incurred for training a crew from base i at base i.

TDYCST(I,J) = (OFF5 x PRDEMO + AMN5 x PRDEMA) x NMTDYD + 2 x DISTNC(I,J) x MILERT x (OFF5 + AMN5)

where

TDYCST(I,J) = Cost of transporting one crew from location j to location i and back again

OFF5 = Number of officer crew members and instructors in crew traveling to simulator location i

PRDEMO = Per diem rate (officer)

AMN5 = Number of enlisted crew members and instructors in crew traveling to simulator location i

PRDEMA = Per diem rate (enlisted)

NMTDYD = Number of TDY days per trip

DISTNC(I,J) = distance in statute miles between base i and j

MILERT = mileage rate for mode of travel to and from simulator location

The TDY cost incurred by transporting a crew from location j to location i must be multiplied by the annuity factor to arrive at the present value of transporting the crew for one mission per year over the life of the comparison. The above logic assumes that once a strategy designating crews to receive training at specific locations has been determined, it will not be altered.

Transportation Model

Cnce a 1) single fixed cost element for each location and 2) transportation costs have been determined between locations the problem begins to assume the form of a warehouse location exercise. The addition of the necessary "subject to" constraints regarding demand and capacity completes the initial problem formulation.

Mathematically, the problem takes the form

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij}X_{ij} + \sum_{i=1}^{n} F_iY_i \qquad \text{Eq 2.1}$$

Subject to the following constraints

$$\sum_{i=1}^{n} X_{ij} = D_j \qquad j = 1,\ldots,n \text{ (Demand)} \qquad \text{Eq 2.2}$$

$$\sum_{j=1}^{n} X_{ij} - S_iY_i = 0, \qquad i = 1,\ldots,n \text{ (Supply)} \qquad \text{Eq 2.3}$$

X_{ij}, C_{ij}, F_i, S_i, D_i, Y_i = 0 (Non-negativity)

Y_i = 0, or some positive integer value for all i (Dummy)

The indicated variables are defined as follows

1) Fixed costs (F_i) - the one time costs associated with installing a simulator at location i to include the costs of hardware, building construction, and freight plus the annual recurring

fixed costs associated with operating and maintaining the simulator.

2) Transportation costs (C_{ij}) - cost to transport a crew from their assigned base j to the simulator location i and back to include meals and incidentals such as parking fees or taxi fares.

3) Availability (S_i) - number of training missions per year that are available for crew training in a given simulator at base i.

4) Demand (D_i) - number of training missions required per year by crews from base j.

5) Decision variable (X_{ij}) - number of crews from base j sent to base i for simulator training each year. This variable was model output rather than input.

6) Number of bases (n) - the number of bases having crews requiring training. This variable also represents the maximum number of potential simulator locations.

7) Y_i - the number of simulators placed at location i. Y_i restricted to zero or some positive integer.

Constraint Equations

Annual demand from the crews stationed at location i (D_i) is computed as follows

$$D_i = NAIRK_i \times NMAIRC$$

where

$NAIRK_i$ = number of aircrews located at location i

$NMAIRC$ = number of simulator missions per year required by member of the crew having the highest training requirement

For example, if a crew is composed of both a pilot, requiring twelve simulator missions per year, and a navigator, requiring sixteen simulator missions per year, the navigator's requirements would be input as NMAIRC.

The demand equations are equality equations in that the demand from crews stationed at base i must exactly equal the sum of the demand satisfied at each of the n bases. As a simple example, the equation

$$X_{A1} + X_{B1} + X_{C1} = 60$$

specifies that crews at location 1 demand 60 missions to meet their training requirements and that this demand must be met from locations A, B, and or C. (For ease in reading the computerized output the first numeric subscript was replaced by a letter subscript. Thus, $X_{111} = X_{A11}$ and confusion is avoided.)

The capacity equations are of the less than or equal to variety. Annual capacity is computed as follows.

$$S_i = MSPDAY \times DAYPYR$$

where

S_i = Capacity in missions per year of one simulator located at base i

MSPDAY = Number of missions per day the simulator is capable of providing

DAYPYR = Number of days per year simulator is capable of being operated

The equation

$$X_{A1} + X_{A2} + X_{A3} - 80Y_1 = 0$$

specifies that each simulator located at location 1(A) has a capacity of 80 missions. Furthermore, the total capacity of location 1(A) cannot exceed the number of missions provided to crews from locations 1, 2, and 3. Thus for a basing problem concerned with minimizing the fixed and variable costs associated with shipping crews among 14 potential simulator locations the objective function will contain 14 fixed cost (F_i) coefficients and 196 transportation cost (C_{ij}) coefficients. Continuing the example, the problem would also contain 14 supply (capacity) and 14 demand constraint equations in the form specified in equations 2.2 and 2.3.

The sheer size of the resulting transportation matrix ($n + n^2$ variables in the objective function given n potential locations,and 2n subject to constraints) necessitates the use of a computerized algorithm. The algorithm chosen for use in this research is the Branch and Bound Mixed Integer Program (BBMIP) of the Multi Purpose Optimization System (MPOS) (10) contained in the CYBER computer. (See Table 2.2 for summary of model variables.)

BBMIP Input

There are several methods of data input for BBMIP and the packed version was chosen due to the sparse nature of the transportation matrix. A sparse matrix is defined

Table 2.2

MODEL VARIABLES

Variable:	Meaning:	Source:
ABPF1	Airmen basic pay factor (Non-rated)	AFR 173-13
ABPF3	Airmen basic pay factor (Acquisition/Training)	AFR 173-13
AMN1	Number of airmen assigned to direct operational duty at simulator location I	Simulator SPO or planning personnel at using command headquarters
AMN2	Number of airmen needed to fulfill base level maintenance requirements	Simulator SPO or planning personnel at using command headquarters
AMN4	Operations and maintenance airmen times airmen turnover factor	Calculated
AMN5	Number of airmen crew members and instructors	AFR 173-13
ANNFAC	Annuity factor adjustment to current year dollars	Calculated
APCS	Permanent change of station costs Dollars/Airman/Year	AFR 173-13
BBMIP	Branch and Bound Mixed Integer Program	MPOS

Table 2.2 (Continued)

MODEL VARIABLES

Variable:	Meaning:	Source:
BLCONT	Cost of constructing the building to house the simulator	Simulator SPO
BNDALL	Default upper bound on all variables not explicitly named in a bound specification	MPOS BBMIP
BNDINT	Default upper bound on all integer variables not explicitly named in a bound specification	MPOS BBMIP
BSMMC	Base Systems Maintenance Manpower Costs	Calculated
CAPCTY(I)	Capacity in missions per year of base I simulator	Simulator SPO
COSTHD	Cost of actual simulator hardware	Simulator SPO
CUNIT1	Cost of first unit hardware	Simulator SPO
DAYPYR	Days per year that the simulator will be operated	Simulator SPO
DEMAND(I)	Demand for training in missions per year at base I	Calculated
DISTNC(I,J)	Distance between base I and J	AFR 177-135
DR	Discount rate	AFR 178-1
F(I)	Total fixed costs	Calculated
FAC	Unit flyaway cost, in millions, of aircraft being simulated	AFR 173-13

Table 2.2 (Continued)

MODEL VARIABLES

Variable:	Meaning:	Source:
LIMIT	Maximum number of iterations that may be executed by BBMIP	MPOS BBMIP
LNCURV	Learning curve adjustment factor	Simulator SPO
MAXCM	Maximum central memory available to run the problem	MPOS BBMIP
MILERT	Mileage rate for mode of travel to and from simulator location	Accounting and Finance Office
MP	Number of simulators to be built per MPOS output, initially set to N	MPOS BBMIP
MSPDAY	Simulator missions that can be accomplished per day	Simulator SPO
NAIRC	Number of crews assigned to a standard squadron	Using command
NAIRK(I)	Number of air crews at base I	Using command
NMAIRC	Number of simulator missions required per crew per year	Using command
NMTDYD	Number of TDY days per trip	Using command
OBPF1	Officer basic pay factor (Non-rated Officer)	AFR 173-13
OBPF2	Officer basic pay factor (Rated Officer)	AFR 173-13

Table 2.2 (Continued)

MODEL VARIABLES

Variable:	Meaning:	Source:
OBPF3	Officer basic pay factor (Acquisition/Training)	AFR 173-13
OFF1	Number of officers assigned to direct operational duty at the simulator location	Simulator SPO
OFF2	Number of officers needed to fulfill base level maintenance requirements	Simulator SPO
OFF4	Operations and maintenance officers times officer turnover factor	Calculated
OFF5	Number of officer crew members and instructors	AFR 173-13
OPCS	Permanent change of station costs Dollars/Officer/Year	AFR 173-13
OPSMAN	Operations manpower costs	Calculated
OTFIXC	Total one time fixed costs	Calculated
PCSCST	Permanent change of station costs	Calculated
PRDEMA	Per day per diem rate (Airmen)	Accounting and Finance Office
PRDEMO	Per day per diem rate (Officer)	Accounting and Finance Office
RCFIXC	Total recurring fixed costs	Calculated
RECMOD	Recurring modification costs	Calculated

Table 2.2 (Continued)

MODEL VARIABLES

Variable:	Meaning:	Source:
SUPNEL	Miscellaneous support personnel costs	Calculated
TDYCST(I,J)	Current dollar cost for TDY trip for crew and instructors from home base to simulator location	Calculated
TRANSC(I)	Cost of transporting the simulator hardware to location I	Simulator SPO
TOVFA	Annual turnover rate factor for airmen	AFR 173-13
TOVFO	Annual turnover rate factor for officers	AFR 173-13
TOVFP	Annual turnover rate factor for pilots	AFR 173-13
TOVFRC	Annual turnover rate factor for rated crewmembers	AFR 173-13
TTRAIN	Technical training costs	Calculated
YRS	Number of years analysis spans Use lesser of aircraft's or simulator's estimated life	AFR 173-13 or Simulator SPO

as one in which a large number of entries are equal to zero. The packed input format assumes any unspecified matrix coefficients are equal to zero and so only nonzero coefficients need be input. Using the first demand constraint of an n = 14 location problem as an example, only 15 of the 211 row entries are nonzero (fourteen 1's representing the coefficients of X_{A1}, X_{B1}, X_{C1}, ..., X_{N1}; and the 'b' column value). The remaining 196 zero entries need not be input and will be set to zero by default when the packed format is selected.

Once the objective function, demand constraints, and supply constraints have been determined the problem is ready for input into MPOS. Integer constraints on Y_i's are specified in the BBMIP Program. Additionally, the number of "subject to" constraints must be specified in the BBMIP program along with the type of constraint (less than, greater than, or equality). Because nonnegativity is a specified requirement for BBMIP the nonnegativity constraints do not need to be restated.

Once initiated, BBMIP first searches for the continuous solution. The value of the objective function in the continuous solution acts as a lower bound for minimization problems. BBMIP then proceeds to constrain the first integer variable to an integer level within its range. This yields a linear program which it proceeds to solve. Assuming a feasible solution exists, the first variable is held at its selected value and the second variable is constrained in a like manner. Proceeding in this fashion alternately constraining variables and solving the resultant linear program BBMIP either 1) determines a feasible solution having constrained all the variables or 2) determines that the integer choices for the variables constrained do not allow a feasible solution. The first case represents a potential optimal solution. In the second case it makes no sense to proceed, since a linear program obtained by adding a constraint to a non-feasible linear program must also be non-feasible. In either case BBMIP makes a new choice for the integer value of the latest constrained variable and proceeds as before. Once a feasible solution is found it serves as an upper bound on the optimal solution. Therefore, if at any point in the procedure the objective function for the (partially) constrained problem equals or exceeds the current "best" feasible solution it is unnecessary for BBMIP to proceed further along that branch. Of course, any additional information regarding specific integer values or ranges for any of the variables or the objective function aids greatly in reducing the iterations needed to solve the problem (10:48-49).

