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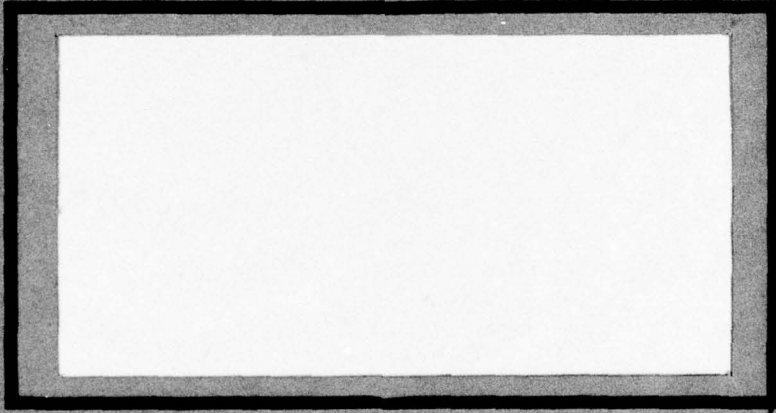
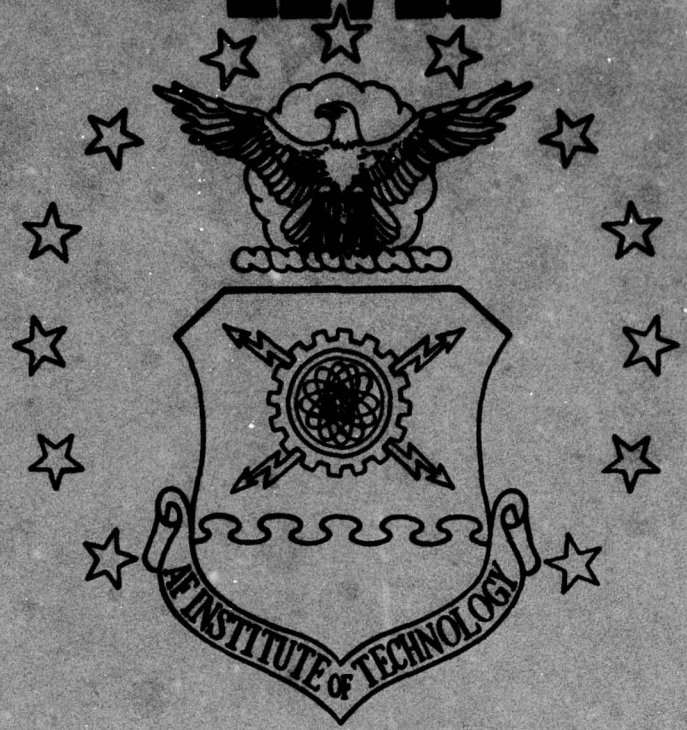


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**OPTIMAL PLACEMENT OF REGIONAL  
FLIGHT SIMULATORS**

David R. Vandenburg, Captain, USAF  
Jon D. Veith, Captain, USAF

LSSR 18-78B

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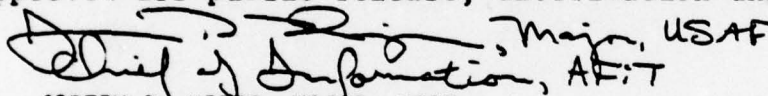


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Due to the depletion of petroleum resources and increasing aircraft operating costs, inflight simulators are assuming a larger role in aircrew training. Simultaneously, increased simulator acquisition and support costs have resulted in fewer simulator systems. Consequently, a regional simulator deployment plan is often used. This plan involves the placement of simulator systems at a number of central locations and transporting students to these locations to accomplish their required training. This research attempted to develop a mathematical model to assist in the placement decision. The model was developed, however a suitable computer algorithm could not be found to solve the resulting equations. Consequently, a model was developed and used to provide suggested student allocation schedules for predetermined simulator location plans. It was concluded that mathematical techniques could be employed to assist in the placement decisions. In addition, it is believed that future improvements in computer software could produce an algorithm capable of solving the model originally developed.

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In Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Logistics Management

By

10 David R. Vandenburg, ~~Colonel, USAF~~ Jon D. Veith, BBA  
~~Colonel, USAF~~

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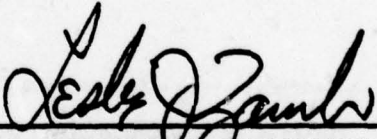
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has been accepted by the undersigned on behalf of the  
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## Chapter I

### STATEMENT OF THE PROBLEM

In today's environment of increasing cost, reduced fuel availability, and complex technology, flight simulation has assumed a major role in aircrew training (16:15). Unfortunately, the cost of simulators<sup>1</sup> has also increased dramatically (17:51). This increase, coupled with reductions in the buying power of the defense budget, has resulted in fewer simulator systems being purchased to support aircrew qualification and proficiency training. As a result, some Major Commands have established a regional simulator deployment concept whereby the simulators are located at selected strategic sites and students are transported to these sites to accomplish their required training.<sup>2</sup>

---

<sup>1</sup>The terms "simulator," "trainer," and "flight simulator" will be used as synonymous even though small differences may exist in the technological base.

<sup>2</sup>The Strategic Air Command (SAC), for example, accomplishes all simulator training for B-52 and KC-135 pilots and copilots from Blytheville AFB, Griffiss AFB, Loring AFB, and Warner Robins AFB through simulators located at Warner Robins AFB (7).

As transportation and billeting costs continue to rise, optimal<sup>3</sup> location of these devices becomes very important. At the present time, however, there appears to be no established methodology to insure that the present simulator systems and those to follow are optimally located. In one instance, the location of regional flight simulators is determined by a subjective staff evaluation involving the efforts of many individuals over an extended period of time (15). While this method may produce effective results, it is inefficient in terms of time and resource consumption. In another example, simulator placement is determined by informal discussions of unit commanders. This method often results in assignments based on the preferences of the most influential agency (19). An objective and economically efficient method is needed to assist management in making decisions for locating regional flight simulators.

#### BACKGROUND

Although flight simulation has been an integral part of flying since the first simulators were built in England

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<sup>3</sup>"Optimal" refers to a course of action considered to be the best in light of predefined criteria and subject to known constraints.

in 1910, simulators required the so-called "fuel crisis" of 1973 to generate any substantial amount of enthusiasm (17:42). As reserves of fuel and other petroleum products began to dwindle and the costs of aircraft operation began to rise, the Air Force and the Department of Defense (DOD) began to evaluate means of reducing costs. Since flight training consumes a large amount of fuel, Air Force and DOD planners sought means of reducing inflight training without diminishing the nation's defensive posture (17:46). In addition, aging aircraft, increased maintenance cost, public awareness of noise and air pollution, and reduced funding reinforced the concept of reduced flying (8:1). Consequently, a goal of a 25 percent reduction of flying hours by 1981 was established (2:8). A closer look at the situation however, convinced planners that if flying time was reduced this much, aircrew proficiency could not be maintained at the required levels through the use of the simulators currently available (1:2). Thus, convinced that improved simulators were necessary, DOD planning personnel began to examine available simulator technology and to evaluate plans to improve and supplement existing simulators (1:6).

### Present Technology

Currently, the Air Force has over 535 simulators and trainers in the active inventory. These include 185 Undergraduate Pilot Training (UPT) procedural trainers, over 200 operational flying simulators, 21 missile trainers, 69 bombing-navigation training simulators, 31 electronic warfare trainers, and 26 gunnery trainers (17:45). Many of these devices, such as B-52 Cockpit Procedural Trainers (CPT), were built in the late 1950s and only a small percentage incorporate motion and visual systems (1:5). Some of the newer models however, are capable of faithfully reproducing all phases of the parent aircraft's mission. Such activities as engine start, taxi, takeoff, bombing, navigation training, inflight refueling, and landing at night in adverse weather can be realistically simulated (11:8). As a result of these factors and the amount of training required, utilization of some simulator systems runs as high as 20 hours a day, six days a week (20:38). Regardless of age and capability, these devices are used in a variety of roles.

### Present Utilization

As previously mentioned, simulators in the current Air Force inventory are used for a number of purposes.

For example, the average student in UPT will spend about 80 hours in a flight simulator and only about 150 hours in an aircraft during his year in training (23). Similarly, a Strategic Air Command (SAC) pilot/copilot team will receive a minimum of 12 hours of emergency and normal procedure training each training quarter<sup>4</sup> (7). Other commands and services are equally determined to use simulators as an effective supplement to inflight training. Air Training Command (ATC) at Mather AFB, for example, has eliminated 48 hours of inflight navigator training per student as a direct result of better simulator utilization (17:50). Similarly, inflight training for electronic warfare officers at Mather AFB has been reduced by over 70 hours per student through simulation (5:19). Although many experts maintain that simulator systems are relatively inexpensive when analyzed in terms of the benefits they provide (17:52), the questions remain, just what will they cost and what benefits can these systems provide?

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<sup>4</sup>A training quarter consists of a three month training period. These begin in January, April, July, and October of each year.

## Costs and Benefits

As stated by Major General Oliver W. Lewis:

Purchase of new simulators is obviously expensive, but the rewards are great. Routinely they amortize themselves before the last item of a sequenced buy is in place [16:52].

Currently, the Air Force has budgeted almost \$2 billion for simulator procurement through 1978 (16:15). Although this represents a sizeable investment, the resultant cost savings can be immense. For example, fuel savings of \$111 million per year have been estimated for the B-52/KC-135/C-130 programs alone (20:103). Similarly, the Boeing Company estimates that it costs \$1400 per hour to fly a multiengine jet aircraft on training flights compared with \$280 per hour to use a simulator. In addition, Boeing analysis indicates that simulator training is at least comparable and is often superior to training received in the aircraft (6:59). Since operating conditions can be adjusted, training near or at the extreme boundaries of the flight envelope<sup>5</sup> can be simulated, a feat often too hazardous to attempt in the actual aircraft (13:60). Other benefits include reduced

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<sup>5</sup>The "flight envelope" refers to the conditions of altitude, airspeed, configuration, and gross weight within which the aircraft is designed to operate. Operation outside of these limits can result in adverse flight characteristics and structural damage to the airframe.

noise and air pollution, reduced airspace congestion, less wear on aircraft, reduced maintenance costs, simplified logistics efforts, and a much safer training environment (17:50). Although these factors are impressive, they are only a hint of things to come.

