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A MULTISTATE MANPOWER PROJECTION MODEL

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FOREWORD

The principal aim of health care research at IIASA has been to develop a family of submodels of national health care systems for use by health service planners. The modeling work is proceeding along the lines proposed in the Institute's current Research Plan. It involves the construction of linked submodels dealing with population, disease prevalence, resource need, resource allocation, and resource supply.

Margaret Pelling, a visitor to IIASA from the Operational Research Service of the Department of Health and Social Security, UK, has developed a submodel for investigating medical manpower planning problems. A multistate projection model, reflecting the multiregional perspectives elaborated and studied at IIASA, is presented in this paper. Its purpose is to define potential manpower deficiencies in market and planned economies, and it may be used for the projection (not prediction) of manpower supply.

Related publications in the Health Care Systems Task are listed at the end of this report.

Andrei Rogers
Chairman
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ABSTRACT

This paper describes the structure and application of a multistate projection model that was developed by the Operational Research Service of the Department of Health and Social Security, UK. The model can be used to calculate the evolution of a multistate manpower or population distribution, with each state's stock classified either by length of time in a state or by age and subdivided into up to four noninteracting population subgroups (e.g., according to sex and country of origin). Both Markov ("push") and Renewal ("pull") flows can be simulated and a wide range of different network configurations can be modeled.

Medical manpower planning problems are also discussed -- in particular the issue of career planning for doctors in the presence of demand constraints -- to exemplify the possible uses of the model. As background, the role of manpower planning in health care planning and the sorts of problems that arise in balancing the supply of, and demand for, any manpower group are outlined.

The generality of the Department of Health and Social Security model is demonstrated by highlighting its structural similarity to the multistate models that have been the subject of study at IIASA in recent years. The model's uses in detecting both potential manpower supply instabilities in market-based manpower systems and planning infeasibilities in planned systems are pointed out. A model run is discussed, based on a hypothetical situation, in which growth rates of one grade in a manpower network lead to supply problems for the whole network. The Appendix contains sample input and output files.

CONTENTS

A MULTISTATE MANPOWER PROJECTION MODEL

1. INTRODUCTION

The subject of this paper is a multistate projection model for studying the evolution of a manpower or population system. The model was developed in the UK by the Department of Health and Social Security's Operational Research Service. The model, which is computerized, consists of a network of states (e.g., grades in a career structure, or regions of residence) and members of the population being studied can be in any of the states. Transitions can be made from state to state, and each state can also receive population from, or lose population to, the "world" outside the system being modeled. The population in each state can be subdivided into up to four non-interacting subgroups. In the applications of the model made to date, these subgroupings have been according to sex and according to whether the population of a particular region is "native" or "foreign". Other descriptors can be used, provided that the total number of subgroups does not exceed four. In the rest of this paper these subgroups will be called "population subgroups".

The population is also characterized by a "history" in each state, either by years spent in that state or by age. The population distribution changes through time as a result of the pattern of flows in the network of states. The model is a tool for calculating this population distribution over time. A wide range of network configurations can be studied, and facilities exist for varying the flow magnitudes during a projection.

The model has been used to investigate medical manpower planning problems in the UK health care system; the role of this type of model in health care planning is discussed below. The model is very similar to that class of multistate population models elaborated and studied at IIASA in recent years. (See, for example, Rogers 1980a for a discussion of these models). Multistate population systems are projected forward in time using measurements or estimates of interstate transition probabilities and survival probabilities. The probabilities are derived either from previously calculated multistate life tables or from direct observation. The models are formulated using matrix algebra. In section 3 of this paper the model developed in the UK will be expressed in matrix terms to demonstrate its similarity with the IIASA work.

Projection models are used in manpower planning to study the "supply" aspects of a manpower system. In no sense, however, do these models make predictions of what the labor force will look like. They simply enable the consequences of assumed trends to be examined. Manpower modeling itself has an importance in health care planning that cannot be over-emphasized. It can be dangerous first to plan other resources for a health service and only after this has been done, to estimate the manpower needed to operate the service. This is because a set of resources, which is optimal for non-manpower resources, may be grossly suboptimal for manpower. A better overall result might be achieved by giving manpower the same status as non-manpower resources in the planning process.

Manpower planning can be summarized in the following way. First, the planner must assess the demand for manpower that a service organized in a particular way would generate. Then, the supply that could meet the demand has to be determined. Estimating supply and demand is in general an iterative process, which stops when an acceptable plan is reached. In such a plan, supply will match demand, at least within suitable tolerance limits. The demand itself would be the manpower part of a complete set of resources designed to give an acceptable service.

In the next section a typical medical career structure will be outlined, and some of the problems that face manpower planners will be listed. In the third section the operation of the model will be described, and a hypothetical example of the model's use will be given in the fourth section. In the final section the versatility of the model will be emphasized. In order to help potential users, the Appendix shows how a typical input data file is constructed, and a detailed user's guide (1981) is available.

2. MEDICAL MANPOWER PLANNING

2.1. The Typical Medical Career Structure

A medical career structure typically has the features shown in Figure 1. Doctors who work in hospitals have a hierarchical grade structure. At the bottom of the network is a grade for probationer doctors. This grade is usually occupied by new graduates. In the grade at the top of the hierarchy is the doctor who is often the leader of a team of doctors and who has most of the responsibility for patients in a specialty. The grades in between contain doctors who are progressively more specialized with increasing seniority of grade. Doctors in these intermediate grades do much of the

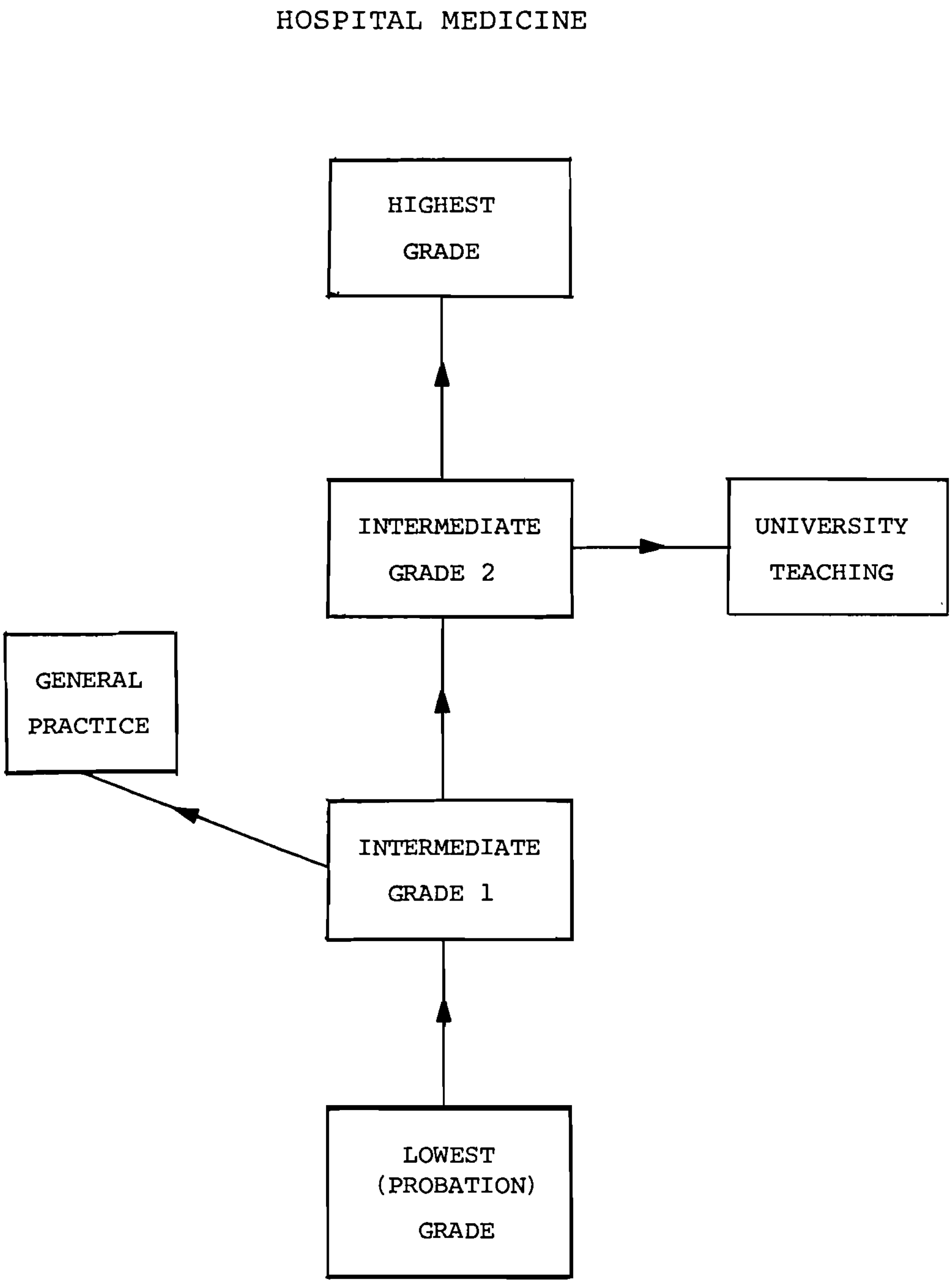

Figure 1. A typical medical career structure.