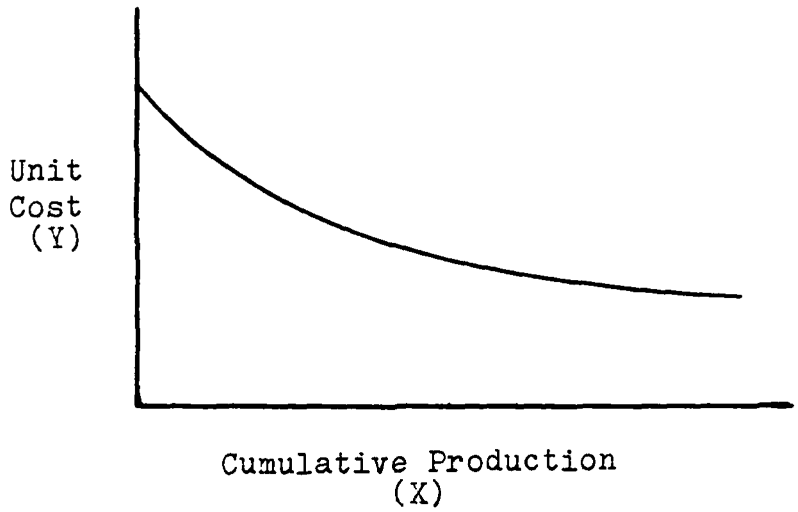
Learning Curve

One of the requirements for any LP formulation in which the objective function is a cost minimization type is cost linearity. The learning curve phenomenon normally occurs in large complex operations that involve the use of skilled labor, such as airframe assembly or simulator construction, and presents a nonlinear cost pattern. To allow the use of linear programming procurement costs will be recomputed based on the costs of acquiring the number of simulators indicated by BBMIP. The new costs will be placed in the equations and the BBMIP routine will be reinitiated. This process will be repeated until the solution stabilizes. A stable solution represents the minimum cost basing strategy and occurs when the number of units in the BBMIP output equals the number of units used to compute the procurement costs. For example, BBMIP could indicate six units based on the cost associated with a nine unit buy. If costs were then recomputed based on a six unit buy and BBMIP output still indicated six facilities the solution has stabilized and represents the minimum cost basing strategy. On the other hand, BBMIP output may indicate that seven facilities are to be built. If this occurs the two pivotal solutions must be forced to stabilize by selectively bounding the Y_i variables (19:15.1). The costs of the six and seven facility solutions must then be compared to determine the minimum cost basing strategy.

The learning curve phenomenon itself is due to management becoming more skillful in organizing the factors of production and labor becoming more adept at executing their assigned tasks (9:602-603).

Figure 2.1

LEARNING CURVE



The equation that fits the above learning cirve is

$$Y = K X^n$$

where

Y = estimated cost of producing the Xth unit

K = cost of producing the first unit

X = the cumulative unit number

$\emptyset = \frac{\log \emptyset}{\log 2}$ = the learning index

$\emptyset$ = the learning rate

(31:302-328)

Unit costs should be available from the SPO or contractor. The learning rate, Ø, should be in the form of a uniform rate (i.e. 90 percent, 80 percent, etc.).

BBMIP output will consist of the specific locations of the simulators comprising the minimum cost alternative, the cost of the selected alternative, and the projected level of usage at each location. The cost of the actual simulator hardware (COSTHD) must then be recomputed based on the number of simulators selected by the model. Because of learning curve considerations COSTHD will be set equal to the average cost for the specified buy. COSTHD will be computed as follows

$$COSTHD = \sum_{I=1}^{MP} (CUNIT1)x(I)^{(LOGLNCURV/LOGZ)}$$

CUNIT1 = cost of first unit simulator hardware

I = the unit number

LNCURV = percentage learning rate (i.e. .80)

MP = number of simulators selected. MP initially set equal to n (number of potential locations). Thus, during the initial run of the model the average contract price will be used. Assuming that a learning curve phenomenon exists and that less than the contracted number of simulators is indicated by BBMIP, a new and somewhat obviously higher average cost will be input on the subsequent run.

For example, a per unit cost of $15,000,000 based on a 10 unit buy is no longer valid if only 6 units are to be purchased. A new per unit cost must be computed based on a six unit buy. Once the procurement costs have been recalculated, BBMIP would again be initiated. This cycle would be repeated until the number of simulators selected stabilizes. Furthermore, assuming the solution stabilizes at six units, no further cost recomputations are required as the minimum cost solution has been found.

MODEL VALIDATION

Model validation is the process of insuring that the model accomplishes what it was intended to do. The two areas of concern in validation are insuring both the internal and external validity of the model.

The primary objective of internal validity is to insure that the computer program actually incorporates the logic intended. This was accomplished by building the program in several parts. Each part was then exercised seperately using simplified problems. Once confidence was established in the partial programs they were placed in the main program. BBMIP was validated through the use of simplified problems which were capable of being solved by enumeration. This process was necessary to insure that the user's understanding of the various commands and inputs agreed with what the authors of BBMIP intended. Several small scale ($n = 2,3$) runs were made to insure the external validity of the programs.

Efforts were also directed to ascertain the maximum problem size, in terms of the number of placement locations, that the model could successfully handle. As stated previously, the transportation matrix increases dramatically as the number of potential facility locations increases. Through a process of trial and error it was determined that the model will handle up to fourteen potential locations. Although computer memory requirements were quite large

(300K) the limiting factor was the Branch and Bound Mixed Integer Program. Attempts to run problems having fifteen potential locations resulted in a BBMIP initiated warning stating that the problem was too large. If the computer memory on the CYBER had been the limiting factor BBMIP would have printed a warning that the computer memory resources had been exceeded (10:55).

The primary objective of external validity is to insure that the model does in fact serve as a useful aid in decision making. Towards this end this thesis effort was forwarded to the Simulator SPO and the Cost Analysis personnel at AFLC. Mr. Robert Coward, Director of New Business at the Simulator SPO, although unable to take the time away from his primary duties to fully dissect the model, did find the time to read this thesis and was extremely interested in the approach taken. In his words, he has long sought and supported the need for useable models that provide reasonable alternatives for decision making (11).

Mr. Stephen R. Klipfel, Chief of the Cost Estimating Branch at HQ AFLC/ACMCE, indicated that he felt the logic incorporated in this research effort with regards to costs was valid and that all necessary costs were included (15). One additional cost element, Software Support, was mentioned for possible inclusion, but it is the researchers' belief that its behavior would be similar to that of a depot level cost and not relevant to this analysis. Further research concerning the relevance and significance of Software Support costs needs to be conducted before it could be included in this model.

Finally, sensitivity analysis will be performed on those model input parameters which have not lent themselves to precise estimation. If significant differences in model output occur while exercising the model throughout the possible ranges of the parameters further efforts should be made to refine the input parameters in question.

SUMMARY

The primary purpose of this research is to develop and validate a mathematical model to assist in optimizing simulator placement. Economic analysis serves as the conceptual framework for the research. Major cost elements were examined for relevance and significance in the context of the research. The questions of present value and learning curve theory are addressed. The chapter also discusses the construction of the computer program used to build the data file suitable for use in the Branch and Bound Mixed Integer Program (BBMIP) of MPOS.

The following chapter demonstrates model capabilities by discussing the acquisition of the B-52G WST. Sensitivity analysis is also discussed.

Chapter III

DEMONSTRATION OF MODEL

This chapter demonstrates the use of the model and includes a sensitivity analysis. The new simulator for the B-52 fleet, the Weapon System Trainer (WST), was chosen to exercise the model because it is an ongoing major acquisition project with potentially large cost savings. Some difficulties were encountered in obtaining data and several assumptions and estimates of data had to be made. The results of this analysis must therefore be viewed with some caution. The analysis nevertheless illustrates the procedure for collecting data and using the model.

The chapter begins with a simplified enumeration of the linear programming model in equation and matrix form. The travel distance matrix used as a starting value for the variable cost array is also shown. Individual input values are examined in turn to explore the ramifications of varying specific parameters and to demonstrate the model's use as a decision making tool.

SIMPLIFIED MODEL

In the previous chapter, equations 2.1, 2.2, and 2.3 state the general mathematical form of the model. Equations 3.1 through 3.9 show a simplified example of the model enumerated for a three location problem. F_i is the coefficient of Y_i and is the computed value of the total one

Minimize:

$$Z = 27561800Y_A + 27503440Y_B + 27525520Y_C + 0X_{A1} + 6887X_{A2} + 11584X_{A3} + 6887X_{B1} + 0X_{B2} + 9711X_{B3} + 11584X_{C1} + 9711X_{C2} + 0X_{C3} \quad \text{(Eq 3.1)}$$

Subject to:

Demand Constraints

Demand Center		
A	$X_{A1} + X_{B1} + X_{C1} = D_A$	(Eq 3.2)
B	$X_{A2} + X_{B2} + X_{C2} = D_B$	(Eq 3.3)
C	$X_{A3} + X_{B3} + X_{C3} = D_C$	(Eq 3.4)

Capacity Constraints

Facility		
A	$X_{A1} + X_{A2} + X_{A3} - Y_1 S_A \leq 0$	(Eq 3.5)
B	$X_{B1} + X_{B2} + X_{B3} - Y_2 S_B \leq 0$	(Eq 3.6)
C	$X_{C1} + X_{C2} + X_{C3} - Y_3 S_C \leq 0$	(Eq 3.7)

Bounds:

$$X_{ij} \geq 0 \quad \text{(Eq 3.8)}$$

$$Y_i = \begin{cases} 0 \text{ if no simulators are to be built at location } i \\ \text{a positive integer if simulator(s) is(are) to to be built at location } i \end{cases} \quad \text{(Eq 3.9)}$$

time and discounted recurring fixed costs. Y_i may take on a value of zero or some positive integer and indicates the number of simulators to be built at location i. The coefficients of X_{ij} variables in the objective function are the discounted costs of transporting crews from location j to location i.

Figure 3.1 is a matrix representation of the three location problem. To allow input into the BBMIP routine, the data must be arranged with the b column first, the integer variables next, and then the non-integer variables. A large portion of the matrix positions in a facility location problem will be occupied by zeros. BBMIP helps to simplify the data input through the use of a packed format. With the packed format, data is identified by its row and column position and the actual value of the parameter. All of the positions in the matrix that are not specifically assigned by row and column designators are assumed to be zero. (For an example of BBMIP packed format see Appendix B).

EXERCISE OF THE MODEL

The B-52G Weapon System Trainer (WST) was chosen to exercise the model and demonstrate its use as a management decision making tool. The nine B-52G locations used in the model are the existing B-52G bases at this time. SAC is currently in the process of rearranging the locations of its D, G, and H model B-52s. No accounting for this change

			b	Y_A	Y_B	Y_C	X_{A1}	X_{A2}	X_{A3}	X_{B1}	X_{B2}	X_{B3}	X_{C1}	X_{C2}	X_{C3}
			0	1	2	3	4	5	6	7	8	9	10	11	12
OBJ FUNCT		0	-	$	$	$	$	$	$	$	$	$	$	$	$
DEMAND	A	1	D_A	0	0	0	1	0	0	1	0	0	1	0	0
	B	2	D_B	0	0	0	0	1	0	0	1	0	0	1	0
	C	3	D_C	0	0	0	0	0	1	0	0	1	0	0	1
CAPACITY	A	4	0	S_A	0	0	1	1	1	0	0	0	0	0	0
	B	5	0	0	S_B	0	0	0	0	1	1	1	0	0	0
	C	6	0	0	0	S_C	0	0	0	0	0	0	1	1	1

Three Location Matrix

Figure 3.1

is incorporated in the demonstration.

Appendix A is the FORTRAN program that was used to calculate the matrix coefficients and assemble them in the BBMIP packed format. Table 3.1 is provided here as a quick and easy reference to the meaning and source of the variables in this demonstration involving the B-52G WST and the source of their values.

Several simplifications were made in this demonstration of the model. For purposes of this demonstration the manning of the simulators was assumed to be the same at all locations. The number of crews demanding simulator training was assumed to be the same at each location except for Barksdale which is a two squadron wing. Therefore, demand for training from Barksdale was set at double the other bases plus an additional demand equal to three crews was included because of training requirements for Eighth Air Force staff and 1st Combat Evaluation Group personnel. The cost of constructing the building to house the simulator was also assumed to be the same at any location. Additionally, per diem rates were assumed to be the same in all situations.

Figure 3.2 is a matrix of distances between any two locations in the problem. Since the matrix is reflexive its input into the program to build the data file can be simplified so that each value in the matrix does not have to be entered individually (reference Appendix A).

