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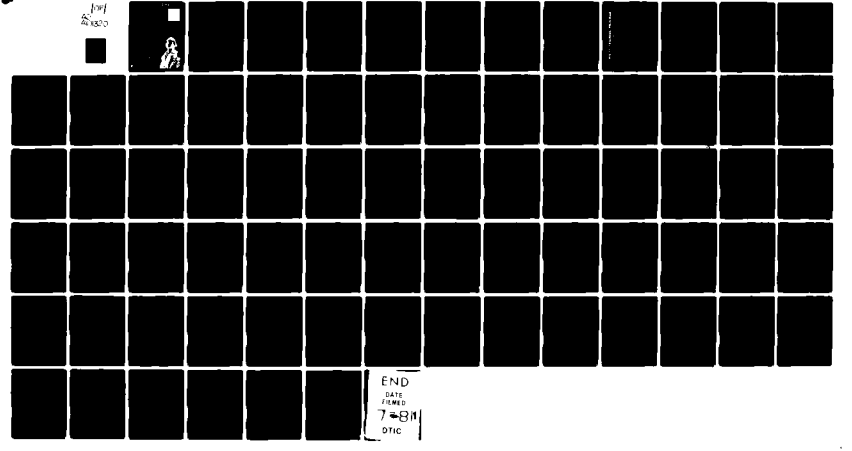

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This paper provides a non-technical functional description of the Dynamic Student Flow Model. Its purpose is to provide:

a. The system requirements to be satisfied that will serve as a basis for mutual understanding between the user community and the developer.

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The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

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School of Engineering and applied Science
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Program in Logistics

FUNCTIONAL DESCRIPTION FOR THE DYNAMIC STUDENT FLOW MODEL

by

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Dicky Wieland
W. L. Wilkinson

1. General

1.1 Purpose. This Functional Description (FD) for the Dynamic Student Flow Model (DSFM) is written to provide the following information.

a. The system requirements to be satisfied that will serve as a basis for mutual understanding between the user and the developer. The user community is considered to be particular elements of:

Office of the Chief of Naval Operations
Naval Military Personnel Command
Naval Education and Training Command
Naval Air Training Command

The developer is the Program in Logistics, The George Washington University under contract to the Office of Naval Research.

b. Descriptive information on system characteristics including the primary and secondary capabilities, preliminary design, and user impacts. The language used herein will be nontechnical and noncomputer oriented insofar as reasonable descriptive precision will allow. More technical language will be deferred to the supporting specialized system documentation to follow.

c. A basis for the development of a realistic system demonstration.

1.2 Project Documentation.

a. The DSFM task was first formally proposed by Reference [1] in July 1977. Reference [2] in January 1978 changed the work period to 1 January 1978 - 31 December 1979.

b. Reference [3] is a technical report that documents the results of exercising a comparatively primitive version of the DSFM on a number of scenarios concerning base closings and squadron decommissionings.

c. Reference [4] is a follow-on technical report that documents the results of exercising an improved version of the DSFM on a wide variety of scenarios. These scenarios tested the versatility of that version of the DSFM with the results that certain strengths and weaknesses became apparent.

d. Reference [5] is the Overview Manual on the DSFM. This document provides a broad nontechnical description of the model beamed to the executive with little time for details. Potential users with an uncertain interest in the model will find adequate definition therein to justify or dismiss further inquiry.

e. In addition to this FD and the Overview Manual, the following system documents will be provided.

(1) User's Manual
(2) Program Specifications and Maintenance Manual
(3) Program Listings

f. An operational version of the DSFM computer program,written in PLI, will be delivered suitable for installation in an environment similar to the one described in Section 4.

g. This Functional Description and other system documentation to follow is being prepared in conformance with the standards set forth in reference [6].

2. System Summary

2.1 Problem Background. The certainty of frequent program changes is a fundamental reality of Naval Aviation Training. The dominant indicator of historic change in flight training requirements is the annual Pilot Training Rate (PTR). The Navy has been markedly unsuccessful in either avoiding or forecasting changes in the PTR. Figure 2.1 delineates the precipitous changes in this 'bottom line' index brought about by external demands on the system. Also displayed in this figure are the actual PTRs as a measure of the system's response to the changing requirements. At times, actual pilot production has varied from these projections by several hundred pilots per year.

PILOT TRAINING PROGRAM

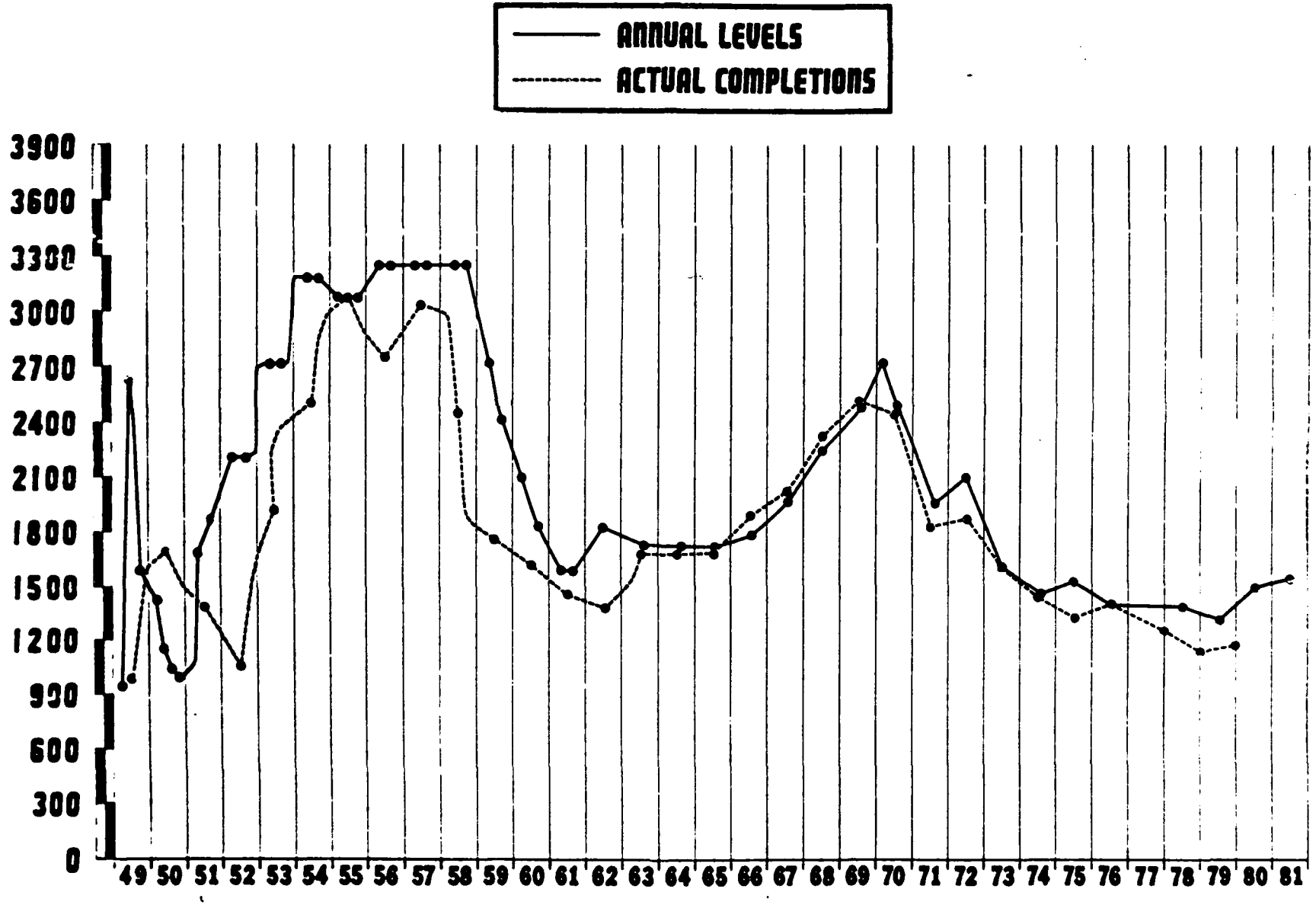

Figure 2.1

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Changes in policy dictated by higher authority coupled with fluctuations in Congressionally authorized funds, available training aircraft, personnel transfer funds, student pilot accessions, Fleet force levels, squadron manning levels, and pilot continuation rates have kept Naval Aviation Training in a constant state of flux. Many of these changes occur on very short notice and require an urgent response at senior command levels. Faced with these perturbations, the continuum of pilot training extending from initial entry into the Undergraduate Pilot Training (UPT) program through Fleet Readiness Squadron (FRS) training is in a continual state of contraction or expansion at the local level. This accordian effect on the pilot training pipelines causes inefficient use of training resources and student aviator pools of significant magnitudes. Failure to ameliorate these conditions will result in substantial waste of material and manpower training resources.

Aside from the crisis situation created in the training system by the external perturbations referred to above, there are enough factors inherent in the flight training process to inhibit the efficacious flow of students through the system. Environmental factors such as weather and the daylight hours per day are, by themselves, a continuing significant considera- tion in the UPT program. Implementing technological advances in aircraft, flight simulators, and flight support training techniques lead to changes in flight hours, syllabi, and the allocation of primary resources. The list of influences leading to internal changes to the system could go on and on. The resulting imperfect scheduling contributes to PTR short- falls, expensive student pools in the UPT program, diversionary assignments upon designation, excessive time to train in some FRSs and empty fleet seats. An overall result of this is a major drain on manpower assigned to Naval Aviation. Training conducted by the UPT program and the FRSs consumes about one-third of the total resources available to the entire Naval Aviation establishment. Frequent changes and the dynamics of the student flow process present the planning, management, and operating personnel with details of such magnitude as to defy any kind of systematic manual treatment.

2.2 Objectives. The fundamental purpose of a good management information system (MIS) is to enable planners and managers to stay on top of the situation, i.e., maximal internal control of events rather than simply reacting to external stimuli. An automated MIS is viewed as a coherent family of models covering a wide range of considerations and objectives. In no sense is such a system seen as a 'push button' solution to management problems. The system would project the results of a plan, but would not produce the plan itself.

Managers should continue to manage and such a system will provide much better tools for getting their job done. The effective implementation of the system would require a staff member to have intimate knowledge of a model's data requirements and its treatment of those data to meet certain objectives. The DSFM is to be a major component in an automated MIS for Naval Air Training.

The application of automated data processing equipment (ADPE) coupled with a data base generally acknowledged to have a high degree of credibility provides the opportunity to develop a quick-response capability to react to precipitous real or proposed changes in training resources or training rates. This offers a twofold capability responsive to the conditions described in Paragraph 2.1 above.

a. The DSFM will provide mathematically rigorous solutions to optimize the student flow through the network of UPT and FRS pilot training. The solutions will be characterized by maximum throughput and minimum time to train. The ready availability of solutions of this kind should alleviate the requirement for a spasm response so often characteristic of crisis manage- ment today. Timely solutions to 'what if' questions, characterized by a clear and defensible identification of maximum achievable production rates, necessary reallocation of available resources, and attendant costs can provide senior echelons in the Naval Air Training establishment the necessary information to effectively ward off the haphazard cut-till-it-hurts type of arbitrary management of budgets. Similary, these solutions will allow quantitative comparison of alternative sources of action under current operational constraints.

b. The DSFM would provide a common structure for discourse among the different planning, management, and operating levels involved in pilot training. Ample latitude for differences of opinion would exist, but differences could be measured quantitatively. Alternative courses of action could be evaluated for internal and external command decisions. As the routine function is performed more effectively, the need for crisis management should diminish.

2.3 Existing Methods and Procedures. It has been recognized that a system needs to be devised that can provide quantitative responses to rapidly changing Navy contingency requirements and to the routine planning cyclical requirements. In real life, the former dominates the latter because the pilot training system, as expensive as it is, is rarely allowed to operate in a steady state mode.

a. Contingencies. The present training management system handles each of these demands on an ad hoc basis, generally by sending requests through the chain of command for recommendations for accommodating action and statements of expected impacts. Accommodating plans rely heavily on intuition garnered from long association with the flight training community. Impact statements are generated for these intuitive plans after long and laborious hand computation of student flow resulting from the assumptions in the plan. In order to respond in the time allowed, most calculations are based upon broad assumptions and crude planning factors. Results are equally crude approximations of impact and are neither subject to audit nor reproducible at a later date. Predicted impacts are thus often accorded little weight by authorities directing changes.

b. Cyclical Planning. The present planning process theoretically derives the UPT PTR and individual FRS quotas based on Fleet needs. This planning is routinely based on planning factors and intuitive judgments. The forecasted productivity often represents an upper bound on the actual results. To the senior staff planner, planning factors represent expectations based on experience. From the acropetal perspective of, say, the training squadron, the planning factor is frequently viewed as a requirement to be met. Notwithstanding, planning factors are essential to any forecasting technique. The danger is in overestimation when they are used as constants in simplistic equations. For example, the environmental factors of weather and daylight hours per day in UPT creates a larger capacity to train in summer than in winter so that the student population experiences an accordion-like action as it progresses through the system. These conditions alone can cause the direct application of planning factors to forecast optimistically in relation to what the future will yield.

2.4 Proposed Methods and Procedures. The DSFM is designed to be a computer-based system for producing student pilot input and output schedules including data for analyses of internal pipeline flows. The schedules are produced for a time period of interest, say three years, and reflect the given planning criteria, e.g., level monthly output. The scope of the DSFM embraces the UPT program and the community of FRSs. The structure of the DSFM is a network where arcs represent the various phases and locations of training phases. Every phase arc in the network has time-to-train and capacity-to-train parameters that are applicable at the actual week of entry into the phase. This feature lends the dynamic dimension to the model. Since we allow these parameters to vary with each week of entry into each phase, there is a large number of individual phase arcs in any network of real interest. In addition, there are

arcs for student input and output plus arcs for the students already on board. At the heart of the DSFM is a rigorous optimizing algorithm* which ensures that every solution delivers the maximum output of graduates under the stated conditions. Moreover, of all maximum output solutions, the given solution has the minimum total time to train. With respect to these two properties, any requirements or performance projections would be very defensible, even under the most critical scrutiny.

The detail in the DSFM solutions is enormous and for some staff analyses, this level of detail will be important. For other purposes, minimum detail with identification of trends would suffice. Indeed, selected outputs of the model will have considerable value at all levels of the flight training system.

Chief of Naval Operations (CNO)
Commander, Naval Military Personnel Command (CNMPC)
Chief of Naval Education and Training (CNET)
Chief of Naval Air Training (CNATRA)
Training Wing Commanders
Training Squadron Commanders

Training organizations, at all echelons, could be provided high visibility periodic displays of areas requiring training management attention on a routine basis to enable these managers to perceive problems in time to do something about them. The DSFM could provide this service without imposing large demands on the training managers to feed the system. The system must, however, be responsive to manager queries concerning the impact on student flow of both real and hypothetical circumstances. The DSFM could provide entry level UPT student input schedules, recommendations for changes to scheduled student pipeline distribution, and individual FRS input schedules.

The DSFM will not require any source data that does not already exist in the Navy system.

2.5 Assumption and Constraints.

a. The DSFM can be a powerful and flexible planning and managerial tool but there is an essential interface between the model and the relevant scenarios that shape the solutions produced by the model. There must be a knowledgeable, responsible person who understands both sides; the capabilities of the model, on the one hand, and the proper interpretation of the scenario as inputs to the model, on the other. While the DSFM will not be able to cope with all conceivable scenarios, the extent to which its capabilities can be exploited will depend on the proficiency of this individual.