routine hospital work. Figure 1 also shows the kind of work that doctors outside hospitals may be doing — e.g., general practice or teaching medical students in universities. Typically, a doctor has to make a decision about whether to remain in hospital work or seek some other kind of post when he or she is in one of the intermediate hospital grades. In the UK, doctors cannot stay indefinitely in one of these grades. Fixed term contracts are the only conditions of employment in such grades.

Two important aspects of any career structure are the number of posts at each grade and the number of students being trained for the career in question. As far as doctors are concerned, some countries exercise total control over these numbers; others exercise no control at all. There are intermediate degrees of control, such as those enforced in the UK by the Department of Health. Numbers of places for medical students are controlled strictly and so are numbers of posts in the probationary grade (called "House Officer"), so that there is a post of this kind available for every newly qualified graduate. There are three main intermediate grades (in ascending order): Senior House Officer, Registrar, and Senior Registrar. The highest hospital grade is Consultant. Numbers of Registrar, Senior Registrar, and Consultant posts are subject to certain controls but posts in the Senior House Officer grade are not. To be more specific, "control" applies to the doctors who have contracts with the UK National Health Service (NHS), not to the minority of doctors in the private sector. The number of general practitioners who are permitted to hold NHS contracts is also controlled.

2.2. Problems in Medical Manpower Planning

The success of a manpower planning exercise will depend, at least in part, on the extent to which the numbers of posts in various grades are controlled. "Demand" is, after all, just a statement of the number of posts at each grade which is considered necessary to operate the service. To make a demand estimate may be little more than a formal exercise if there is no guarantee that the resulting plan can be implemented. Even if it can be implemented, the setting of a demand figure is no easy task. An attempt should be made to relate numbers of posts to some measure of workload and budgetary constraints. What is more, demand will not be a static quantity — for instance, workload may change over time as a result of planned changes in the manner of delivering health care (e.g., a change in the proportions of hospital and community care provided).

Success in meeting a demand for manpower depends on how the manpower is distributed through its grade structure at the start of the planning period. There are limits on how rapidly this distribution can be made to change. For example, in terms of the UK medical career structure, a plan that required all Senior Registrars to be promoted to Consultant in the course of a year would be infeasible. (Senior Registrars need to spend about four years in that grade to gain enough experience.) There is also a different sort of constraint on how the manpower distribution can be allowed to change, because the career should not become unattractive due to slow promotion. (Even in a health care system in which the numbers of posts are not controlled to meet demand, the problem of planning career progress may occur.) Not surprisingly, individuals prefer to be promoted through the grade structure at a steady rate, without encountering bottlenecks caused by too many people competing for too few vacancies.

Besides promotion (i.e., interstate transitions), flows into and out of the grade network are extra variables for the manpower planner to consider. The size of the flow into the lowest grade is constrained mainly by outputs from training, which are themselves the result of past intakes to training and the length of the training period. Flows into higher grades, i.e., recruitment from outside the manpower system, offer an alternative way of meeting the demand of promotion from within the system. To decide on the right level of recruitment is a problem in itself — too high a level could force promotion within the system to be too slow. Flows out of the manpower system, i.e., wastage, are not controllable. The future effects of wastage trends can be taken into account, but any manpower plan should be made robust to fluctuations in such trends.

All these considerations are given an extra dimension by the presence in the manpower system of groups with distinctly different histories of labor force participation. For example, males and females fall into two such groups. In the UK, native and foreign doctors also behave differently. Typically, many doctors come to the UK from overseas to stay for a period of about five years, and then they return home. Even these relative behavior differences are not static. Recent legislation enacted in the UK may reduce greatly the inflow of doctors from overseas.

The model outlined in the next section allows the planner to make year-by-year projections of numbers in grades, by time in grade or age and by sex and region of origin. (Other descriptors may be used in place of sex and origin, as mentioned in the Introduction.) It is possible to fix the growth rate for any grade and therefore to represent a demand profile. Thus the effect on the manpower system of setting a demand target, given a prevailing supply trend, can be investigated. For medical manpower, separate specialties or groups of similar specialties can be examined. In other manpower systems, analogous divisions may occur. If the model is used for this purpose, the stocks and the inter-specialty flows must be defined with care. In the lower grades, for instance, it may be difficult to assign a doctor to a particular specialty.

3. OPERATION OF THE MODEL

3.1. General Features

The operation of the model is based on the identity:

Number of a particular = Number of Manpower - Leavers(flow) + Joiners(flow) (1)
Type of Manpower
Next year (stock) this year (stock)

By "this year" and "next year" are meant two dates exactly one year apart. If we call stocks K, leavers L and joiners J, equation (1) becomes

$$K_\alpha(i + 1) = K_\alpha(i) - L_\alpha(i) + J_\alpha(i) \qquad (2)$$

The particular type of manpower is represented by α; that is, α describes the state. Successive years are labelled i, i+1, i+2, etc. Projections, which are possible for a period of up to 15 years, are made by applying equation (2) to each state, as many times as there are years in the projection period. The interstate and external flows can be made explicit by writing (2) as:

$$K_\alpha(i + 1) = K_\alpha(i) - {}_\beta F_\alpha(1) + {}_\alpha F_\gamma(i) - W_\alpha(i) + J_\alpha(i) \qquad (3)$$

Here, ${}_{\beta}F_{\alpha}(i)$ is the flow leaving state α to go to state β and ${}_{\alpha}F_{\gamma}(i)$ is the flow that state α receives from a third state γ. In general there is more than one donor state, and state α will in turn donate flows to more than one state. $W_{\alpha}(i)$ is the wastage flow to a <u>sink</u> outside the network, and $J_{\alpha}(i)$ is the inflow from a corresponding <u>source</u> (not necessarily the same as the sink).

The network being modeled can include up to 20 states, arranged in any configuration and up to 75 flows. The choice of states to include in the network (rather than to leave out like sources or sinks) must be made by the user to suit a particular application. If there is no obvious or expected relationship between the size of a flow and the size of the population that is the source of the flow, then it may be appropriate to represent this as an external flow. If, however, there is a possibility that the source may be significantly depleted by the flow from it at some stage in the projection period, then it may be safer to include the source in the network. Otherwise the impossibility of a non-zero flow from a completely depleted source may occur when the model is run.

The model permits equation (3) to be used in a "push" or "pull" mode for any state. In the push mode, all the flow values are specified in advance. In the pull mode, $K_{\alpha}(i + 1)$, together with some of the flows, is specified, and the remaining flows, which must be flows <u>into</u> state α, are calculated so as to satisfy equation (3)*. Up to two pull flows from other states into any one state can be modeled.

For states whose population is subdivided by years-in-state, up to 10 single-year bands are available, but the

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*It is of course quite possible that, as a result of specifying some of the flows, state α will overshoot its target value. In that case, the pull flow(s) into α will be zero and the overshot value will be output.

number of grades times the number of bands should not exceed 200. The final band may accommodate all those individuals who have spent m+ years in the state, if there are (m + 1) bands. This method of subdivision is appropriate for modeling populations that are not expected to stay very long in a state, e.g., the more junior members of a labor force in a highly qualified profession. The option of subdividing by age rather than years-in-state is provided, but only five states can have an age subdivision. This is appropriate for the more senior members of a workforce, who may stay a long time in a state, leaving only on retirement, which is a strongly age-dependent flow. It should be noted that there is one important limitation on the use of age subdivisions. They can be used only to study the behavior of adult populations in detail, because the age bands are defined as:

<25, 25-29, 30-34,...etc.