Table 3.1

B-52G WST VARIABLES

Variable:	Meaning:	Source:
ABPF1	Airmen basic pay factor (Non-rated)	AFR 173-13
ABPF3	Airmen basic pay factor (Acquisition/Training)	AFR 173-13
AFSCX2	Number of 341x2 personnel	SAC HQ/XPHD
AFSCX4	Number of 341x4 personnel	SAC HQ/XPHD
AFSCX6	Number of 341x6 personnel	SAC HQ/XPHD
AMN1	Number of airmen assigned to direct operational duty at simulator location I	SAC HQ/XPHD
AMN2	Number of airmen needed to fulfill base level maintenance requirements	SAC HQ/XPHD
AMN4	Operations and maintenance air-men times airmen turnover factor	Calculated
AMN5	Number of airmen crew members and instructors traveling to the simulator location	Standard B-52 crew No instructors
ANNFAC	Annuity factor adjustment to current year dollars	Calculated
APCS	Permanent change of station costs Dollars/Airman/Year	AFR 173-13
BBMIP	Branch and Bound Mixed Integer Program	MPOS

Table 3.1 (Continued)

B-52G WST VARIABLES

Variable:	Meaning:	Source:
BLCONT	Cost of constructing the building to house the simulator	Simulator SPO
BNDALL	Default upper bound on all variables not explicitly named in a bound specification	MPOS BBMIP
BNDINT	Default upper bound on all integer variables not explicitly named in a bound specification	MPOS BBMIP
BSMMC	Base Systems Maintenance Manpower Costs	Calculated
CAPCTY(I)	Capacity in missions per year of base I simulator	Simulator SPO
COSTHD	Cost of actual simulator hardware	WST Contract
CUNIT1	Cost of first unit hardware	Simulator SPO
DAYPYR	Days per year that the simulator will be operated	Simulator SPO
DEMAND(I)	Demand for training in missions per year at base I	SACR 51-52 Calculated
DFSTSP	Defensive Systems Training Specialist (AFSC 341x2)	Simulator SPO
DGFTSS	Digital Flight Simulator Specialist (AFSC 341x4)	Simulator SPO
DISTNC(I,J)	Distance between base I and J	AFR 177-135

Table 3.1 (Continued)

B-52G WST VARIABLES

Variable:	Meaning:	Source:
DNTTDV	Digital Nav/Tac Training Device Specialist (AFSC 341x6)	Simulator SPO
DR	Discount rate	AFR 178-1
EW	B-52 Electronic Warfare Officer training costs	Calculated
EWTCST	Training cost to replace B-52 Electronic Warfare Officer	HQ USAF/ACMC
F(I)	Total fixed costs	Calculated
FAC	Unit flyaway cost, in millions, of aircraft being simulated	AFR 173-13
GNTCST	Training cost to replace B-52 Gunner	AFR 173-13
GUNS	B-52 Gunner training costs	Calculated
LIMIT	Maximum number of iterations to be executed by BBMIP	MPOS BBMIP
LNCURV	Learning curve adjustment factor	Simulator SPO
MAXCM	Maximum central memory available to run the problem	MPOS BBMIP
MILERT	Mileage rate for mode of travel to and from simulator location	Accounting and Finance Office
[illegible]	Number of simulators to be built per MPOS output, initially set to N	MPOS BBMIP

Table 3.1 (Continued)

B-52G WST VARIABLES

Variable:	Meaning:	Source:
MSPDAY	Simulator missions that can be accomplished per day	Simulator SPO
NAIRC	Number of crews assigned to a standard squadron	SAC HQ
NAIRK(I)	Number of air crews at base I	Calculated
NAV	B-52 Navigator training costs	Calculated
NMAIRC	Number of simulator missions required per crew per year	SACR 51-52
NMTDYD	Number of TDY days per trip	Simulator SPO
NTRCST	Training costs to replace B-52 Navigator	HQ USAF/ACMC
OBPF1	Officer basic pay factor (Non-rated)	AFR 173-13
OBPF2	Officer basic pay factor (Rated)	AFR 173-13
OBPF3	Officer basic pay factor (Acquisition/Training)	AFR 173-13
OFF1	Number of officers assigned to direct operational duty at the simulator location	SAC HQ/XPHD
OFF2	Number of officers needed to fulfill base level maintenance requirements	SAC HQ/XPHD
OFF4	Operations and maintenance officers times officer turn-over factor	Calculated

Table 3.1 (Continued)

B-52G WST VARIABLES

Variable:	Meaning:	Source:
OFF5	Number of officer crew members and instructors traveling to simulator location	Standard B-52 crew No instructors
OPCS	Permanent change of station costs Dollars/Officer/Year	AFR 173-13
OPSMAN	Operations manpower costs	Calculated
OTFIXC	Total one time fixed costs	Calculated
PCSCST	Permanent change of station costs	Calculated
PILOT	B-52 Pilot training costs	Calculated
PRDEMA	Per diem rate (Airman)	Accounting and Finance Office
PRDEMO	Per diem rate (Officer)	Accounting and Finance Office
PTRCST	Training costs to replace B-52 Pilot	HQ USAF/ACMC
RCFIXC	Total recurring fixed costs	Calculated
RECMOD	Recurring modification costs	AFR 173-13
SUPNEL	Miscellaneous personnel support costs	SAC HQ
TDYCST(I,J)	Current dollar cost of TDY trip for crew and instructors from home base to simulator location	Calculated

Table 3.1 (Continued)

B-52G WST VARIABLES

Variable:	Meaning:	Source:
TRANSC(I)	Cost of transporting the simulator hardware to location I	WST Contract
TOVFA	Annual turnover rate factor for airmen	AFR 173-13
TOVFO	Annual turnover rate factor for officers	AFR 173-13
TOVFP	Annual turnover rate factor for pilots	AFR 173-13
TOVFRC	Annual turnover rate factor for rated crewmembers	AFR 173-13
TTRAIN	Technical training costs	Calculated
X2COST	Training costs to replace 341X2	AFR 173-13
X4COST	Training costs to replace 341X4	AFR 173-13
X6COST	Training costs to replace 341X6	AFR 173-13
YRS	Number of years analysis spans Use lesser of aircraft's or simulator's estimated life	AFR 173-13

TO \ FROM	A	B	C	D	E	F	G	H	I
A Barksdale	0	409	1046	2079	1426	2035	1931	661	1220
B Blytheville	409	0	792	2013	1056	1664	2127	542	836
C Seymour J.	1046	792	0	2625	663	1125	2859	468	940
D Fairchild	2079	2013	2625	0	2457	2787	839	2480	1914
E Griffiss	1426	1056	663	2457	0	660	2775	1054	598
F Loring	2035	1664	1125	2787	660	0	3294	1538	1114
G Mather	1931	2127	2859	839	2775	3294	0	2563	2447
H Robins	661	542	468	2480	1054	1538	2563	0	1013
I Wurtsmith	1220	836	940	1914	598	1114	2447	1013	0

Distances Between Locations

Figure 3.2

Analysis of Results (Best Estimate Variables)

The initial simulator hardware costs were based on buying nine simulator units. The model indicated that the purchase of six units (the minimum needed to satisfy the training demand) would satisfy all constraints at a lesser total cost. Hardware costs were recomputed based on a six unit buy and BBMIP was then reinitiated. The solution stabilized and therefore represents the minimum cost basing strategy.

Figure 3.3 is a summary of the solution arrived at using BBMIP. The figure shows all of the bases from which simulator time is demanded and the locations the crews from each base should go to satisfy that demand. This solution to the facility location problem indicates that simulators should be built at Barksdale, Blytheville, Seymour Johnson, Loring, Mather, and Wurtsmith Air Force Bases. Simulators should not be built at Fairchild, Griffiss, or Warner Robins. All of the demand for training from the nine bases can be satisfied by six simulators with additional (slack) capacity at Blytheville and Loring. For an example of BBMIP output see Appendix D. For the program to implement BBMIP in the APOS library see Appendix C.

Best Estimate Solution

Figure 3.3

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	200	640						80		280	1200
C Seymour J.			640					560			1200
D Fairchild											0
E Griffiss											0
F Loring					160	640				400	1200
G Mather				560			640				1200
H Robins											0
I Wurtsmith				80	480				640		1200
Demand	1400	640	640	640	640	640	640	640	640	680	

(Missions/Year)

SENSITIVITY ANALYSIS

Several of the variables in this problem could only be estimated. Other variables were assumed to remain constant. Because of the imperfect knowledge inherent in estimation, the input values of these variables were set above and below the best estimate value to assess the sensitivity of the solution to the variable. The best estimate values of all variables for the problem are shown in the FORTRAN program (see Appendix A). During sensitivity analysis only the value of one variable was changed at a time. The values for all of the other variables were maintained at their best estimated value. The sensitivity analyses conducted on the variables will be discussed in turn. In addition, Table 3.2 consolidates the results of the analyses to aid in the comparison of the results.

Learning Curve Factor

The personnel at the Simulator SPO at Wright-Patterson were contacted and asked for their best estimate of the learning curve factor that might be expected in the acquisition of a new simulator system. They surmised that a 94% to 96% learning curve factor could reasonably be expected. Therefore, a 95% learning curve factor was chosen as the best estimate to exercise the model.

Analysis runs were first made with the assumption of a nine unit buy and the cost and learning effect spread over those nine units. The resulting solution showed a

Table 3.2

SENSITIVITY ANALYSIS RESULTS

Variable	A	B	C	D	E	F	G	H	I	COST
Learning Curve										
80%	X	X	X			X	X		X	$163,641,840
85%	X	X	X			X	X		X	$170,248,711
90%	X	X	X			X	X		X	$177,264,859
93%	X	X	X			X	X		X	$181,673,792
* 95%	X	X	X			X	X		X	$184,696,979
97%	X	X	X			X	X		X	$187,787,773
100%	X	X	X			X	X		X	$192,551,632
First Unit Cost										
$13,000,000	X	X	X			X	X		X	$160,848,353
* $17,000,000	X	X	X			X	X		X	$184,696,979
$25,000,000	X	X	X			X	X		X	$225,737,636
Mileage Rate										
$0.00	X	X	X		X			X	X	$174,187,346
$0.05	X	X	X			X	X		X	$179,525,068
* $0.10	X	X	X			X	X		X	$184,696,979
$0.16	X	X	X			X	X		X	$190,903,262
$0.25	X	X	X			X	X		X	$200,212,694
$0.55	X	X	X	X		X	X		X	$231,045,103
$0.90	X	X	X	X	X	X	X		X	$248,390,461
$1.15	X	X	X	X	X	X	X	X	X	$254,539,108
Discount Rate										
8%	X	X	X			X	X		X	$190,927,565
* 10%	X	X	X			X	X		X	$184,696,979
15%	X	X	X			X	X		X	$172,293,419
Per Diem Rate										
$20	X	X	X			X	X		X	$181,179,824
* $35	X	X	X			X	X		X	$184,696,979
$50	X	X	X			X	X		X	$188,214,125

* Best Estimate Solution

Table 3.2 (Continued)

SENSITIVITY ANALYSIS RESULTS

Variable	A	B	C	D	E	F	G	H	I	COST
Useful life										
5 Years	X	X	X			X	X		X	$158,764,053
* 10 Years	X	X	X			X	X		X	$184,696,979
15 Years	X	X	X			X	X		X	$200,799,273
Personnel Support										
$ 50,000	X	X	X			X	X		X	$182,853,609
* $100,000	X	X	X			X	X		X	$184,696,979
$150,000	X	X	X			X	X		X	$186,540,349
Crews/Base										
12	X			X	X	X		X		$155,379,682
14	X	X		X	X			X		$159,580,302
* 16	X	X	X			X	X		X	$184,696,979
18	X	X	X	X		X	X		X	$208,314,875
20	X	X			X	X	X	X	X	$216,912,479
Missions/Crew										
* 40	X	X	X			X	X		X	$184,696,979
44	X	X	X			X	X		X	$186,490,318
48	X	X	X	X		X	X		X	$210,535,538
51	X	X	X			X	X	X	X	$214,604,504
52	X	X	X	X		X	X	X	X	$230,421,290
Missions/Day										
3	X	X	X	X		X	X	X	X	$227,944,863
* 4	X	X	X			X	X		X	$184,696,979
5	X			X		X		X	X	$158,690,430

* Best Estimate Solution

six unit buy would satisfy demand and optimize cost. The model was then run again assuming a six unit buy and distributing the learning effect and cost savings over those six units.

Analysis runs were made with learning curve factors of 80%, 85%, 90%, 93%, 95%, 97%, and 100%. An 80% learning curve factor was considered the most optimistic that might be expected and 100% provided a base line comparison with no learning effect.

Figure 3.4 shows the results of the learning curve analysis. Although varying the learning curve factor resulted in the same solution with regard to the number and locations of simulators, a difference of nearly $29 million