#### Future Simulator Systems

As previously mentioned, flight simulator procurement programs were re-emphasized during the early 1970s (8:1). Since the normal lead time for a simulator system has traditionally been about seven years, the results of these efforts should become apparent in the near future (1:11). New integration of technology and packaging evolved by the Singer Company, present owners of the Link Corporation, has resulted in an 80 percent reduction of simulator space requirements. In addition, new hydraulic systems have increased the realism of the motion response and the use of computer generated imagery projected on the windscreen has produced a very realistic simulator package (25:61-62).

Older, present use systems will also benefit from this new era of technology. Computerized visual displays are presently being added to FB-111 simulators at Pease AFB and Plattsburgh AFB, and night visual training systems

will be added to KC-135 simulators at Castle AFB in late 1978 (22:123). Procurement of limited visual systems for the C-5/C-141 simulators (which already possess an advanced motion system) has been accelerated and the Military Airlift Command (MAC) hopes to have the systems operational in 1978 (25:61). These additions, coupled with a computer "instant replay" feature, which allows students to watch their own performance, promises to rejuvenate some of our present systems much more cheaply than the purchase of new systems (13:61). However, all systems, old or new, will require effective management if effective and efficient results are to be realized.

#### Management of Programs

Because of the magnitude of expenditures and intensified interest in simulator technology by Air Force Systems Command (AFSC) and the using commands, Headquarters USAF and DOD are taking a critical look at the management procedures involved in the development of flight simulators (24:101). As a result, the Simulator Systems Program Office (SIMSPO) is placing a new emphasis on maximum commonality of parts and parts management, and more extensive use of contractor maintenance (24:101). In addition, the Air

Force Inspector General recently determined that effectiveness and efficiency of operating policies at the base level were excellent, however, problems were found in the areas of personnel support and guidance for simulator utilization. Consequently, auditors recommended the strengthening of the overall management of simulator operations, improved logistic support and improved utilization of personnel, among other factors (9:2). It is apparent that many new systems are, or will soon be, available (26:4). How they will be deployed and managed may well influence their effectiveness and efficiency.

#### JUSTIFICATION

As previously discussed, flight simulator systems are assuming an increased role in aircrew training. While emphasis has been placed on efficient acquisition of new simulator systems (16:15), personnel responsible for the deployment and management of these systems state that insufficient quantitative tools exist to determine whether the resultant placement of the simulator systems is economically optimal (19). In most instances, regional deployment of these systems is done subjectively with no quantitative evaluation of operating or life cycle costs

(LCC). Consequently, the resulting placement of the systems may or may not be the optimal placement from an economic standpoint (19).

For example, 14 Air Force Reserve and Air National Guard (ANG) units are scheduled to receive five A-7 flight simulators. Personnel at USAF Headquarters have indicated that no objective methodology exists to determine where these simulators will be located. The placement will be done by examining a map and approximating five central locations (15). Due to rising transportation and fuel costs, even a slightly less than optimal placement of the simulators may result in needless expenditures of scarce resources. These expenditures will likely be increased many times in the coming years and since moving an established system is also costly, proper placement at the establishment of the program is vital. In addition, personnel at USAF Headquarters expect to encounter the same situation as the F-4 and A-10 aircraft are phased into the ANG and AF Reserve inventories (19). Any improved methodology developed could be used repeatedly in the future.

An extensive literature review did not reveal any indication that a quantitative approach has been developed to assist in the determination of the placement of these

simulator systems. This apparent lack of quantitative methodology prevents a valid cost comparison and determination of the optimal placement. A mathematical model would assist management personnel responsible for determination of the locations of regional flight simulators and provide a vehicle for making valid cost comparisons.

#### OBJECTIVE

The purpose of this study is to develop and validate a mathematical model that can be used to assist in the determination of the economically optimal location for regional flight simulators and the allocation of students to these simulators.

#### SUMMARY

As new and modified simulator systems are phased into the operational inventory and present systems are redistributed, proper placement of regional support units should be assured. A quantitative model may assist in the optimal placement of the systems and provide a concrete basis for the decisions necessary for their management. The model could result in reduced costs and improved management support in this important area of aircrew training.

## Chapter II

### METHODOLOGY

This chapter describes the methodology used in the development of the model, beginning with a statement of the research questions used to guide and direct the research. A discussion of expected model development is then presented through the definition and description of the variables considered important to the study and a discussion of the methodology involved in cost determinations. Assumptions and known model limitations will then be addressed. Subsequently, the development of a computer algorithm to simplify use of the model and a proposed method of validation will be presented.

### RESEARCH QUESTIONS

The following questions were developed to guide the study.

1. What type of model would best satisfy the stated objectives?

2. What variables should be considered in the development of this model?

3. What factors will influence the various costs used in the model and how can these costs be estimated?

#### DEVELOPMENT OF THE MODEL

A mixed integer linear programming<sup>6</sup> model appeared to be the most suitable form of mathematical model for this type of problem (3:112). Because of the problem structure involving a placement decision as well as a student allocation problem, two types of decision variables are necessary. A mixed integer programming model thus appeared to be the best approach. As a first step in using this technique, all variables relevant to the problem must be identified and defined.

#### Definition of Variables

The following variables will be investigated:

1. Fixed Costs ( $F_j$ ). Fixed costs are the one time costs associated with installing a regional flight simulator system at location  $j$ . This amount may include any

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<sup>6</sup>A short discussion of linear programming is presented in Appendix A.

necessary building construction or renovation such as air conditioning, electrical and sewer hookups, and the costs associated with any necessary increases in messing and billeting facilities. Also included is the cost to move the simulator system from its present location to base j. This cost is expected to be unique to each location.

2. Transportation Costs ( $C_{i,j}$ ). Transportation costs are the costs to transport a student from his assigned base i, to base j for simulator training, and back to base i. The figure consists of the actual cost of the transportation, the cost of any necessary 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 to be used.

3. Availability ( $S_j$ ). This variable is the number of students per month that can be trained at base j if a regional flight simulator system is located there. This number is determined by the available training periods, the length of these training periods, the required number of training periods per student, and messing and billeting facilities available. It represents the maximum number of students per month that can be supported by base j.

4. Demand ( $d_i$ ). This variable represents the number of students per month from base  $i$  that require simulator training. In general, the number can be obtained from unit rosters corrected for projected gains and losses.

5. Decision Variable ( $X_{ij}$ ). The number of students from base  $i$  sent to base  $j$  for simulator training each month. This variable actually represents an output of the model rather than a predetermined quantity.

6. Number of simulator systems available ( $N$ ). This number represents the maximum number of simulators available or to be purchased.

#### Estimation of Transportation Costs

To simplify use of the final model, a direct method of computing the transportation costs ( $C_{ij}$ ) was desirable. Analysis of these costs indicated that they are a function of the distance between the bases, the mode of transportation used, and the time frame involved (18). Consequently, a linear or higher order function involving these factors may exist which will allow the direct computation of an estimate for the transportation costs based on the distance involved and the mode of transportation used.

To determine if this relationship exists and if so, how accurately the function will predict costs, the following methodology was used.

1. Historical data on transportation costs was obtained from the Wright-Patterson AFB Accounting and Finance Office (AFO). This data consisted of costs in dollars, distances involved, modes of transportation used, and dates of the trips, from actual travel vouchers. The data thus represented a sample of the population of Air Force travel costs. Initially, it was assumed that this data is representative of the entire population (18).

2. The data obtained from the AFO was analyzed using regression techniques<sup>7</sup> to determine what relationship exists between travel costs and distance involved. A relationship of the form,  $Cost = \sum [A_i Y_i + B_i Y_i D_{ij}]$ , was expected where  $A_i$  and  $B_i$  are regression coefficients associated with mode  $i$ ,  $Y_i$  is a 0-1 dummy variable equal to 1 if mode  $i$  is used and 0 otherwise and  $D_{ij}$  is the distance between location  $i$  and location  $j$ .

---

<sup>7</sup>Regression analysis is a technique used to predict the value of one quantitative variable by using its relationship with one or more additional quantitative variables (21:391).

3. The relationship was then validated using data withheld from the original sample and data obtained from other bases.

4. After the validity of the expression was assured, a computer program was developed to compute the cost array  $C_{ij}$  based on the distance from base  $i$  to base  $j$  and the mode of travel to be used.

#### Model Form

A review of current mathematical modeling techniques indicates that a mixed integer linear programming model was the best approach to the problem (3:112). Consequently, the model was expected to assume the following form:

$$\text{Minimize Cost (Z)} = \sum_{i=1}^n \sum_{j=1}^m C_{ij} X_{ij} Y_j + \sum_{j=1}^m F_j Y_j \quad \text{Eq 2.1}$$

Subject to the following constraints:

$$\sum_{i=1}^n X_{ij} = d_j \quad j=1, m \quad (\text{Demand}) \quad \text{Eq 2.2}$$

$$\sum_{j=1}^m X_{ij} \leq S_i \quad i=1, n \quad (\text{Supply}) \quad \text{Eq 2.3}$$

$$\sum_{j=1}^m Y_j \leq N \quad (\text{Availability}) \quad \text{Eq 2.4}$$

$$X_{ij}, C_{ij}, F_j, S_j, d_i, Y_j \geq 0 \quad (\text{Non-negativity})$$

$$Y_j = 0, 1 \quad \text{all } j \quad (\text{Dummy})$$

The indicated variables are as defined in the previous sections.