---

*See Appendix A.

b. While the DSFM ingests data which is derived from normal planning and operating data, there is no common agent which controls all the source dated required. Moreover, there is an interpretive quality to transforming the source data into acceptable data for the DSFM. For example, the pacing resource for capacity to train in UPT is most often the available aircraft inventory, but during some transition period, the constraining resource may, in fact, be instructor pilots. The determination of the pacing resource could be routinized, of course, but this would entail the collection and processing of more source data than if some knowledgeable person in touch with the system simply points out the constraining resource and the time period it serves as such. If in doubt, calculations covering two or more resources could determine the real constraint. The main idea is to minimize the source data requirements. The responsibility for maintaining a current data base must be fixed, to be sure, but additional personnel should not be necessary since the DSFM assumes much of the current burden for manual manipulation of data.

c. The model does not explicitly comprehend the Navy Flight Officer (NFO) training program except where the Student Naval Aviator (SNA) program shares some training facility such as in the Naval Aviation Schools Command (NASC) and in some of the FRSs. When facilities are shared, the NFO community is considered only to the extent necessary to project the throughput of SNAs. An analogous DSFM for NFOs could be developed, of course, but such is not considered here.

d. The DSFM is not designed to be operated in an interactive mode, but rather in a batch mode. The design of an interactive program is entirely feasible, but that version is considered more properly a follow-on effort after the user community becomes confortable with the batch version.

e. The DSFM requires a large scale computer for its operation. This is basically because of the large networks induced by the one-week time interval. Training events, like classes, start and stop in weekly intervals or multiples thereof, so for some detailed schedules the weekly interval is essential. For many planning purposes, however, a DSFM with monthly or quarterly intervals would be sufficient. A DSFM with these intervals is feasible and would fit easily into a number of the minicomputer systems.

3. Detailed Characteristics

3.1 Specific Performance Requirements. The DSFM will be expected to serve in two basic roles: one routine and the other ad hoc.

The routine function will be to produce student input and output schedules for the UPT program and for the FRS training requirements. Schedules are to be produced at periodic intervals and on call when a substantial change in the production requirements or operating circumstances is anticipated. Schedules are to be characterized as representing the maximum allowable throughput with the minimum time to train. Format for the final input schedules are to be suitable for official publication.

The ad hoc function is to serve as a planning tool. The model is to provide a relatively quick-response capability to react to changes, either real or hypothetical, in training resources or to the training rate requirements. The following specific objectives will be addressed.

a. The model will aid in determining whether planned production goals can still be met given a training resource crisis situation.

b. The model will aid in reducing the impact of changes in available student pilots, training aircraft, maintenance support, instructor pilots, funds and other resources.

c. The model will aid in identifying the optimal allocation of training resources in response to a crisis situation.

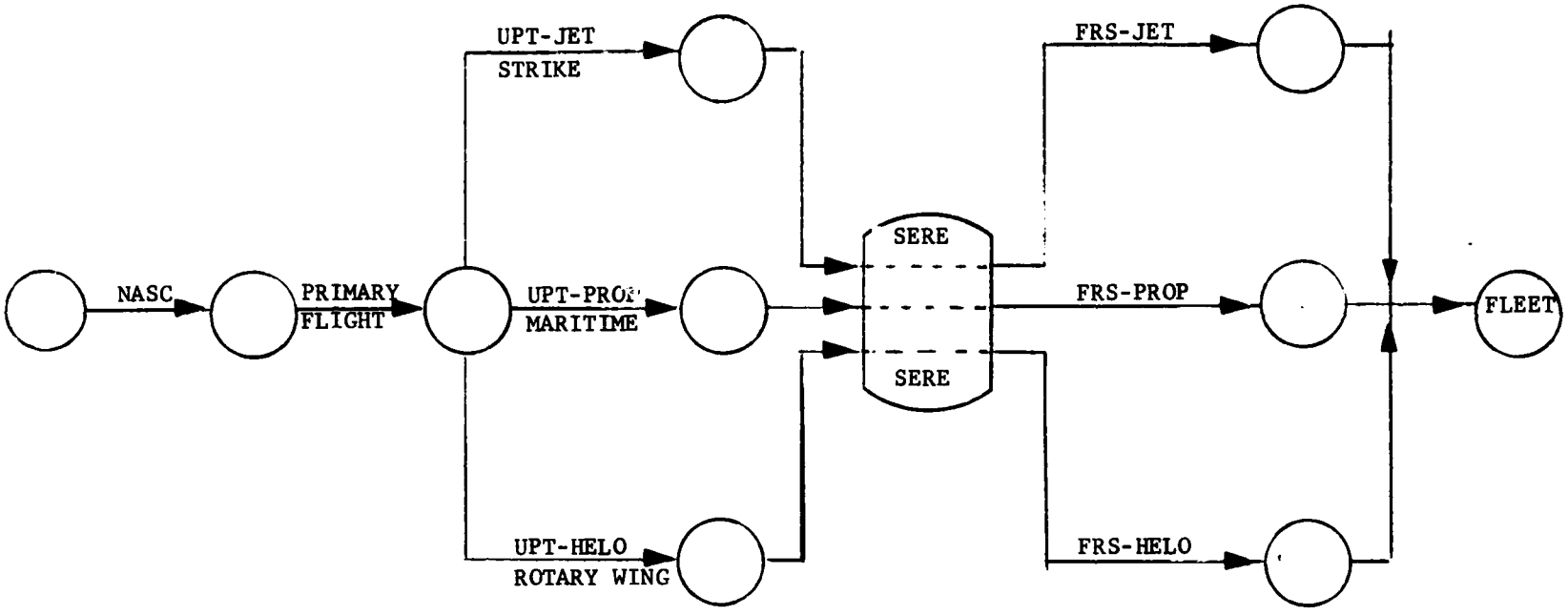
d. The model will aid in the identification of critical constraints and the quantification of any penalty incurred because of the constraints.

e. The model will identify slack resources which may be released or reassigned.

f. The model will aid managers in planning phase-in of major changes to the curriculum.

3.1.1 Scope. The DSFM must embrace the pilot training activities of the UPT and the FRS communities. Figure 3.1 is the most primitive of networks representing this process. A more definitive representation of the UPT network is delineated in Figures 3.2 and 3.3. The abbreviations used for the various phases of training are listed in Figure 3.4.

The FRS network, which feeds from the UPT-JET pipeline, is in Figure 3.5. The MISCELLANEOUS arc includes all those FRS activities not otherwise listed. The circular arc is for the Selectively Retained Graduates (SERGRADS) who feed back into the UPT program as instructor pilots (IPs) immediately upon graduation. Similarly, Figures 3.6 and 3.7 are for the PROP and HELO FRSs,