Flows are permitted from states subdivided by years-in-state (called T-states) to states subdivided by age (A-states) but not vice-versa. At the start of a projection, any T-flow into an A-state is calibrated by giving the flow an age distribution, which is part of the input data.*

Push flows between two states and wastage out of a state are represented in the model in the same way, i.e., as rates. Either an overall rate for a state is specified, (applied to the stock at the start of any year), or up to four separate rates are given for the different population subgroups in a state. A percentage is specified by which

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*Each T-state has a "Time Since Qualifying" (TSQ) distribution -- see final paragraph of section 3.1. Changes in the TSQ distribution of the flow from a T-state are converted by the model into changes in the age distribution of the flow as it enters an A-state.

such a rate varies from year to year; this percentage can be zero. Then, for T-states, a set of weighting factors is used to represent each year-band's relative contribution to an overall rate for the state. For A-states, age-specific wastage rates are used, and these are fixed for a projection. Age-specific weighting factors for interstate flows are not available.

When a pull flow occurs out of a T-state, each year-band in each population subgroup has its own weighting factor to determine its contribution to the flow. The mechanism therefore resembles the one for push flows. For A-states, only four population subgroup weighting factors can be input. The age distribution of each population subgroup in an A-state is preserved in the flow, as it is for push flows. If two states contribute to a pull flow, the weighting factors must represent this competition as well as that occurring among the different population subgroups and years-in-state bands (for T-states) within a state. Pull and push flow weights for any flow can take a number of different values in a projection period. The size of a pull flow depends on the target state's specified growth in a year. Either a growth rate (with percentage annual increment or decrement) can be specified, or the actual size of the state's population in each year of the projection period can be input.

Entrants to a state from outside the network are almost always specified as actual numbers. The only exception occurs when the state is a pull flow destination. It is then possible to specify a percentage of "vacancies" that are earmarked for external entrants. Within this overall percentage, separate percentages for population subgroups can be input, together with annual increments/decrements on these percentages.

The computerized model processes flows in the order in which they are input; this order is therefore important.

The rules are:

(i) Wastage flows are first specified.
(ii) All push flows must be specified next.
(iii) The pull flows are then specified. It is possible for pull flows to leave states which are themselves pull destinations. These pull flows must be specified next.
(iv) Pull flows into target states are then specified.
(v) Finally, external entrants into states must be specified.

In order that stages (iii) and (iv) are compatible, in a hierarchical system, pull flows for the most senior state in the hierarchy must be specified first, followed by pull flows for the next senior, and so on. (See the Appendix for an example.)

There are a few other mechanisms in the model which are worth mentioning at this stage.

Promotion Flows: For each state, a set of population subgroup-specific (and year-band specific, for T-states) "unpromotable" percentages can be input. The flow (push or pull) out of a band is halted if it would make the stocks numbers fall below these percentages. This can be regarded as a quality control device. In the case of a pull flow, a given band's contribution might, if unrestrained, deplete that band's stock to below the unpromotable percentage. If this happens, no "unpromotables" are promoted; the deficit is made up by pulling more population from undepleted bands, in proportion to their weights. This process is repeated, if necessary, until no more promotable stock is available. Any resulting shortfall in the target state is carried forward to the following year in the projection. Any unpromotable percentage can take different values in the different years of a projection period.

Whole-Time-Equivalents (WTEs): In some manpower systems, it is usual for many individuals to work part-time. It is therefore misleading to equate the numbers of individuals and the numbers of posts. The model allows a whole-time-equivalent ratio to be input for all population subgroup year bands (T-states) or age groups (A-states) in the base year of the projection. This ratio, when multiplied by the total population of the band, gives the number of WTEs (and hence posts). The ratio for a band stays fixed during a projection. The overall ratio for a state will therefore change if the distribution of population among the state's bands changes. The WTE feature is essentially a device for monitoring likely, or necessary, changes in number of posts in a grade.

Time Since Qualifying (TSQ): For all T-states, in a hierarchical grade system, the model calculates another time characteristic -- the years which have elapsed since some defined event in the past. In the case of the UK medical manpower system, this event is graduation from medical school, thus the name Time Since Qualifying. A TSQ distribution is input for the lowest year band in every population subgroup in the lowest state of the hierarchy of grades, in the base year of the projection period. The distribution for the next higher band is obtained by ageing the lowest band's distribution by one year, while keeping its shape intact, and a corresponding procedure is followed for all the other bands. The next higher state in the hierarchy has its TSQ distributions derived from those of the lowest state. In general, the lowest band of the next higher state contains promotees who have spent various lengths of time in the lowest state. The TSQ distribution of this lowest band is therefore a weighted -- and "aged" -- sum of the TSQ distributions of the lowest state's bands. All the higher bands are dealt with in the same way as the higher bands in the lowest state. External entrants, with their (in general, different) TSQ distribution, are allowed for. This process is repeated for each state in the hierarchy. The procedure is inappropriate for non-hierarchical systems and must be bypassed (see Appendix).

3.2. Matrix Representation

The matrix representation of multistate population models is discussed extensively in IIASA literature of recent years, e.g., Rogers 1978, 1980b. A useful summary is given by Propoi and Willekens (1978). The evolution of a network of states is expressed by the linear homogeneous equation:

$$\underset{\sim}{K}(t + 1) = \underset{\sim}{G}(t)\underset{\sim}{K}(t) + \underset{\sim}{U}(t) \qquad (4)$$

$\underset{\sim}{K}(t)$ is a column vector whose elements represent the distributions (over age, years-in-state) of each state's population at time t(i.e., a particular year). $\underset{\sim}{G}(t)$ is a matrix whose elements are transition rates and survival rates. The matrix multiplication of $\underset{\sim}{G}(t)$ and $\underset{\sim}{K}(t)$ summarizes the act of multiplying each of the elements of $\underset{\sim}{K}(t)$ by the appropriate transition or survival rates. $\underset{\sim}{U}(t)$ describes the exogenous part of the population's growth. In general, both $\underset{\sim}{G}(t)$ and $\underset{\sim}{U}(t)$ may consist of a mixture of controllable (i.e., controllable by policy makers) and uncontrollable variables. The homogeneous part of (4) represents a closed system -- i.e., one with no inflow from outside the network. $\underset{\sim}{U}(t)$ can represent migration into a region or recruits to a manpower grade structure.

$\underset{\sim}{G}(t)$ is often assumed to be constant over time. Liaw (1980) exploits the properties of the eigenvalues and eigenvectors of a constant $\underset{\sim}{G}$ to derive an analytic solution to the multistate population projection problem, which shows the way in which the population converges to stability after a disturbance. Propoi and Willekens (1978) discuss $\underset{\sim}{U}(t)$ in terms of a policy matrix $\underset{\sim}{D}(t)$ operating on a further vector $\underset{\sim}{V}(t)$. (In a manpower network, $\underset{\sim}{V}(t)$ could represent the entire population outside the network. $\underset{\sim}{D}(t)$ could then express the recruitment policy designed to select personnel from this outside population.)

Computerized multistate population models have been used at IIASA to study population growth in a number of countries. It is not appropriate here to enter into a detailed discussion of these applications; see for example Rogers (1980b), Willekens and Rogers (1978). It is worth pointing out one or two things, however. The effect on population growth of migration, compared with fertility and mortality, has been analyzed by Rogers and Willekens (1978). Willekens (1980) discusses the making of labor force projections, using as "states" the economically active and inactive sectors of the population. Results from studies of this sort are of crucial importance in planning a variety of services for a population, and in determining how economic and social policies for a country or region may be formed and implemented.