### Assumptions

The following assumptions were made to guide the research.

1. Costs of operating a simulator system are the same at any base once the system is installed and the installation costs are paid.
2. All available simulator systems will be installed and operated (15).
3. A simulator system can be scheduled for use up to 20 hours per day, six days per week. This will leave 4 hours per day and one day per week for preventive maintenance and/or surge training requirements (10).

### Limitations

The following model limitations have been recognized:

1. The solution generated by the model is economically optimal within the identified cost structure

only. Subjective factors such as unit commander preference will not be accounted for.

2. The model does not consider the possibility of buying additional simulator systems. The number available is assumed to represent the maximum number of systems possible within resource constraints.

3. The model developed is intended to be used as a basis for initial deployment.

#### DEVELOPMENT OF COMPUTER ALGORITHMS

The model developed is envisioned to be in the form:

$$\text{Minimize } Z = \sum [C_{ij}X_{ij}Y_j + F_jY_j]$$

subject to supply and demand constraints. While a simple problem of this type may be solvable using manual computational techniques, a large problem consisting of many variables would be difficult or impossible to solve without the use of a computer (27:225). Consequently, development of the model was to be accompanied by the development of a computer algorithm to activate the model. There are several algorithms within the Computational Resources for Engineering and Training Education (CREATE) system believed to be capable of solving this type of linear

programming problem. One of these was to be adapted and modified to the specific model developed. The accuracy of the program used would then be validated simultaneously with the model.

#### PROPOSED MODEL VALIDATION

The model and computer program developed were to be validated in two steps. The first step would consist of model activation using simplified data of a reduced magnitude as to permit solution by enumeration. This would allow verification of the accuracy of the mathematical processes involved and evaluation of the logic statements used by the computer. This would also permit the accomplishment of sensitivity analysis on the model to determine the effects of inaccurate data or cost estimation errors on the suggested solution.

The second step in the validation process was to involve use of the model to determine the optimal placement of the five ANG A-7 simulators discussed previously. Cost and system availability were to be obtained from the office of primary responsibility (OPR) (AF/XOOTD) and this data would be used to activate the model. Because preliminary decisions would have been made, a cost comparison between

the model solution and the subjective decisions previously made could be formulated. In addition, this comparison would allow the evaluation of the model assumptions and basic criteria. Any discrepancies between model criteria and the factors which the OPR considers to be most important should have been obvious.

#### SUMMARY

This study is an attempt to develop a mathematical model which can be used to assist in the determination of the optimal placement of regional flight simulators. Background research indicates that a mixed integer linear programming relationship of the form:

$$\text{Minimize Cost} = \sum [C_{ij}X_{ij}Y_j + F_jY_j]$$

subject to various constraints will provide an effective basis for the model. This study was to develop and validate the model and a computer program capable of solving the system of equations generated.

After validation, the model would be used to assist in the determination of the optimal location for five A-7 simulator systems being phased into the ANG and AF Reserve inventories. Subsequent problems involving similar

efforts with F-4 and A-10 simulator systems may also find the model developed useful (15).

## Chapter III

### ANALYSIS

This chapter is a discussion of the results obtained from research into the A-7 simulator problem and the attempted solution through the use of an optimal placement model. Model development is first described, followed by a discussion of the relationships derived between personnel transportation costs and travel distances. The results of an extensive search for a computer algorithm to solve the placement model are then presented. Finally, the results of a transportation type model to determine student allocation to a given simulator placement are discussed.

### MODEL DEVELOPMENT

#### Formulation

After consideration of several alternative model forms, a mixed integer linear programming structure was selected because it appeared to best fit the perceived problem (3:112). The general model developed is as follows:

$$\text{Objective: Minimize Cost} = \sum_{i=1}^n \sum_{j=1}^m C_{ij} X_{ij} Y_i + \sum_{k=1}^n F_k Y_k$$

$$\text{subject to: } \sum_{i=1}^n X_{ij} = d_j \quad j=1, m \quad (\text{Demand})$$

$$\sum_{j=1}^m X_{ij} \leq S_j \quad i=1, n \quad (\text{Supply})$$

$$\sum_{j=1}^m Y_j \leq N \quad (\text{Availability})$$

$$X_{ij}, C_{ij}, Y_i, F_k, d_j, S_j, N \geq 0 \quad (\text{Non Negativity})$$

$$Y_j = 0, 1 \quad \text{all } j \quad (\text{Dummy})$$

### Definition of Variables

$X_{ij}$  is a decision variable representing the number of students to be sent from base  $i$  to base  $j$  for simulator training.

$C_{ij}$  is the transportation cost to send a student from base  $i$  to base  $j$  for simulator training.

$Y_i$  is a dummy variable equal to 1 if base  $i$  is chosen as a simulator site and 0 otherwise.

$F_j$  is the fixed cost to activate base  $j$  as a simulator site. This cost includes any construction and installation of the simulator itself plus additional costs to expand billeting and food service facilities when necessary. The cost is a one time charge which would be unique to each base.

The variable  $d_i$  is the number of students from base  $i$  to be trained during any specified training period.

$S_j$  represents the maximum number of students that can be trained at simulator location  $j$  during each training period. This number is determined by the maximum capacity of the site.

### Specific Application

The model developed was used to analyze the recent placement of A-7 simulators and the associated problem of student allocation. The objective function and constraints used in the analysis are given below.

$$\text{Minimize Cost} = \sum_{i=1}^{14} \sum_{j=1}^5 C_{ij} X_{ij} Y_i + \sum_{j=1}^{14} F_j Y_j$$

$$\text{Subject to } \sum_{i=1}^{14} X_{ij} \leq 132 \quad j = 1, 5$$

$$\sum_{j=1}^5 X_{ij} \geq 26 \quad i=1, 14$$

$$\sum_{i=1}^{14} Y_i = 5$$

$$X_{ij}, C_{ij}, Y_i, F_j \geq 0$$

Because there are 14 bases involved, the system of equations contains  $14^2$  or 196 possible  $X_{ij}$  values, 196  $C_{ij}$  values, 14  $F_j$  values and 14  $Y_i$  values. The system thus expands into a series of 21 equations involving 210 variables and 210 constants.

### Assumptions

The following assumptions were made during the development of the model.

1. Each simulator location can support all normal training requirements for a maximum of 132 pilots per month through the use of two eight hour shifts per day, five days per week. This allows for the possibility of a third eight

hour shift and expanded work week for surge requirements (10).

2. When fully operational, each base will require simulator training for 26 pilots each month (15).

3. The 14 bases to be supported are located at Tucson AZ, Colorado Springs CO, Albuquerque NM, Sioux Falls SD, Sioux City IO, Des Moines IO, Tulsa OK, Detroit MI, Toledo OH, Columbus OH, Springfield OH, Pittsburgh PA, Columbia SC, and San Juan Puerto Rico (15).

4. At least one simulator system must be located at Tucson AZ because it has been designated an initial training facility (19).

5. The manpower and maintenance costs of operating a simulator system will be the same at each base once the system is installed and all installation costs are paid.

6. All five currently available simulator systems will be installed and operated. After the placement model was developed, an acceptable method of estimating the transportation cost values  $C_{ij}$  was needed.

## TRANSPORTATION COST RELATIONSHIPS

### Cost Model

A relationship between travel costs and travel distances was needed to provide an accurate estimate of travel costs for planning purposes. This relationship would reduce the effort involved in calculating the costs required in the placement model. Regression analysis performed on transportation cost data obtained from the Wright-Patterson AFB Accounting and Finance Office (AFO) resulted in the following multiple regression model:

$C_{ij} = 29.218 + 0.066 D_{ij}$  for travel by commercial aircraft and

$C_{ij} = 0.024 + 0.070 D_{ij}$  for travel by private automobile

where

$C_{ij}$  is the cost to transport a student from base i to base j expressed in FY 77 dollars and

$D_{ij}$  is the distance from base i to base j in statute miles.

### Validation

Validation of the derived relationships was accomplished in two steps. First, tests of statistical

significance were accomplished on the relationships derived from the Wright-Patterson transportation cost data. In addition to a Pearson correlation coefficient of 0.99 or better, "F" and "t" tests indicated that the relationships were significant at the  $\alpha = 0.01$  level.

The second validation step consisted of model activation using cost and distance data obtained from Blytheville and McChord Air Force bases. A comparison of the results obtained with those obtained from the Wright-Patterson data indicate that they did, in fact, come from the same population of cost data. It also supports the conclusion that the relationships derived are valid for all CONUS Air Force unit locations. A detailed discussion of the procedures involved in the derivation and validation of these cost-distance relationships can be found in Appendix B.

### Assumptions

The following assumptions were made concerning the data and variables used in constructing the model.

1. The data obtained from the Wright-Patterson AFB AFO is representative of the population of Air Force personnel travel costs. This is believed to be valid because

all CONUS units use the same standard distance tables and travel payment regulations (18).

2. POV reimbursements are based on convenience to the individual and are costed at \$0.07 per mile (18).

3. Transportation between bases less than or equal to 300 miles apart will be via POV. Transportation between bases in excess of 300 miles apart will be via commercial aircraft due to travel time considerations (18).

4. If available, military aircraft passenger service will be used at no cost to the unit because special flights will not be scheduled to meet transportation needs (15,18).

5. The cost to transport a student from base i to base j is the same as the cost to transport a student from base j to base i.

6. The cost to transport a student from base i to base i is zero.

#### Model Limitations

The following model limitations have been recognized.

1. The model developed is only considered valid over the range of 50 to 3000 miles due to absence of data outside this range.