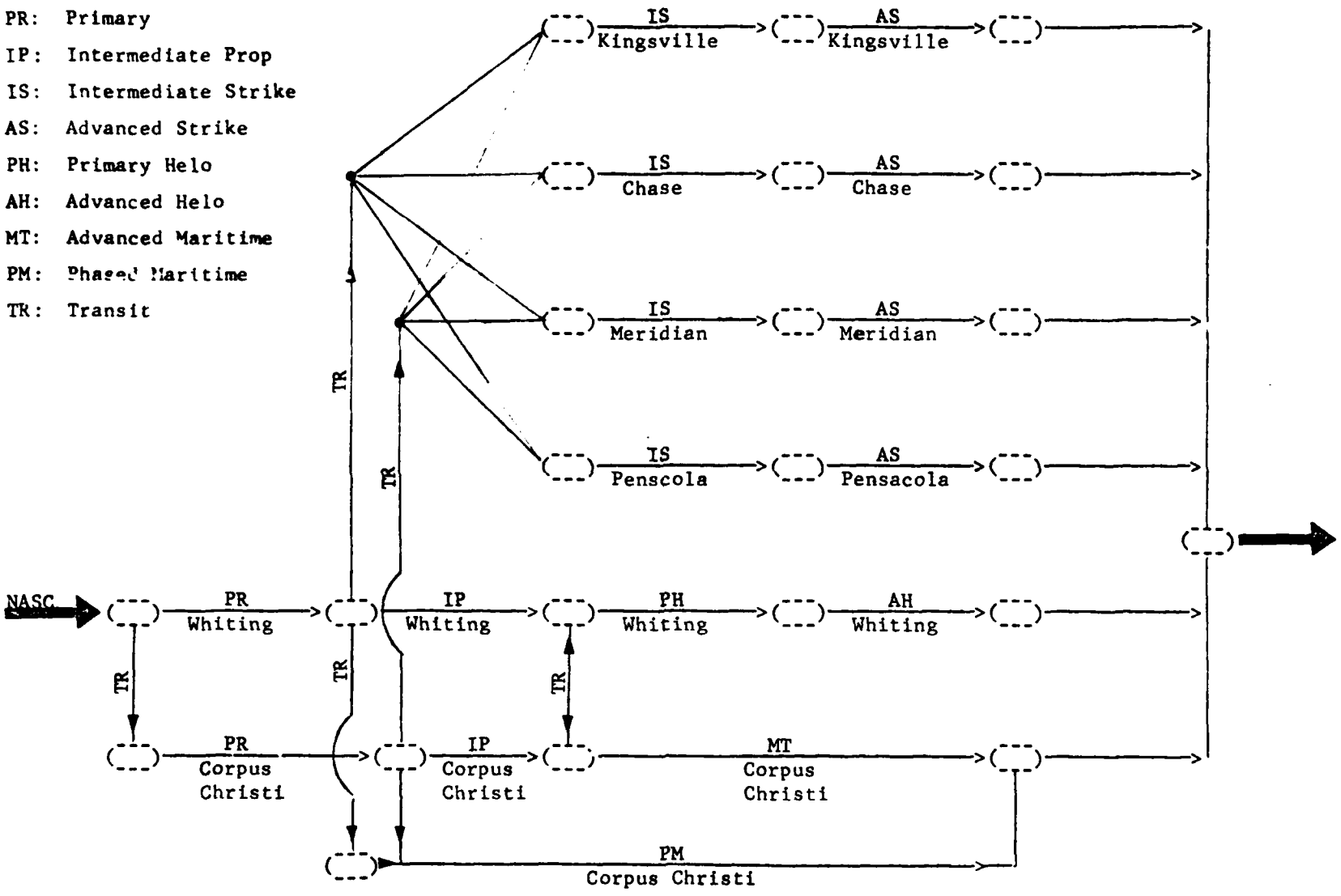
NASC: Naval Aviation Schools Command

UPT: Undergraduate Pilot Training

FRS: Fleet Readiness Squadron

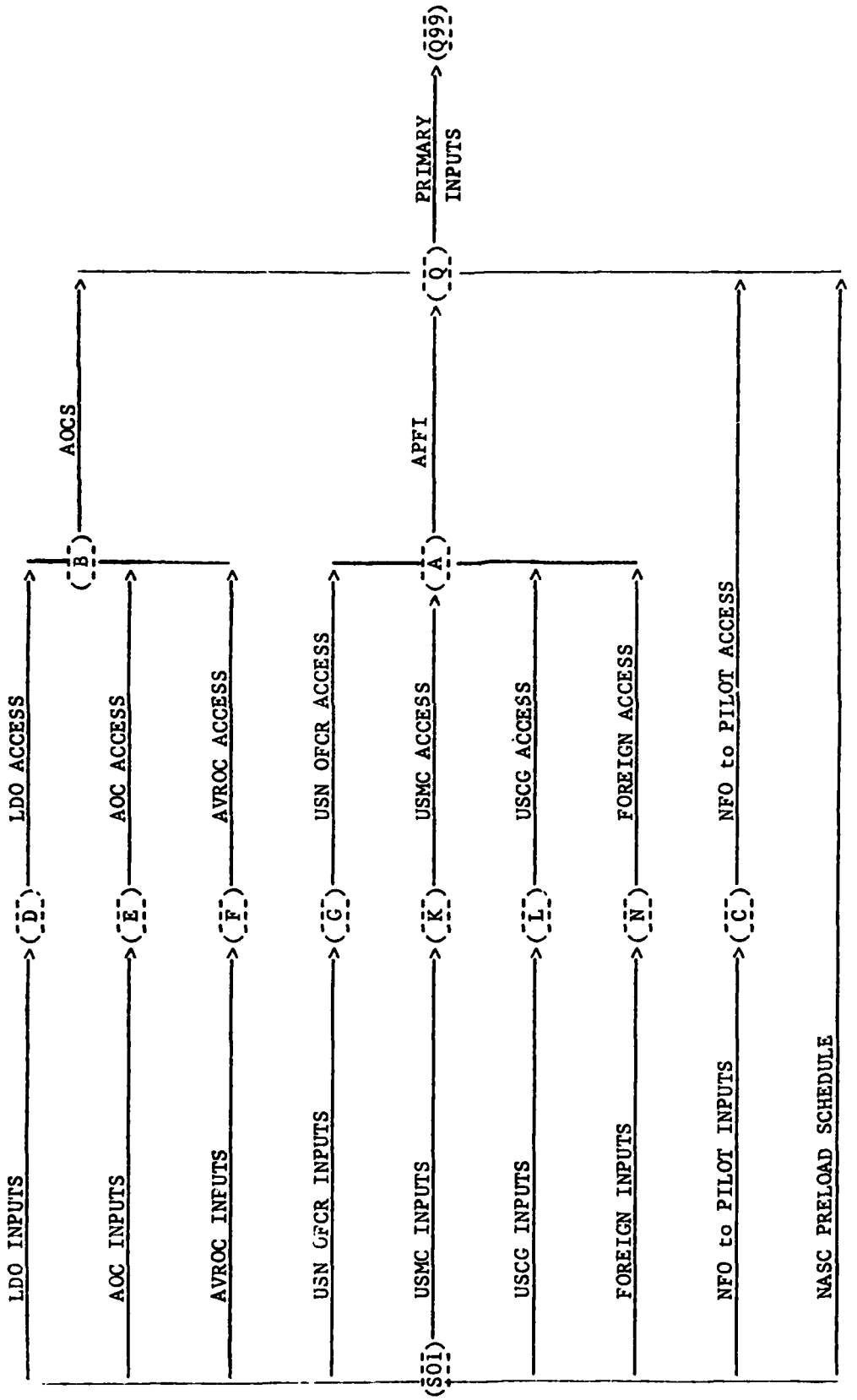
General DSFM Network

Figure 3.1



Geographical UPT Network

Figure 3.2



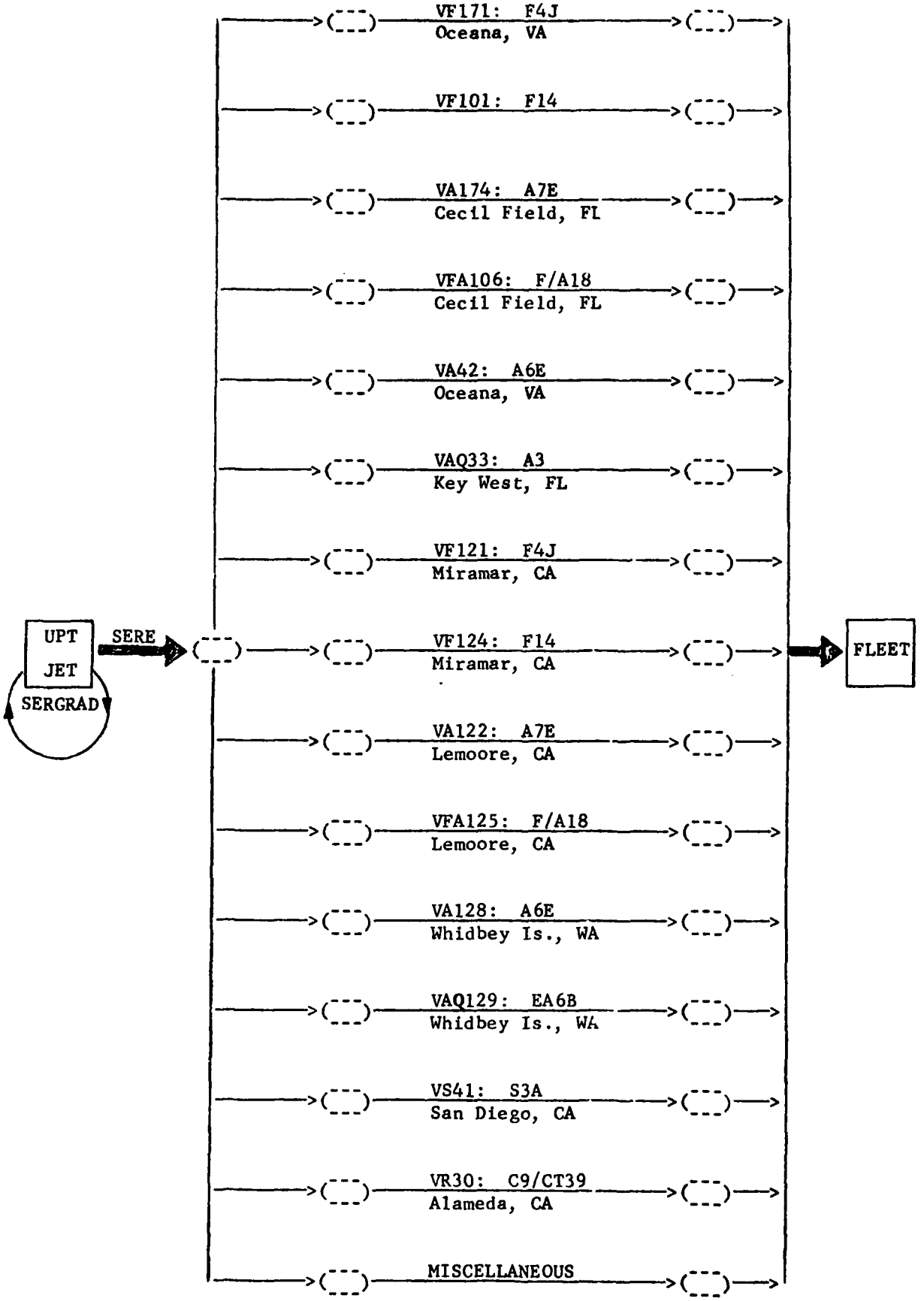
NASC NETWORK

Figure 3.3

Phase ID	Phase Name	Naval Air Station	Remarks
NASC	Naval Aviation Schools Command	Pensacola FL	This is a ground school to indoctrinate prospective flight school students. There is a separate course for officers (APFI) and for officer candidates (AOCS); the latter course being eight weeks longer.
APFI	Aviation Preflight Indoctrination		
AOCS	Aviation Officer Candidate School		
PR	Primary	Whiting FL Corpus Christi TX	The initial phase of flight training. A screening process prepatory to being assigned to pipeline training.
IP	Intermediate Maritime/Helo	Whiting FL Corpus Christi TX	An intermediate phase in propellor driven aircraft prepatory to entering the advanced prop phase or primary helo phase.
IS	Intermediate Strike	Kingsville TX Chase TX (Beeville) Meridian MS Pensacola FL	The basic jet training phase.
AS	Advanced Strike	Same as IS	The advanced and final phase of jet UPT.
MT	Advanced Maritime	Corpus Christi TX	The advanced and final phase of prop UPT.
PM	Phased Maritime	Corpus Christi TX	This is a combination of IP and MT using the advanced multi-engine prop training aircraft.
PH	Primary Helo	Whiting FL	The initial phase of rotary wing training.
AH	Advanced Helo	Whiting FL	The advanced and final phase of rotary wing UPT.
SERE	Survival, Evasion, Resistance & Escape	Brunswick, ME San Diego CA	"Survival" School is usually conducted enroute from UPT to the Fleet Readiness Squadron.
FRS	Fleet Readiness Squadron	Various East & West Coast Locations	Transition training in the type aircraft to be flown in a fleet squadron. Often referred to as an 'RS'.

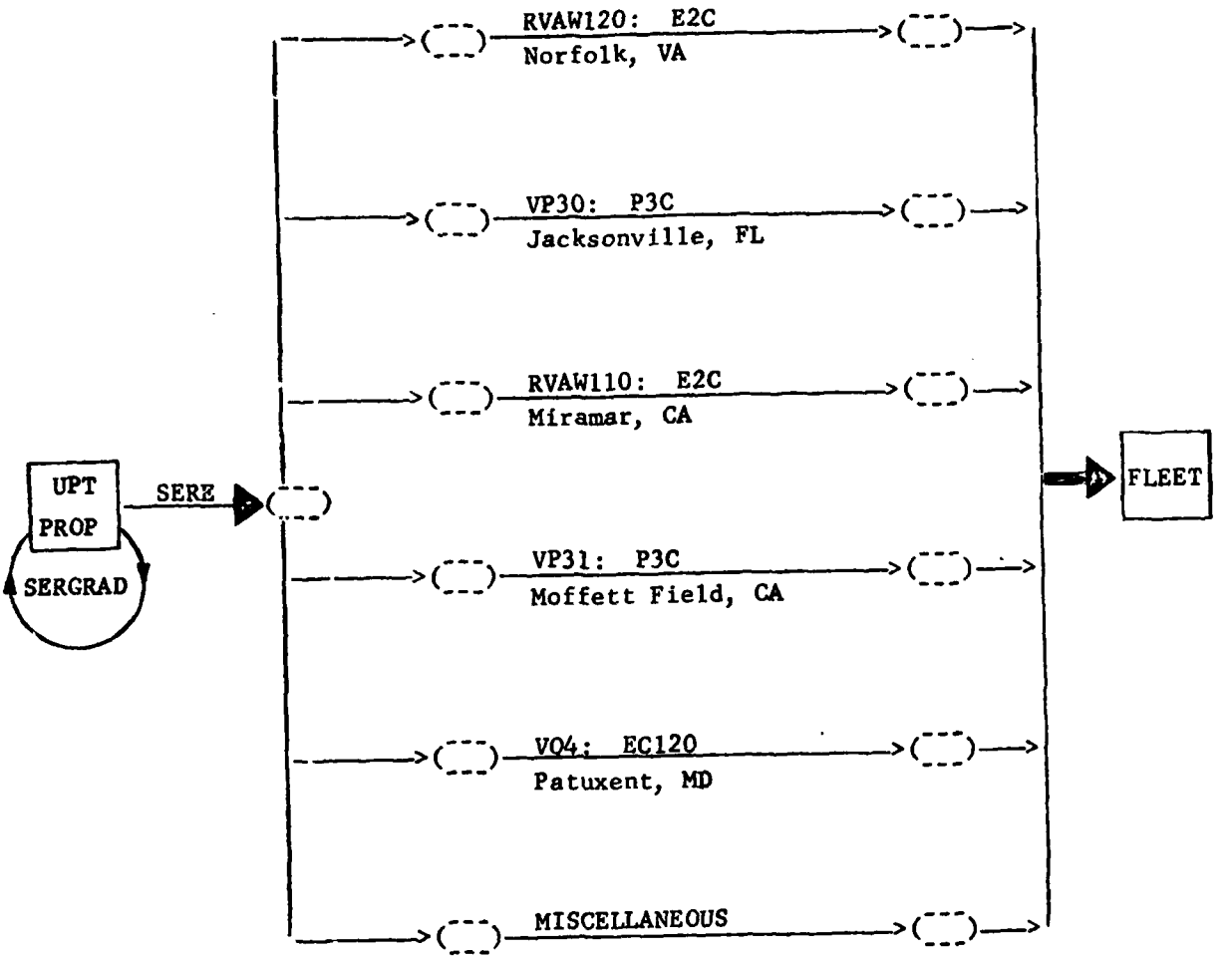
Training Phase Abbreviations

Figure 3.4



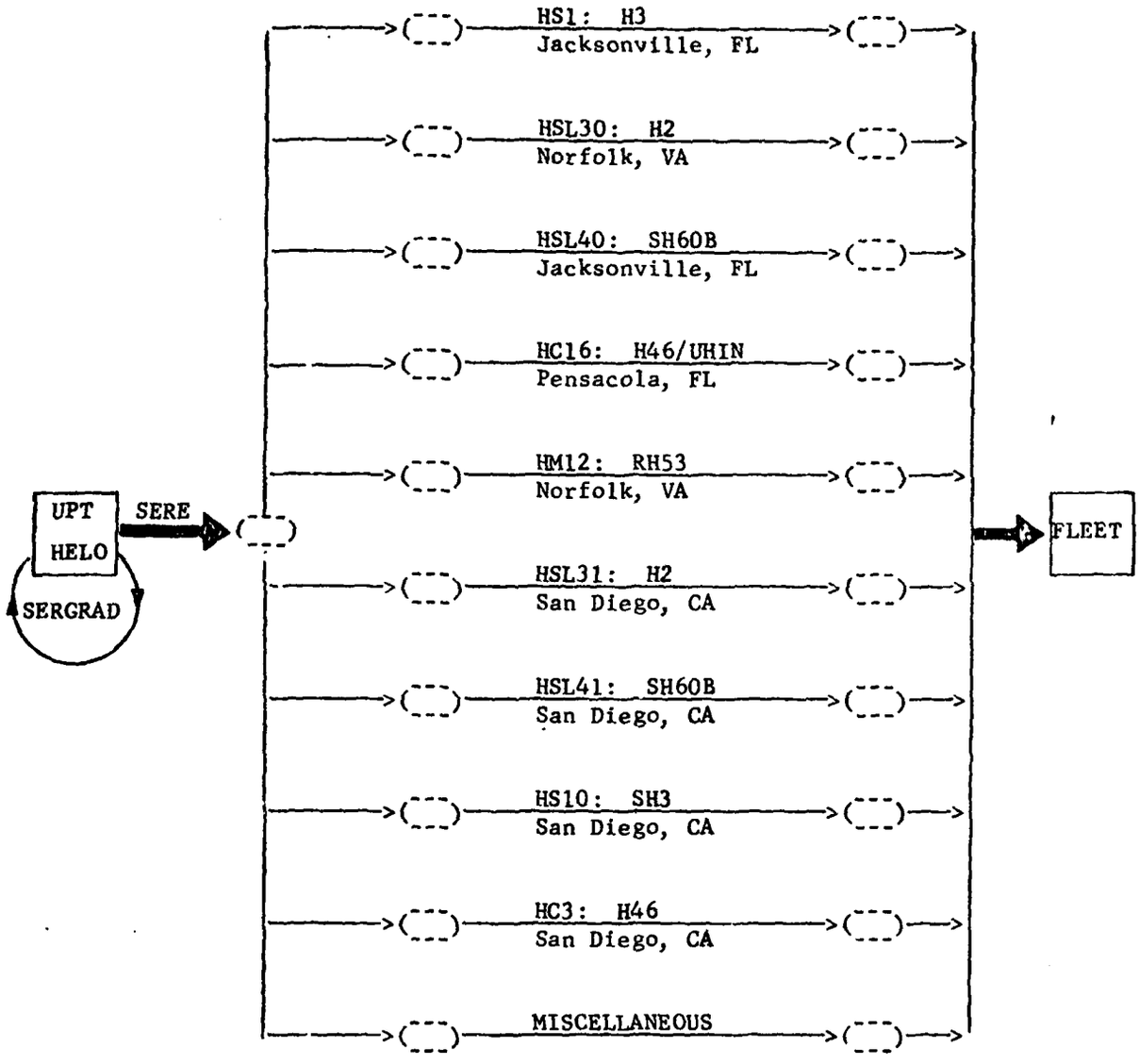
JET-FRS-NETWORK

Figure 3.5



PROP—FRS-NETWORK

Figure 3.6



HELO-FRS-NETWORK

Figure 3.7

respectively. Survival, Evasion, Resistance and Escape (SERE) training is conducted for most pilots while enroute from UPT to their first Fleet Readiness Squadron (FRS) assignment. Graduates of the UPT jet, prop, and helo pipelines are mixed in classes of finite capacity; however, they must retain their jet, prop or helo pilot identity for subsequent assignments. SERE is modeled separately since it functions as a valve on the flow of graduates from UPT to FRS.

It is emphasized here that these networks are only contemporary representations of the different segments of flight training. The networks in the DSFM are not fixed, but may be quite different -- this flexibility is described more fully in subsection 3.1.4.

The DSFM will provide student flow solutions for a three year period. That is, it will embrace three years of PTRs and provide the necessary student input schedules to achieve that level of production. If the PTRs are not feasible under the circumstances, then the student input schedule will be the best feasible one which minimizes the PTR shortfalls. This three year period is referred to in the text as the 'time period of interest.' It may, of course, be varied if desired.

3.1.2 Accuracy. Accuracy within the DSFM is mainly a matter of faithful reproduction of stored data. Most of the calculations are integer and, as such, are to be exact. For those calculations that are not integer in value, the calculations are implemented using short form floating point format. This format is accurate to five significant places.

The most significant point regarding accuracy in the DSFM is the conversion of fractional information to integer values. This is most often required when adjusting integer student pipeline flow values, e.g., JET pipeline graduates, to integer phase input/output values, e.g., Intermediate Strike phase, using the planning factors for both phase attrition and postphase attrition. In these instances, the fractional values resulting from a conversion are ordered in time. Beginning with a remainder of zero and time zero, the sum of the next value in time and the current remainder is converted to the nearest integer. This integer value is then subtracted from the actual sum and the difference becomes the new remainder. This process is repeated through time until all values for a given time series have been processed. In this manner, the cumulative value for any point in time is within one-half student of the adjusted value.

Input values supplied to the DSFM and their interpretation vary by the type of data being supplied. For example, PTRs are supplied as unsigned four digit numbers and are interpreted as integers, Weather Factors are supplied as three digit unsigned numbers and are interpreted as thousandths, and Daylight Hours are supplied as three digit unsigned numbers and are interpreted as tenths. Other values are supplied as free form values with the form locating the decimal point and/or sign when required. This free form is sometimes required to be contained in four characters and other times allowed to be any representation allowed by the host language, i.e., PL/I.

3.1.3 Validity. Validity checks, both numerical and logical, are built into the software as appropriate to monitor the input data and internal processing. The real measure of validity of the input source data for a model of this kind is the realism of the data and this requires experienced subjective judgements at times. The DSFM is designed around the operating data that are routinely reported through the chain of command. The model works well with these data when the system is expected to operate under 'planning factor' conditions throughout the planning period. These are also the conditions when you need the model the least. The model serves the greatest need when changes affecting training capacity have occurred, are imminent, or are planned. These are changes that do not fall into the normal reporting channels. The frequency of change increases as the pressure on the training system to produce beyond its normal rated capacity increases. Good management practices require ad hoc changes to relieve system stress. The utility of the DSFM, no different from any other predictive model, is a direct function of the realism and currency of the input data. The rate of change of input data is not a problem to the model, but timeliness has a marked effect on the accuracy of the results. Maximum effectiveness of the DSFM will be achieved when it is exercised by a person with detailed knowledge of the training process who sits in a position in the Naval Aviation training organization where he has routine access to planning data and is cognizant of all changes to actual operating circumstances when or before they occur.

3.1.4 Flexibility. The structure of the DSFM is a network which has a physical representation that relates to the real planning world. Moreover, the model can produce results for each segment of the network that provide data for analyses down to minute detail. One could say that the DSFM is no more than a network and an algorithm married by a computer program and be qualitatively correct. It is this rudimentary relationship, however, which provides the intrin-

sic power and flexibility of the system. It is of no consequence to the logic of the DSFM whether it operates on a simple network as in Figure 3.1 or more complex ones as in Figures 3.2 through 3.7. Moreover, the optimizing algorithm is not locked in -- others may be used. It is in the level of detail in the structure of the network and the operational interpretation of the structure that each version of the DSFM acquires its own character. In this fashion the DSFM can be tailored to the requirements of any level in the command hierarchy or a staff element at any or all levels. Traditionally, the higher the authority, the less detail desired. This is clearly true with respect to the depth of detail, but does not always correlate with respect to the range of detail. All command levels have an interest in fundamentals like the productivity of the system. The Chief of Naval Operations is interested in the pipelines meeting their PTRs; however, a Training Wing Commander of a jet base is interested in whether he can meet or exceed his share of the jet PTRs and the related flow of students. With respect to the range of detail, staff interest in a particular set of details may occur at all levels of command. Suppose a staff element is tasked to evaluate a scenario calling for increased production at a training base -- a level of production in excess of experience factors. Knowing what resources are available and programmed, the question is what will be needed. The root data needed to determine most of the required resources are student onboard loads, flight hour activity and phase graduation rates. The DSFM will produce these data week by week for the base in question.

3.1.5 Timing. As described above under Flexibility, the DSFM may take on several versions with different online storage requirements and computation times depending on the scope and detail included in the network. The simpler versions are adequate for many purposes, quicker in response time and more economical to process. They should, however, be verified from time to time against a parallel run of a detailed 'benchmark' version of the DSFM, lest the planning become too optimistic with respect to future realities.