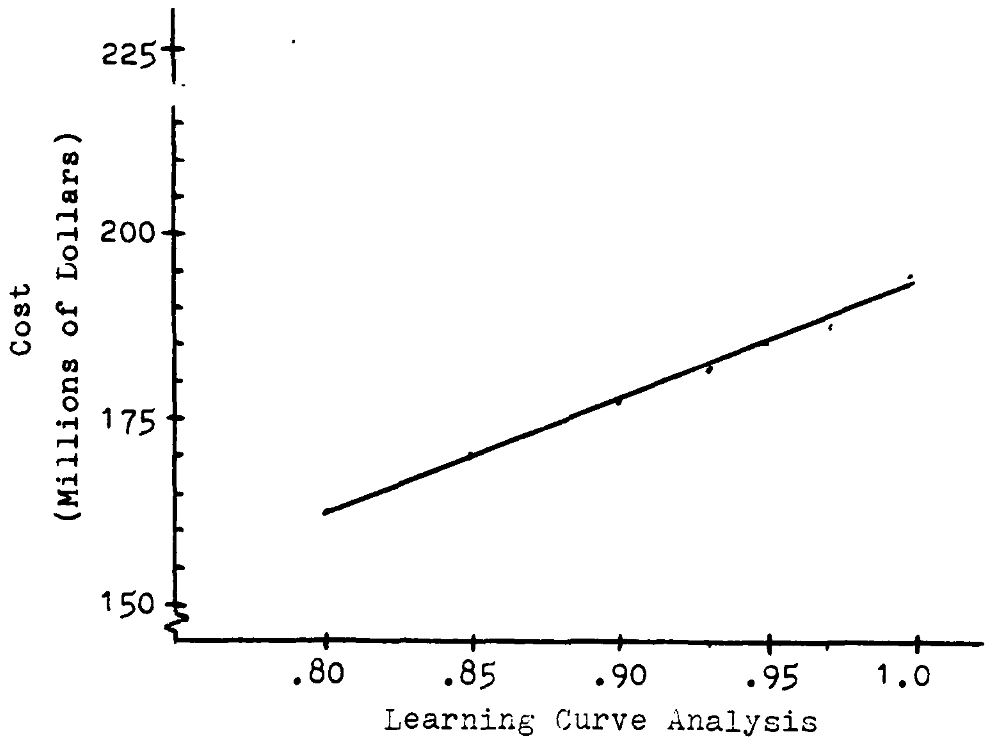


Figure 3.4

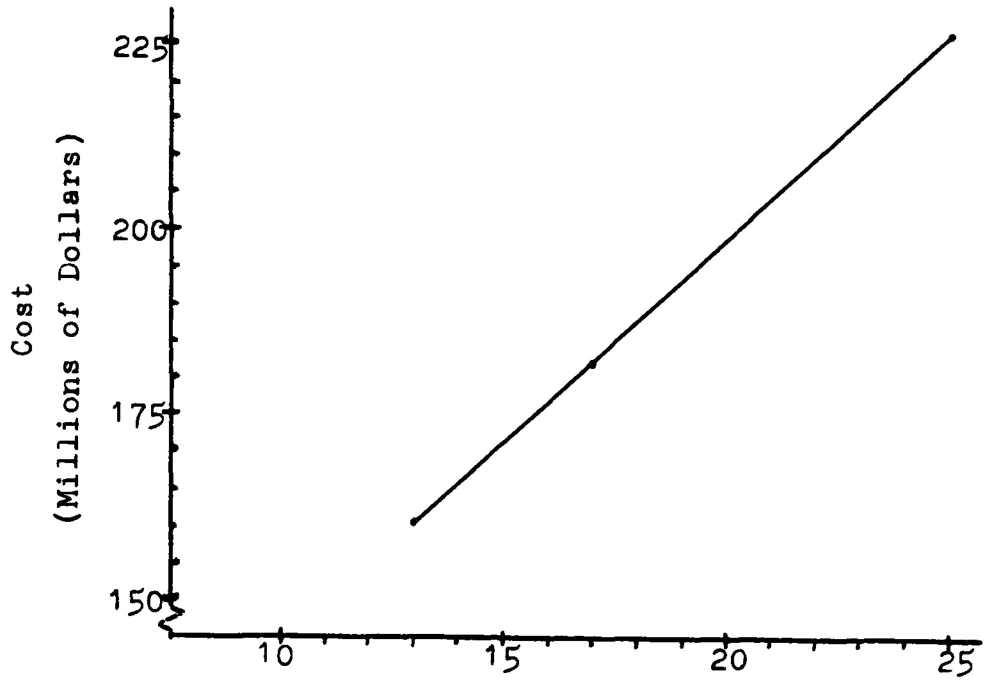
exists between the costs obtained when using the most optimistic learning curve factor (80%) and the most pessimistic factor (100%).

First Unit Cost

In order to use the WST program to exercise the model a significant assumption concerning hardware costs had to be made. The WST simulators were purchased from the Singer Company in lot buys with each unit in the lot at the same fixed price. R & D costs were recovered by Singer on the sale of the first two lots. Succeeding lots were priced significantly less.

In order to demonstrate the model's ability to incorporate learning curve effect a first unit cost was needed. This value was estimated by taking a simple average of the unit prices for all the lots. This average was then rounded off to $17 million.

Analysis runs were made assuming a six unit buy, a learning curve factor of 95%, and a first unit cost of $13 million, which approximated the unit price of the first lot (see Figure 3.5). Each run resulted in an optimal solution that was identical to the best estimate solution with regard to the number and locations of the simulators. The unit price of the hardware is the single largest cost component. As expected the change in the first unit cost produced a very significant linear change in the total cost of the project.



First Unit Cost
(Millions of Dollars)
Figure 3.5

Mileage Rate

For this exercise it was assumed that travel from a location without a simulator to a location with a simulator would be accomplished in one of three ways. First, B-52 crews could fly a normal training sortie but instead of landing at their home station they would land at another B-52 base that had a simulator. After accomplishing their simulator training, planning a return mission, and obtaining any required crew rest the crew would fly another regular training mission and land at their home station. The mileage costs in this instance would be zero since the cost incurred for the aircraft, fuel, maintenance, etc.

would have been incurred anyway under normal training.

A second mode of travel would be by government or private auto. The FORTRAN program for computing and building the data file allows the user to simply insert the appropriate POV mileage rate or similar cost factor rate for a government auto.

The third mode of travel would be by commercial airlines. If this is the assumed mode of travel for the analysis, the (2 x DISTNC(I,J) x MILERT) factor in the TDYCST (I,J) equation (see Appendix A) should be replaced by a cost array representing the round trip ticket price per person from base I to J.

In exercising the model a cost per mile rate of $.10 was used. The cost of an airline ticket between several of the locations of interest were obtained from the Scheduled Airline Ticket Office (SATO) at Wright-Patterson AFB. These costs were then divided by the appropriate distances between the locations. A cost per mile rate ranging between $.04 and $.07 was obtained. With a POV rate of $.16 per mile, $.10 per mile appeared to be a reasonable estimate to begin the analysis.

Varying the mileage rate from zero up to $.25 per mile resulted in the same number and location solution as the best estimate solution. The optimal solution cost varied by over $25 million with the change in mileage rate (see Figure 3.6).

AD-A123 782 A PLACEMENT MODEL FOR FLIGHT SIMULATORS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYSTEMS AND LOGISTICS E P GEBHARD ET AL. SEP 82 2/2

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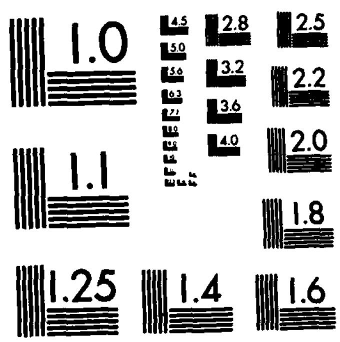

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

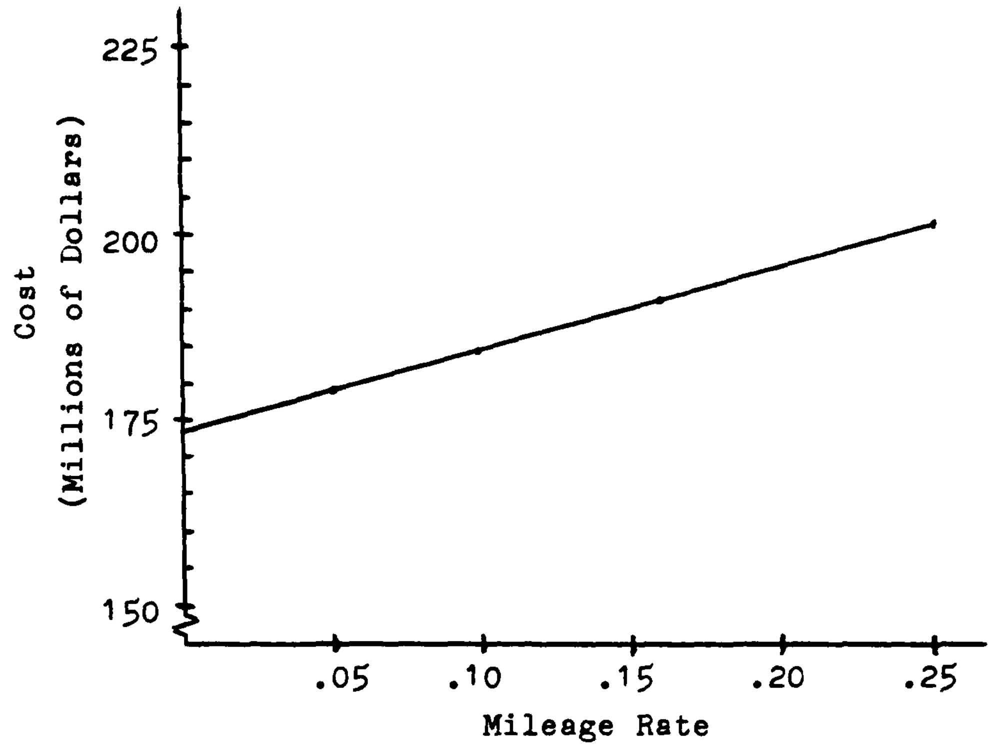

Figure 3.6

Since varying the mileage rate from zero to $.25 per mile resulted in the same solution with respect to the number and location of the simulators, it was of interest to determine the mileage rate where it became more cost effective to have additional simulators. Figure 3.7 shows the results of varying the mileage rate from zero to $1.25 per mile. As the graph shows, when the cost per mile reaches $.55 it is better to build a seventh simulator. In the same way when the cost reaches $.90 and $1.15 it is better to build the eighth and ninth simulators. This analysis indicates that with all other factors remaining the same the travel cost would have to raise to approximately $1.15 per mile before it became cost effective to build a simulator at each demand location.

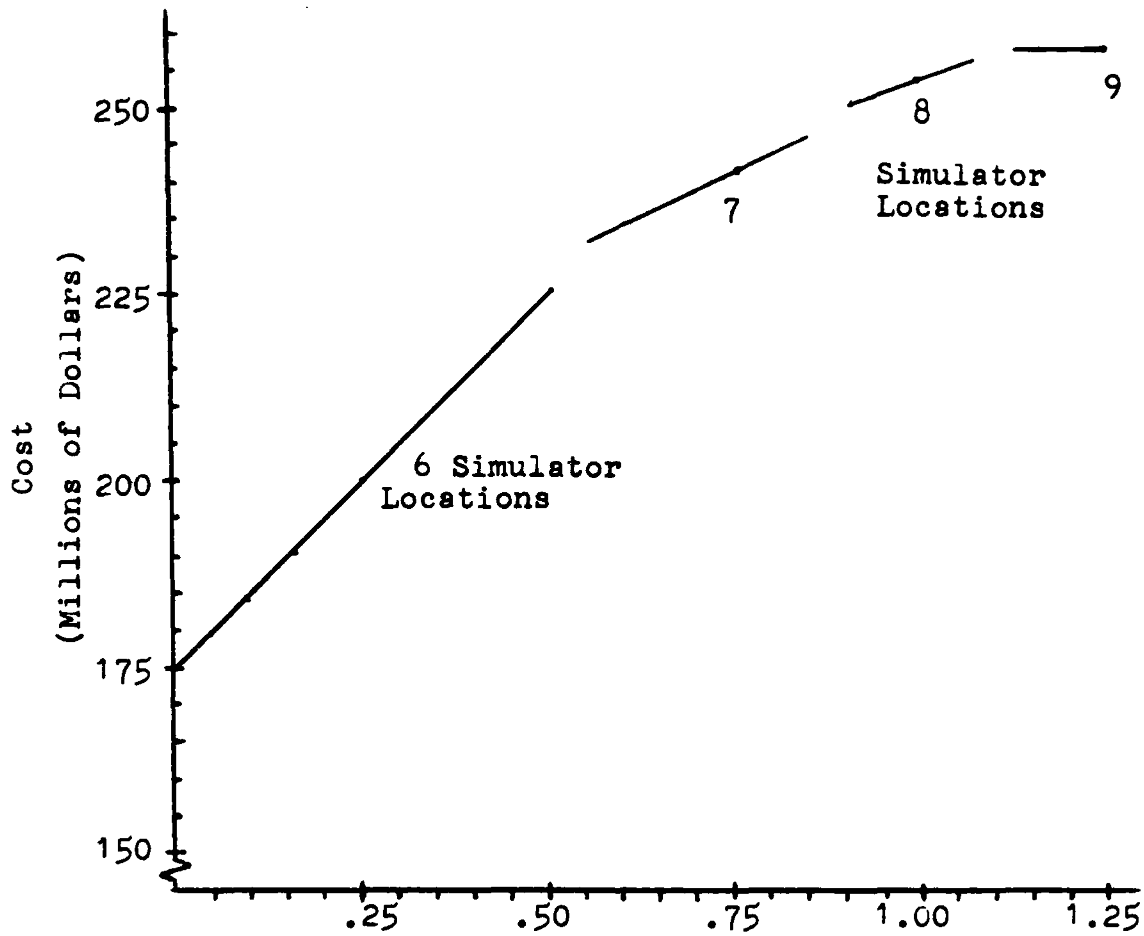

Figure 3.7

Discount Rate and Useful Life

The model uses a discount rate and an estimate of the useful life of the facility to calculate an annuity factor. The cost factors in the model are then multiplied by the annuity factor to adjust the cost streams to their present values. A standard Air Force planning factor rate of 10%

was used as the best estimate of the discount rate (24:3-3). According to AFR 173-13 the estimated useful life of a major electronic system is 10 years (28:1-1). This value was used as the projected useful life of a simulator and therefore represents the timespan of the analysis. Figure 3.8 shows the change in total cost of the project as the discount rate goes from 8% to 15%. Figure 3.9 shows the change in total cost as the number of years in which expenses are incurred is varied from 5 to 15 years.