If we turn specifically to the UK model, the elements of the various matrices and vectors represent age bands or years-in-grade bands for each state (or grade). Because each state's population can be subdivided into four population subgroups which are non-interacting, equation (4) applies to a single population subgroup. $\underset{\sim}{U}(t)$ is expressed as a set of numbers, and not in the form of a further matrix $\underset{\sim}{D}(t)$ operating on a vector $\underset{\sim}{V}(t)$. This is because the model was designed to represent in detail a relatively <u>small subgroup</u> of the labor force. If, for example, $\underset{\sim}{V}(t)$ is the population of a country, then:

$$\underset{\sim}{U}(t) << \underset{\sim}{V}(t)$$

Any errors in $\underset{\sim}{D}(t)$ could therefore lead to large errors in $\underset{\sim}{U}(t)$, if $\underset{\sim}{U}(t)$ is specified as $\underset{\sim}{U}(t)=\underset{\sim}{D}(t)\underset{\sim}{V}(t)$. The chosen formulation of $\underset{\sim}{U}(t)$ does not, of course, prevent the model from being used for relatively large manpower groups. In the UK model, the $\underset{\sim}{G}(t)$ matrices can be time-dependent or time-independent. The operation of $\underset{\sim}{G}(t)$ upon $\underset{\sim}{K}(t)$ expresses push flows. In order to represent the pull flow facility of the UK model in matrix terms, extra vectors need to be introduced, to express the withdrawal of population from donor states and the addition of this population to pull flow destination states. The matrix representation of the model is then:

$$\underset{\sim}{K}(t+1) = \underset{\sim}{G}(t)\underset{\sim}{K}(t) + \underset{\sim}{Q}(t) - \underset{\sim}{R}(t) + \underset{\sim}{U}(t) \tag{5}$$

The structure of the vectors $\underset{\sim}{Q}(t)$ and $\underset{\sim}{R}(t)$, as well as typical $\underset{\sim}{G}(t)$, can best be seen with reference to the simple example of Figure 2.

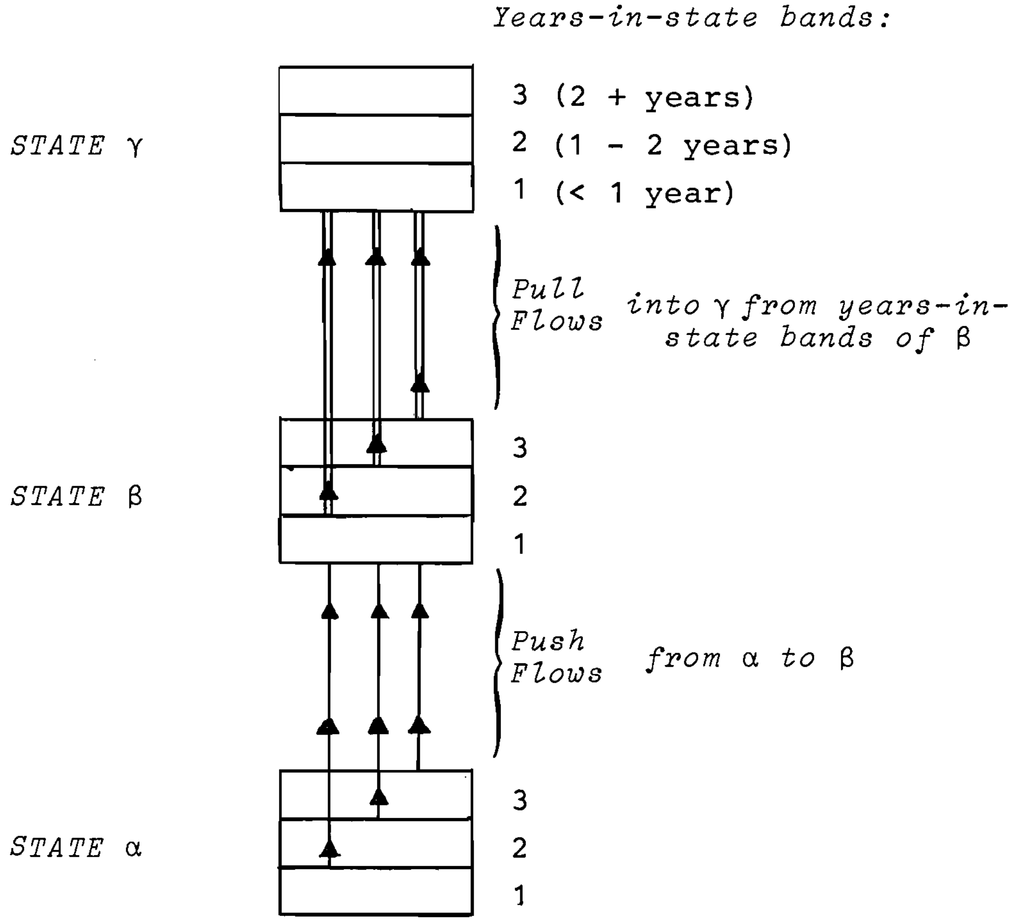

Figure 2. Simple network to illustrate the manpower equation in matrix terms.

If the matrix $\underset{\sim}{G}(t)$ and the vectors $\underset{\sim}{Q}(t)$, and $\underset{\sim}{R}(t)$ are expanded to show individual elements, they appear as:

$\underset{\sim}{G}(t)$:

$$\begin{pmatrix}
1-W_{\gamma 3} & 1-W_{\gamma 2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1-W_{\gamma 1} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1-W_{\beta 3} & 1-W_{\beta 2} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1-W_{\beta 1} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & P_{\alpha 3} & P_{\alpha 2} & P_{\alpha 1} \\
0 & 0 & 0 & 0 & 0 & 0 & \begin{matrix}(1-W_{\alpha 3}\\ -P_{\alpha 3})\end{matrix} & \begin{matrix}(1-W_{\alpha 2}\\ -P_{\alpha 2})\end{matrix} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \begin{matrix}1-W_{\alpha 1}\\ -P_{\alpha 1}\end{matrix} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}$$

(In this expansion, W is a wastage rate and P is a push flow rate. Time dependence enters via the annual percentage increments that can be specified for wastage and push flows.)

$\underset{\sim}{Q}(t)$:

$$\begin{pmatrix}
0 \\
0 \\
Q_{\beta 3} + Q_{\beta 2} + Q_{\beta 1} \\
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{pmatrix}$$

$\underset{\sim}{R}(t)$:

$$\begin{pmatrix}
0 \\
0 \\
0 \\
Q_{\beta 3} \\
Q_{\beta 2} \\
Q_{\beta 1} \\
0 \\
0 \\
0
\end{pmatrix}$$

The elements $Q_{\beta 3}$, $Q_{\beta 2}$, $Q_{\beta 1}$ represent the population pulled from the three years-in-state bands of state β, in a particular year of the projection, and added to state γ. In this example, it is assumed that any population entering a state has not been in that state before, and so goes only into the first years-in-state band.

In section 5, a few points are made about the potential applicability of the UK model to population, as well as manpower, systems. These points serve to emphasize the similarity of the UK model to those developed at IIASA.

4. APPLICATION OF THE MODEL TO PLANNING PROBLEMS

The example discussed in this section is concerned with the possible consequences of achieving planned growth rates for certain grades in a manpower career structure. Suppose that desirable growth rates for certain key grades have been establisbed. Suppose also that the magnitudes of the wastage flows and the external recruitment flows are expected to retain their present values. Then the sizes of the stocks in the particular grades which supply the key grades will depend directly on the growth of those key grades. Certain combinations of growth rates of the key grades may have unfortunate effects, such as rapid build-up or depletion of stocks in the grades which supply the key grades. The dangers of this were mentioned in section 2. To summarize those arguments: Supply instabilities of this nature could undermine the success of an entire resource plan, by <u>enforcing</u> the abandonment of the grade growth rates which were originally planned.

The grade network is shown in Figure 3. The results of using the model to detect future supply instabiltiies in a simple hypothetical grade structure are shown in Figures 4 and 5.