3.2 System Functions. The use of the DSFM through a responsive data processing system will give the Navy a common structure for discourse among the different planning and management levels involved in flight training. Some particular capabilities follow.

a. Produce a schedule of student weekly inputs into Primary Flight Training over a one to three year projected period stating the requirements for an optimal student flow through all the pipelines under the conditions of a given scenario.

b. Produce a suitably formatted schedule of student weekly inputs into the NASC over a one to three year projected period which provides the entrants for the schedule produced in (a) above or any other feasible schedule.

c. Determine the maximum throughput of the training system for a given scenario with shortfalls, when occurring, to the PTR explicitly stated by pipeline and year.

d. Determine required capacity to train by weeks, phase, and location to produce a given set of PTRs.

e. Determine where the training bottlenecks are in the system.

f. Determine where excess capacities exist in the system.

g. Determine the surge capacity of the system if additional personnel, spare parts, funds, etc., were made available to increase the aircraft utilization.

h. Determine the expected number of student-weeks spent in pools and their location, which will result from a given plan or policy.

i. Provide information leading to improved PTR assignments to training wings and squadrons.

j. Provide data for staff analysis leading to improved pipeline balancing of capacities to train by phase and location.

k. Provide expected tracks for students to follow as they enter the system at a particular week.

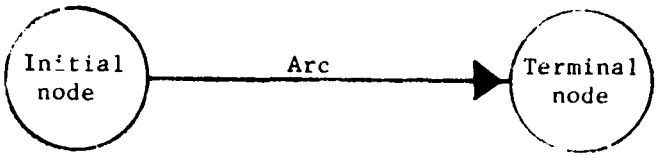
l. Provide a measure of the effect of different planning policies and scheduling criteria; e.g., level input, level output, uniform student loading.

m. Match UPT output schedules with FRS input schedules.

n. Match FRS output schedules with planned Fleet Squadron requirements for replacement pilots.

o. Assist staffs in planning for transition to new equipment, facilities or curriculum.

3.3 Inputs. The structure of the DSFM is a network composed of arcs and nodes as delineated below.



In a typical DSFM network, the arcs and nodes are numbered in the thousands.

Each node has a unique NAME. In the UPT DSFM, the name is in three parts, XYZ, where;

X is an alpha character identifying that class of nodes, e.g., the initial node of the Primary flight phase;

Y is the sequence number of the fiscal year, 1 through 5, e.g., if the start time for the DSFM were in FY79, then '1' would indicate FY79 and '5' would indicate FY83; and

Z is a number indicating the week number, 1 through 52, in the fiscal year.

In the sequel, XYZ will be referred to as defined above.

Each arc is assigned three parameters:

Time duration in weeks,
Maximum capacity in the number of students per week, and
Minimum capacity in the number of students per week.

The time duration of an arc is always equal to the year and week (the YZ) of the terminal node minus the year and week of the initial node except when including any part of the Christmas holidays. When a Christmas holiday week is included it is automatically counted as zero. The time duration may be zero, but is never negative. If the arc represents a phase of training, say Primary, then the time duration would be the expected time to train for a student entering the phase at the time (the YZ) of the initial node. He would be expected to complete the phase at the end of the week immediately preceding the time of the terminal node - - ready to start the next event at the time (YZ) of the terminal node.

The maximum and minimum capacities are two non-negative numbers where the minimum is, of course, never greater than the maximum. For a feasible flow solution, the flow in every arc must be on or between these upper and lower bounds. The upper bound may be thought of as the 'permitted' flow and the lower as the 'required' flow. The lower bound is very useful when a fixed flow is

essential such as an established student input schedule. The arc capacities are effective for events which start at the time (YZ) of the initial node.

The DSFM comprehends only time durations and capacities, but the arcs in the network must represent a variety of events and activities. Figure 3.8 is an attempt to group or classify the different kinds of arcs for expository purposes.

Student Input Schedule. The input schedule of students into the Naval Aviation Schools Command (NASC) are formally published each year for the following FY inputs. Changes are sometimes made during the year to reflect changing conditions or experience. To the extent that an input schedule is known, the min/max capacities of the weekly input arcs would be identical, i.e., the minimum required and the maximum allowed are the same. Beyond that time period, one can set the upper capacity to some extremely large value and the lower to zero and let the DSFM solve for the optimal input schedule. Alternatively, one can do the same for the entire five-year time period and compare the optimum schedule with the existing input schedule. Intermediate constraints on the available input schedules are clearly possible. The time duration of these input arcs is zero.

Preload of Onboard Students. The DSFM can be initiated at any time during the year that the onboard student load is known. These students are called the preload. If the best estimate of the distribution of onboard students is that they are evenly distributed with respect to weeks-to-go in phase, then the phase length (in weeks) minus one* is divided into the number of students to determine the size of each preload (onboard) class. These classes then have one week-to-go, two weeks-to-go, etc. If there is reason to believe that the onboard students are not uniformly distributed in the weeks-to-go in phase, then the actual or estimated distribution can be entered accordingly. The time duration of each preload arc is equal to the weeks-to-go for the class represented, i.e., 1, 2,..., time duration minus one. The min/max capacity of each preload arc is equal to the number of students in the represented preload class.

Phase Training. These arcs represent the actual training in the flight training process. In UPT, a class starts every week excepting two weeks during the Christmas period. The time and capacity to train in UPT are affected by seasonal changes, if nothing else. A full explanation of how these are calcu-

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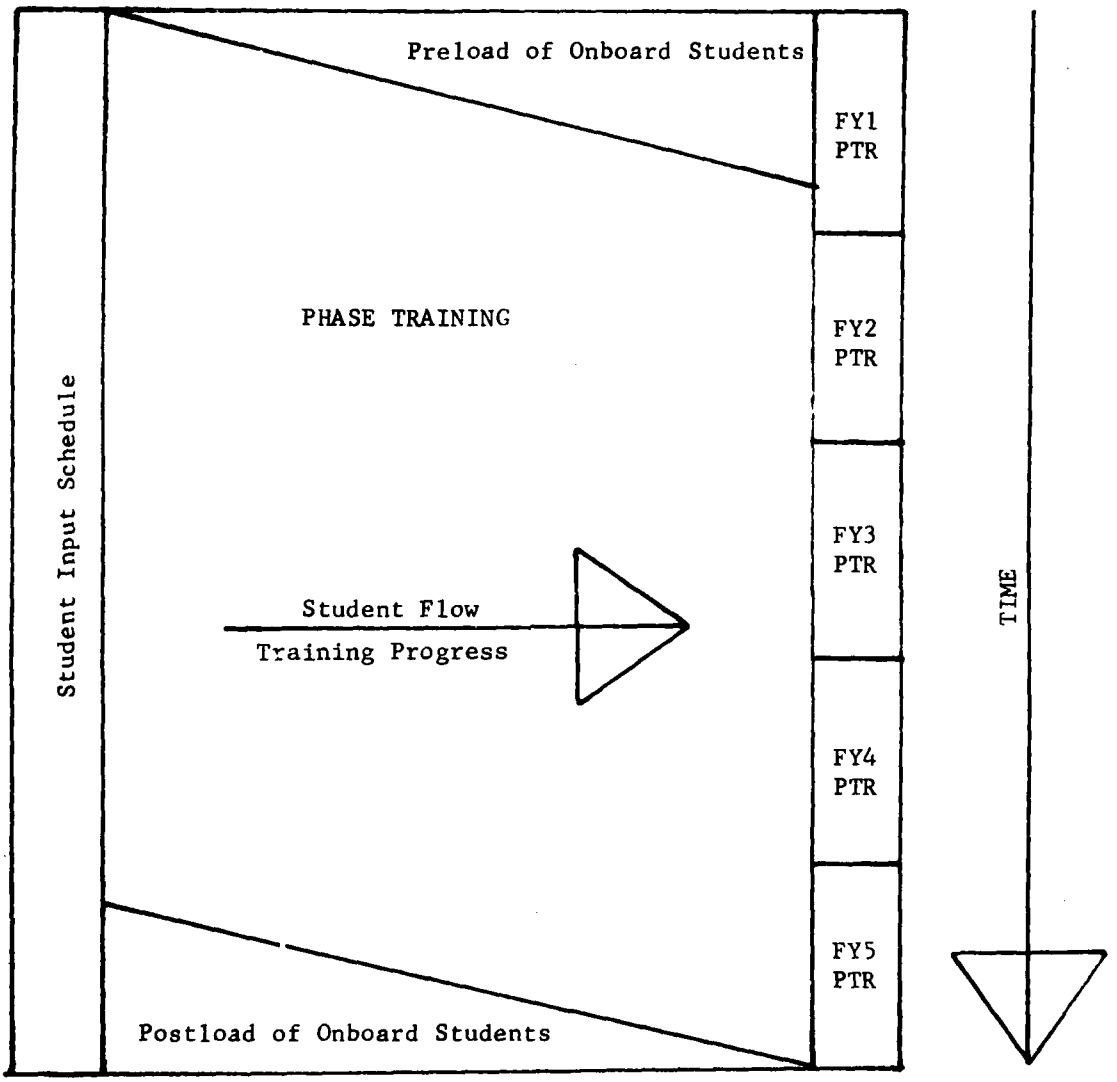
*The minus one reflects the convention that no onboard student has the full number of weeks-to-go in completing the phase. The full number of weeks are required by any students in a pool awaiting entry into the phase.



Categories of Arcs in the UPT DSFM Network

Figure 3.8

lated will be given in a later section. These parameters are also affected by other factors ranging from a modest change in the aircraft inventory to a complete cessation of a phase of training. In the schema presented in Figure 3.8, flight students enter at the left, matriculate through the flight training program to the right and finally are designated a Naval Aviator or lost due to attrition of one kind or another.

Postload of Onboard Students. For the input schedule developed by the DSFM to be accurate, the network must exist such that all students entering the system during the time period of interest graduate within the time period modeled. Considering that the time period of interest begins sometime during the first year modeled, that five years are modeled, and that the longest training path is on the order of one year, the DSFM can model that portion of the first year following the start of the time period of interest thru the next three years. In normal use, the DSFM has been called upon to model three years including the year that begins the time period of interest.

PTR. These arcs are normally set to the PTR for each year. They may be set for a time interval as small as a week. This could be useful in determining the effect on training throughput of different policies on expected output, e.g., level monthly outputs. Alternatively, the PTR could be set to infinity and the resulting flow solution would represent the maximum throughput of the training system.

Student Pools. Student pools are defined as those students available to start a particular phase of training in which there is no room and, as a consequence, must be held over for a class beginning one or more weeks later. Pool arcs permit a student who has completed a phase to wait week by week until there is an opening in the next phase. Since the algorithm used in the DSFM seeks the maximum student flow with the minimum time to train, pooling is shunned except in instances where increased total feasible flow will result. Referring again to Figure 3.8, if the actual training activities are viewed as moving from left to right and down with time, then the pool arcs are decending vertical arcs since no training is taking place.

Transits. These arcs are sometimes necessary to represent a nominal transit time in weeks between phases where there is a significant geographical separation. As in the pool arcs, transit arcs are vertical since no training is being conducted.

While the DSFM can only comprehend nodes and arcs and the three arc parameters:

Time to train
Maximum capacity (permitted flow), and
Minimum capacity (required flow),

it can be seen from the above that a variety of operational and management information can be represented in those terms.

The initial developmental experience with the DSFM was confined to the post-NASC UPT program. The times and capacities to train in the flight segment of that program are heavily influenced by environmental factors such as weather and daylight hours available. The FRSs are not dominated by these factors, but suffer from other contraints. The specific input data discussed in the sequel will be in the framework of the UPT program. A rationale for computing the times and capacities to train will be described. It is believed at this time that these same parameters for the FRS portion of the DSFM network are more likely to be specified than computed. Accordingly, the discourse for the FRS portion will be expressed in more general terms.

3.3.1 UPT Required Inputs. The following inputs are required as source data to prepare the input parameters for the UPT DSFM network. All of these data already exist in the Navy system.

a. PTRs by pipeline for the time period of interest, normally three to five years. See Figure 3.9 for a typical PTR listing used by Navy planners. The DSFM does not keep track of flight students by source, i.e., whether Navy, Marine, etc. The five-year totals and percentages were added for use in the preparation of DSFM inputs.

b. A list of the training phases and their sequence in the flight training process. Include delay times, if any, for each phase-to-phase transition. Figure 3.2 displays a typical network for the UPT program.

c. For each phase, location, and type aircraft:

(1) average weeks to train
(2) attrition rate for students in each phase of training
(3) average total aircraft time per phase graduate (includes all overhead hours)
(4) percentage of flyable weather by month (Figure 3.10)
(5) daylight hours by month (Figure 3.11)

PILOT TRAINING RATE (PTR)
FY79-83

	JET	PROP	HELO	TOTALS
FY79				
NAVY	375	295	215	885
MARINE	165	0	305	470
CG&F	30	47	54	131
TOTALS	570	342	574	1,486
FY80				
NAVY	318	316	251	885
MARINE	158	0	292	450
CG&F	30	47	54	131
TOTALS	506	363	597	1,466
FY81				
NAVY	324	322	254	900
MARINE	188	0	282	470
CG&F	30	47	54	131
TOTALS	542	369	590	1,501
FY82				
NAVY	342	340	268	950
MARINE	188	0	282	470
CG&F	30	47	54	131
TOTALS	560	387	604	1,551
FY83				
NAVY	342	332	276	950
MARINE	188	0	282	470
CG&F	30	47	54	131
TOTALS	560	379	612	1,551
5-YR TOTAL	2,738	1,840	2,977	7,555
5-YR PERCENTAGES	36.2%	24.4%	39.4%	100%

Note: PTR for FY84 same as for FY83.

Figure 3.9

CNATRA WEATHER FACTORS

WLW:11/26/79

LOCATION & PHASE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE.
WHITING FIELD													
PR & IP	.872	.695	.784	.593	.716	.679	.742	.771	.842	.700	.789	.728	.743
PH	.907	.777	.850	.724	.799	.789	.849	.869	.951	.803	.896	.868	.840
AH	.917	.849	.860	.697	.819	.803	.858	.903	.956	.848	.927	.906	.862
CORPUS CHRISTI													
PR & IP	.829	.751	.696	.544	.631	.592	.622	.642	.837	.916	.876	.768	.721
MT	.949	.930	.919	.796	.852	.896	.919	.922	.964	.977	.966	.907	.917
KINGSVILLE													
IS	.914	.887	.860	.757	.866	.866	.876	.876	.929	.954	.917	.887	.882
AS	.912	.928	.852	.796	.878	.823	.838	.825	.925	.960	.928	.904	.881
CHASE													
IS	.894	.874	.831	.731	.818	.835	.848	.825	.935	.949	.915	.875	.860
AS	.922	.901	.859	.796	.849	.856	.857	.868	.938	.952	.939	.909	.838
MERIDIAN													
IS	.865	.834	.860	.721	.811	.789	.812	.830	.898	.821	.873	.815	.828
AS	.890	.820	.841	.688	.788	.764	.799	.789	.875	.798	.865	.814	.812
PENSACOLA													
IS	.913	.373	.912	.748	.834	.795	.823	.856	.933	.807	.907	.864	.854
AS	.924	.853	.913	.842	.842	.787	.823	.846	.956	.840	.889	.899	.867

PR: PRIMARY
IP: INTERMEDIATE MARITIME/HELO
PH: PRIMARY HELO
AH: ADVANCED HELO

MT: ADVANCED MARITIME
IS: INTERMEDIATE STRIKE
AS: ADVANCED STRIKE

DATA BASE: OCT 1974 through SEP 1979
CNATRA (N-21) 6 NOV 1979

Figure 3.10

DAYLIGHT FLYING HOURS

MONTH	SUNRISE	SUNSET	DAYLIGHT HOURS/DAY MINUS ONE
OCT	0601	1729	10.5
NOV	0625	1704	9.7
DEC	0648	1702	9.2
JAN	0657	1722	9.4
FEB	0641	1748	10.1
MAR	0610	1808	11.0
APR	0533	1828	11.9
MAY	0506	1847	12.7
JUN	0458	1902	13.1
JUL	0509	1902	12.9
AUG	0527	1841	12.3
SEP	0544	1805	11.4
			11.2 average

Reference: Sunrise and sunset times were taken from a 1976 World Almanac for the 15th of each month at 30° north latitude.

Note: The daylight flying day is defined as beginning one-half hour after sunrise and ending one-half hour before sunset. Further, normal operations are based on a five-day week, 50-week training year and 240 scheduled days per year.