2. Mission requirements may require travel by commercial aircraft to meet training schedules even though travel by POV is less costly (15).

3. Travel to and from island locations will always require the use of military or civil aircraft passenger service.

### SIMULATOR PLACEMENT MODEL SOLUTION

#### Algorithm Availability

After the transportation cost values in the placement model were determined, a computer algorithm was needed to obtain a model solution. At this point, several problems were encountered. First, data for the fixed cost variable  $F_j$  was not available (15). This restricted the value of any possible solution somewhat, however it was believed that valid results could still be obtained if the  $F_j$  values were treated as all being equal. This implied that installation and operating costs were the same at all bases. The validity of this assumption is not known, however, sensitivity analysis on the model would provide an indication of the amount of error introduced by the assumption. After this decision was made, several computer

algorithms were examined to evaluate their capability to solve the proposed allocation model.

#### Program LINPRO

The first computer algorithm to be evaluated for possible use was a program developed by the Rand Corporation for the solution of resource allocation problems (12:7). This program, named LINPRO, was examined to determine if it could handle a mixed integer problem of the magnitude required by the placement model. Although preliminary analysis indicated that the program would solve mixed integer allocation problems, it could only work with a maximum of 26 different variables and 26 constraint equations (12:15). Since the placement and allocation problem as identified and structured involved a total of 210 variables and at least 21 equations, the program was discarded as inadequate for the solution of this problem.

#### CREATE Library Program

After discarding LINPRO as unsuitable, two library programs maintained on the CREATE system were examined. The first program to be evaluated, also called LINPRO, is a program designed to maximize an objective function subject to relevant constraints. While the program could be

modified to minimize an objective function by changing the signs of the coefficient values involved, the program was not readily amenable to solution of mixed integer problems. In addition, the maximum problem size was restricted to 30 variables and 18 equations. This program was thus also discarded.

The next computer algorithm to be examined was a FORTRAN program also maintained within the CREATE system library. This program, called LINPROG, was designed to compute optimal solutions for linear programming problems and was sophisticated enough to handle multiple objective functions as well as mixed integer problems. The program appeared to be well suited to the allocation model developed, however, it, too, was restricted by size and data capacity to a maximum of 50 variables and 30 constraints. For this reason, the program was also discarded. After examining several other programs, all of which were even smaller than LINPROG, a HONEYWELL program called LP 6000 was found.

#### HONEYWELL LP 6000

After extensive research into the capabilities of the LP 6000 algorithm, it was determined that the program could work with 4096 variables and 16000 constraints.

Although the code could handle a multiple objective function and was designed to solve resource allocation problems involving a mixed integer solution, the presence of the two types of variables in the objective function ( $X_{ij}$  and  $Y_j$ ) defied solution to the allocation problem involved in this research (14). Since neither variable could be dropped from the model without destroying the realism and applicability of the model, and no larger computer algorithms could be found within the CREATE system, an alternate approach to the location and student allocation problem was needed.

## STUDENT ALLOCATION

### The Placement Problem

Attempts to solve the simulator placement and student allocation problems simultaneously were unsuccessful because of failure to locate a suitable computer algorithm to solve the model equations. Consequently, the decision was made to solve the student allocation problem for several logical simulator placement proposals and compare the resultant personnel transportation costs. While this approach only solves the allocation problem and does not generate a truly economically optimal placement solution,

it does answer some of the tactical questions involved. The inability to analyze the fixed cost factors due to lack of data further reduces the value of the solution and further analysis should begin there.

A CREATE library program called TRANSPO<sup>8</sup> was used to assign students from each of the 14 bases involved to one of 5 preselected simulator locations. The output indicates which simulator base should be used to support each base requiring simulator support and also indicates how many additional students could be trained at that base without adding a third shift operation.

#### Air Staff Proposed Placement

The first assignment problem evaluated involved the simulator placement suggested by USAF headquarters (15). This plan involves the placement of simulators at Tucson AZ, Colorado Springs CO, Des Moines IO, Columbus OH, and Columbia SC. Analysis of the TRANSPO model output resulted in the assignment schedule and transportation cost figures illustrated in Table 3-1. Although the assignments indicated are logical when examined on a map, the program

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<sup>8</sup>A program listing and sample output from program TRANSPO are included in Appendix C.

output cost does not include any fixed charges for activating a base as a simulator location. Thus, an assignment based on transportation costs alone may or may not be the most economical overall. In addition, the existence of military aircraft passenger service between two bases could drastically change the cost picture.

As can be seen from Table 3-1, each base with a simulator serves its own assigned pilots in addition to those of nearby bases. This assignment plan also results in 106 excess training periods per month at Tucson AZ to handle upgrade training and initial qualification training as desired by the using agencies (15). Each simulator location is operating within the constraints established for a two shift operation. The transportation cost estimate was \$16,495.18 per month, which compared very favorably with the other placement plans cited in the following paragraphs.

#### Central Site Placement

As an alternative to the Air Staff proposed placement, the TRANSPO model was evaluated assuming placement of all 5 available simulators at Tucson. It is believed that this placement would significantly reduce installation

and simulator maintenance costs, however transportation costs would be increased. Since operating cost data were not available, a realistic comparison of the total costs involved was not possible. As expected, however, transportation costs climbed to \$92,283.36 per month.

#### Alternate Overseas Placement

As a third placement alternative, the model was evaluated with the placement of one simulator at Tucson, one at Des Moines, two at Columbus and one at San Juan. This placement was designed to eliminate the transportation of students to and from San Juan. The placement could result in a reduction of installation and maintenance costs due to having simulators at only four bases, yet the size of this reduction is unknown. Transportation cost, on the other hand, increased slightly to \$18,138.38 per month. The resultant assignment schedule is illustrated in Table 3-2. Again, due to lack of cost data, a valid total cost comparison of the proposed placement with other alternatives was not possible. Further analysis of cost comparison should begin with an evaluation of installation, operating, and maintenance costs.

## SUMMARY

Although no algorithm was found to solve the placement and assignment model developed, several suggested placements were evaluated in terms of the transportation costs involved. Any total cost analysis of the proposed placements should include a determination of the installation, operating, and maintenance costs involved at each possible location. Considering only transportation costs, the Air Staff proposed simulator allocation appears to be the most cost effective.

Table 3-1

STUDENT TRAINING ASSIGNMENTS  
AIR STAFF PROPOSED PLACEMENT

	Tucson	Colorado Springs	Des Moines	Columbus	Columbia
Tucson	26	0	0	0	0
Colorado Sp	0	26	0	0	0
Des Moines	0	0	26	0	0
Columbus	0	0	0	26	0
Columbia	0	0	0	0	26
Albuquerque	0	26	0	0	0
Sioux Falls	0	0	26	0	0
Sioux City	0	0	26	0	0
Tulsa	0	0	26	0	0
Springfield	0	0	0	26	0
Toledo	0	0	0	26	0
Detroit	0	0	0	26	0
Pittsburgh	0	0	0	26	0
San Juan	0	0	0	0	26
Open Periods	106	80	28	2	80
TOTAL TRANSPORTATION COST - \$16,495.18					

Table 3-2

STUDENT TRAINING ASSIGNMENTS  
ALTERNATE OVERSEAS PLACEMENT

	Tucson	Des Moines	Columbus	San Juan
Tucson	26	0	0	0
Colorado Sp	0	26	0	0
Des Moines	0	26	0	0
Columbus	0	0	26	0
Columbia	0	0	26	0
Albuquerque	26	0	0	0
Sioux Falls	0	26	0	0
Sioux City	0	26	0	0
Tulsa	0	26	0	0
Springfield	0	0	26	0
Toledo	0	0	26	0
Detroit	0	0	26	0
Pittsburgh	0	0	26	0
San Juan	0	0	0	26
Open Training	80	2	108	106
TOTAL TRANSPORTATION COST - \$18,138.38 per month				

## Chapter IV

### CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the conclusions drawn from research into a simulator placement and student allocation model along with associated recommendations for future research. First the objectives of the study are described and summarized. The actual results are then presented, followed by an analysis of why the results obtained differed from the established objectives. The final section provides a listing of recommended areas for future research.

### CONCLUSIONS

#### Desired Objectives

The authors make the basic assumption that simulator training is a significant contributor to continued pilot proficiency during a period of limited resources for aircrew training. Consequently, the central objective of this research effort was the development of a mathematical model to assist in the placement of regional flight

simulator systems. The model was also expected to indicate an optimal student allocation schedule to minimize total system transportation costs. This information would have given the agency responsible for the placement an objective comparison of total system costs to evaluate possible placement alternatives. It would also provide an estimate of the costs needed for budgeting purposes.

As documented in previous chapters, the placement model was developed as a mixed integer linear programming expression. The model involves an estimate of the costs incurred with the movement, installation, maintenance, and staffing for each specified simulator location. In addition, the costs of building or upgrading required billeting and food service facilities were to be considered. Finally, the costs to send personnel to and from each proposed simulator location complete the cost structure involved. By identifying these costs, it was believed that the model would encourage decision makers to consider total system cost. In addition, a system's view of the placement problem would encourage an evaluation of subjective factors such as recreational facilities in the local area and the

environmental impact of a simulator system on that area. However, the research results were not entirely as expected.

### Results Obtained

Although a mathematical simulator placement model was developed, a lack of cost data and a suitable computer algorithm capable of model solution prevented validation and use of the developed model. In general, the mathematical techniques and algorithms examined appear to be capable of providing a solution to either the simulator placement problem or the student allocation problem, but lack the necessary sophistication to solve both problems simultaneously. Therefore, the model which evolved could be used only to provide a student allocation plan for the simulator placements which had already been determined subjectively. This model, based entirely on personnel transportation costs, also provides an estimate of the total transportation costs for each proposed placement, thus providing a basis for comparison between simulator placement alternatives. The resulting comparison, however, does not consider the fixed costs such as installation,

operating, and maintenance charges, and is therefore of limited use.