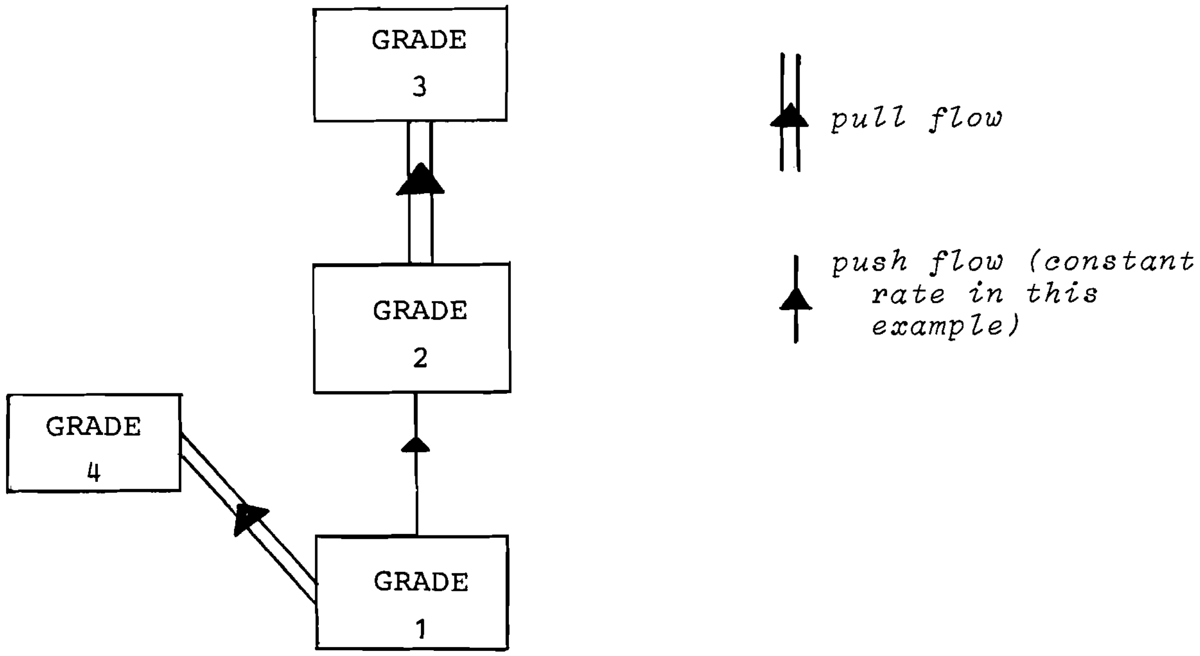

Figure 3. Hypothetical grade network.

The grades are all T-states. The flows into the key grades 3 and 4 (which could be hospital consultants and general practitioners) are modeled as pull flows. The growth rates input for grades 3 and 4 are summarized in Table 1. The grade network, the growth rates, the base year stocks, and the details of the results are fictitious,but grades 3 and 4 could be hospital consultants and general practitioners, respectively. It has been assumed, for simplicity in the example, that the grade 1-grade 2 push flow rate must remain fixed.

Table 1. Growth rates for selected grades in a hypothetical grade structure.

Run number	Grade 4	Grade 3
1	1%	2%
2	2%	2%
3	1%	4%

Figure 3 shows the numbers in the grades which would occur over fifteen years if the input asssumptions are justified. Run 3, with a relatively high growth of grade 3, shows a steady decline in the population of grades 1 and 2. Clearly, a growth rate of this size for grade 3 could not be sustained indefinitely. Runs 1 and 2 show stable populations in grades 1 and 2. Therefore the hypothetical manpower system is robust to at least a limited range of growth possibilities for grade 4. Figure 4 can be interpreted as showing how the grades (1 and 2) which are the source of manpower for the key grades 3 and 4 react to being depleted at given rates. For this reason, stocks in grades 1 and 2 have been added together. Figure 5 shows one effect on grade 2, in particular, of imposing the growth rates of run 3. The high growth rate of grade 3 is the factor which causes trouble. This is shown up in the steadily falling number of years' experience of those being promoted from grade 2 to meet the demands of the grade 3 growth rate.

To conclude this section: the model has helped to identify a situation in which growth rates for one grade (grade 3) which are higher than a certain value could lead to serious imbalances in grade populations. The model could be used in this way to help planners set realistic growth rates -- or, if certain growth rates must be met, to establish that increased recruitment from outside the grade network is necessary.

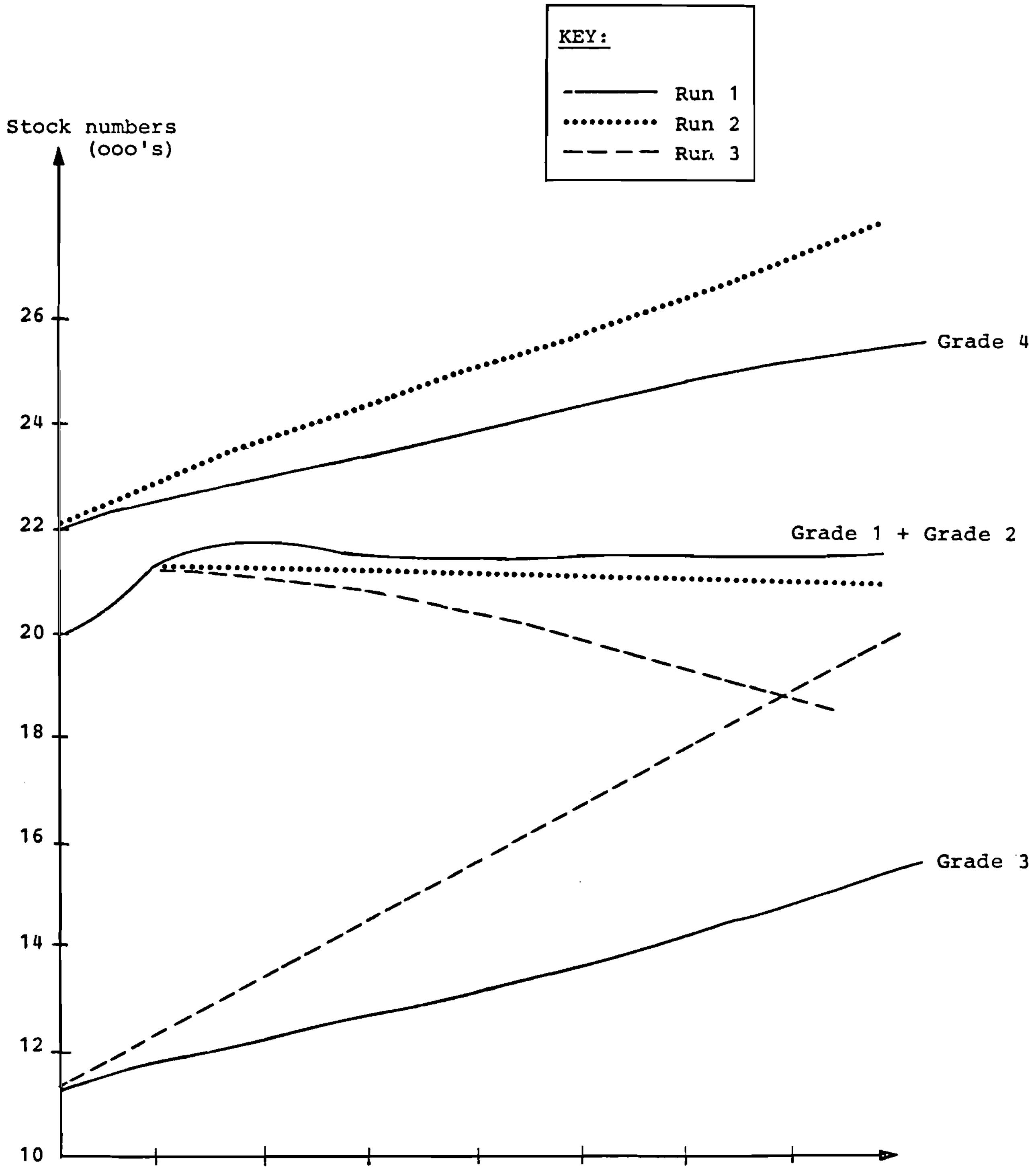

Figure 4. Grade growth for hypothetical grade structure.