Figure 3.11

Note: The first three of these data are standard planning factors that are maintained by CNET and CNATRA. The fourth item is maintained as a running average over the last five or more years at CNET and CNATRA. The UPT training bases all lie close to the 30th parallel so one table of daylight hours holds for all (Figure 3.11).

d. Inventories of aircraft and their simulators by type, phase, and location by quarter of each fiscal year during the time period of interest. The expected annual utilization of each type aircraft and simulator is also required.

e. Student onboard loads and student pools by phase and location as of the start date of the DSFM exercise. A good source of these data is the "Aviation Statistical Report" published monthly by CNATRA.

f. Student input schedule into the Naval Aviation schools Command (NASC). These schedules are published annually by CNO and sometimes updated during the year. Figure 3.12 is an example.

3.3.2 Computed UPT Data. The 'Required Inputs' in 3.3.1 above provide the source data for computing a variety of data essential to the proper operation of the UPT DSFM.

a. PTRs - These are totaled for the number of years for which they are given. Then the percentages for each of the JET, PROP, and HELO pipelines are calculated (See Figure 3.9). These pipeline percentages are a factor in calculating postphase attritions and the allocation of the same type of aircraft among phases.

b. Postphase Attrition. Postphase attrition represents the expected loss in the number of phase graduates before final graduation from UPT. The projected PTRs and the proportionate share of the total by each of the three pipelines figure into the calculation of postphase attrition. The proportion of each pipeline would not matter if it were not for the sharing of such phases as Primary and Intermediate Prop/Helo.

Figure 3.13 illustrates a typical display of postphase attritions and related data. The computations are carried out from right to left in the figure starting with the pipeline percentages calculated from the PTR table. Multiplying this percentage by 100 will give the number of every 100 pipeline graduates for a particular pipeline. For JET, this is 36.2. Dividing this number by one minus the Advanced Strike phase attrition, 8%, then 36.2/.92 = 39.3, the number

PILOT TRAINING PROGRAM

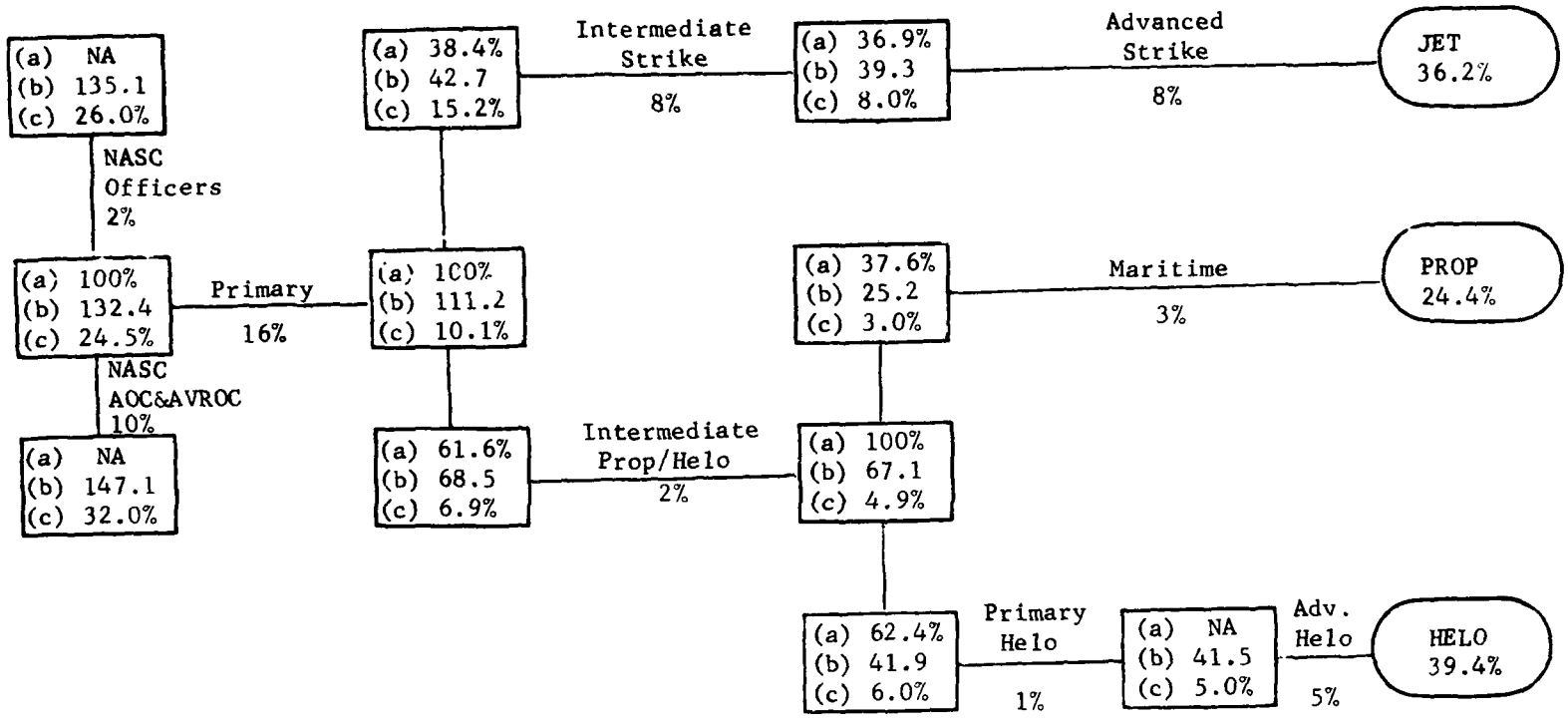
FY-78 INPUT
(THIRD AND FOURTH QUARTERS)

		AOC				AVROC				OFFICER				USMC				USCG				FOREIGN			
		P		A		P		A		P		A		P		A		P		A		P		A	
CV/CVN	CL NO	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM
6/3	25	5	220			0	115			3	279			13	325			2	27						
6/10	26	0	220			0	115			1	280			6	331			0	27						
6/17	27	10	230			0	115			1	281			6	337			0	27						
6/24	28	0	230			0	115			1	282			6	343			0	27						
7/1	29	5	235			0	115			0	282			6	349			1	28						
7/8	30	0	235			0	115			1	283			6	355			0	28						
7/15	31	10	245			0	115			5	288			6	361			0	28						
7/22	32	0	245			0	115			3	291			6	367			0	28						
7/29	33	5	250			0	115			1	292			6	373			0	28						
8/5	34	0	250			0	115			1	293			6	379			0	28						
8/12	35	20	270			0	115			5	298			6	385			0	28						
8/19	36	0	270			0	115			5	303			12	397			0	28						
8/26	37	15	285			0	115			7	310			12	409			0	28						
9/3	38	0	285			5	120			5	315			12	421			11	39						
9/10	39	20	305			5	125			9	324			12	433			6	45						
9/17	40	0	305			5	130			14	338			12	445			2	47						
9/24	41	15	320			5	135			13	351			12	457			2	49						
10/1	42	0	320			0	135			5	356			12	469			0	49						
10/7	43	20	340			0	135			10	366			12	481			4	53						
10/14	44	0	340			0	135			10	376			12	493			0	53						
10/21	45	15	355			0	135			16	392			12	505			0	53						
10/28	46	0	355			0	135			15	407			12	517			0	53						
11/4	47	20	375			0	135			12	419			13	530			4	57						
11/11	48	0	375			0	135			6	425			13	543			0	57						
11/18	49	15	390			0	135			2	427			13	556			0	57						
11/25	50	0	390			0	135			8	435			13	569			0	57						
TOTAL			390				135				435				569				57				71		

NOTES: 1. P - Planned Input; A - Actual Input; CM - Cumulative Input; WK - Weekly Input.
2. Planned inputs are based upon FY-79 Pilot Training Rates and consideration of the current student pilot load. OPNAV authorization required for significant input changes.
3. AOC input does not include attrition subsequent to reporting to NAS Pensacola and prior to actual enrollment into Naval Aviation Schools Command.

Figure 3.12

DOWNSTREAM ATTRITION



(a): This is the percentage of all inputs from a common phase to achieve the right balance of outputs based on a five-year average of PTRs.

(b): This is the number of inputs at this phase level to achieve the right balance for all pipelines in every 100 total graduates.

(c): This is the downstream attrition suffered by the inputs at this phase level.

Note: The percentages shown under the lines connecting the boxes are the phase attritions. This is the loss of students from the number entering the phase to the number of graduates from the phase.

Figure 3.13

of entries into the Advanced Strike phase. Similarly, for the Intermediate Strike phase, 39.3/.92 = 42.7. The postphase attrition suffered by entries into the Intermediate Strike phase is: (42.7 - 36.2)/42.7 = 15.2%. When two or more pipelines share a common phase such as Primary, then the proportionate number of pipeline entries are aggregated, i.e., 42.7 for JET and 68.5 for PROP and HELO for a total of 111.2. The total number of graduates is 100, therefore (111.2 - 100.0)/111.2 = 10.1% postphase attrition when it is not known which pipeline the Primary phase graduate will enter. When this is known, then the postphase attrition changes, e.g., to 15.2% for JET.

c. Pipeline Graduates. Internal calculations in the UPT DSFM are executed in units of pipeline graduates. This technique has served well in coping with the attrition problem in network flows. This requires that the arc capacities must be appropriately deflated to account for the postphase attrition. The manner in which this is done will be described by the categories of arcs delineated in Figure 3.8. Postphase attrition in Figure 3.13 will be used for expository purposes.

Student Input Schdule. Weekly inputs reduced by 26.0% for officer and 32.0% for officer candidates.

Preload of Onboard Students. The total number of students in a phase is reduced by an attrition factor that combines one-half of the inphase attrition and all of the postphase attrition.* For Intermediate Strike, the deflating factor is (1-.04)(1-.08) = .96x.92 = .88 . The use of one-half of the inphase attrition is a manifestation of the assumption that the onboard phase load is uniformly distributed in weeks-to-go-in-phase and also in the likelihood of being attrited. If something different is known about the distribution of either, then a different average of the in-phase attrition should be made.

Phase Training. The full training capacities are reduced by the postphase attrition shown at the terminal of each phase. For example, the capacities for Intermediate Strike would be reduced by 8.0%.

Student Postload. These capacities need no reduction. They have already been reduced as Phase Training arcs.

PTR. These capacities need no reductions.

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*This is a close approximation when inphase attrition is not abnormally large, say, under 25%. A more precise value can be calculated but the difference is of little consequence in this range.

d. Flight Simulators. The availability of sophisticated training devices (OFT and FIT) can have a marked effect on the total training capacity of various phases of the training pipeline. Although flight simulators are not generally considered to be a constraining resource, to some extent they substitute directly for aircraft in pursuing training objectives. The availability of flight simulators can be very significant to the productivity of the actual aircraft on board since there can be a substantial difference between the aircraft hours required per phase graduate with and without the simulators. Particular care must be exercised in adjusting flight hours per phase graduate to accommodate introduction schedules for new simulators or changes in the syllabus mix of aircraft and simulator flight hours.

e. Aircraft Inventories. The number of assignable aircraft in the UPT inventory is stable for the most part; however, when introducing a new aircraft or when phasing out an older aircraft, the expected number by time period can be an elusive factor. The programmed inventories of training aircraft can be obtained from various sources. Judgment may be required in ironing out discrepancies in some cases. While the DSFM can accommodate weekly changes in aircraft inventories, a more practical interval would seem to be quarterly. Figure 3.14 is an example of these inventories.

In allocating aircraft of the same type among phases, the pipeline percentages of the total PTR again play a part. Both the T28 and the T34C are allocated between Primary and Intermediate PROP/HELO for purposes of the UPT DSFM. Consider the following example.

Average Total Aircraft Hours per Phase Graduate

Aircraft	Primary Phase	Intermediate PROP/HELO Phase
T28	86.2	29.8
T34C without 2B37	109.5	38.4
T34C with 2B37	87.0	29.9

With reference to Figure 3.13, the postphase attrition chart, it is noted that:

38.4% of the Primary graduates go to the JET pipeline, and
61.6% go the Intermediate PROP/HELO phase.

AIRCRAFT INVENTORIES

	Type A/C	FY80 Q1	FY80 Q2	FY80 Q3	FY80 Q4	FY81 Q1	FY81 Q2	FY81 Q3	FY81 Q4	FY82 Q1	FY82 Q2	FY82 Q3	FY82 Q4
Whiting:													
Primary &	T34C	152	151	153	161	169	170	169	168	167	166	165	165
Intermediate	2B37	3	7	10	13	13							
Corpus:													
Primary & Intermediate	T28	94	94	93	93	85	72	62	53	42	29	16	4
Corpus:													
Maritime	T44A	55				54				53			
	2F29	1	2	3	4	4							
Whiting:													
Primary Helo	TH57	27	28										
Advanced Helo	TH1	61											
Kingsville:													
Basic Jet	T2C	44											
Advanced Jet	TA4	49											
Chase:													
Basic Jet	T2C	46											
Advanced Jet	TA4	48											
Meridian:													
Basic Jet	T2C	34											
Advanced Jet	TA4	31											
Pensacola:													
Basic Jet	T2C	15											
Advanced Jet	TA4	13											

Note: Blank entries on a line indicate a repeat of the last value entered on the left.

Figure 3.14

Therefore:

T28

100% of students get 86.2 hours in Primary	86.2 hrs.
61.6% of students get 29.8 hours in Intermediate	18.4 hrs.
	104.6 hrs./student (on the average)

86.2/104.6 = 82.4% assigned as Primary aircraft

18.4/104.6 = 17.6% assigned as Intermediate aircraft

T34C without 2B37

100% of students get 109.5 hours in Primary	109.5
61.6% of students get 38.4 hours in Intermediate	23.7
	133.2 hrs/student

109.5/133.2 = 82.2% assigned as Primary aircraft

23.7/133.2 = 17.8% assigned as Intermediate aircraft

T34C with 2B37

100% of students get 87.0 hours in Primary	87.0
61.6% of students get 29.9 hours in Intermediate	18.4
	105.4 hrs/student

87.0/105.4 = 82.5% assigned as Primary aircraft

18.4/105.4 = 17.5% assigned as Intermediate aircraft

f. Weeks to Train. The average number of weeks to train a phase graduate is one of the standard planning factors. Given this average, then the weekly variations due to seasonal changes in the weather and daylight hours will be automatically calculated by the DSFM program. This weekly time to train is defined as the time in weeks that a student could expect to spend in completing the phase if he enters the phase at the beginning of that particular week.

Since the weeks-to-train parameter is automatically computed, an explicit description of how these computations are made is in order; but, first, a few words about the rationale underlying the calculations. It can be noted from historical data that, for a phase involving flight training, winter classes are, in general, longer than summer classes. It can also be noted that available daylight flyable hours (daylight hours times weather factor) are less in the winter than in the summer. Since most UPT phases are predominately daylight flight training, the inverse relationship between available daylight flyable hours and class length is taken to be a cause and effect relationship. The

basic assumption is that total number of required daylight flyable hours remains constant for the completion of each class without regard to the time of the year; this assumption being consistent with the fact that winter classes are longer than summer classes.

The relevant planning factors are:

L	Annual average class length in weeks
H_{ij}	Daylight hours on day i of the jth week
W_{ij}	Weather factor on day i of the jth week
D_{ij}	Work day factor(1 -> workday, 0 -> non-workday)

The flyable hours during the jth week are then:

$$F_j = \sum_{i=1}^{7} D_{ij} W_{ij} H_{ij} .$$

The annual average flyable hours per training week, F, may be calculated based on 50 training weeks per year (two weeks off at Christman):

$$F = \sum_{j=1}^{52} F_j/50 .$$

Therefore, the average flyable hours available to the average class of length L is F x L and it is this value that is used to determine the length of a particular class.

The sum of the flyable hours available to a class of length n-weeks starting in week j is:

$$F_j^n = \sum_{k=j}^{j+n-1} F_k .$$

To find the length, L_j, of the jth class, the minimum integer n is sought that satisfies:

$$\text{Min} \left\{ n \middle| F_j^n \geq FL \right\} .$$

Then,

$$L_j = \begin{cases} n, \text{ if } (F_j^n - FL)/(F_j^n - F_j^{n-1}) \leq .5 , \\ n-1, \text{ otherwise.} \end{cases}$$

g. Capacity to Train. A basic input to the UPT DSFM is the average number of phase graduates per week for every phase in the system. This average is based on the maximum production rate to be expected over an entire year for the same operating circumstances. The number need not be used in the DSFM over an entire year but the average weekly production rate must be averaged over a year as though it would be. When this number has been appropriately reduced to pipeline graduates by the postphase attrition, as explained earlier, it is called C. Given this input parameter, then the weekly variation in the capacity to train for a particular phase is automatically computed by the following relationship:

$$C_j = CL/L_j$$

where C_j is defined as the maximum class size of the pipeline graduates to enter at the beginning of the jth week.