The research also provided an insight into some of the problem areas involved with simulator placement. For example, the complexity of the factors influencing the placement decision, coupled with the necessity to consider political and environmental consequences is immense. Additionally, an analysis of the decision process indicates that unit commander preferences are often very important in the placement process. Although this study did not address these issues directly, it is felt that a solution based on total cost consciousness would encourage the inclusion of these factors in the placement decision process.

Although an economically optimal placement was not developed, analysis of the allocation results suggested some conclusions. First, an evaluation of the Air Staff placement of the Air National Guard A-7 simulators indicated that the actual locations selected by the Air Staff appear to be economically sound. Their locations provided for feasible student allocations and the lowest transportation costs of the alternatives evaluated. This tended to support the conclusion that subjective evaluations could be quickly evaluated in terms of transportation

costs and would provide an additional input to the decision-making process. It should be noted, however, that a lack of total system cost data weakens this argument somewhat. Second, when installation and maintenance data are included, the alternate overseas placement may possibly be more cost effective. This placement avoids transporting students to and from Puerto Rico and the time lost in transit. Once again, however, lack of cost data precludes any firm conclusion.

As a management tool, the model permits an objective comparison and analysis of several possible alternatives. It can prove to be very useful, particularly if installation and operating costs can also be incorporated. Therefore, it was concluded that the results of the research, though not as complete or comprehensive as originally envisioned, can provide a useful management tool to assist in simulator allocations.

#### Analysis of Differences

Several conclusions were formulated explaining why the results obtained differed from those expected. First, data concerning the costs of moving, installing, and supporting a simulator system were either unknown or

unavailable. Without these costs, a total cost analysis of a placement proposal is not possible. This lack of data also forces the researcher to make questionable assumptions concerning these costs, assumptions which are difficult to evaluate.

Second, the inability to locate or develop a computer algorithm capable of dealing with the complexity of the placement model precluded solution of the primary model. Although several algorithms were evaluated, none was found to be sufficient to cope with the size and complexity of the problem. Consequently, the overall research objective was not entirely satisfied. If a computer algorithm capable of a model solution was to be developed, the research effort could probably be completed as originally envisioned.

#### RECOMMENDATIONS

The research effort described in this paper has generated the following recommendations for future related research into the simulator placement problem.

1. Prior to any additional analysis of simulator placement proposals, a thorough study of all moving, installation, maintenance, and support costs should be made.

Without an estimate of these costs, a total cost analysis is not possible and an economic comparison of proposals is probably meaningless.

2. A computer algorithm should be located or designed to allow utilization of the placement model developed in this research effort.

3. Simulator system placement decisions should involve an evaluation of such subjective factors as the quality of billeting facilities and the effects of a simulator system on the local economy. Morale factors involved with sending a student into a particular area for training and the possible use of military aircraft passenger service should also be evaluated.

4. The feasibility of purchasing additional simulators as a means of reducing total operating costs should also be investigated. Quite possibly, the savings in transportation costs over the life of the system will more than offset the cost of the additional simulator. Developments in the concepts and techniques of life cycle costing might be put to good use in this area.

5. In general, further investigation into alternative placement models is needed. It is possible that a

simplified model could be developed to provide the economically optimal placement desired.

6. A model should be developed to determine the optimal number of simulator systems required to support a given weapon system. Although the number of A-7 simulators has already been determined, future systems may involve sufficient resource flexibility to purchase additional simulator systems.

APPENDIX A

DESCRIPTION OF LINEAR PROGRAMMING

## APPENDIX A

### DESCRIPTION OF LINEAR PROGRAMMING

#### Definition

Linear programming (LP) is a mathematical technique for the determination of the best allocation of limited resources. More specifically, LP is a method of solving problems in which a stated objective function must be maximized or minimized within certain constraints. Linear programming techniques are often used as a management tool to allocate limited resources so as to satisfy existing supply and demand constraints (27:224).

#### Requirements for an LP Problem

Regardless of the definition or specific usage of LP, five basic requirements must be met before the technique can be employed in the solution of a problem (27:224-226).

1. First and most important, a well defined objective function must be formulated. This may be an expression to maximize a profit or to optimize the allocation

of limited resources. In all instances, the function must be clearly defined mathematically.

2. Second, alternative courses of action must exist. If they do not, the problem has, in essence, solved itself as the manager really has no choice to make.

3. All equations and inequalities must describe the problem in linear form. This means that all the equations comprising the objective function and the constraints must be of degree one.

4. All relationships between the factors effecting the problem must be expressible as mathematical relationships, either as equalities or inequalities. Simply stated, this requirement specifies that all variables must be interrelated.

5. Finally, resources must be limited. If they are not, the problem is probably not a realistic portrayal of the situation and the solution is meaningless.

### Solving LP Problems

Many procedures have been developed to solve LP problems. Simple problems in two variables may be solved graphically (3:95). More complex problems may be solved using Simplex algorithms or computer programs using such

algorithms (3:220). The reader should consult any LP text for a more detailed discussion of the exact procedures involved in the solution of these problems.

#### Advantages of LP Methods

If correctly formulated, an LP problem and solution has many advantages over subjective solutions. Most importantly, an LP solution will indicate the optimal course of action or most effective use of limited resources. Interestingly, a by-product of the solution is that formulation of the problem forces the manager to be objective and to sort out all relevant variables. This may result in an evaluation of which variables are really important and which variables are based on subjective preference only. Finally, the LP solution considers all indicated variables and the bottlenecks caused by the limited nature of the resources involved. Thus, an LP solution is the optimal solution within the constraints identified (27:226).

#### Limitations of LP Methods

Any representation of reality has its limitations and LP is no exception. Because it is a simplification of reality, problem formulation may not include all relevant

variables. Similarly, the relationships assumed may be a function of time and, consequently, must be kept current. The assumption of linearity may also introduce errors into the final result. In short, the solution will be only as good as the validity of the assumptions made and the simplifications used (27:226).

APPENDIX B

DETERMINATION OF TRANSPORTATION  
COST RELATIONSHIPS

## APPENDIX B

### DETERMINATION OF TRANSPORTATION COST RELATIONSHIPS

This appendix describes the methodology used in the development of the transportation cost model, beginning with a statement of the research questions used to guide and direct the research. A discussion of the model development is then presented through the definition and description of the variables considered important to the study and a discussion of the methodology involved in cost determinations. Assumptions and known model limitations will then be addressed. Subsequently, the development of a computer algorithm to simplify use of the model and method of validation will be presented.

#### RESEARCH QUESTIONS

The following questions were developed to guide the study.

1. What variables should be considered in the development of the model?

2. What type of model would best satisfy the stated objectives?

#### DEVELOPMENT OF THE MODEL

A multi-term linear cost function involving the distance to be traveled and the mode of transportation used appeared to be the most suitable form of mathematical model for this type of problem (3:28). As a first step in using this technique, all variables considered to be relevant to the problem were identified and defined.

#### Definition of Variables

The following variables were investigated.

1. Distance ( $D_{ij}$ ). This variable represents the distance from base  $i$  to base  $j$  in statute miles. These values were provided by the Wright-Patterson AFB Accounting and Finance Office and are used by this office to determine all travel payments.

2. Transportation costs ( $C_{ij}$ ). This variable is the actual cost in dollars to transport a student from base  $i$  to base  $j$  using commercial aircraft, private automobile, or government aircraft. Commercial aircraft and

private automobile costs are from historical data. All costs are expressed Fiscal Year 77 dollars.

### Model Form

The model developed is of the form

$$\text{Cost}_{ij} = \sum a_k Y_k + \sum b_k Y_k D_{ij}$$

where:

$\text{Cost}_{ij}$  is the cost to transport a student from base i to base j.

$a_k$  and  $b_k$  are regression coefficients associated with mode of transportation k.

$Y_k$  is a dummy variable equal to 1 if mode k is used and 0 otherwise, and

$D_{ij}$  is the distance in statute miles from base i to base j.

The distances ( $D_{ij}$ ) are from documents used by the Wright-Patterson AFB AFO to calculate travel costs. The regression coefficients  $a_k$  and  $b_k$  were obtained by two simple linear regressions on historical data obtained from the AFO.

## ASSUMPTIONS

The following assumptions were necessary to reduce the model to a manageable level.

1. The data obtained from the WPAFB AFO is representative of the population of the Air Force travel costs.

2. POV rates are based on convenience to the individual and costed at \$0.07 per mile (18).

3. Transportation between bases less than or equal to 300 miles apart will be via POV. Transportation between bases in excess of 300 miles apart will be via commercial air (18).

4. Military air, if available, will be used at zero cost to the unit because special flights will not be scheduled to meet transportation needs (18).

5. Cost to transport a student from base  $i$  to base  $j$  is the same as to transport a student from base  $j$  to base  $i$ .

6. Cost to transport a student from base  $i$  to base  $i$  is zero.

## MODEL LIMITATIONS

The following model limitations have been recognized.

1. The model developed is only considered valid over the range of 50 to 2500 miles due to absence of data outside this range.

2. Mission requirements may require travel by commercial air due to time constraints even though travel by POV is less costly (15).

## DEVELOPMENT OF COMPUTER ALGORITHM

To simplify the task of computing the cost values and typing these values into a computer file for later use, a FORTRAN IV program was developed. This program uses the flexibility of the interactive terminals within the CREATE system to ask for the required inputs as the cost values are calculated and stored on a permanent file. All the user must do is input the number of bases involved and the distance between these bases. A flowchart, program listing, and sample output is included in this appendix.

## RESULTS

Regression of the cost to transport a student by commercial aircraft with the distance involved yielded the following results.

1. A Scattergram examination indicated that a strong linear relationship exists between costs and distances traveled.

2. Analysis of the residual error plots indicate that:

(a) The error terms appear to be uncorrelated over the entire range of data.