Per Diem Rate

The variable cost component of this model includes not only the travel costs for the crew to and from the simulator location but also the per diem cost to cover food and lodging while the crew is away from their home station. For simplicity the per diem rate was assumed to be the same at all locations. This simplification may not be realistic in all applications of the model, and the model would therefore have to be modified to allow per diem rates to be input by specific location.

The travel pay section of the Accounting and Finance Office at Wright-Patterson AFB was contacted for a best estimate of the per diem rate to be used in the model. Their information showed that $50 per day was the maximum rate except in special high cost areas and that $20 per day was a reasonable minimum. Sensitivity analysis was therefore

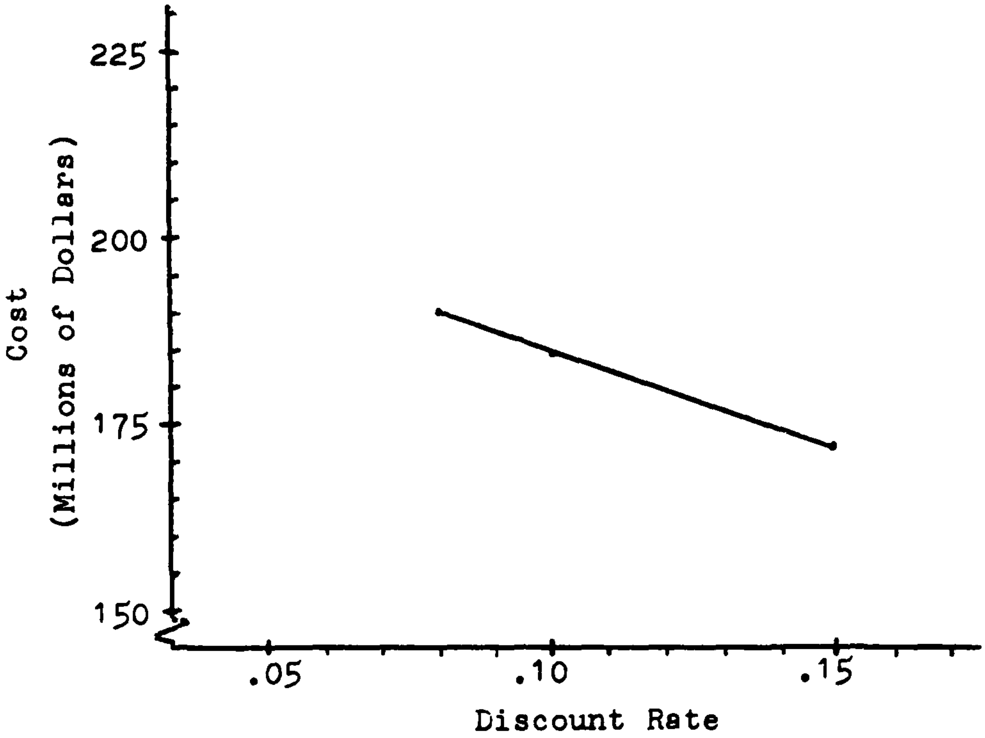

Figure 3.8

Figure 3.9

accomplished at the minimum, maximum, and mid-point rate of $35 per day.

Figure 3.10 shows the relatively small change that per diem rate changes made on the total costs of the optimal solutions. All solutions agreed with the best estimate solution with respect to the number and location of facilities.

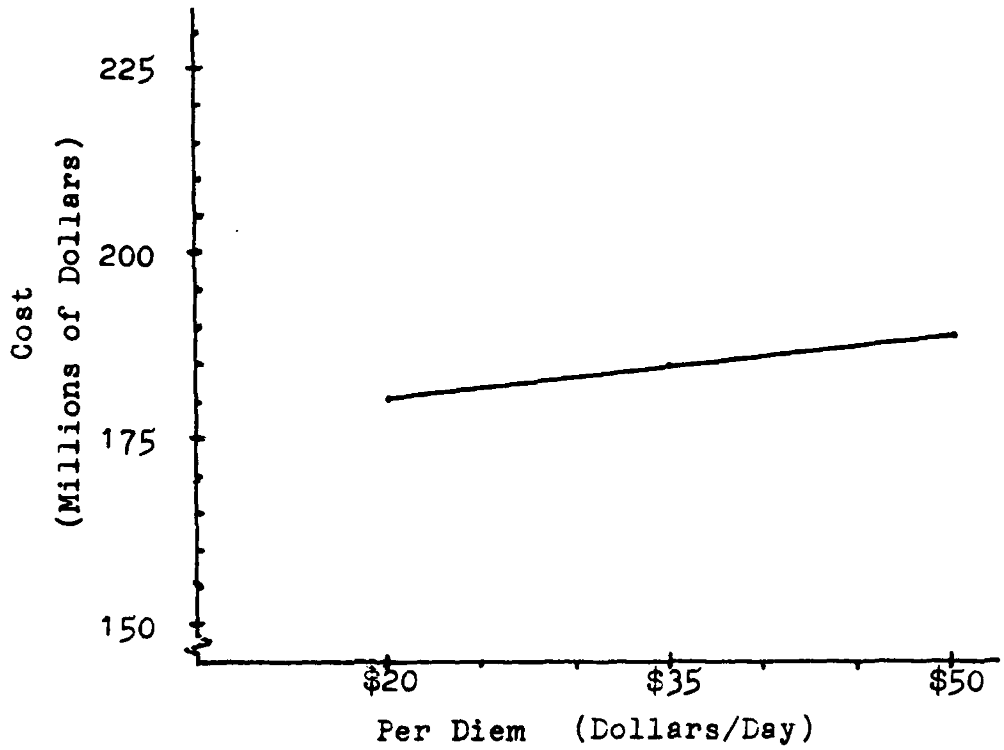

Figure 3.10

<u>Miscellaneous Personnel Support Costs</u>

The various cost components that are included in this recurring fixed cost category are listed in Chapter II. A best estimate of this cost factor was obtained from SAC Headquarters. The estimate was based on a computerized

Cost Oriented Resource Estimating (CORE) model and totaled $100,000 (20). Because of the uncertainties involved in this estimated cost, sensitivity analysis was accomplished using values 50% higher and lower than the SAC provided estimate. Figure 3.11 shows the very small change this factor caused over the range of analysis.

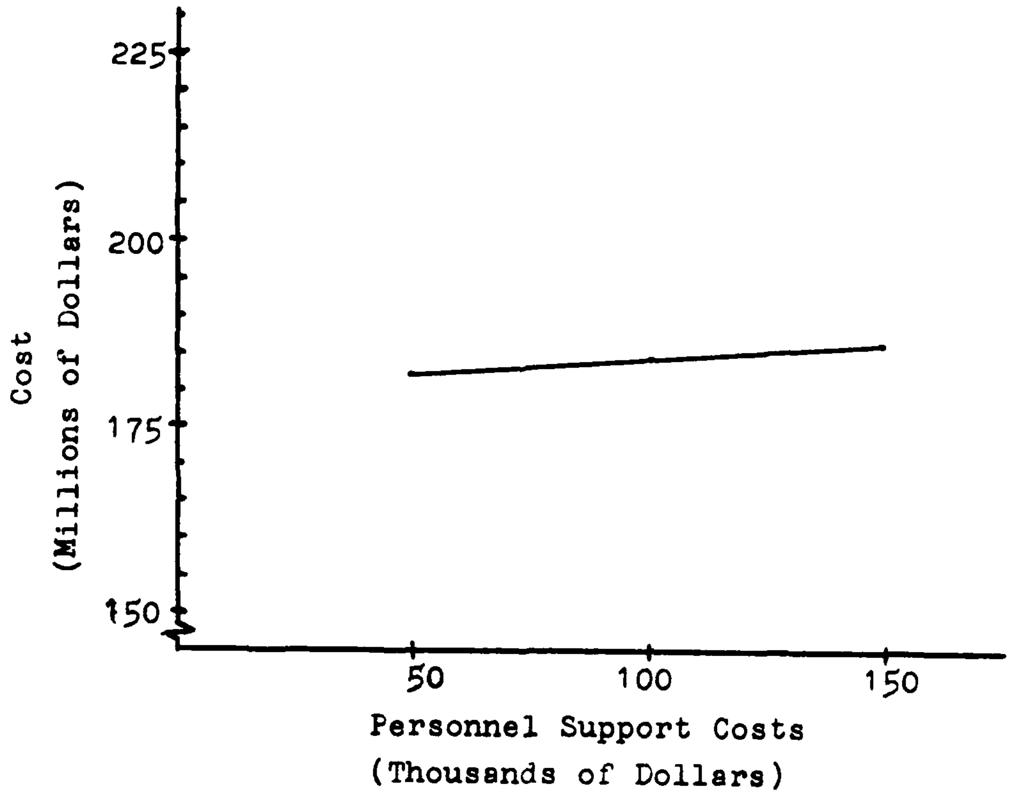

Figure 3.11

Demand For Training

Demand for simulator training was analyzed from two points of view. First, the number of aircrews per base was varied. Sixteen crews per base was set as a best estimate starting value. This value was then increased and decreased by 25%. The second method of analysis was to vary the number of simulator training missions each crew would require. Forty simulator missions per crew per year was determined to be a best estimate of the minimum training required. This minimum value was then increased by 10%, 20%, and 30% in order to determine any changes in the number and location of simulators caused by the increased demand. Additional runs were also made in both cases to find the break points where it became necessary to have another simulator in the solution.

Figure 3.12 shows the results of varying the number of crews at each base. Five simulators were enough to satisfy the demand until the size of the crew force exceeded fourteen crews per base. Six simulators were enough

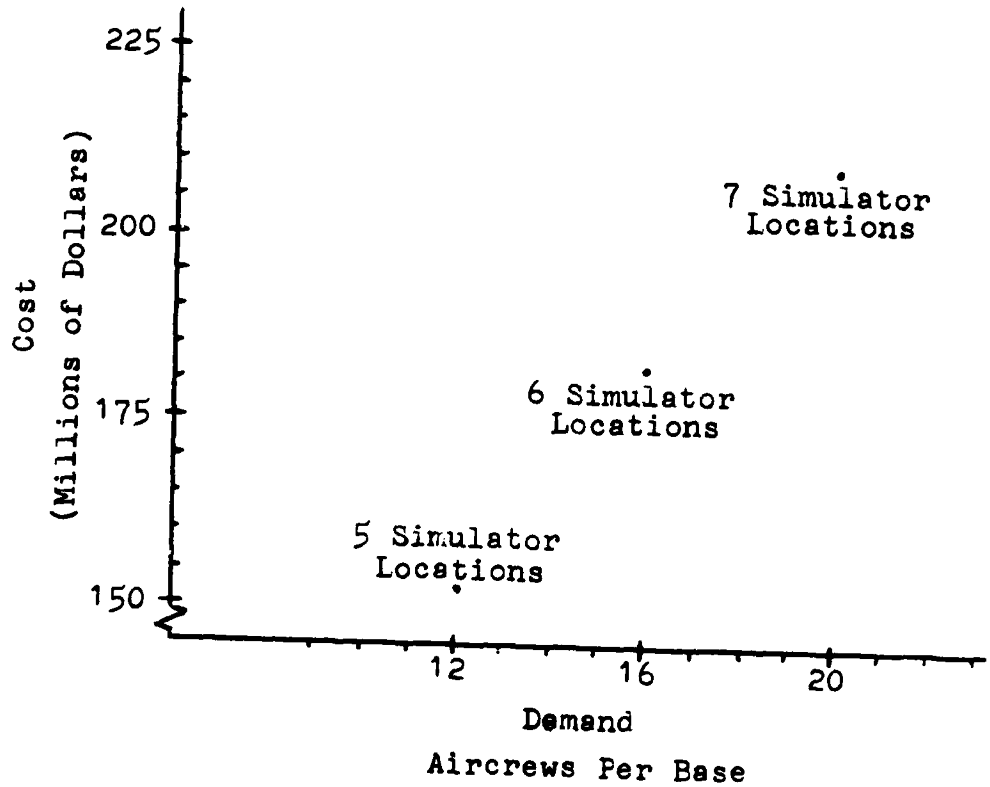

Figure 3.12

to satisfy the demand until the size of the crew force exceeded eighteen crews per base. Figures 3.13, 3.14, and 3.15 show which locations were selected and where training would be accomplished for the best estimate solution and the break point solutions.

Figure 3.16 shows the results of varying the number of missions per aircrew. Six simulators satisfied the demand until more than 44 missions per crew were needed. Seven simulators satisfied the demand until more than 51 missions per crew were demanded. If more than 54 missions per crew per year was needed, a simulator would have to be built at each of the nine locations. Figures 3.17, 3.18, and 3.19 show the locations selected and where training would be accomplished for each of the break points.