The above computation results in the product of each arc's capacity to train and time to train remaining relatively constant. Use of this algorithm results in a more even onboard student population than does a fixed capacity scheme. However, it still exhibits a more pronounced seasonal variation than is desired.

This seasonal variation in student onboard load can be further reduced by taking into account all classes onboard at a point in time when determining the capacity of any one class. First, note that all of the classes onboard for a given week must share the training resources available. Also, that a class of k weeks must, on the average, receive 1/k of its training each week. Now, for a training phase, define:

$\bar{L}$ The annual average time to train independent of the training year.

$\bar{C}_j$ The annual average weekly training capacity in effect for year j week i .

Then, calculate the sum of the timestotrain for all classes onboard at one time for each week in a year, independent of the training year, to be:

$$T \Big|_{i=1}^{52} = \sum_{k=1}^{52} (W_i \varepsilon A_k)(t_k)$$

Where $(W_i \; A_k) = 1$ if arc k spans week i (0 otherwise) and where t_k is the timetotrain for arc k . In this case only 50 arcs represent a training phase, one for each week beginning weeks 1 thru 12 and 15 thru 52. Only the week number is of interest, i.e., the training year is of no concern.

The capacity for each of the n arcs representing a training phase, including the designation by year, is then calculated as:

$$C_k \Big|_{k=1}^{n} = \sum_{j=1}^{5} \sum_{i=1}^{52} \frac{(W_{ji} \varepsilon A_k) \; \bar{L} \; (\bar{C}_{jk})}{T_i}$$

Where $(W_{ji} \varepsilon A_k) = 1$ if arc k spans year j week i (0 wise) and the other other variables are as defined above.

Many scenarios call for one or more changes to C for a particular phase. Unlike L, C can be changed at any week during the time period of interest. Aircraft inventories change over time. Syllabi are modified. When a phase is terminated, the capacities are reduced to zero at the time when no more entries are allowed into the phase. New phases can be initiated by the reverse representation.

The method of determining the value of C is independent of the operation of the DSFM. One method is to base the determination on the planning factor for aircraft utilization as in Figure 3.15. The final column in this tabulation contains "Pipeline Graduates per Aircraft per Year." This factor multiplied by the programmed aircraft inventories in Figure 3.14 will yield values for C shown in Figure 3.16. This method provides a good benchmark; however, if the capacity to train is not constrained by the number of available aircraft, but by maintenance manning level, number of effective instructors on board, or some other resource, possibly students, then the computation for C should reflect these constraints.

The C_j may be individually specified for each week or for some of the weeks. The automatic computation for C_j will be only for those time spans that that are specified.

AIRCRAFT PRODUCTIVITY IN PIPELINE GRADS/YEAR

PHASE NAME	TYPE AIRCRAFT	FLIGHT HOURS/ AIRCRAFT/ YEAR	FLIGHT HOURS/ PHASE GRAD	POST-PHASE ATTRITION	FLIGHT HOURS/ PIPELINE GRAD	PIPELINE GRADS/ AIRCRAFT/ YEAR
Primary	T34C*	800	109.5	10.1	121.8	6.57
	T34C	800	87.0	10.1	96.8	8.26
	T28	622	86.2	10.1	95.9	6.49
Intermediate Prop/Helo	T34C*	800	38.4	4.9	40.4	19.80
	T34C	800	29.9	4.9	31.4	25.48
	T28	622	29.8	4.9	31.3	19.87
Maritime	T44A#	800	136.0	0.0	136.0	5.88
	T44A	800	108.3	0.0	108.3	7.39
Primary Helo	TH57	643	42.1	5.0	44.3	14.51
Advanced Helo	TH1	578	80.5	0.0	80.5	7.18
Basic Jet	T2C	543	134.0	8.0	145.7	3.73
Advanced Jet	TA4	580	144.7	0.0	144.7	4.01

*without 2B37
#without 2F29

Figure 3.15

CAPACITIES: PHASE GRADS/WEEK

	Type A/C	FY80 Q1	FY80 Q2	FY80 Q3	FY80 Q4	FY81 Q1	FY81 Q2	FY81 Q3	FY81 Q4	FY82 Q1	FY82 Q2	FY82 Q3	FY82 Q4
Whiting:	T34C												
Primary		164	176	192	220	230	231	230	230	228	226	225	225
Intermediate		107	118	130	143	153	153	153	148				
Corpus:	T28												
Primary		100	100	100	100	91	77	66	57	45	31	17	4
Intermediate		68	68	68	68	60	52	44	36	23	20	12	4
Corpus:	T44A												
Maritime		65	68	71	75	80				78			
Whiting:													
Primary Helo	TH57	78	81										
Advanced Helo	TH1	88											
Kingsville:													
Basic Jet	T2C	33											
Advanced Jet	TA4	39											
Chase:													
Basic Jet	T2C	34											
Advanced Jet	TA4	38											
Meridian:													
Basic Jet	T2C	25											
Advanced Jet	TA4	25											
Pensacola:													
Basic Jet	T2C	11											
Advanced Jet	TA4	10											

Note 1: All capacities are shown in tenths, i.e., 164 --> 16.4 grads/week.

Note 2: Blank entries on a line indicate a repeat of the last value entered on the left.

Figure 3.16

h. Student Onboard Load. The UPT system is roughly a year in length and, as such, about one year's input of students are in the system at any point in time. The current state of the system for purposes of starting up the DSFM is accounted for by preloading the network with a flow representing the students in the system at the beginning of the time period of interest.

If the best estimate of the distribution of onboard students is that they are evenly distributed with respect to weeks to go in phase, then the DSFM will automatically calculate this distribution. The DSFM considers the phase length in weeks for that particular time of the year and divides the number of students on board by that number of weeks minus one. The minus one reflects the convention that no onboard student at start time has the full number of weeks to go in completing the phase. The full number of weeks are required by any students in a pool awaiting entry into the phase.

If there is reason to believe that the onboard students are not uniformly distributed in the weeks to go in phase, then the actual or estimated distribution can be manually entered.

An example of the onboard student phase load and pools awaiting entry into the various phases are tabulated in Figure 3.17. These data were taken from the Aviation Statistical Report for 1-30 September 1978.

i. Scheduled Student Entries. The source document for the student entry schedule into the Naval Aviation Schools Command (NASC: a preparatory phase before starting flying in the Primary phase) is the current OPNAVNOTE 1542. Figure 3.12 shows a sample of the format of this schedule.

The DSFM will start with the entry of students into the Primary phase of flight training with a separate subroutine to process the entries into the NASC and produce an entry schedule into Primary flight training. Two things must be considered before the entries into Primary can be determined. First, the NASC class duration to find the entry date and, second, that attrition suffered while in the NASC. These factors are different for each of two groups of student inputs: "officers and officer candidates." There may be other variations for special groups entering as Student Naval Aviators (SNAs). XXX

Many problems anticipated for the DSFM will involve the determination of an optimum input schedule. Working the problem backwards, so to speak, requires unambiguous rules for the assignment of students to each of the two groups of students entering the NASC. This distinction is not necessary at the entry

INITIAL STUDENT LOADS*

	Students	Reduced for Postphase Attrition
Onboard Loads		
Phased Primary		
Corpus	28	21
Whiting	88	66
Primary		
Corpus	120	102
Whiting	382	326
Intermediate Prop		
Corpus	6	6
Whiting	51	48
Intermediate Strike		
Corpus	141	124
Whiting	84	74
Advanced Strike		
Corpus	71	68
Whiting	39	37
Maritime		
Corpus	123	122
Primary Helo		
Whiting	55	52
Advanced Helo		
Whiting	41	40
Pools Awaiting Entry into:		
Primary	385	300
Intermediate Strike		
Corpus	54	46
Whiting	24	20
Advanced Strike		
Corpus	8	7
Whiting	9	8
Maritime or Primary Helo	10	10

*Ref: CNATRA "Aviation Statistical Report" 1-30 September 1978.

Figure 3.17

point into the Primary flight phase of training. The network in Figure 3.3 or an analogous one would be used for the creation of student input schedules which would be optimum in the sense of satisfying the Primary flight entry requirements.

3.3.3 SERE. Graduates of UPT receive survival training at an East Coast location near Brunswick, ME and a West Coast location near San Diego, CA enroute to their Fleet Readiness Squadrons Classes convene about three times per month at both locations. Since students graduate from UPT every week, there are occasions where no class is immediately available. Similarly, there are times when graduates from SERE cannot be accommodated by FRS convening dates without a delay of some weeks. While the DSFM cannot provide a perfect match, it can suggest improvements to minimize loss of time between a student's designation as a Naval Aviator and his entry into formal FRS training.

3.3.4 FRS Inputs. It is anticipated that planning factors will have more direct application in this portion of the DSFM network than in the UPT portion. FRS planning factors are routinely updated annually in accordance with OPNAV INSTRUCTION 3760.13. Training progress is reported in accordance with OPNAV INSTRUCTION 3500.31D.

There are over 25 FRSs. Each of them is unique in some way from the others, perhaps by mission, syllabus, student body, environment, available facilities or operating circumstances. There are some fairly common characteristics, however, that contrast with the UPT program.

a. Student Body. Starting dates for classes are a month or more apart while UPT has 50 classes a year. This presents, roughly speaking, something analogous to a gear with 50 teeth trying to mesh with a gear of the same diameter with 12 or fewer teeth. Class sizes are usually smaller than the classes entering Primary flight in UPT, although more categories of students are trained in an FRS. The categories are the following ones.

CAT I - Full syllabus - normally first tour pilots - occasionally experienced - first tour in type - all UPT grads are CAT I.

CAT II - Approximately 70-80% of syllabus - normally not current - second tour in type.

CAT III - Approximately 40-50% of syllabus - current in model.

CAT IV - Varies from 10% for tactical to 65% for helo - this is the miscellaneous category.

CAT V - Foreign and special student syllabus.

The NFO community also has members in the training classes of many of the FRSs, which involves shared syllabi and coordinated scheduling.

b. The FRS flight training is not usually the dominant activity at the air facility at which it is located. In the UPT program, just the opposite is true.

c. Weather and daylight hours are significant factors in the training rate in UPT, but these factors have much less influence on the more advanced FRS training.

d. UPT has a dedicated aircraft carrier, the LEXINGTON, for carrier qualification flights. The LEXINGTON gets some use by the FRS community, but most squadrons require the larger fleet carrier. The availability of fleet carrier deck time is, to some extent, a variable. This is, perhaps, the biggest single constraint on the training rate of the tactical FRSs.

3.4 Outputs. The routine outputs from the DSFM are designed to respond to a broad spectrum of information requirements from command, staff, management and operational levels. In total, the output is quite voluminous, but, in general, the higher the echelon, the more the information is aggregated and the less voluminous it becomes.

3.4.1 Basic UPT DSFM Outputs.

a. The following types of information are routinely available from this subsystem of the DSFM. The information may be displayed by weekly, quarterly or annual increments.

(1) Students entering a phase of training.
(2) Phase training capacity for entrants.
(3) Students graduating a phase of training.
(4) Phase training capacity for graduates.

(5) Students attriting from a phase of training.

(6) Students on board in a phase of training.

(7) Phase onboard capacity.

(8) Unused phase training capacity for entrants.

(9) Unused phase training capacity for graduates.

(10) Students in pool status at entry to a phase of training.

(11) Students in transit to next phase of training.

(12) Resource utilization by phase of training.

(13) Resource planned by phase of training.

b. Types 12 and 13 above allow phase graduates (Type 12) and phase capacity (Type 13) to be converted through planning factor information to list resource requirements, both utilized and planned, respectively. Examples of the resources that can be displayed are:

(1) Aircraft flight hours.

(2) Instructor flight hours.

(3) Aircraft inventory.

(4) Instructors.

(5) Maintenance personnel.

(6) Director costs -

Aircraft Operation (OMN)

POL

O&I-level maintenance

Aircraft Rework (OMN)

Engine overhaul

Component rework

SDLM

Replenishment Spares (APN)

Personnel (MPN)

Indirect costs -

Indirect (OMN)

Indirect (MPN)

As a practical matter, Types 12 and 13 data will be aggregated at the quarterly and annual levels only, since weekly increments would appear to have little worth.

c. The standard formats for information Types 1 through 11 have been geared for the executive, staff and analyst levels.

(1) Executive Summary. This is a one page report giving yearly values only. Figure 3.18 is a typical example listing the data elements normally displayed.

(2) Staff Summary: This is a quarterly report displaying one of the data types 1 through 13 by phase, then another by phase and so forth. Figure 3.19 is an example of a partial listing for Phase Graduates (Type 3) by quarter for three years.

(3) Analyst Report: This report displays the weekly values for any data element by phase for Types 1 through 11. In the example, Figure 3.20, there is a listing of the number of student-weeks in pools awaiting entry (Type 10) into the Advanced Strike phase. Pools can be seen building, peaking out, then diminishing and continuing to cycle in that manner. Part of this is due to seasonal variation in environmental conditions, but some is due to a less than optimum student input schedule into Primary and some may be due to an imbalance in the total system. One would have to look at the total analyst listings to get a grasp of the cause for this effect. The point here is that the weekly breakdown of student flow activity would give the trained analyst a probe into student flows not heretofore possible. Annual totals may be sufficient to sound the alarm at the executive and senior staff levels, but the detailed analyst listing provides the necessary tools for an intrinsic comprehension of what is being projected and the explicit recommendations for action to avoid the unwanted events.

3.4.2 NASC DSFM Outputs.

a. The NASC network is normally run following a UPT network run. The student pilot flow requirements are then set to match the input requirements into the Primary flight training phase for as many years as the UPT DSFM was run. This is normally set at three years. The specific output of the NASC DSFM is a student input schedule for SNAs by source, i.e., AOC, USMC, USCG, etc. These schedules are produced typically for three years hence. Figure 3.21 is an example of a one-year schedule. This can be compared to the OpNav example in Figure 3.12 for format similarity.

b. Following the production of the SNA input schedules, the NFO/AI/AMDO schedule is developed in much the same way except that the inputs are matched to NASC output requirements that were established outside the UPT DSFM. The NASC classes start each week, excepting the Christmas holidays, and they have a fixed maximum size. A minimum number of student seats are reserved

PATHFINDER - DYNAMIC STUDENT FLOW MODEL
05/14/81 BASIC UPT - FY81 WK1 - SOLUTION 8A.26 075151

EXECUTIVE SUMMARY

	FY81	FY82	FY83
GRADUATES			
JET	562	545	567
MARITIME	396	422	437
HELO	579	640	668
PTR			
JET	576	634	646
MARITIME	396	422	437
HELO	579	640	668
TOTAL	1551	1696	1751
SHORTFALLS			
JET	14	89	79
MARITIME	0	0	0
HELO	0	0	0
STUDENTS FROM SCHOOLS COMMAND	2092	2294	2244
STUDENT-WEEKS IN POOLS	3901	5283	7290
CNATRA AOB	1667	1778	1882
IN PHASE	1547	1627	1691
IN TRANSIT	41	44	45
IN POOL	78	105	145

Figure 3.18

1 05/14/81 PATHFINDER - DYNAMIC STUDENT FLOW MODEL
BASIC UPT - FY81 WK1 - SOLUTION 8A.28 075151

FULL STAFF SUMMARY

GRADUATES		FY81	FY82	FY83
STUDENTS FROM SCHOOLS COMMAND		2092	2294	2244
	FQ1	470	537	479
	FQ2	490	446	455
	FQ3	545	638	638
	FQ4	587	673	672
PRIMARY		1681	1805	1867
	FQ1	333	366	400
	FQ2	331	366	372
	FQ3	540	573	594
	FQ4	477	500	501
INTERMEDIATE STRIKE		577	595	628
	FQ1	137	113	114
	FQ2	127	123	123
	FQ3	143	174	206
	FQ4	170	185	185
ADVANCED STRIKE		562	545	567
	FQ1	121	116	118
	FQ2	118	110	129
	FQ3	186	156	157
	FQ4	137	163	163
PHASED MARITIME		396	422	437
	FQ1	77	88	88
	FQ2	81	88	88
	FQ3	122	136	151
	FQ4	116	110	110