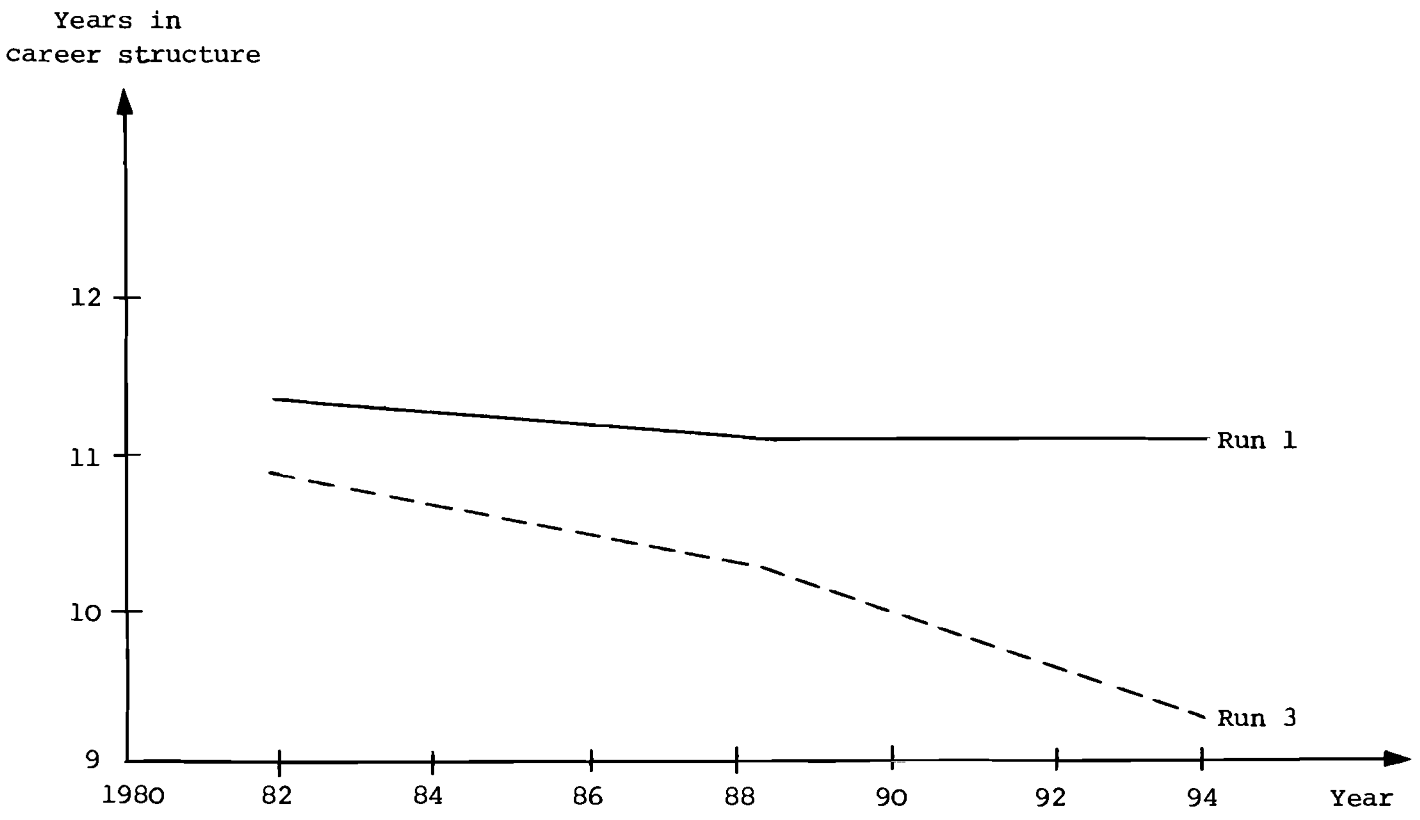

Figure 5. Inflows to grade 3: years since entering grade structure, for promotees from grade 2.

5. CONCLUSION

This paper has described a projection model for manpower or population systems, in terms deliberately chosen to emphasize the generality of application of the model. As a conclusion, the important features are summarized here.

Both market-based and completely planned manpower systems can be modeled, because any flow can be specified as "push" or as "pull", and also flows into the system from outside can be included. A market-based system might typically be modeled as a network of push flows. The model could then be used to explore the consequences for grade growth of continuing the prevailing flow trends or imposing hypothetical flow rates. Conversely, a network incorporating pull flows, so that every grade's growth was fixed in advance of the planning (i.e., projection) period, would be appropriate for a completely planned system. This approach allows the user to discover the sizes of the flows which would be necessary to meet the grade growth targets. In either case (market-based system or planned system), the model facilitates the detection, in advance, of features such as:

- Undesirable accumulations or depletions of manpower in any grade (see sections 2, 4)
- Infeasible recruitment requirements. For instance, a plan which required large numbers of personnel in senior grades to be recruited from outside the system might be unrealistic.

The network of states to be modeled can be hierarchical or it can be non-hierarchical. A hierarchical network typically represents the manpower system for a profession. Such a network can also be used to model a population system defined in terms of certain characteristics, such as "never married", "married", "divorced", "one child", "two children", etc. A non-hierarchical network can represent active and inactive states of a labor force, or a number of geographical regions among which there are flows of migrants, to name but two examples. "Push" flow networks are likely to be more appropriate than "pull" flows for population systems. However, it could be instructive to set a hypothetical target for the size of a region's population over a given projection period, for instance, in order to produce a labor force of a given size. Then the model could be used to determine the magnitudes of the flows necessary to meet the target, and hence the feasibiltiy of meeting such a target.

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APPENDIX: A Typical Input Data File and Corresponding Output

The user begins by constructing the network of states and deciding, for each state, whether it is to be an A-state or a T-state. Next, the nature of each interstate flow -- push or pull -- is fixed. The data file described in this Appendix is based on the network of Figure A1. This is part of the UK medical career structure, but it is emphasized that the format of the data file is general to all networks. The data file is shown in Figure A2. The filename is MODEL 40. Lines which begin * or > contain operators.

Line 10: Various types of output information are available. Each type has an index number (see Figure A3). The index numbers for the types needed are input in the *OPTION line.

Line 11: The *PRINT operator is used to specify the years in the projection period for which the output information specified in *line 10* is required. Summaries only for all other years are output (see Figure A4).

Lines 20, 22, 23, 30, 50: These lines specify the title which appears at the head of the outputs (Figure A4). Lines 22, 23 specify that asterisks should be placed around