Capacity

The best estimate of the capacity of the simulators was arrived at with the aid of the WST personnel working in the Simulator SPO at Wright-Patterson AFB. The current plans are to operate the simulators sixteen hours per day six days per week. Capacity in number of hours per day was restated in the number of missions per day by assuming that a simulator training mission would take four hours. Therefore, estimated capacity equaled four missions per day. This best estimate was varied to accomplish three and five missions per day which would be equivalent to operating

Demand

16 Aircrews Per Base

Figure 3.13

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	200	640						80		280	1200
C Seymour J.			640					560			1200
D Fairchild											0
E Griffiss											0
F Loring					160	640				400	1200
G Mather				560			640				1200
H Robins											0
I Wurtsmith				80	480				640		1200
Demand	1400	640	640	640	640	640	640	640	640	680	

(Missions/Year)

Demand

14 Aircrews Per Base

Figure 3.14

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	40	560							480	120	1200
C Seymour J.											0
D Fairchild				560			560			80	1200
E Griffiss					560	560			80		1200
F Loring											0
G Mather											0
H Robins			560					560			1200
I Wurtsmith											0
Demand	1240	560	560	560	560	560	560	560	560	280	

(Missions/Year)

Demand
18 Aircrews Per Base
Figure 3.15

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	360	720						120			1200
C Seymour J.			720					480			1200
D Fairchild				720						480	1200
E Griffiss											0
F Loring					360	720				120	1200
G Mather							720			480	1200
H Robins											0
I Wurtsmith					360			120	720		1200
Demand	1560	720	720	720	720	720	720	720	720	1000	

(Missions/Year)

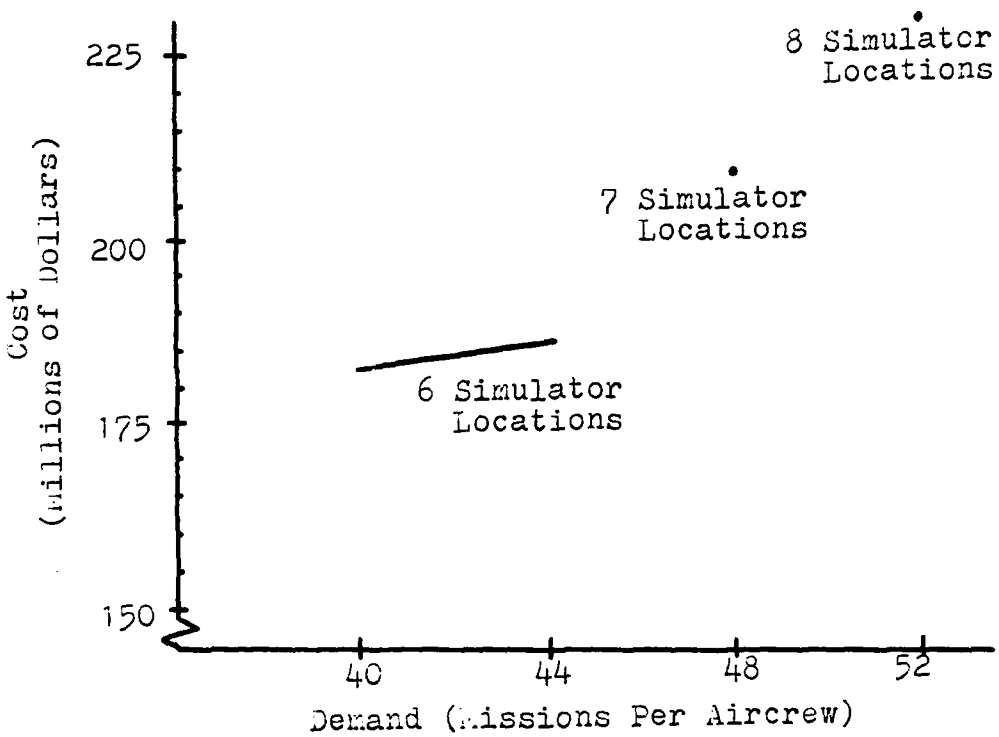
8 Simulator Locations
7 Simulator Locations
6 Simulator Locations
225
200
175
150
Cost (Millions of Dollars)
40
44
48
52
Demand (Missions Per Aircrew)

Figure 3.16

Demand

44 Missions Per Aircrew

Figure 3.17

FROM / TO	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	340	704						156			1200
C Seymour J.			704					496			1200
D Fairchild											0
E Griffiss											0
F Loring					468	704				28	1200
G Mather				496			704				1200
H Robins											0
I Wurtsmith				208	236			52	704		1200
Demand	1540	704	704	704	704	704	704	704	704	28	

(Missions/Year)

Demand

51 Missions Per Aircrew

Figure 3.18

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	288	816		96							1200
C Seymour J.			816		384						1200
D Fairchild											0
E Griffiss											0
F Loring					384	816					1200
G Mather				384			816				1200
H Robins	297							816		87	1200
I Wurtsmith				336	48				816		1200
Demand	1785	816	816	816	816	816	816	816	816	87	

(Missions/Year)

Demand

54 Missions Per Aircrew

Figure 3.19

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	336	864									1200
C Seymour J.	18		864		192					126	1200
D Fairchild				864						336	1200
E Griffiss											0
F Loring					336	864					1200
G Mather							864			336	1200
H Robins	336							864			1200
I Wurtsmith					336				864		1200
Demand	1890	864	864	864	864	864	864	864	864	798	

(Missions/Year)

the simulator for twelve or twenty hours per day. Disregarding Sundays and holidays approximately 300 days per year are available for training.

Figure 3.20 shows the cost of the optimal solution in each of the cases analyzed and the number of simulators required in each solution. Figures 3.21, 3.22, and 3.23 show the location selected and where training would be accomplished for each of the cases analyzed.

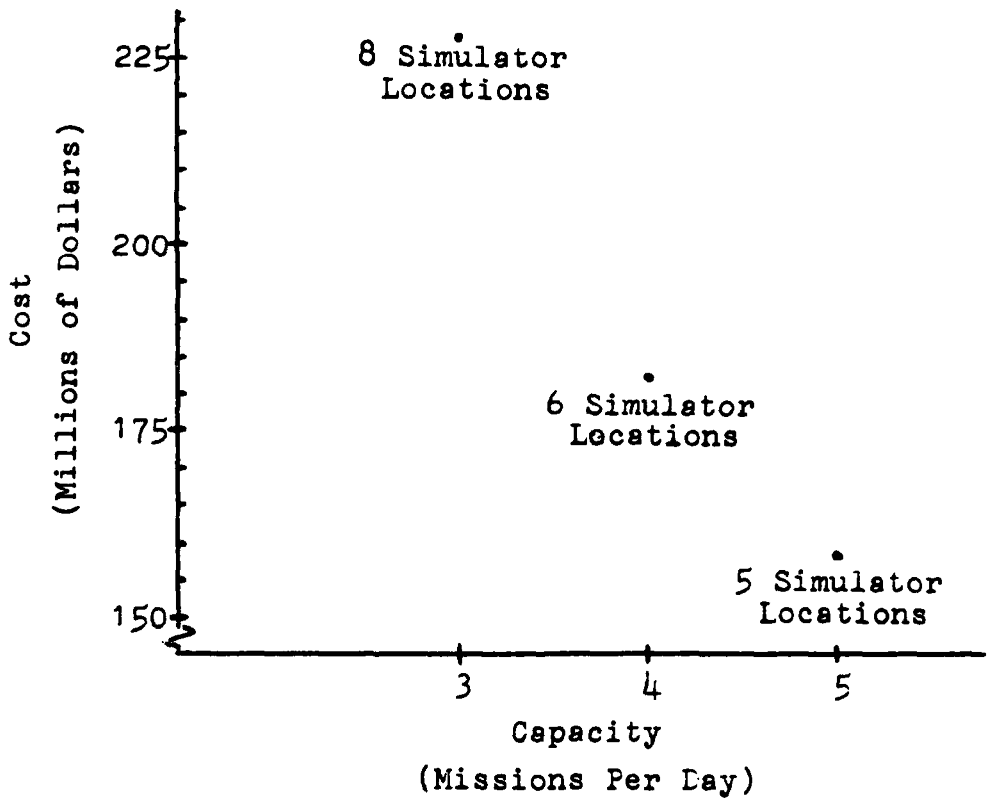

Figure 3.20

Capacity

3 Missions Per Day

Figure 3.21

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	900										900
B Blytheville	260	640									900
C Seymour J.			640		120					140	900
D Fairchild				640						260	900
E Griffiss											0
F Loring					260	640					900
G Mather							640			260	900
H Robins	240							640		20	900
I Wurtsmith					260				640		900
Demand	1400	640	640	640	640	640	640	640	640	680	

(Missions/Year)

Capacity
4 Missions Per Day
Figure 3.22

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1200										1200
B Blytheville	200	640						80		280	1200
C Seymour J.			640					560			1200
D Fairchild											0
E Griffiss											0
F Loring					160	640				400	1200
G Mather				560			640				1200
H Robins											0
I Wurtsmith				80	480				640		1200
Demand	1400	640	640	640	640	640	640	640	640	680	

(Missions/Year)

Capacity
5 Missions Per Day
Figure 3.23

TO \ FROM	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	1400	100									1500
B Blytheville											0
C Seymour J.											0
D Fairchild				640			640			220	1500
E Griffiss											0
F Loring					100	640				760	1500
G Mather											0
H Robins		220	640					640			1500
I Wurtsmith		320			540				640		1500
Demand	1400	640	640	640	640	640	640	640	640	980	

(Missions/Year)

SUMMARY

This chapter is an analysis of a simulator location problem which is presented to demonstrate the use of the model as a management tool. The B-52 Weapon System Trainer program was used as a basis for the demonstration. Because of the inability to obtain all of the factual data needed and several simplifications that were made, any conclusions drawn from the demonstration should be viewed with caution.

The use of the model was demonstrated and sensitivity analysis conducted. Only one variable at a time was changed while all others were held at the best estimate values. This is not a necessary condition of the analysis but was done so that the impact of a specific variable would be more readily apparent. Any combination of variables can be adjusted in the model in order to find the answers to a wide range of "what if" questions.

This model is not designed to be the "decision maker". It is a management tool that requires the user to gather and organize the data. The model allows the user to manipulate the desired variables and assess their impact on the problem solution. An optimal numeric solution is provided but is solely based on cost. It must be understood that not all of the variables relating to the basing decision can be quantified. This model does however provide the decision maker with a valuable data source to aid in the decision process.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains a summary of the research effort and discusses the results and conclusions reached through this thesis. Following this, a number of possible areas for further research are detailed.

SUMMARY OF RESEARCH EFFORTS

An extensive literature review did not disclose any acceptable solutions to the problem of analyzing alternative basing strategies. Model development began with a detailed discussion of the costs associated with alternative simulator training basing strategies.

The cost elements were collected into fixed and variable accounts. Recurring fixed costs were discounted and added to the nonrecurring fixed costs to arrive at a single fixed cost value. Variable costs were also discounted. Once single values for the fixed and variable costs had been determined and the constraint equations specified the problem assumed the form of a warehouse location exercise. The use of a computerized mixed integer programming algorithm was necessary due to the size of the transportation matrix.

Learning curve theory was also incorporated into the methodology. To overcome the linearity requirement of linear programming an iterative strategy was selected through which procurement costs were recomputed based on the number of simulators selected. This cycle was repeated until the number of simulators selected stabilized. Model capabilities and a sensitivity analysis were demonstrated using data from the B-52G WST program.

CONCLUSIONS

The use of flight simulators will continue to increase due to

1) the rising costs of aircraft flight operations,
2) the inherent safety and control provided by simulators, and
3) the population's increasing concern with noise and air pollution.

The movement towards greater realism or fidelity in simulator operations has and will continue to be a driving force behind the increasing costs of simulator acquisition. The rising costs of simulator acquisition and support coupled with the fact that aircrews are stationed at numerous geographic locations provides the impetus for modeling a cost effective solution to simulator basing.

This research effort has led to the most complete determination to date of the costs of alternative simulator basing strategies. The cost element table contained in Chapter II defines the various costs of simulator training in terms of behavior, relevance, and significance. Costs which did not vary in response to changes in the number or location of the simulators were deemed not relevant. Additionally, costs which were relevant but of minor consequence were deemed insignificant.

A fixed charge mixed integer programming model was developed to estimate the costs of alternative basing strategies. Furthermore, given 1) the number and location of aircrews needing training, 2) the potential simulator locations, and 3) the necessary cost data as defined in Chapter II, the model will yield the minimum cost simulator basing strategy (number and location of simulators) which satisfies the training demand.

Model capabilities were demonstrated after gathering data concerning the B-52G WST. Model output using best estimates of the input variables indicated that six WST's could satisfy the training demand. The WST's could be located such that a significant cost savings would be realized by trading off increased transportation costs for reduced fixed costs.

RECOMMENDATIONS

The research accomplished thus far has resulted in the following recommendations for future research related to developing a model for the comparison of the costs of alternative simulator basing strategies.

1) The model does not address the potential cost savings resulting from the placement of multiple simulators at

one location. The savings in terms of reduced support costs may be substantial.

2) An investigation of software support costs should be conducted to ascertain the relevance and significance of this cost element with respect to this research effort.

3) The model, as presented, includes only monetarily quantifiable costs. Major subjective inputs, such as commander preferences regarding simulator placement, may be possibly included by the use of utility function or goal programming techniques.