Figure 3.19

PATHFINDER - DYNAMIC STUDENT FLOW MODEL
05/14/81 BASIC UPT - FY81 WK1 - SOLUTION 8A.26 075151

ANALYST REPORT

AVERAGE STUDENT WEEKS IN POOLS					FY81	FY82	FY83
INTO PRIMARY					58	67	74
FQ1	19	46	74	FQ3	87	74	74
FW01	0	0	74	FW27	99	74	74
FW02	0	3	74	FW28	118	74	74
FW03	0	6	74	FW29	112	74	75
FW04	0	14	74	FW30	96	74	74
FW05	0	17	74	FW31	91	74	74
FW06	0	74	74	FW32	86	74	74
FW07	8	74	74	FW33	79	74	74
FW08	23	74	74	FW34	83	74	74
FW09	59	76	74	FW35	81	74	74
FW10	61	74	74	FW36	74	74	74
FW11	63	74	74	FW37	74	74	74
FW12	21	74	74	FW38	74	74	74
				FW39	75	74	74
FQ2	90	74	74	FQ4	35	74	74
				FW40	71	75	74
FW15	51	83	74	FW41	75	74	74
FW16	52	74	74	FW42	70	74	74
FW17	72	74	74	FW43	62	74	74
FW18	72	74	74	FW44	55	74	74
FW19	75	74	74	FW45	46	74	74
FW20	109	74	74	FW46	29	74	74
FW21	105	74	74	FW47	18	74	74
FW22	112	74	74	FW48	4	74	74
FW23	116	74	74	FW49	12	74	74
FW24	111	74	74	FW50	14	74	74
FW25	108	74	74	FW51	8	74	74
FW26	101	74	74	FW52	1	74	74

Figure 3.20

OSPM 10.10/8.26 **PROPOSED AVIATION (PILOT) INPUT LOADING PLAN - FY82 THROUGH FY84** 2/17/81

FY 82		AOC				AVROC				OFFICER				USMC				USCG				FOREIGN			
		P		A		P		A		P		A		P		A		P		A		P		A	
CL CVN	CL NO	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM
			312																						
10/05/81	1#	15	327			2	2			15	15			13	13			0	0			5	5		
10/12/81	2	15	342			2	4			12	27			10	23			2	2			0	5		
10/19/81	3	15	357			2	6			14	41			11	34			2	4			0	5		
10/26/81	4	15	372			2	8			5	46			10	44			0	4			0	5		
11/02/81	5	15	387			2	10			4	50			10	54			1	5			0	5		
11/09/81	6	15	402			0	10			5	55			10	64			0	5			0	5		
11/16/81	7	15	417			0	10			14	69			10	74			0	5			0	5		
11/23/81	8	15	432			0	10			5	74			11	85			0	5			0	5		
11/30/81	9	16	448			0	10			4	78			10	95			2	7			0	5		
12/07/81	10	20	468			0	10			4	82			10	105			2	9			0	5		
12/14/81	11	24	492			0	10			16	98			15	120			0	9			5	10		
1/11/82	12	24	516			0	10			14	112			10	130			2	11			0	10		
1/18/82	13	24	540			0	10			12	124			11	141			2	13			0	10		
1/25/82	14	24	564			0	10			15	139			10	151			2	15			0	10		
2/01/82	15	24	588			0	10			11	150			10	161			2	17			0	10		
2/08/82	16	24	612			0	10			9	159			11	172			2	19			2	12		
2/15/82	17	24	636			0	10			4	163			11	183			2	21			5	17		
2/22/82	18	24	660			0	10			14	177			13	196			2	23			0	27		
3/01/82	19	24	684			0	10			7	184			20	216			2	25			5	22		
3/08/82	20	24	708			0	10			8	192			18	234			2	27			0	22		
3/15/82	21	24	732			0	10			6	198			10	244			2	29			4	26		
3/22/82	22	25	757			0	10			6	204			13	257			0	29			5	31		
3/29/82	23	25	78[illegible]			0	10			7	211			18	275			[illegible]	29			[illegible]	31		
4/05/82	24	24	806			0	10			7	218			19	294			1	30			0	31		
4/12/82	25*	35	841			0	10			7	225			19	313			1	31			2	33		

\# AOC classes 1-[illegible] contain AOC students from AVROC [illegible]. There are no AVROC [illegible] for FY82 [illegible] 125 will enter AOCS during the 3rd and 4th quarters of FY 82 as FY83 accessions. * AOCS class [illegible] is composed of 35 prospective flying EDOs.

Figure 3.21a

OSPN 10.10/8.20 **PROPOSED AVIATION (PILOT) INPUT LOADING PLAN - FY82 THROUGH FY84** 2/17/81

FY 82			AOC				AVROC				OFFICER				USMC				USCG				FOREIGN			
			P		A		P		A		P		A		P		A		P		A		P		A	
CL CVN	CL NO		WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM
				841				10				225				313				31				33		
4/19/82	26		14	855			0	10			7	232			14	327			2	33			3	36		
4/26/82	27		14	869			0	10			7	239			17	344			2	35			5	41		
5/03/82	28		15	884			0	10			7	246			16	360			1	36			4	45		
5/10/82	29		15	899			0	10			7	253			20	380			1	37			6	51		
5/17/82	30		14	913			0	10			7	260			21	401			1	38			5	56		
5/24/82	31		15	928			0	10			15	275			15	416			0	38			1	57		
5/31/82	32		14	942			0	10			15	290			20	436			0	38			0	57		
6/07/82	33		15	957			0	10			15	305			20	456			0	38			5	62		
6/14/82	34		14	971			0	10			15	320			20	476			0	38			1	63		
6/21/82	35		15	986			0	10			15	335			20	496			0	38			4	67		
6/28/82	36		24	010			0	10			15	350			20	516			0	38			5	72		
7/05/82	37		25	25			9	9			15	365			20	536			2	40			2	74		
7/12/82	38		24	49			9	18			15	380			20	556			2	42			3	77		
7/19/82	39		24	73			10	28			15	395			20	576			2	44			2	79		
7/26/82	40		24	97			10	38			15	410			21	597			2	46			2	81		
8/02/82	41		25	122			10	48			15	425			10	607			1	47			0	81		
8/09/82	42		20	142			3	51			15	440			20	627			1	48			1	82		
8/16/82	43		20	162			3	54			15	455			20	647			1	49			1	83		
8/23/82	44		20	182			4	58			15	470			12	659			2	51			0	83		
8/30/82	45		20	202			3	61			6	476			10	669			2	53			0	83		
9/06/82	46		20	222			4	65			4	480			10	679			1	54			0	83		
9/13/82	47		20	242			3	68			4	484			11	690			1	55			0	83		
9/20/82	48		20	262			3	71			7	491			10	700			1	56			0	83		
9/27/82	49		20	282			4	75			4	495			10	710			1	57			0	83		
/ /											20	515														

Figure 3.21b

during the SNA calculations for the NFO/AI/AMDO communities. The final schedule is constrained by the residual classroom capacities remaining from the SNA schedule. Figure 3.22 is a one-year example which matches with the SNA schedule in Figure 3.21.

c. Figure 3.23 is a working schedule of all NASC students showing that the maximum class size has not been violated. This schedule may be used for making trade-offs between student types. Figure 3.23 is a combination of Figures 3.21 and 3.22.

3.4.3 FRS DSFM Outputs. The output of the UPT DSFM subsystem provides the inputs to the FRS DSFM subsystem. This is suboptimization in the strict sense of the continuous flow of students from entry into UPT until they are assigned to a fleet squadron, but there is general agreement among the principals that the critical linkages in the production chain are in the UPT program and will remain so for an indefinite time in the future. Moreover, any partitioning of the total network has a practical payoff in terms of data processing storage space and running times. The outputs from the FRS DSFM will be a selected subset of the output Types 1 through 11 listed in 3.4.1 (a) as may be requested by the user community.

3.4.4 SNA Training Paths. The DSFM will have the capability of decomposing all flow solutions into separate paths for student entrants to pipeline graduation or attrition in the UPT DSFM subsystem. Each path will be the shortest one possible in terms of time to train. The list of paths will be ordered by departure date which may be used to generate a report relating pipeline graduations to time of entry into the system. Since the UPT DSFM does not distinguish among the different student sources, i.e., Navy AOC, Navy officers, USMC, etc., this report would provide a convenient device for scheduling different students by source with their different pipeline attrition rates.

4. Environment

The DSFM requires what is best described as a modern medium scale general purpose computing system. That is, such a system exhibits reasonable response times when exercising the DSFM.

The system described below under Sections 4.1 (Hardware) and 4.2 (Software) represents the developmental environment for the DSFM.

4.1 Equipment Environment. The developmental hardware system has been an IBM 370/148 configured as follows:

PROPOSED AVIATION (NFO/AI/AMDO) INPUT LOADING PLAN

2/25/81

FY 82		NFOC				AVROC				OFFICER				USMC				AI				AMDOC			
		P		A		P		A		P		A		P		A		P		A		P		A	
CL CVN	CL RO	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM
			173																21				15		
10/05/81	1	10	183			0	0			5	5			2	2			2	23			1	16		
10/12/81	2	10	193			0	0			5	10			2	4			1	24			1	17		
10/19/81	3	10	203			0	0			5	15			2	6			2	26			1	18		
10/26/81	4	10	213			0	0			5	20			1	7			1	27			1	19		
11/02/81	5	10	223			0	0			5	25			1	8			2	29			1	20		
11/09/81	6	10	233			0	0			5	30			1	9			1	30			0	20		
11/16/81	7	10	243			0	0			5	35			1	10			2	32			1	21		
11/23/81	8	9	252			0	0			5	40			1	11			1	33			1	22		
11/30/81	9	9	261			0	0			5	45			1	12			2	35			1	23		
12/07/81	10	9	270			0	0			5	50			1	13			1	36			1	24		
12/14/81	11	9	279			0	0			5	55			1	14			2	38			1	25		
1/11/82	12	9	288			0	0			5	60			1	15			1	39			0	25		
1/18/82	13	9	297			0	0			5	65			1	16			2	41			1	26		
1/25/82	14	9	306			0	0			5	70			1	17			1	42			1	27		
2/01/82	15	9	315			0	0			5	75			1	18			2	44			1	28		
2/08/82	16	9	324			0	0			5	80			1	19			1	45			1	29		
2/15/82	17	9	333			0	0			5	85			1	20			2	47			1	30		
2/22/82	18	9	342			0	0			5	90			1	21			1	48			0	30		
3/01/82	19	9	351			0	0			5	95			1	22			2	50			1	31		
3/08/82	20	9	360			0	0			5	100			1	23			1	51			1	32		
3/15/82	21	9	369			0	0			5	105			1	24			2	53			1	33		
3/22/82	22	9	378			0	0			5	110			1	25			1	54			1	34		
3/29/82	23	9	387			0	0			5	115			1	26			2	56			1	35		
4/05/82	24	9	396			0	0			5	120			1	27			2	58			1	36		
4/12/82	25	9	405			0	0			5	125			1	28			1	59			0	36		

Figure 3.22a

PROPOSED AVIATION (NFO/AI/AMDO) INPUT LOADING PLAN

2/25/81

FY 82			NFOC				AVROC				OFFICER				USNC				AI				AMDOC			
			P		A		P		A		P		A		P		A		P		A		P		A	
CL CVN	CL NO		WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM	WK	CM
				405				0				125				28				59				36		
5/19/82	26		9	414			0	0			5	130			1	29			1	60			1	37		
5/26/82	27		9	423			0	0			5	135			1	30			2	62			1	38		
6/02/82	28		9	432			0	0			5	140			1	31			1	63			1	39		
6/09/82	29		9	441			0	0			5	145			1	32			2	65			1	40		
6/16/82	30		9	450			0	0			5	150			1	33			1	66			0	40		
6/23/82	31		9	459			0	0			5	155			1	34			2	68			1	41		
6/30/82	32		9	468			0	0			5	160			1	35			1	69			1	42		
7/07/82	33		15	483			0	0			4	164			1	36			2	71			1	43		
7/14/82	34		15	498			0	0			8	172			1	37			1	72			1	44		
7/21/82	35		15	513			0	0			5	177			1	38			2	74			1	45		
7/28/82	36		15	528			0	0			4	181			1	39			1	75			0	45		
8/04/82	37		8	8			0	0			5	186			1	40			2	2			1	1		
8/11/82	38		10	18			0	0			4	190			1	41			1	3			1	2		
8/18/82	39		8	26			0	0			5	195			1	42			2	5			1	3		
8/25/82	40		9	35			0	0			5	200			1	43			1	6			1	4		
9/01/82	41		7	42			0	0			18	218			1	44			2	8			1	5		
9/08/82	42		18	60			2	2			7	225			1	45			1	9			1	6		
9/15/82	43		18	78			1	3			7	232			1	46			2	11			1	7		
9/22/82	44		18	96			1	4			7	239			2	48			1	12			1	8		
9/29/82	45		18	114			1	5			6	245			2	50			2	14			1	9		
10/06/82	46		18	132			1	6			6	251			2	52			1	15			1	10		
10/13/82	47		18	150			1	7			6	257			2	54			2	17			1	11		
10/20/82	48		18	168			2	9			6	263			2	56			1	18			1	12		
10/27/82	49		18	186			0	9			6	269			2	58			2	20			1	13		
/ /	50																									

Figure 3.22b

NASC FLOW CHART

2/25/81

F Y 8 2		A O C S							A P F I						
						A V R O C			N A V Y		U S M C		USCG		FORN
CL CVN	CL NO	AOC	NFOC	A I	AMDO	SNA	NFO	TOTAL	SNA	NFO	SNA	NFO	SNA	TOTAL	SNA
10/05/81	1	17	10	2	1	0	0	30	15	5	13	2	0	35	5
10/12/81	2	17	10	1	1	0	0	29	12	5	10	2	2	31	0
10/19/81	3	17	10	2	1	0	0	30	14	5	11	2	2	34	0
10/26/81	4	17	10	1	1	0	0	29	5	5	10	1	0	21	0
11/02/81	5	17	10	2	1	0	0	30	4	5	10	1	1	21	0
11/09/81	6	15	10	1	0	0	0	26	5	5	10	1	0	21	0
11/16/81	7	15	10	2	1	0	0	28	14	5	10	1	0	30	0
11/23/81	8	15	9	1	1	0	0	26	5	5	11	1	0	22	0
11/30/81	9	16	9	2	1	0	0	28	4	5	10	1	2	22	0
12/07/81	10	20	9	1	1	0	0	31	4	5	10	1	2	22	0
12/14/81	11	24	9	2	1	0	0	36	16	5	15	1	0	37	5
1/11/82	12	24	9	1	0	0	0	34	14	5	10	1	2	32	0
1/18/82	13	24	9	2	1	0	0	36	12	5	11	1	2	31	0
1/25/82	14	24	9	1	1	0	0	35	15	5	10	1	2	33	0
2/01/82	15	24	9	2	1	0	0	36	11	5	10	1	2	29	0
2/08/82	16	24	9	1	1	0	0	35	9	5	11	1	2	28	2
2/15/82	17	24	9	2	1	0	0	36	4	5	11	1	2	23	5
2/22/82	18	24	9	1	0	0	0	34	14	5	13	1	2	35	0
3/01/82	19	24	9	2	1	0	0	36	7	5	20	1	2	35	5
3/08/82	20	24	9	1	1	0	0	35	8	5	18	1	2	34	0
3/15/82	21	24	9	2	1	0	0	36	6	5	10	1	2	24	4
3/22/82	22	25	9	1	1	0	0	36	6	5	13	1	0	25	5
3/29/82	23	25	9	2	1	0	0	37	7	5	18	1	0	31	0
4/05/82	24	24	9	2	1	0	0	36	7	5	19	1	1	33	0
4/12/82	25	35	9	1	0	0	0	45	7	5	19	1	1	33	2