(b) The expected error for any value is zero.

(c) The variance of the error terms appears to be constant.

(d) The error distribution is symmetric about zero with the greatest number of data points at or near zero.

Normality is assumed, but not proven conclusively.

The regression equation was found to be:

$$\text{Cost (\$)} = 29.21804 + 0.06593 D_{ij}$$

with

$$\text{Pearson Correlation} = 0.9909$$

Coefficient of determination ( $R^2$ ) = 0.098179

Standard error of the estimate ( $\sigma_y$ ) = 6.15872

Standard error ( $\sigma_{y/x}$ ) = 0.00087

F statistic = 5769.07112

All based on a sample size of 109 cases.

In a like manner, regression of the cost to transport a student by private automobile with the distance involved yielded the following.

1. Scattergram examination indicated that a strong linear correlation exists between the cost to transport a student and the distance involved.

2. Analysis of residual error plots indicated that all residual errors were too small to plot. This is reasonable since the data was generated on the basis of \$.07 per mile. The regression yielded the following results:

Cost (\$) = 0.02357 + 0.07002  $D_{ij}$

Coefficient of Determination ( $R^2$ ) = 0.99996

Pearson Correlation ( $r$ ) = 1.000

Standard error of the estimate ( $\sigma_{y/x}$ ) = 0.00004

F statistic = 2991667.21207

Analysis of methods of predicting transportation costs for military aircraft from the distance involved resulted in the following assumptions.

1. If a military aircraft is available, it will be used, however the cost of that transportation will not depend on the number of passengers carried. Consequently, an accurate determination of passenger costs per mile is not possible.

2. For the specific problem involved in this study, military aircraft will likely be used for passenger service only if it can be incorporated into a crew proficiency training flights. Thus no additional cost is incurred for the transportation.

3. Standard cost figures are available but are listed as an average cost per hour for a specific aircraft. To determine a valid cost per passenger mile, it is necessary to assume an aircraft type, an aircraft model, a typical gross weight, standard day conditions,<sup>9</sup> calm winds, and a standard passenger load. These assumptions weaken the argument severely. In fact, due to these requirements,

---

<sup>9</sup>Standard day conditions are defined as 15° centigrade at sea level with a temperature lapse rate of 2° centigrade per 1000 feet increase in altitude.

it is believed that any costing of transportation by military aircraft will have to be done on an individual basis. Consequently, no cost to the unit is assumed for transportation by military aircraft.

These results combine to yield overall relationships of:

Cost ( $C_{ij}$ ) = 29.218 + 0.066  $D_{ij}$  for travel by commercial aircraft and

Cost ( $C_{ij}$ ) = 0.024 + 0.070  $D_{ij}$  for travel by POV.

$D_{ij}$  is the distance from base  $i$  to base  $j$  in statute miles.

#### VALIDATION

The original intent of this effort was to validate the results obtained through the use of "F" and "t" tests of statistical significance on the regression coefficients. A close look at the numbers generated however, led to the conclusion that this probably was not necessary. Consequently, one of the regressions was tested simply to illustrate the procedures involved.

Using the relationship for cost of transportation  
by commercial aircraft:

$$C = 29.21804 + 0.06593 D_{ij}$$

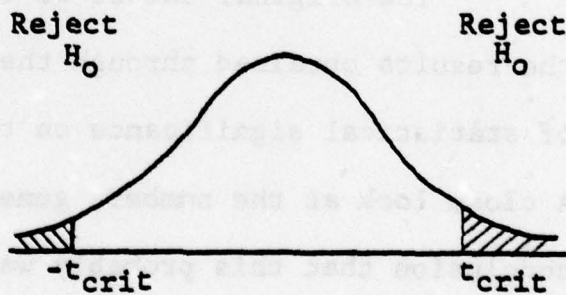
we wish to test the hypothesis

$$H_0 : B = 0 \quad \text{where } B \sim N(0, \sigma) \text{ (assumed)}$$

$$H_a : B \neq 0$$

If the null hypothesis ( $H_0$ ) can be rejected, the regression equation can be assumed to be efficient. If not, a simple average cost should be used, regardless of distance involved. The sample statistic will be evaluated against a critical value of that statistic and the null hypothesis will be rejected or not rejected in accordance with the following criteria:

If  $|t_{\text{stat}}| > |t_{\text{crit}}|$   
reject  $H_0$  and conclude  
that  $B \neq 0$  at that  
level of significance.

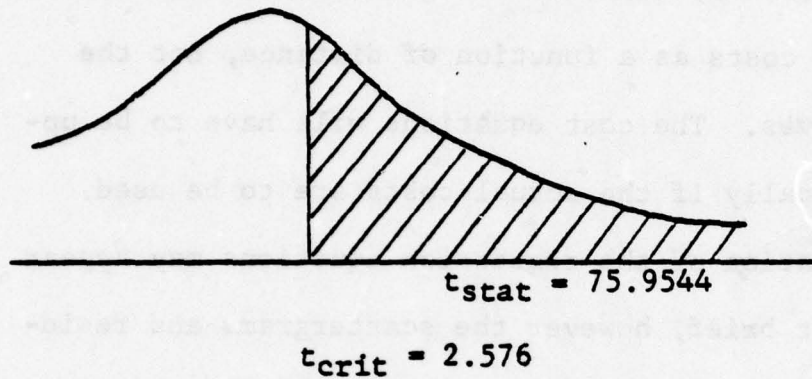


For this example, using  $\alpha = 0.01$ ,

$$t_{\text{crit}} = \pm t_{\frac{\alpha}{2}} ; \quad n-2 = 107 = 2.576 \quad (21:707)$$

$$t_{\text{stat}} = \sqrt{F} = \sqrt{5769.071} = 75.9544 \text{ from SPSS output}$$

the following situation exists:



Therefore, the null hypothesis is rejected and we conclude that  $B \neq 0$  at this level of significance (21).

Similar tests could be conducted on the other regression coefficients, but common sense indicates that this is not necessary.

#### CONCLUSIONS

If the assumptions made earlier are valid, the relationships developed should be sufficiently accurate for their intended purpose. Consequently, the project has satisfied all stated objectives. However, some general observations about the project are in order.

The project began with the intent to examine the costs as time correlated, however, the only data that was readily available was for 1977. Consequently, the time series phenomena was not investigated. This did not damage the results however, because our real interest was in a comparison of costs as a function of distance, not the costs themselves. The cost equations will have to be updated periodically if the actual costs are to be used.

Validation of the regression equations may appear to be somewhat brief, however the scattergrams and residual plots imply a high degree of confidence in the equations generated. The magnitude of "F" and "t" statistics generated indicate that they are well above any possible critical values, and to construct and test hypothesis concerning these values would simply be a mathematical exercise. If one accepts the model assumptions and limitations, the validity of the expressions should be self-evident.

LIST TDYCOST

```

001C THIS PROGRAM COMPUTES THE TRANSPORTATION COSTS OF
002C SENDING MILITARY PERSONNEL TDY BY EACH OF THREE
003C MODES OF TRAVEL. (MIL AIR, COM AIR, AND POV).
004C THE COSTS ARE EXPRESSED IN DOLLARS AND ARE
005C CORRECT AS OF FEB 1978.
006C
010 DIMENSION C(25,25,3)
011C
015C INITIALIZE VARIABLES
020 I=0
030 J=0
032 K=0
033C
035C READ IN NUMBER OF BASES INVOLVED
040 PRINT,"PLEASE INPUT THE NUMBER OF BASES INVOLVED"
045 READ,N
050 PRINT,"PLEASE INPUT THE INDEX FOR THE BASE OF ORGIN,"
055 PRINT,"THE INDEX FOR THE DESTINATION BASE, AND THE"
060 PRINT,"DISTANCE BETWEEN THE TWO IN MILES."
074C COMPUTE NUMBER OF COSTS INVOLVED
075 NN=(N**2.-N)/2
076C
085C READ IN VALUES FOR I,J, AND DISTANCE.
095 DO 90 K=1,NN
100 20 READ,I,J,DIJ
101C
105C COMPUTE COSTS BY EACH MODE
150 C(I,J,1)=DIJ
155 C(J,I,1)=C(I,J,1)
170 C(I,J,2)=2*(29.4723+.0685*DIJ)
175 C(J,I,2)=C(I,J,2)
190 C(I,J,3)=2*(00.0138+.0700*DIJ)
191 C(J,I,3)=C(I,J,3)
192 90 CONTINUE
195C
196C PRINT HEADINGS AND COSTS
200 PRINT," "
210 PRINT," "
220 PRINT," "
230 PRINT,"          COST MATRIX VALUES"
240 PRINT,"          *****"
250 PRINT,"          SOURCE  DEST    DIJ      COM AIR  POV"
260 DO 200 K=1,N
270 DO 300 L=1,N
280 WRITE (6,1000) K,L,C(K,L,1),C(K,L,2),C(K,L,3)
282 1000 FORMAT (10X,I2,7X,I2,3(3X,F7.2))
290 300 CONTINUE
300 200 CONTINUE
310 PRINT,"          *****"
315C
320 STOP "END OF DATA"

```

APPENDIX C

DESCRIPTION AND LISTING  
OF PROGRAM TRANSP

## APPENDIX C

### DESCRIPTION AND LISTING OF PROGRAM TRANSPRO

This appendix is a description and listing of the transportation type algorithm used to solve the student allocation problem. Consequently, a description of the required program inputs is given. A sample problem is then presented along with the solution output. The appendix then concludes with a program listing.

#### Description

Program TRANSPRO is based on an algorithm to solve the transportation problem. For example, given  $M$  sources, each capable of supplying a finite amount of a product and  $N$  destinations, each having a specified requirement for this product, this algorithm will develop a shipping pattern so as to satisfy all demands and minimize total transportation costs.