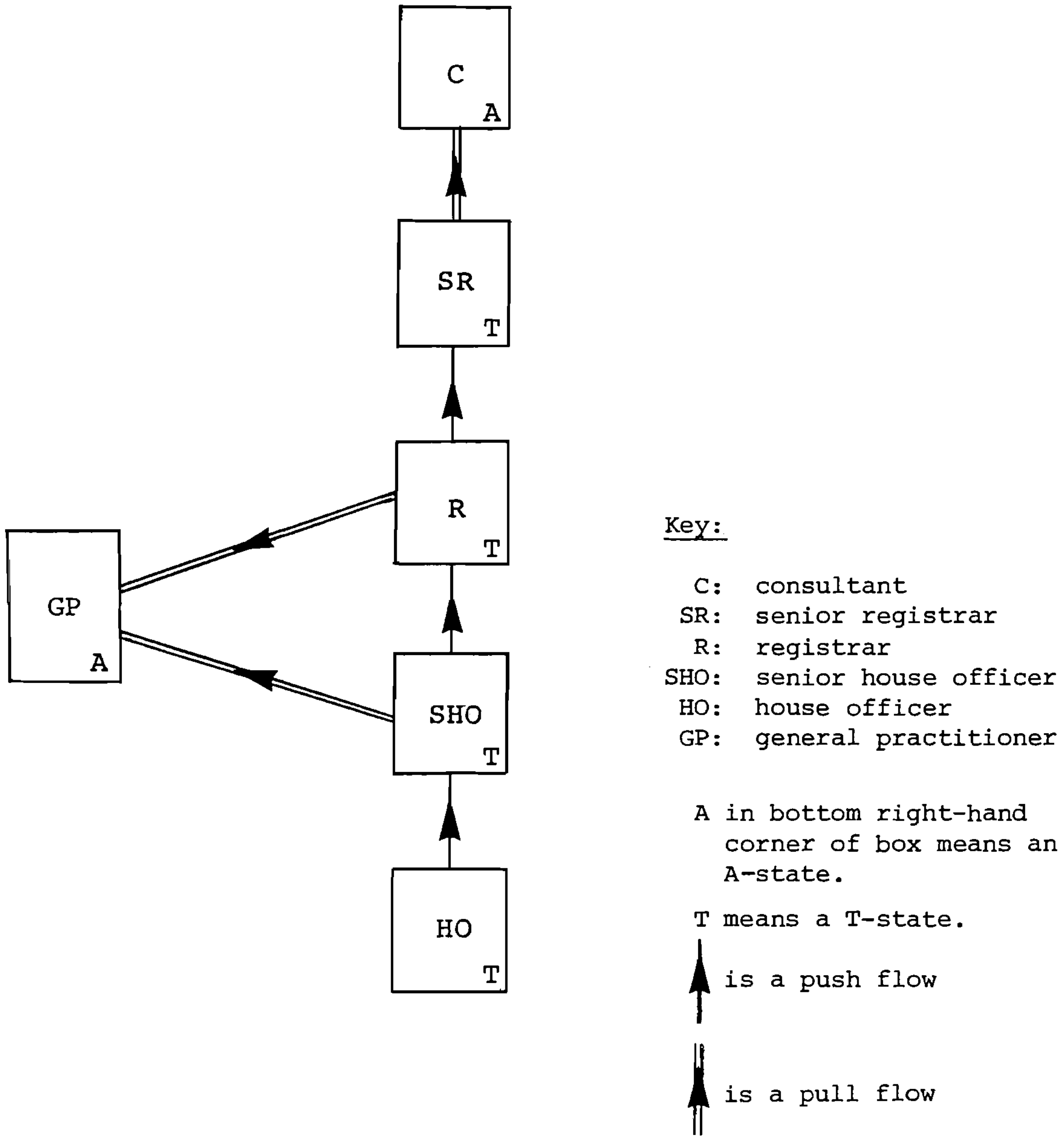


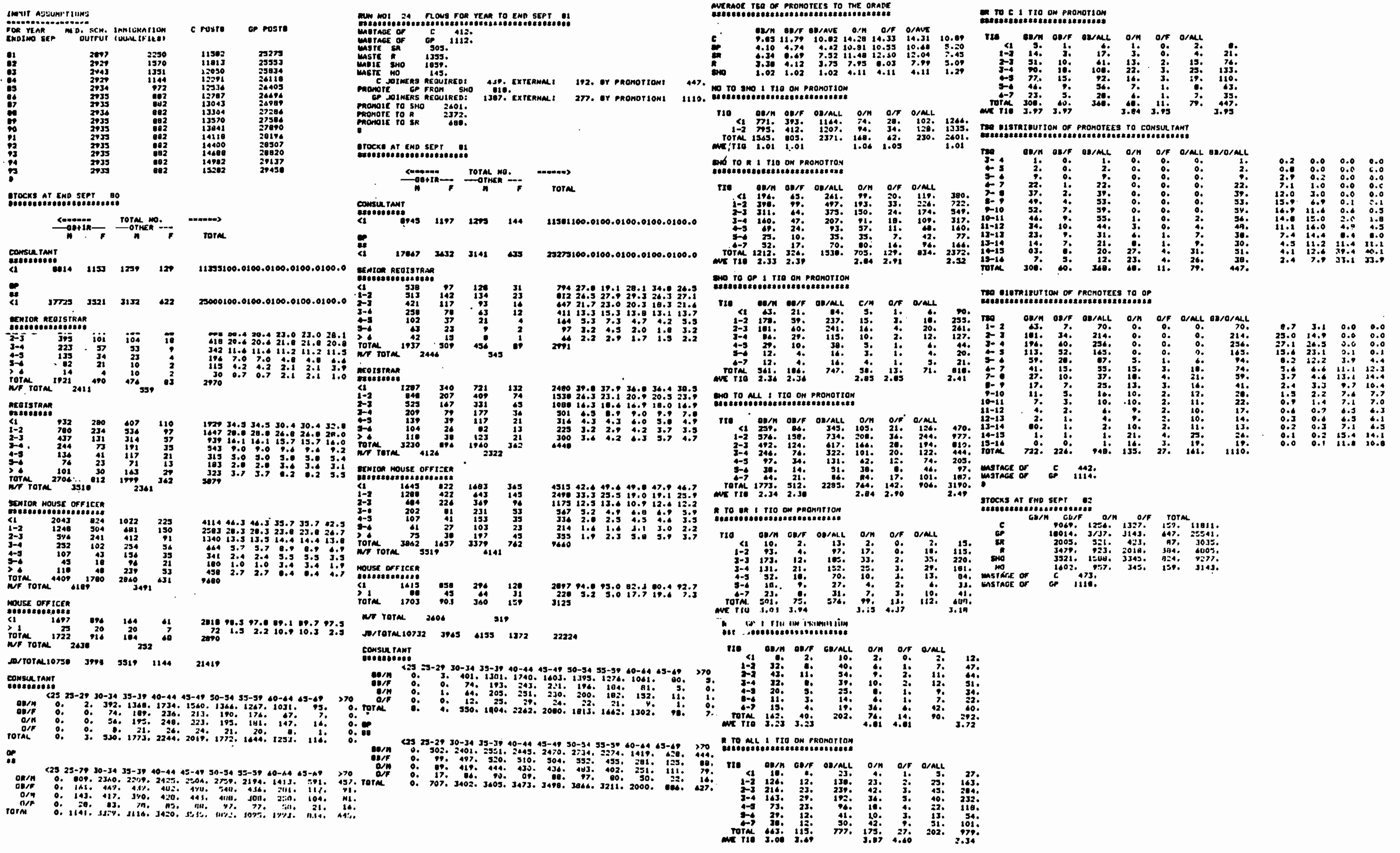
Figure A1. The example network: a part of the UK medical career structure.

```
MODEL40      13:29        05/13/81

10 #OPTION 3 4 5 7 8 9 10 12 13 14 15 16
11 #PRINT 1 5 10 15
20 #TITLE
22 '*************************************'
23 ' '
30 'PRODUCTION RUN 80 STOCKS'
50 'SELCOM A'
110 #DEF
120 C CONSULTANT 1 A
130 GP GP 1 A
140 SR 'SENIOR REGISTRAR' 7 T
150 R REGISTRAR 7 T
160 SHO 'SENIOR HOUSE OFFICER' 7 T
170 HO 'HOUSE OFFICER' 2 T
180 #DIM
185 ORIGIN GB+IR OTHER
190 SEX M F
210 #TRACE
220 #TIME 15
240 #STOCKS 80
242 >M7 GP
243 TN 0 809 2360 2209 2425 2506 2759 2194 1413 591 457
244 WTE 0 800 2200 2100 2300 2410 2610 2000 1400 590 450
245 LR .04 .1 .1 .12 .12 .12 .12 .13 .1 .1 .14 .14 .15 .1 .1 .2 .2 .1 .2 .23 .5 .9
246 JD 0 .1 .1 .1 .2 .2 .1 .1 .05 .05 0
247 TN 0 161 469 439 402 478 548 436 281 117 91
248 WTE 0 149 300 400 450 434 540 420 270 98 85
249 LR .03 .09 .1 .1 .1 .11 .11 .12 .13 .13 .12 .14 .2 .1 .3 .3 .2 .3 .3 .5 .6 .9
250 JD 0 .05 .05 .1 .1 .2 .1 .2 .1 .1 0
251 TN 0 143 417 370 428 443 400 388 250 104 81
252 WTE 0 130 410 385 410 430 480 360 230 92 70
253 LR .01 .02 .03 .04 .05 .1 .1 .1 .12 .12 .13 .13 .14 .14 .15 .16 .17 .2 .3 .4 .6 .9
254 JD 0 .05 .06 .04 .1 .1 .15 .2 .3 0 0
255 TN 0 28 83 78 85 88 97 77 50 21 16
256 WTE 0 20 75 60 70 76 83 70 45 18 13
257 LR .01 .01 .02 .02 .04 .1 .1 .12 .12 .13 .13 .14 .14 .13 .13 .15 .16 .16 .2 .3 .7 .9
258 JD 0 .04 .06 .05 .05 .2 .2 .1 .1 .1 .1
300 >M6 SR
301 TN 565 507 395 223 135 82 14 144 129 101 57 34 21 4 157 119 104 53 23 10 10 27 21 18 9 4 2 2
302 WTE 550 450 380 218 115 78 10 130 120 87 45 30 19 3 140 107 88 43 18 5 6 25 18 15 9 4 2 2
303 P2 10 10 10 10 10 10 10 15 15 15 15 15 15 15 10 10 10 10 10 10 10 20 20 20 20 20 20 20
304 PJ 1 1 1 1 1 1 1 3 3 3 3 3 3 3 1 1 1 1 1 1 1 3 3 3 3 3 3 3

500 #TSQ
501 HO
582 J 100 1 100 1 100 4 100 4
583 RC 9 1 9 1 9 1 9 1
584 EW 1
585 SHO
586 J 0 0 0 0 80 6 80 6
587 RC 1 1 2 2 1 1 1 1 1 1 2 1 1 1 1 1 1 2 1 1 1 1 1 1 2 1 1 1
589 EW 0.5 0.25 0.15 0.1
590 R
591 J 0 0 0 0 10 7 10 7
592 RC 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
593 EW 0.5 0.3 0.15 0.05
594 SR
595 J 0 0 0 0 0 0 0 0
596 RC 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
597 EW 0.5 0.3 0.15 0.05
600 #FLOWS
610 >W C
620 >W GP
630 >W SR 17 0
632 T2 .7 .7 .7 .7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
650 >W R 12 28 34 34 0 0 0 0
652 T2 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9 1.6 3.2 2.9 2.9
660 >W SHO 15 30 19 19 0 0 0 0
665 T2 0.8 1.6 1 1 0.8 1.6 1 1 0.8 1.6 1 1 0.8 1.6 1 1 0.8 1.6 1 1 0.8 1.6 1 1 0.8 1.6 1 1
670 >W HO 5 0
672 T2 1 1.8 1 1 1 1.8 1 1
680 >PULL C SR 2 0
681 24 2.4 2.4 1.2 0 0 0 0
683 T2 .052 .04 .05 .04 .104 .08 .1 .08 .62 .48 .6 .48 1.246 .96 1.2 1.2 1.246 .96 1.2 1.2 1.246 .96 1.2 1.2 1.246 .96 1.2 1.2
690 >PULL GP SHO 1.1 0
692 15 3 1 1 0 0 0 0
694 T2 1.05 1.05 .18 .18 3.15 3.15 .5 .5 3.78 3.78 .6 .6 2.73 2.73 .45 .45 2.73 2.73 .45 .45 2.73 2.73 .45 .45 1.2 1.2 .2 .2
700 >PULL GP R
705 T2 .28 .28 .15 .15 1.04 1.04 .3 .3 1.4 1.4 .75 .75 1.77 1.77 1.08 1.08 1.77 1.77 1.08 1.08 1.77 1.77 2.16 2.16 1.77 1.77 4.32 4.
710 >PM SHO HO 90 0
712 T2 1 1 1 1 100 100 100 100
720 >PM R SHO 24.5 0
732 T2 .63 .63 .63 .57 1.26 .63 .91 .57 1.51 1.26 .91 .82 1.51 1.51 .91 .82 1.26 1.51 .91 .82 1.26 1.26 .91 .82 1.26 1.26 .91 .82
750 >PM SR R 11.7 0
752 T2 .31 .29 .11 .09 3.15 .29 1.09 .09 6.3 2.87 2.17 .94 5.25 5.73 1.63 1.88 2.62 6.69 .87 2.36 2.62 3.34 .87 1.88 2.62 3.82 .87 1
760 >AGE HO
770 >AGE SHO
780 >AGE R
790 >AGE SR
800 >JT HO
810 1615 1594 1559 1509 1469 1427 1384 1341 1299 1256 1256 1256 1256 1256 1256
820 858 912 960 998 1042 1085 1128 1171 1213 1256 1256 1256 1256 1256 1256
830 296 290 287 283 280 277 274 271 267 264 264 264 264 264 264
840 128 133 137 139 143 146 149 153 156 159 159 159 159 159 159
850 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
860 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
870 55 39 33 28 24 22 22 22 22 22 22 22 22 22 22
880 28 19 17 14 12 11 11 11 11 11 11 11 11 11 11
900 >JS SHO
901 DE 0
902 DE 0
903 FY 1491 1041 895 759 643 583
904 FY 298 208 179 152 129 117
905 >JS SHO
906 DE 320
907 FT 120
908 FT 166 116 99 84 71 65
909 FT 33 23 20 17 14 13
910 >JS R
911 DE 300
912 FT 100
913 FT 110 77 66 56 48 43
914 FT 22 15 13 11 10 9
920 >JS SR
921 DE 150
922 DE 90
923 FY 29 20 18 14 13 12
924 FY 18 12 11 9 8 7
940 #RUN 15
950 #STOP
```