Figure 3.23a

NASC FLOW CHART

2/25/81

FY 82		AOCS							APFI						
						AVROC			NAVY		USMC		USCG		FORN
CL CVN	CL NO	AOC	NFOC	A I	AMDO	SNA	NFO	TOTAL	SNA	NFO	SNA	NFO	SNA	TOTAL	SNA
4/19/82	26	14	9	1	1	0	0	25	7	5	14	1	2	29	3
4/26/82	27	14	9	2	1	0	0	26	7	5	17	1	2	32	5
5/03/82	28	15	9	1	1	0	0	26	7	5	16	1	1	30	4
5/10/82	29	15	9	2	1	0	0	27	7	5	20	1	1	34	6
5/17/82	30	14	9	1	0	0	0	24	7	5	21	1	1	35	5
5/24/82	31	15	9	2	1	0	0	27	15	5	15	1	0	36	1
5/31/82	32	14	9	1	1	0	0	25	15	5	20	1	0	41	0
6/07/82	33	15	15	2	1	0	0	33	15	4	20	1	0	40	5
6/14/82	34	14	15	1	1	0	0	31	15	8	20	1	0	44	0
6/21/82	35	15	15	2	1	0	0	33	15	5	20	1	0	41	4
6/28/82	36	24	15	1	0	0	0	40	15	4	20	1	0	40	5
7/05/82	37	25	8	2	1	9	0	45	15	5	20	1	2	43	2
7/12/82	38	24	10	1	1	9	0	45	15	4	20	1	2	42	3
7/19/82	39	24	8	2	1	10	0	45	15	5	20	1	2	43	2
7/26/82	40	24	9	1	1	10	0	45	15	5	21	1	2	44	2
8/02/82	41	25	7	2	1	10	0	45	15	18	10	1	1	45	0
8/09/82	42	20	18	1	1	3	2	45	15	7	20	1	1	44	1
8/16/82	43	20	18	2	1	3	1	45	15	7	20	1	1	44	1
8/23/82	44	20	18	1	1	4	1	45	15	7	12	2	2	38	0
8/30/82	45	20	18	2	1	3	1	45	6	6	10	2	2	26	0
9/06/82	46	20	16	1	1	4	1	45	4	6	10	2	1	23	0
9/13/82	47	20	16	2	1	3	1	45	4	6	11	2	1	24	0
9/20/82	48	20	18	1	1	3	2	45	7	6	10	2	1	26	0
9/27/82	49	20	18	2	1	4	0	45	4	6	10	2	1	23	0
	50														

Figure 3.23b

1 - IBM 370/148 CPU with 2 million bytes of real memory
6 - 3330-1 Disk Drives
2 - 3330-11 Disk Drives
4 - 3350 Disk Drives
7 - 3420-5 Tape Drives (800 BPI/1600 BPI)
2 - 3203 Printers
1 - 3505 Card Reader
1 - 3525 Card Punch
1 - 3705 Telecommunications Controller
1 - DATA 100 RJE Station

4.2 Support Software Environment. The development support software environment has been as follows:

OS/VSI Release 6.0E - Operating System
JESI - Job Entry Subsystem
RES - Remote Job Entry Subsystem
APLSV - Dial-up Time Sharing Language
6 - 256k User Problem Program Partitions
(up to 1024k Partition available upon request)
(Various) Compilers and Applications Packages
(PL/I Optimizing Compiler, VM/370 Facility)

4.3 Interfaces. The DSFM does not interface with any known systems although the DSFM detailed outputs may generate inputs for several such systems.

4.4 Security and Privacy. The DSFM does not use nor does it generate any classified information. It contains no data affected by the Privacy Act.

REFERENCES

[1] The George Washington University, Program in Logistics letter Serial 60411 dated 5 July 1977.

[2] The George Washington University, Program in Logistics letter Serial 60426 dated 31 January 1978.

[3] CAVES, WILLIAM E. and W. L. WILKINSON (1977). Dynamic flight student flow model. Technical Paper Serial T-362. Program in Logistics, The George Washington University.

[4] CAVES, WILLIAM E., DICKY WIELAND and W. L. WILKINSON (1979). An exercise of the dynamic student flow model. Technical Paper Serial T-398. Program in Logistics, The George Washington University.

[5] CAVES, WILLIAM E., DICKY WIELAND and W. L. WILKINSON (1980). Dynamics Student Flow Model: An overview. Technical Paper Serial T-420. Program in Logistics, The George Washington University.

[6] Department of Defense Standard 7935.1-S, dated 13 September 1977. Automated Data Systems Documentation Standards.

APPENDIX A

AN OUT-OF-KILTER METHOD FOR MINIMAL COST FLOW PROBLEMS

Background. The Out-of-Kilter (OOK) algorithm by D. R. Fulkerson provides a powerful method for solving minimal cost network flow problems. The method is very general in the sense that:

(a) lower bounds as well as capacities are assumed for each arc flow, and are dealt with directly;

(b) the cost coefficient for an arc is arbitrary in sign;

(c) the method can be initiated with any circulation, feasible or not, and any set of node numbers. Node numbers may be interpreted as potentials or prices.

These properties of the OOK will be made more precise in the sequel.

The OOK first appeared in the literature in Reference [1]. Then later, in Reference [2], it was integrated into a book on network flows.

Motivation. The properties of the OOK mentioned above offer a compelling opportunity to predict, investigate, and control student flows in the context of the flight training program. Consider a 'supply and demand' network where the supply is represented by the student input schedule into the initial indoctrination ground school (NASC) plus the students already on board. The demand side is represented by the Pilot Training Requirements (PTR) by time periods. The intermediate network is composed of the various phases of the flight training process in as much detail as desired. To each arc in the full network there are assigned three parameters: a time duration, which is the cost coefficient of the OOK; and an upper and lower bound on student flows

in the arc. The upper bound is permissive and the lower is required for a feasible solution.

The time duration most often represents the time in weeks to complete a phase; however, for some events like student inputs to NASC or students graduating as part of the PTR, the time duration is simply zero.

The upper bound on the flow is set to limit the allowable flow. This could be limited by available student inputs, training resources or, say, the desirable PTR. Alternatively, this upper limit could be set arbitrarily high to determine the maximum throughput of the system.

The lower bound represents the minimum acceptable flow. This could be the scheduled student inputs, the PTR, or the minimum acceptable class size, if there is to be a class at all. The upper and lower flow bounds may, of course, coincide.

The freedom to assign these three arc parameters provides the means of interpreting a wide variety of scenarios in terms of the OOK.

A significant property of the OOK is the ability to start with any flow, feasible or not. For example, in actual applications, one is often interested in seeing what changes will occur in an optimal solution when some of the given data are altered. This method is tailored for such an examination, since the old solution can be used to start the new problem, thereby greatly decreasing computation time.

Notation, Definitions and Problem Formulation. Let $G = [N;A]$ be a finite directed network with N representing the node set and A the arc set. In the node set, there are two distinct nodes. The node s is the source and the node t is the sink or terminal node of the network. To each arc (x,y) in N there is associated three integers:

$\ell(x,y)$, the arc lower flow bound;

$c(x,y)$, the arc upper bound or capacity;

$a(x,y)$, the arc cost, with

$0 \leq \ell(x,y) \leq c(x,y)$.

The $a(x,y)$ is arbitrary in sign. (In the context of the DSFM, cost represents time to train.) The flow in (x,y) is denoted by $f(x,y)$. The value of the flow f from s to t is termed v.

The minimal cost flow problem is sometimes described in the following way.

(1) Minimize $\Sigma\ a(x,y)\ f(x,y)$,

(2) subject to:

$$f(x,N) - f(N,x) = \begin{cases} -v, & x = t \\ 0, & x \neq s,t \\ v, & x = s \end{cases}, \qquad \text{all } x \in N ,$$

(3) $$\ell(x,y) \leq f(x,y) \leq c(x,y) , \qquad \text{all } (x,y) \in A .$$

In the context of the OOK, it is convenient to state this problem in circulation form by replacing (2) with:

(4) $$f(x,N) - f(N,x) = 0, \qquad \text{all } x \in N$$

Thus, if it is desired to construct a feasible flow from s to t of given value v that minimizes (1), one can merely add a return arc (t,s) with $\ell(t,s) = c(t,s) = v$, $a(t,s) = 0$, to get the problem in circulation form. Or, if it is desired to construct a maximal feasible flow from s to t that minimizes (1), one can take $\ell(t.s) = 0$, c(t,s) large and a(t,s) negatively large.

Of course, feasible circulations may not exist. In this case, the algorithm would normally terminate. (For purposes of the DSFM, the algorithm has been modified to proceed to the next out-of-kilter arc in an attempt to get as many arcs in kilter as possible. From an operational perspective, one is interested to learn 'how much' is the system out of kilter if, indeed, it is at all. In the modification, care is taken to see that an examined out-of-kilter arc is never re-examined. This is essential to ensure termination of the algorithm.)

Let node numbers $\pi(x)$ be a vector of integers, one component for each node x. These node numbers are one of the dual variables and may be interpreted as potentials or prices. Optimality properties for the problem are that the implications:

(5) $\quad a(x,y) + \pi(x) - \pi(y) > 0 \text{ - - -> } f(x,y) = \ell(x,y)$

(6) $\quad a(x,y) + \pi(x) - \pi(y) < 0 \text{ - - -> } f(x,y) = c(x,y)$

hold for all (x,y). That is, if the flow f is a feasible circulation, and if there is a pricing vector π such that (5) and (6) hold, then f is optimal.

The notation is shortened by setting:

$$\bar{a}(x,y) = a(x,y) + \pi(x) - \pi(y) \quad . \tag{7}$$

Then, for given π and circulation f, an arc (x,y) is in just one of the following states:

$$(\alpha) \quad \bar{a}(x,y) > 0, \; f(x,y) = \ell(x,y),$$

$$(\beta) \quad \bar{a}(x,y) = 0, \; \ell(x,y) \leq f(x,y) \leq c(x,y),$$

$$(\gamma) \quad \bar{a}(x,y) < 0, \; f(x,y) = c(x,y),$$

$$(\alpha_1) \quad \bar{a}(x,y) > 0, \; f(x,y) < \ell(x,y),$$

$$(\beta_1) \quad \bar{a}(x,y) = 0, \; f(x,y) < \ell(x,y),$$

$$(\gamma_1) \quad \bar{a}(x,y) < 0, \; f(x,y) < c(x,y),$$

$$(\alpha_2) \quad \bar{a}(x,y) > 0, \; f(x,y) > \ell(x,y),$$

$$(\beta_2) \quad \bar{a}(x,y) = 0, \; f(x,y) > c(x,y),$$

$$(\gamma_2) \quad \bar{a}(x,y) < 0, \; f(x,y) > c(x,y).$$

An arc is <u>in kilter</u> if it is in one of the states α, β, γ; otherwise the arc is <u>out of kilter</u>. Thus, to solve the problem, it suffices to get all arcs in kilter, since optimality properties are (5) and (6).

With each state that an arc (x,y) can be in, we associate a non-negative number, called the <u>kilter number</u> of the arc in the given state. An in-kilter arc has kilter number 0; the arc kilter numbers corresponding to each out-of-kilter state are listed below:

$$(\alpha_1) \text{ or } (\beta_1): \quad \ell(x,y) - f(x,y),$$

$$(\gamma_1): \quad \bar{a}(x,y)[f(x,y) - c(x,y)],$$

$$(\alpha_2): \quad \bar{a}(x,y)[f(x,y) - \ell(x,y)],$$

$$(\beta_2) \text{ or } (\gamma_2): \quad f(x,y) - c(x,y) \quad .$$

Thus, out-of-kilter arcs have positive kilter numbers. The kilter numbers for states α_1, β_1, β_2, γ_2 measure infeasibility for the arc flow f(x,y) while the kilter numbers for states γ_1, α_2 are, in a sense a measure of the degree to which the optimality properties (5) and (6) fail to be satisfied.

The algorithm concentrates on a particular out-of-kilter arc and attempts to put it in kilter. It does this in such a way that all in-kilter arcs stay in kilter, whereas the kilter number for any out-of-kilter arcs either decreases or stays the same. Thus, all arc kilter numbers are monotone non-increasing throughout the computation.

The Out-of-Kilter Algorithm. Enter with any integral circulation f and any set of node integers π. Next locate an out-of-kilter arc (s,t) and go on to the appropriate case below.

$[\alpha_1]$ $\bar{a}(s,t) > 0$, $f(s,t) < \ell(s,t)$. Start a labeling process at t, trying to reach s, first assigning t the label $[s^+, \varepsilon(t) = \ell(s,t) - f(s,t)]$. The labeling rules are:

(8) If x is labeled $[z^{\pm}, \varepsilon(x)]$, y is unlabeled, and if (x,y) is an arc such that either

(a) $\bar{a}(x,y) > 0$, $f(x,y) < \ell(x,y)$,

(b) $\bar{a}(x,y) \leq 0$, $f(x,y) < c(x,y)$,

then y receives the label $[x^+, \varepsilon(y)]$, where

$$\varepsilon(y) = \min [\varepsilon(x), \ell(x,y) - f(x,y)] \text{ in case (a)},$$

$$\varepsilon(y) = \min [\varepsilon(x), c(x,y) - f(x,y)] \text{ in case (b)}$$

(9) If x is labeled $[z^{\pm}, \varepsilon(x)]$, y is unlabeled, and if (y,x) is an arc such that either

(a) $\bar{a}(y,x) \geq 0$, $f(y,x) > \ell(y,x)$,

(b) $\bar{a}(y,x) < 0$, $f(y,x) > c(y,x)$,

then y receives the label $[x^-, \varepsilon(y)]$, where

$$\varepsilon(y) = \min [\varepsilon(x), f(y,x) - \ell(y,x)] \text{ in case (a)},$$

$$\varepsilon(y) = \min [\varepsilon(x), f(y,x) - c(y,x)] \text{ in case (b)}.$$

If breakthrough occurs (that is, s receives a label), so that a path from t to s has been found, change the circulation f by adding $\varepsilon(s)$ to the flow in forward areas of this path, subtracting $\varepsilon(s)$ from the flow in reverse arcs, and finally adding $\varepsilon(s)$ to $f(s,t)$. If nonbreakthrough, let X and $\bar{X}$ denote labeled and unlabeled sets of nodes, and define two subsets of arcs:

$$A_1 = \{(x,y) | x \varepsilon X,\ y \varepsilon \bar{X},\ \bar{a}(x,y) > 0,\ f(x,y) \leq c(x,y)\} ,$$

$$A_2 = \{(y,x) | x \varepsilon X,\ y \varepsilon \bar{X},\ \bar{a}(y,x) < 0,\ f(y,x) \geq \ell(x,y)\} .$$

Then let

$$\delta_1 = \min [\bar{a}(x,y)] ,$$

$$\delta_2 = \min [\bar{a}(y,x)] ,$$

$$\delta = \min (\delta_1, \delta_2) .$$

(Here δ_i is a positive integer or ∞ according as A_i is non-empty or empty.) Change the node integers by adding δ to all $\pi(x)$ for $x \in \bar{X}$.

$[\beta_1]$ or $[\gamma_1]$ $\bar{a}(s,t) = 0$, $f(s,t) < \ell(s,t)$ or $\bar{a}(s,t) < 0$, $f(s,t) < c(s,t)$. Same as $[\alpha_1]$, except $\varepsilon(t) = c(s,t) - f(s,t)$.

$[\alpha_2]$ or $[\beta_2]$ $\bar{a}(s,t) > 0$, $f(s,t) > \ell(s,t)$, or $\bar{a}(s,t) = 0$, $f(s,t) > c(s,t)$. Here the labeling process starts at s , in an attempt to reach t . Node s is assigned the label $[\bar{t}, \varepsilon(s) = f(s,t) - \ell(s,t)]$. The labeling rules are (8) and (9) again. If breakthrough, change the circulation by adding and subtracting $\varepsilon(t)$ to arc flows along the path from s to t ; then subtract $\varepsilon(t)$ from $f(s,t)$. If non-breakthrough, change the node numbers as above.

$[\gamma_2]$ $\bar{a}(s,t) < 0$, $f(s,t) > c(s,t)$. Same as $[\alpha_2]$ or $[\beta_2]$, except $\varepsilon(s) = f(s,t) - c(s,t)$.

The labeling process is repeated for the arc (s,t) until either (s,t) is in kilter, or until a non-breakthrough occurs for which $\delta = \infty$. In the latter case, stop. (There is no feasible solution.) In the former case, locate another out-of-kilter arc and continue. When no out-of-kilter arc exists, the algorithm terminates with the desired feasible flow solution f having been determined.

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