To use the program, data is entered on lines 10000 through 99999. Each data line consists of a line number

followed by the required pieces of data, each separated by a comma. The required data entries are as follows.

1. Line 10000 contains the line number, a data statement, the number of sources, and the number of destinations.

2. Line 10010 contains the line numbers, a data statement, and the amount of product each source can supply.

3. Line 10020 contains the line number, a data statement, and the amount of product required by each destination.

4. Line 10030 contains the line number, a data statement, and the transportation cost to move one unit from source number 1 to each of the destinations.

5. The remaining data lines consist of a line number, a data statement and the cost to move one unit of product from a source to each destination. There will be one line of transportation cost data for each source.

6. Since the amount of product supplied must equal the amount required, a dummy source or destination must often be added to provide or absorb excess products. This dummy is treated as any other source or destination except that the transportation costs involved are considered to

be zero since no product is actually shipped to or from this location.

### Sample Problem

In this sample problem, three factories supply a product to five destinations. Factory number one can supply 1000 units of the product per week; factory number two can supply 800 units per week, and the third factory can supply 600. The demand of each of the five destinations is 400, 700, 300, 500, and 500 units per week, respectively. Transportation costs from factory number one to each source are \$4, \$6, \$7, \$4, and \$6 per unit, respectively. Transportation costs from the second factory to each destination are \$7, \$5, \$8, \$5, and \$8 per unit. Similarly, units cost \$6, \$4, \$6, \$7, and \$5 to transport from the third factory to each destination.

### Data Input

The data for this problem is listed below.

```
10000 DATA 3,5
10010 DATA 1000, 800, 600
10020 DATA 400, 700, 300, 500, 500
10030 DATA 4, 6, 7, 4, 6
10040 DATA 7, 5, 8, 5, 8
10050 DATA 6, 4, 6, 7, 5
RUN
```

Program Output

The output generated in solving this problem is illustrated below.

400	0	0	400	200
0	700	0	100	0
0	0	300	0	300

The total minimum cost of the solution = 11700.

This means that factory number one should ship 400 units to destination number one, 400 units to destination four, and 200 units to destination five. Factory two should ship 700 units to destination two and 100 units to destination four each week. Similarly, factory three should send 300 units to destination three and 300 units to destination five each week. The total transportation costs will be \$11,700 per week.

```

100REM  TRANPO          (BASIC PROBLEM BEGINS AT LINE 570)
110REM
115REM  -----
120REM  DESCRIPTION--ALGORITHM TO SOLVE THE TRANSPORTATION PROBLEM
125REM
130REM  THE TRANSPORTATION PROBLEM RECEIVED ITS NAME BECAUSE IT ARISES
140REM  VERY NATURALLY IN THE CONTEXT OF DETERMINING OPTIMAL SHIPPING
150REM  PATTERNS. HOWEVER, MANY PROBLEMS HAVING NOTHING TO DO WITH
160REM  TRANSPORTATION FIT THE MATHEMATICAL MODEL FOR THE TRANSPORTA-
170REM  TION PROBLEM, AND CAN BE SOLVED BY ONE OF ITS EFFICIENT PRO-
180REM  CEDURES. TO ILLUSTRATE AN EXAMPLE OF THE TRANSPORTATION PROB-
190REM  LEM, SUPPOSE THAT M FACTORIES SUPPLY N WAREHOUSES WITH A CER-
200REM  TAIN PRODUCT. FACTORY I (I=1TOM) PRODUCES A(I) UNITS, AND WARE-
210REM  HOUSE J (J=1TON) REQUIRES B(J) UNITS. SUPPOSE THAT THE COST OF
220REM  SHIPPING FROM FACTORY I TO WAREHOUSE J IS DIRECTLY PROPORTIONAL
230REM  TO THE AMOUNT SHIPPED, AND THAT THE UNIT COST IS C(I,J). LET THE
240REM  DECISION VARIABLES, X(I,J), BE THE AMOUNT SHIPPED FROM FACTORY I
250REM  TO WAREHOUSE J. WHAT SHIPPING PATTERN (VALUES OF X(I,J)) MINIMIZES
260REM  TOTAL TRANSPORTATION COST?
270REM  *****
280REM  THE TRANSPORTATION ALGORITHM USED IN THIS PROGRAM HAS BEEN TRANS-
290REM  LATED INTO BASIC FROM ALGOL, AND CAME FROM THE COMMUNICATIONS OF
300REM  THE ACM,V9,#12,DEC 66. THE NATURE OF THE ALGORITHM IS EXPLAINED
310REM  IN AN ARTICLE BY FORD AND FULKERSON, "SOLVING THE TRANSPORTATION
320REM  PROBLEM",M.S.,1956. IN THE PROGRAM'S DOCUMENTATION, THIS ARTICLE
330REM  IS REFERRED TO AS "F+F".
340REM  *****
345REM
350REM  INSTRUCTIONS-- TYPE "RUN" AND FOLLOW INSTRUCTIONS.
390REM
395REM  -----
400REM  DATA SHOULD BE ENTERED IN THE FOLLOWING FORMAT:
410REM  10000 DATA M,N      'THE DIMENSIONS OF THE DISTRIBUTION MATRIX
420REM  10010 DATA A(I)     'FOR I=1 TO M, EACH FACTORY'S SUPPLY CAPACITY
430REM  10020 DATA B(J)     'FOR J=1 TO N, EACH WAREHOUSE'S DEMAND CAPACITY
440REM  10030 DATA C(1,J) REM  J=1 TO N, THE FIRST ROW OF THE COST MATRIX
450REM  10040 DATA C(2,J) REM  J=1 TO N, SECOND ROW OF THE COST MATRIX.....
460REM  100X0 DATA C(M,J) REM  J=1 TO N, THE LAST ROW OF THE COST MATRIX
500REM
520REM  * * * * *
540REM  STEP 1
550REM  READ THE DIMENSIONS OF THE DISTRIBUTION MATRIX M,N, THE SUPPLY
560REM  AND DEMAND VECTORS,A(M),B(N), AND THE COST MATRIX,C(M,N).
570  PRINT "HAVE YOU ENTERED DATA BEGINNING IN LINE 10000?"
580  PRINT "IF NOT, LIST PROGRAM FOR INSTRUCTIONS"
590  PRINT
600  DIM A(20),B(20),C(20,20),X(20,20),N(20),U(20),G(20)
610  DIM V(20),T(20),R(20),S(50),L(500)
620  READ M,N
630  MAT X=ZER(M,N)
640  MAT V=CON

```

```

650 MAT T=ZER
660 FOR I=1 TO M
670 READ A(I)
675 LET A8 = A8 + A(I)
680 NEXT I
690 FOR J=1 TO N
700 READ B(J)
705 LET B8 = B8 + B(J)
710 NEXT J
714 IF A8=B8 THEN 720
716 GO TO 3350
720 MAT READ C(M,N)
730REM -----1
740REM STEP 2
750REM SCAN EACH ROW OF THE COST MATRIX TO DISCOVER MINIMUM COST CELLS
760REM FOR EACH ROW SET H=THE MINIMUM COST CELL, AND REDUCE THE COST
770REM OF EACH CELL IN THE ROW BY H. THE MINIMUM COST CELL NOW BECOMES
780REM A ZERO COST CELL
790 FOR I=1 TO M
800 LET N(I)=(I-1)*N
810 NEXT I
820 LET C=G=0
830 FOR I=1 TO M
840 LET H=99999
850 FOR J=1 TO N
860 IF C(I,J)>=H THEN 880
870 LET H=C(I,J)
880 NEXT J
890 FOR J=1 TO N
900 LET C1=C(I,J)-C(I,J)-H
910 IF C1<>0 THEN 950
920 LET V(J)=0
930 LET N1=N(I)-N(I)+1
940 LET L(N1)=J
950 NEXT J
960 LET C=H*A(I)+C
970 NEXT I
980REM -----2
990REM STEP 3
1000REM SCAN THOSE COLUMNS WITH NO ZERO COST CELLS TO DISCOVER THE
1010REM MINIMUM COST CELL. FOR EACH OF THESE COLUMNS, SET H=THE MIN-
1020REM IMUM COST CELL, AND REDUCE THE COST OF EACH CELL IN THE COLUMN
1030REM BY H. AGAIN THE MINIMUM COST CELL BECOMES A ZERO COST CELL.
1040 FOR J=1 TO N
1050 IF V(J)=0 THEN 1180
1060 LET H=99999
1070 FOR I=1 TO M
1080 IF C(I,J)>=H THEN 1100
1090 LET H=C(I,J)
1100 NEXT I
1110 FOR I=1 TO M
1120 LET C1=C(I,J)-C(I,J)-H
1130 IF C1<>0 THEN 1160
1140 LET N1=N(I)-N(I)+1