APPENDIX A

FORTRAN PROGRAM
TO BUILD DATA FILE

```
      PROGRAM SIM

 THIS IS A PROGRAM TO EXAMINE OPTIMAL SIMULATOR LOCATIONS

      REAL ABPF1,ABPF3,OBPF1,OBPF2,OBPF3
      REAL APCS,OPCS,TOVFA,TOVFO,DR
      REAL TRANSC(14),F(14),PILOT,NAV,EW,GUNS
      REAL BLCONT(14),COSTHD,LNCURV,MILERT
      REAL FAC,NMTDYD,PRDEMO,PRDEMA,DAYPYR,CUNIT1
      REAL NAIRC,NMAIRC,TDYCST(14,14),CAPCTY(14)
      REAL RCFIXC,OTFIXC(14),DEMAND(14),DISTNC(14,14)
      REAL OFSMAN,BSMMC,SUPNEL,TTRAIN,PCSCST,RECMOD
      REAL DFSTSP,DGFTSS,DNTTDV
      REAL AFSCX2,AFSCX4,AFSCX6
      REAL X2COST,X4COST,X6COST
      REAL TOVFP,TOVFRC,PTRCST,NTRCST,EWTCST,GNTCST
      INTEGER I,J,K,M,N
      INTEGER AMN1,AMN2,AMN4,AMN5
      INTEGER OFF1,OFF2,OFF4,OFF5
      INTEGER MSPDAY,YRS
      INTEGER NAIRK(14),MP


 AMN1(I) = NUMBER OF AIRMEN (OR CIVILIANS OF SIMILIAR PAY GRADE)
             THAT ARE ASSIGNED TO DIRECT OPERATIONAL DUTY AT
             SIMULATOR LOCATION I
 AMN2(I) = NUMBER OF AIRMEN (OR CIVILIANS OF SIMILIAR PAY GRADE)
             NEEDED TO FULFILL BASE LEVEL MAINTENANCE REQUIREMENTS
             FOR SIMULATOR OPERATIONS
 AMN4(I) = (AMN1(I) + AMN2(I))*TOVFA
 AMN5(I) = NUMBER OF AIRMEN CREW MEMBERS AND INSTRUCTORS
             TRAVELING TO THE SIMULATOR LOCATION
 TOVFA   = ANNUAL TURNOVER RATE FACTOR FOR AIRMEN
 OFF1(I) = NUMBER OF OFFICERS (OR CIVILIAN OF SIMILIAR PAY GRADE)
             THAT ARE ASSIGNED TO DIRECT OPERATIONAL DUTY AT
             SIMULATOR LOCATION I
 OFF2(I) = NUMBER OF OFFICERS (OR CIVILIAN OF SIMILIAR PAY GRADE)
             NEEDED TO FULFILL BASE LEVEL MAINTENANCE REQUIREMANTS
             FOR SIMULATOR OPERATIONS
 OFF4(I) = (OFF1(I)+OFF2(I)+)*TOVFO
 OFF5(I) = NUMBER OF OFFICER CREW MEMBERS AND INSTRUCTORS
             TRAVELING TO THE SIMULATOR LOCATION
 TOVFO = ANNUAL TURNOVER RATE FACTOR FOR OFFICERS
 ABPF1 =  AIRMEN BASIC PAY FACTOR  (NON-RATED)
 OBPF1 = OFFICER BASIC PAY FACTOR  (NON-RATED)
 OBPF2 = OFFICER BASIC PAY FACTOR  (RATED OFFICER)
 ABPF3 =  AIRMEN BASIC PAY FACTOR  (ACQUISITION/TRAINING)
 OBPF3 = OFFICER BASIC PAY FACTOR  (ACQUISITION/TRAINING)
 APCS  = PERMENENT CHANGE OF STATION COST  (DOLLARS/AIRMEN/YR)
 OPCS  = PERMENENT CHANGE OF STATION COST  (DOLLARS/OFFICER/YR)
 OTFIXC(I) = TOTAL ONE TIME FIXED COST OF SIMULATOR I
 CUNIT1 = COST OF FIRST UNIT HARDWARE
 COSTHD = COST OF ACTUAL SIMULATOR HARDWARE
 TRANSC(I) = COST OF TRANSPORTING THE SIMULATOR TO LOCATION I
 BLCONT(I) = COST OF CONSTRUNCTING AND OUTFITTING THE BUILDING TO
```

```
          HOUSE SIMULATOR
LNCURV = LEARNING CURVE ADJUSTMENT FACTOR
DISTNC(I,J) = TRAVEL DISTANCE BETWEEN HOME BASE I AND SIMULATOR
              LOCATION. INITIAL INPUT STARTING VALUE
              FOR VARIABLE COST ARRAY
MILERT = MILAGE RATE FOR MODE OF TRAVEL TO AND FROM
          SIMULATOR LOCATION
PRDEMA = PER DAY PERDIEM RATE (AIRMEN)
PRDEMO = PER DAY PERDIEM RATE (OFFICER)
NMTDYD(I) = NUMBER OF TDY DAYS PER TRIP
NAIRC = NUMBER OF CREWS ASSIGNED TO A STANDARD SQUADRON
NAIRK(I) = NUMBER OF AIR CREWS AT BASE I
NMAIRC = NUMBER OF SIM MISSIONS REQUIRED PER CREW PER YEAR
FAC= UNIT FLYAWAY COST, IN MILLIONS, OF AIRCRAFT BEING SIMULATED
ANNFAC = ANNUNITY FACTOR ADJUSTMENT TO CURRENT YEAR DOLLARS
MSPDAY = SIMULATOR MISSIONS THAT CAN BE ACCOMPLISHED PER DAY
DAYPYR = DAYS PER YEAR THAT THE SIMULATOR WILL BE OPERATED
DFSTSP = DEFENSIVE SYSTEMS TRAINING SPECIALIST
AFSCX2 = NUMBER OF 341X2 PERSONNEL
X2COST = TRAINING COST TO REPLACE 341X2
DGFTSS = DIGITAL FLIGHT SIMULATOR SPECIALIST (AFSC 341X4)
AFSCX4 = NUMBER OF 341X4 PERSONNEL
X4COST = TRAINING COST TO REPLACE 341X4
DNTTDV = DIGITAL NAV/TAC TRAINING DEVICE SPECIALIST (AFSC 341X6)
AFSCX6 = NUMBER OF 341X6 PERSONNEL
X6COST = TRAINING COST TO REPLACE 341X6
PILOT  = B-52 PILOT TRAINING COSTS
TOVFP  = PILOT TURNOVER FACTOR
PTRCST = TRAINING COST TO REPLACE B-52 PILOT
NAV    = B-52 NAVIGATOR TRAINING COSTS
TOVFRC = TURNOVER FACTOR FOR NON-PILOT RATED CREWMEMBERS
NTRCST = TRAINING COST TO REPLACE B-52 NAVIGATOR
EW     = B-52 ELECTRONIC WARFARE OFFICER TRAINING COSTS
EWTCST = TRAINING COST TO REPLACE B-52 ELECT WARFARE OFFICER
GUNS   = B-52 GUNNER TRAINING COSTS
GNTCST = TRAINING COST TO REPLACE B-52 GUNNER

OPSMAN = OPERATIONS MANPOWER COSTS
BSMMC  = BASE SYSTEMS MAINTENANCE MANPOWER COSTS
SUPNEL = MISC. SUPPORT PERSONNEL COSTS
TTRAIN = TECHNICAL TRAINING COST
PCSCST = PERMENENT CHANGE OF STATION COSTS
RECMOD = RECURRING MODIFICATION COSTS
DEMAND(I)=DEMAND FOR TRAINING IN MISSIONS PER YEAR AT BASE I
CAPCTY(I)= CAPACITY IN MISSIONS PER YEAR OF BASE I SIMULATOR
    MP = NUMBER OF SIMULATORS TO BE BUILT PER MPOS OUTPUT,
         INITIALLY SET TO N
    DR = DISCOUNT RATE
   YRS = NUMBER OF YEARS ANALYSIS SPANS
         USE LESSER OF AIRCRAFT'S OR SIMULATOR'S
         ESTIMATED LIFE
     N = NUMBER OF POSSIBLE SIMULATOR LOCATIONS
     N=9

     AMN1=2
     AMN2=23
     AMN5=1
     ABPF1=15382.Ø
     TOVFA=.171
     PRDEMA=35.Ø
     OFF1=6
     OFF2=3
     OFF5=5
     OBPF1=33278.Ø
```

```
      OBPF2=36239.Ø
      TOVFO=.Ø86
      PRDEMO=35.Ø
      APCS=61Ø.Ø
      OPCS=14Ø8.Ø
      FAC=38.Ø
      NAIRC=16.Ø
      NMAIRC=4Ø.Ø
      NMTDYD=3.Ø
      CUNIT1=17ØØØØØØ.Ø
      MILERT=Ø.1Ø
      LNCURV=1.Ø
      TRANSC(1)=81434
      TRANSC(2)=23Ø73
      TRANSC(3)=45154
      TRANSC(4)=111Ø49
      TRANSC(5)=5429
      TRANSC(6)=54832
      TRANSC(7)=1327Ø5
      TRANSC(8)=16286
      TRANSC(9)=16286
      DO Ø6 I=1,N
         BLCONT(I)= 375ØØØØ.Ø
Ø6    CONTINUE
      DR=.1Ø
      YRS=1Ø
      MSPDAY=4
      DAYPYR=3ØØ.Ø
      MP=9
      AFSCX2=9
      X2COST=8894
      AFSCX4=9
      X4COST=14859
      AFSCX6=13
      X6COST=16819
      TOVFP=.142
      TOVFRC=.1Ø8
      PTRCST=399585
      NTRCST=1381Ø9
      EWTCST=138597
      GNTCST=312366


      COMPUTE ANNUITY FACTOR BASED ON DISCOUNT RATE AND YEARS
        OF OPERATION
      ANNFAC = (1 - (1+ DR)**(-YRS))/DR
9ØØ   FORMAT(5X,I3,3X,I3,3X,F13.2)


 OPERATIONS MANPOWER
      OPSMAN=(AMN1*ABPF1)+(OFF1*OBPF2)

 BASE SYSTEMS MAINTENANCE MANPOWER
      BSMMC=(AMN2*ABPF1)+(OFF2*OBPF1)

MISC PERSONNEL COSTS FOR SUPPORT OF SIMULATOR OPERATIONS
      SUPNEL=784ØØ+216ØØ

TECHNICAL TRAINING COST
      DFSTSP=TOVFA*AFSCX2*X2COST
      DGFTSS=TOVFA*AFSCX4*X4COST
      DNTTDV=TOVFA*AFSCX6*X6COST
      PILOT=TOVFP*2*PTRCST
      NAV=TOVFRC*2*NTRCST
```

```
      EW=TOVFRC*2*EWTCST
      GUNS=TOVFRC*2*GNTCST
      TTRAIN=DFSTSP+DGFTSS+DNTTDV+PILOT+NAV+EW+GUNS

  PERMANENT CHANGE OF STATION
      AMN4 = (AMN1 + AMN2) * TOVFA
      OFF4 = (OFF1    +OFF2    )   *TOVFC

      PCSCST=(AMN4*APCS)+(OFF4*OPCS)

  RECURRING MODIFICATION COST
      RECMOD=922Ø*(FAC**.74116)

 CALCULATE TOTAL RECURRING FIXED COSTS
      RCFIXC=OPSMAN+BSMMC+SUPNEL+TTRAIN+PCSCST+RECMOD
         RCFIXC=RCFIXC*ANNFAC


 PROCUREMENT COST
         COSTHD=Ø.Ø
      DO Ø5 I=1,MP
         COSTHD=COSTHD+CUNIT1*I**(ALOG1Ø(LNCURV)/ALOG1Ø(2.))
 Ø5   CONTINUE
      COSTHD=COSTHD/MP
      DO 1Ø I=1,N
         OTFIXC(I)=TRANSC(I)+BLCONT(I)+COSTHD
 1Ø   CONTINUE


 CALCULATE TOTAL FIXED COSTS
      M=Ø
      DO 2Ø I=1,N
         F(I)=RCFIXC+OTFIXC(I)
            WRITE(1,9ØØ) M,I,F(I)
 2Ø   CONTINUE

   INPUT  PORTION OF THE N BY N DISTANCE MATRIX ABOVE THE MAIN
   DIAGONAL.

      DISTNC(1,2)=4Ø9
      DISTNC(1,3)=1Ø46
      DISTNC(1,4)=2Ø79
      DISTNC(1,5)=1426
      DISTNC(1,6)=2Ø35
      DISTNC(1,7)=1931
      DISTNC(1,8)=661
      DISTNC(1,9)=122Ø
      DISTNC(2,3)=792
      DISTNC(2,4)=2Ø13
      DISTNC(2,5)=1Ø56
      DISTNC(2,6)=1664
      DISTNC(2,7)=2127
      DISTNC(2,8)=542
      DISTNC(2,9)=836
      DISTNC(3,4)=2625
      DISTNC(3,5)=663
      DISTNC(3,6)=1125
      DISTNC(3,7)=2859
      DISTNC(3,8)=468
      DISTNC(3,9)=94Ø
      DISTNC(4,5)=2457
      DISTNC(4,6)=2787
      DISTNC(4,7)=839
      DISTNC(4,8)=248Ø
      DISTNC(4,9)=1914
      DISTNC(5,6)=66Ø
      DISTNC(5,7)=2775
```

```
      DISTNC(5,8)=1054
      DISTNC(5,9)=598
      DISTNC(6,7)=3294
      DISTNC(6,8)=1538
      DISTNC(6,9)=1114
      DISTNC(7,8)=2563
      DISTNC(7,9)=2447
      DISTNC(8,9)=1013

      DO 25 I=1,N
         DO 25 J=1,N
            IF (I.LT.J) THEN
               DISTNC(J,I)=DISTNC(I,J)
            ENDIF
25    CONTINUE

CALCULATE VARIABLE COST IN MPOS PACKED FORMAT
      DO 30 I=1,N
         DO 30 J=1,N
            IF (I.EQ.J) THEN
               TDYCST(I,J)=0.0
            ELSE
               TDYCST(I,J)=  (OFF5*PRDEMO + AMN5*PRDEMA )*
     C                NMTDYD + 2*DISTNC(I,J)*MILERT*(OFF5+AMN5)
               TDYCST(I,J)=TDYCST(I,J)*ANNFAC
            ENDIF
30    CONTINUE


OUTPUT FILE IN MPOS PACKED FORMAT
      M=0
      K=N
      DO 40 I=1,N
         DO 40 J=1,N
            K=K+1
            IF (TDYCST(I,J) .GT.0.0) THEN
              WRITE(1,900)M,K,TDYCST(I,J)
            ENDIF
40    CONTINUE


CALCULATE ANNUAL DEMAND FOR LOCATION I
      DO 45 I=1,N
         NAIRK(I)=NAIRC
45    CONTINUE


  ENTER NUMBER OF CREWS AT EACH LOCATION I
    IF DIFFERENT FROM STANDARD BASE CREW MANNING
      NAIRK(1)=35
      DO 50 I=1,N
         DEMAND(I)=NAIRK(I)*NMAIRC
50    CONTINUE

WRITE DEMAND IN MPOS PACKED FORMAT
      J=0
      DO 60 I=1,N
            WRITE(1,900) I,J,DEMAND(I)
60    CONTINUE

      R=1.0
      DO 70 I=1,N
         DO 70 J=1,N
            WRITE(1,900) I,((N*J)+I),R
```

```
7Ø    CONTINUE

CALCULATE ANNUAL CAPACITY FOR SIMULATORS
      DO 8Ø I=1,N
         CAPCTY(I)=MSPDAY*DAYPYR
         CAPCTY(I)=(-1)*CAPCTY(I)
         WRITE(1,9ØØ) (I+N),I,CAPCTY(I)
8Ø    CONTINUE

      R=1.Ø
      DO 9Ø I=1,N
         DO 9Ø J=1,N
            WRITE(1,9ØØ) (I+N),((N*I)+J),R
9Ø    CONTINUE

      STOP
      END
```