```

```

1150 LET L(N1)=J
1160 NEXT I
1170 LET C=H*B(J)+C
1180 NEXT J
1190REM -----3
1200REM STEP 4
1210REM SCAN EACH ROW FOR ZERO COST CELLS. IF ROW SUPPLY IS LESS THAN
1220REM COLUMN DEMAND, FILL AS MUCH OF THE DEMAND AS POSSIBLE WITH EN-
1230REM TIRE ROW SUPPLY. IF ROW SUPPLY EQUALS OR IS GREATER THAN COLUMN
1240REM DEMAND, FILL ENTIRE DEMAND WITH AS MUCH SUPPLY AS IS NEEDED.
1250REM RECALCULATE THE RESIDUAL ROW SUPPLY AND COLUMN DEMAND. AT THIS
1260REM POINT WE HAVE ONLY ALLOCATED AVAILABLE SUPPLY TO FILL THE ZERO
1270REM COST DEMAND CELLS IN EACH ROW.
1280 FOR I=1 TO M
1290 LET A1=A(I)
1300 LET N1=N(I)
1310 FOR U=(I-1)*N+1 TO N1
1320 IF A1=0 THEN 1440
1330 LET J=L(U)
1340 LET B1=B(J)
1350 IF B1=0 THEN 1430
1360 LET H=A1
1370 IF A1<B1 THEN 1390
1380 LET H=B1
1390 LET X(I,J)=H
1400 LET A1=A1-H
1410 LET B(J)=B1-H
1415REM GO TO SUB "IN".
1420 GOSUB 2960
1430 NEXT U
1440 LET A(I)=A1
1450 LET G=G+A1
1460 NEXT I
1470REM -----4
1480REM STEP 5
1490REM IF CUMULATIVE RESIDUAL SUPPLY IS EXHAUSTED, WE HAVE REACHED THE
1500REM FINAL SOLUTION TO THE PROBLEM.
1510 IF G=0 THEN 3260
1520REM -----5
1530REM STEP 6
1540REM THE LABELING PROCESS IS BEGUN, EACH ROW WITH RESIDUAL SUPPLY IS
1550REM LABELED IN ACCORDANCE WITH "F+F'S" TREATMENT, P.27.
1560 MAT R=ZER
1570 LET K=0
1580 FOR I=1 TO M
1590 IF A(I)=0 THEN 1640
1600 LET K=K+1
1610 LET U(K)=I
1620 LET G(I)=99999
1630 GOTO 1650
1640 LET G(I)=0
1650 NEXT I

```

```

1660REM -----6
1670REM STEP 7
1680REM SCAN EACH LABELED ROW LOOKING FOR ZERO COST CELLS NOT APPEARING
1690REM IN PREVIOUSLY LABELED COLUMNS. THE COLUMNS IN WHICH SUCH ZERO
1700REM COST CELLS ARE FOUND ARE IN TURN LABELED. IF THERE IS A BREAK-
1710REM THROUGH, DISCONTINUE LABELING PROCESS AND TRANSFER TO LINE 1260,
1720REM "F+F", P.28.
1730 LET L=0
1740 FOR U=1 TO K
1750 LET I=U(U)
1760 LET N1=N(I)
1770 FOR S=(I-1)*N+1 TO N1
1780 LET J=L(S)
1785REM -----J5-----
1790 IF R(J)<>0 THEN 1840
1800 LET R(J)=I
1810 LET L=L+1
1820 LET V(L)=J
1830 IF B(J)>0 THEN 2120
1840 NEXT S
1850 NEXT U
1860REM -----7
1870REM STEP 8
1880REM CONTINUES LABELING PROCESS,IF POINT OF NONBREAKTHROUGH IS REACH-
1890REM ED TRANSFER TO LINE 1540.
1900 IF L=0 THEN 2460
1910 LET K=0
1920 FOR V=1 TO L
1930 LET J=V(V)
1940 LET L1=T(J)
1950 FOR S=T(J-1)+1 TO L1
1960 LET I=S(S)
1970 IF G(I)<>0 THEN 2010
1980 LET G(I)=J
1990 LET K=K+1
2000 LET U(K)=I
2010 NEXT S
2020 NEXT V
2030 IF K=0 THEN 2460
2040 GOTO 1660
2050REM -----8
2060REM STEP 9
2070REM BREAKTHROUGH PROCEEDURE OCCURS WHEN WE HAVE LABELED A COLUMN
2080REM THAT HAS RESIDUAL DEMAND>0. "F+F",P.29 EXPLAINS THE BREAKTHROUGH
2090REM PROCEEDURE. IF RESIDUAL SUPPLY IS EXHAUSTED, THEN THE SOLUTION
2100REM HAS BEEN REACHED. OTHERWISE RECOMMENCE LABELING PROCEEDURE BY
2110REM TRANSFERING TO LINE 850.
2120 LET H=B(J)
2130 LET P=J
2140 LET I=R(J)
2150 LET J=G(I)
2160 IF J<>99999 THEN 2200

```

```

2170 IF A(I)>=H THEN 2230
2180 LET H=A(I)
2190 GO TO 2230
2200 IF X(I,J)>=H THEN 2140
2210 LET H=X(I,J)
2220 GOTO 2140
2230 LET J=P
2240 LET B(J)=B(J)-H
2250 LET A(I)=A(I)-H
2260 LET G=G-H
2270REM ----- RE1 -----
2280 LET I=R(J)
2290 LET X1=X(I,J)
2300 LET X(I,J)= X1 +H
2310 IF X1<>0 THEN 2330
2320 GOSUB 2960
2330 LET J=G(I)
2340 IF J=99999 THEN 1510
2350 LET X1=X(I,J)-X(I,J)-H
2360 IF X1<>0 THEN 2270
2370 GOSUB 3080
2380 GOTO 2270
2390REM -----9-----
2400REM STEP 10
2410REM NONBREAKTHROUGH PROCEEDURE OCCURS WHEN WE CAN CARRY LABELING
2420REM PROCESS NO FURTHER, AND A BREAKTHROUGH HAS NOT BEEN REACHED.
2430REM "F+F", P.30-31 EXPLAINS THE NONBREAKTHROUGH PROCEEDURE. WHEN THIS
2440REM PROCEEDURE IS COMPLETED, RECOMMENCE LABELING PROCEEDURE BY TRANS-
2450REM FERING TO LINE 850.
2460 LET K=0
2470 LET L=N+1
2480 FOR J=1 TO N
2490 IF R(J)<>0 THEN 2530
2500 LET K=K+1
2510 LET V(K)=J
2520 GOTO 2550
2530 LET L=L-1
2540 LET V(L)=J
2550 NEXT J
2560 LET H=99999
2570 FOR I=1 TO M
2580 IF G(I)=0 THEN 2640
2590 FOR S=1 TO K
2600 LET J=V(S)
2610 IF C(I,J)>=H THEN 2630
2620 LET H=C(I,J)
2630 NEXT S
2640 NEXT I
2650 FOR I=1 TO M
2660 LET F=0
2670 IF G(I)=0 THEN 2690

```

```

2680 LET F=1
2690 LET N1=(I-1)*N
2700 FOR S=L TO N
2710 LET J=V(S)
2720 IF F=0 THEN 2750
2730 LET C1=C(I,J)
2740 GOTO 2760
2750 LET C1=C(I,J)=C(I,J)+H
2760 IF C1<>0 THEN 2790
2770 LET N1=N1+1
2780 LET L(N1)=J
2790 NEXT S
2800 FOR S=1 TO K
2810 LET J=V(S)
2820 IF F=0 THEN 2850
2830 LET C1=C(I,J)=C(I,J)-H
2840 GOTO 2860
2850 LET C1=C(I,J)
2860 IF C1<>0 THEN 2890
2870 LET N1=N1+1
2880 LET L(N1)=J
2890 NEXT S
2900 LET N(I)=N1
2910 NEXT I
2920 LET C=H*G+C
2930 GOTO 1520
2940REM -----10
2950REM STEP 11
2960REM GOSUB "IN"
2970 LET L1=T(J)
2980 FOR T=T(N) TO L1 STEP -1
2990 LET S(T+1)=S(T)
3000 NEXT T
3010 FOR T=J TO N
3020 LET T(T)=T(T)+1
3030 NEXT T
3040 LET S(L1+1)=I
3050 RETURN
3060REM -----11
3070REM STEP 12
3080REM GO SUB "OUT"
3090 LET L1=T(J)
3100 FOR T=T(J-1) +1 TO L1
3110 IF S(T)<>I THEN 3140
3120 LET S=T
3130 GOTO 3150
3140 NEXT T
3150 FOR T=J TO N
3160 LET T(T)=T(T)-1
3170 NEXT T
3180 LET L1=T(N)

```

```

3190 FOR T=S TO L1
3200 LET S(T)=S(T+1)
3210 NEXT T
3220 RETURN
3230REM -----12
3240REM STEP 13
3250REM PRINT THE SOLUTION MATRIX, AND THE TOTAL MINIMUM COST OF SOLUTION.
3260 PRINT "THE SOLUTION MATRIX ="
3270 MAT PRINTX;
3280 PRINT
3290 PRINT "THE TOTAL MINIMUM COST OF THE SOLUTION =",C
3295 STOP
3300REM -----13
3350 IF A8 > B8 THEN 3380
3360 PRINT "TOTAL DEMAND EXCEEDS TOTAL SUPPLY."
3370 GO TO 3390
3380 PRINT "TOTAL SUPPLY EXCEEDS TOTAL DEMAND."
3390 PRINT "FOR THIS PROGRAM, THESE QUANTITIES MUST BE EQUAL."
3400 STOP
10000 DATA 15,5
10010 DATA 26,26,26,26,26,26,26,26,26,26,26,26,26,26,296
10020 DATA 132,132,132,132,132
10030 DATA 0,178.68,250.20,315.55,335.68
10040 DATA 178.68,0,151.15,234.44,292.39
10050 DATA 250.20,151.15,0,146.08,221.97
10060 DATA 315.55,234.44,146.08,0,149.64
10070 DATA 335.68,292.39,221.97,149.64,0
10080 DATA 119.22,118.40,194.57,261.98,288.42
10090 DATA 252.80,148.13,39.79,180.60,259.38
10100 DATA 243.07,139.23,28.31,170.60,248.14
10110 DATA 201.84,151.97,118.40,172.65,203.75
10120 DATA 308.15,236.50,141.14,7.59,154.84
10130 DATA 321.44,227.59,155.39,22.15,169.78
10140 DATA 331.71,236.50,144.30,34.47,181.83
10150 DATA 340.62,254.85,162.65,26.91,149.64
10160 DATA 462.41,428.84,363.77,299.38,238.41
10170 DATA 0,0,0,0,0
99999 END

```

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