APPENDIX B

EXAMPLE OF MPOS PACKED FORMAT

0	1	27343789.00
0	2	27285423.00
0	3	27307509.00
0	4	27373404.00
0	5	27267784.00
0	6	27317187.00
0	7	27375060.00
0	8	27278641.00
0	9	27278641.00
0	11	6886.83
0	12	11583.74
0	13	19200.54
0	14	14385.66
0	15	18876.11
0	16	18109.27
0	17	8744.55
0	18	12856.72
0	19	6886.83
0	21	9710.87
0	22	18713.89
0	23	11657.47
0	24	16140.55
0	25	19554.47
0	26	7867.50
0	27	10035.31
0	28	11583.74
0	29	9710.87
0	81	11340.41
0	82	12866.72
0	83	10035.31
0	84	10802.15
0	85	17983.92
0	86	8280.42
0	87	12085.13
0	88	21913.98
0	89	11340.41
1	0	1400.00
2	0	640.00
3	0	640.00
4	0	640.00
5	0	640.00
6	0	640.00
7	0	640.00
8	0	640.00
9	0	640.00

1	10	1.00
1	19	1.00
1	28	1.00
1	37	1.00
1	46	1.00
1	55	1.00
1	64	1.00
1	73	1.00
1	82	1.00
2	11	1.00
2	20	1.00
2	29	1.00
2	38	1.00
2	47	1.00
2	56	1.00
2	65	1.00
2	74	1.00
2	83	1.00
9	18	1.00
9	27	1.00
9	36	1.00
9	45	1.00
9	54	1.00
9	63	1.00
9	72	1.00
9	81	1.00
9	90	1.00
10	1	-1200.00
11	2	-1200.00
12	3	-1200.00
13	4	-1200.00
14	5	-1200.00
15	6	-1200.00
16	7	-1200.00
17	8	-1200.00
18	9	-1200.00
10	10	1.00
10	11	1.00
10	12	1.00
10	13	1.00
10	14	1.00
10	15	1.00
10	16	1.00
10	17	1.00
10	18	1.00

APPENDIX C

CONTROL CARDS TO IMPLEMENT
FOURTEEN LOCATION MPOS PROGRAM

```
BSMIP
TITLE
SIMULATOR COSTING
INTEGER
Y1 TO Y14
VARIABLES
Y1 TO Y14
XA1 TO XA14
XB1 TO XB14
XC1 TO XC14
XD1 TO XD14
XE1 TO XE14
XF1 TO XF14
XG1 TO XG14
XH1 TO XH14
XI1 TO XI14
XJ1 TO XJ14
XK1 TO XK14
XL1 TO XL14
XM1 TO XM14
XN1 TO XN14
PACKED
MINIMIZE
CONSTRAINTS 28
ØØØØØØØØØØØØØØ++++++++++++++
REWIND
FORMAT
(3X,I3,3X,I3,3X,F13.2)
READ TAPE14
BNDALL 14ØØ
BNDINT 3
LIMIT 5ØØØ
MAXCM 35ØØØØ
OPTIMIZE
```

APPENDIX D

EXAMPLE OF MPOS OUTPUT

PROBLEM INPUT SUMMARY

CONSTRAINTS		VARIABLES		NON-ZEROS		PARAMETERS	BOUNDS	
EQS=	14	INT=	14	NUMBER=	4Ø6	TOL= .1ØØE-Ø7	INT=	.3ØØE+Ø1
LES=	14	TOTAL=	21Ø	PERCENT=	6.9Ø	EPS=DEFAULT	ALL=	.14ØE+Ø4
GES=	Ø	NOUB=	Ø			LIMIT= 5ØØØ		
TOTAL=	28	NOLB=	Ø			RSCALE= .1ØØE+Ø1		

VARIABLE TABLE

1 - Y1	2 - Y2	3 - Y3	4 - Y4	5 - Y5	6 - Y6
7 - Y7	8 - Y8	9 - Y9	1Ø - Y1Ø	11 - Y11	12 - Y12
13 - Y13	14 - Y14	15 - XA1	16 - XA2	17 - XA3	18 - XA4
19 - XA5	2Ø - XA6	21 - XA7	22 - XA8	23 - XA9	24 - XA1Ø
25 - XA11	26 - XA12	27 - XA13	28 - XA14	29 - XB1	3Ø - XB2
31 - XB3	32 - XB4	33 - XB5	34 - XB6	35 - XB7	36 - XB8
37 - XB9	38 - XB1Ø	39 - XB11	4Ø - XB12	41 - XB13	42 - XB14
43 - XC1	44 - XC2	45 - XC3	46 - XC4	47 - XC5	48 - XC6
49 - XC7	5Ø - XC8	51 - XC9	52 - XC1Ø	53 - XC11	54 - XC12
55 - XC13	56 - XC14	57 - XD1	58 - XD2	59 - XD3	6Ø - XD4
61 - XD5	62 - XD6	63 - XD7	64 - XD8	65 - XD9	66 - XD1Ø
67 - XD11	68 - XD12	69 - XD13	7Ø - XD14	71 - XE1	72 - XE2
73 - XE3	74 - XE4	75 - XE5	76 - XE6	77 - XE7	78 - XE8
79 - XE9	8Ø - XE1Ø	81 - XE11	82 - XE12	83 - XE13	84 - XE14
85 - XF1	86 - XF2	87 - XF3	88 - XF4	89 - XF5	9Ø - XF6
91 - XF7	92 - XF8	93 - XF9	94 - XF1Ø	95 - XF11	96 - XF12
97 - XF13	98 - XF14	99 - XG1	1ØØ - XG2	1Ø1 - XG3	1Ø2 - XG4
1Ø3 - XG5	1Ø4 - XG6	1Ø5 - XG7	1Ø6 - XG8	1Ø7 - XG9	1Ø8 - XG1Ø
1Ø9 - XG11	11Ø - XG12	111 - XG13	112 - XG14	113 - XH1	114 - XH2
115 - XH3	116 - XH4	117 - XH5	118 - XH6	119 - XH7	12Ø - XH8
121 - XH9	122 - XH1Ø	123 - XH11	124 - XH12	125 - XH13	126 - XH14
127 - XI1	128 - XI2	129 - XI3	13Ø - XI4	131 - XI5	132 - XI6
133 - XI7	134 - XI8	135 - XI9	136 - XI1Ø	137 - XI11	138 - XI12
139 - XI13	14Ø - XI14	141 - XJ1	142 - XJ2	143 - XJ3	144 - XJ4
145 - XJ5	146 - XJ6	147 - XJ7	148 - XJ8	149 - XJ9	15Ø - XJ1Ø
151 - XJ11	152 - XJ12	153 - XJ13	154 - XJ14	155 - XK1	156 - XK2
157 - XK3	158 - XK4	159 - XK5	16Ø - XK6	161 - XK7	162 - XK8
163 - XK9	164 - XK1Ø	165 - XK11	166 - XK12	167 - XK13	168 - XK14
169 - XL1	17Ø - XL2	171 - XL3	172 - XL4	173 - XL5	174 - XL6
175 - XL7	176 - XL8	177 - XL9	178 - XL1Ø	179 - XL11	18Ø - XL12
181 - XL13	182 - XL14	183 - XM1	184 - XM2	185 - XM3	186 - XM4
187 - XM5	188 - XM6	189 - XM7	19Ø - XM8	191 - XM9	192 - XM1Ø
193 - XM11	194 - XM12	195 - XM13	196 - XM14	197 - XN1	198 - XN2
199 - XN3	2ØØ - XN4	2Ø1 - XN5	2Ø2 - XN6	2Ø3 - XN7	2Ø4 - XN8
2Ø5 - XN9	2Ø6 - XN1Ø	2Ø7 - XN11	2Ø8 - XN12	2Ø9 - XN13	21Ø - XN14

INPUT TRANSLATION TIME = .368Ø SECONDS

--- NEW INTEGER-FEASIBLE SOLUTION ---

SUMMARY OF RESULTS AT ITERATION 3391

OBJECTIVE FUNCTION = 280071793.340

VARIABLE TAG	VARIABLE NAME	BASIS/ BOUNDS	INTEG/ CONTIN	ACTIVITY LEVEL	OPPORTUNITY COST
1	Y1	IF	I	1.0000000	8205834.9999999
14	Y14	IF	I	1.0000000	5222489.0000000
13	Y13	IF	I	0.0000000	116419.0000002
11	Y11	IF	I	1.0000000	10857.0000001
12	Y12	IF	I	0.0000000	116419.0000003
10	Y10	IF	I	1.0000000	10857.0000001
4	Y4	IF	I	1.0000000	12047260.0000000
7	Y7	IF	I	0.0000000	10435680.9999999
9	Y9	IF	I	1.0000000	9947360.9999999
3	Y3	IF	I	1.0000000	8815111.9999998
2	Y2	IF	I	1.0000000	8232437.0000005
8	Y8	IF	I	0.0000000	10534486.9999995
5	Y5	IF	I	0.0000000	2095011.0000001
6	Y6	IF	I	1.0000000	14041725.6599979
15	XA1	B	C	1200.0000000	--
30	XB2	B	C	640.0000000	--
45	XC3	B	C	640.0000000	--
60	XD4	B	C	640.0000000	--
-28	--SLACK	B	C	560.0000000	--
90	XF6	B	C	640.0000000	--
89	XF5	B	C	30.0000000	--
97	XF13	B	C	480.0000000	--
135	XI9	B	C	640.0000000	--
150	XJ10	B	C	640.0000000	--
165	XK11	B	C	640.0000000	--
180	XL12	B	C	0.0000000	--
195	XM13	B	C	0.0000000	--
210	XN14	B	C	640.0000000	--
-16	--SLACK	B	C	280.0000000	--
131	XI3	B	C	560.0000000	--
161	XK7	B	C	30.0000000	--
63	XD7	B	C	560.0000000	--
29	XB1	B	C	200.0000000	--
36	XB8	B	C	80.0000000	--
152	XJ12	B	C	400.0000000	--
-25	--SLACK	B	C	240.0000000	--
166	XK12	B	C	240.0000000	--
153	XJ13	B	C	160.0000000	--
50	XC3	B	C	560.0000000	--

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