Figure A2. Typical input data file.

Output index number	Nature of output
1	Prints out stock input data
3	Prints origin/sex specific stock numbers and whole-time-equivalents (see later) for years specified under *PRINT
4	Prints only stock numbers (if only numbers are required, 3 must be speciifed as well as 4)
5	Prints interstate flow sizes and wastage (overall, not origin/sex/age or years-in-state specific)
7	Prints are breakdowns of A-states, in five bands. The ranges are: <25, 25-29, ..., 65-69, $\geq$70. If 7 is required, 3 and 4 must be input
8	Prints base year stocks in same format and outputs and other years
9	Prints origin/sex/years-in-state specific stocks together with percentage distributions over years-in-state (if 9 is needed, 3 and 4 must also be specified)
10	Prints average time since a specified event (e.g., leaving medical school) of interstate flows
11	Prints average time since a specified event against years-in-state for stocks
12	Prints distributions corresponding to 10
14	Prints origin/sex/years-in-state specific interstate flows (see 10)
15	Prints some input data for UK medical manpower; this is not for general use. The input data printed cover numbers graduating from UK medical schools, growth rates for senior grades, and inflows of qualified doctors from overseas
16	Prints summary (i.e., not origin/sex/age or years-in-state specific) stocks and flows for those projection years not specified in *PRINT

Figure A3. Output index numbers.



```
INPUT ASSUMPTIONS
*****************
FOR YEAR    MED. SCH. IMMIGRATION     C POSTS    GP POSTS
ENDING SEP    OUTPUT (QUALIFIED)

81             2897      2250         11502      25275
82             2929      1570         11813      25553
83             2943      1351         12050      25834
84             2929      1144         12291      26118
85             2934       972         12536      26405
86             2935       887         12787      26494
87             2935       882         13043      26989
88             2936       882         13304      27284
89             2935       882         13570      27584
90             2935       882         13841      27890
91             2933       882         14118      28176
92             2935       882         14400      28507
93             2935       882         14688      28820
94             2935       882         14982      29137
95             2933       882         15282      29458
*

STOCKS AT END SEPT   80
************************

          <======     TOTAL NO.      ======>
         ---GB+IR---  ---OTHER ---
            M     F      M      F      TOTAL

CONSULTANT
**********
<1       8814  1153   1259    129     11355100.0100.0100.0100.0100.0

GP
**
<1      17725  3521   3132    422     25000100.0100.0100.0100.0100.0

SENIOR REGISTRAR
****************
----  -     ---    ...    ---    --     [illegible] [illegible] 20.4 23.0 23.0 28.1
2-3       395   101    104     18     418 20.6 20.6 21.8 21.8 20.8
3-4       223    57     53      9     342 11.6 11.6 11.2 11.2 11.5
4-5       135    34     23      4     196  7.0  7.0  4.8  4.8  6.6
5-6        82    21     10      2     115  4.2  4.2  2.1  2.1  3.9
> 6        14     4     10      2      30  0.7  0.7  2.1  2.1  1.0
TOTAL    1921   490    476     83    2970
M/F TOTAL    2411        559

REGISTRAR
*********
<1        932   280    607    110    1929 34.5 34.5 30.4 30.4 32.8
1-2       780   234    536     97    1647 28.8 28.8 26.8 26.8 28.0
2-3       437   131    314     57     939 16.1 16.1 15.7 15.7 16.0
3-4       244    73    191     35     543  9.0  9.0  9.6  9.6  9.2
4-5       136    41    117     21     315  5.0  5.0  5.8  5.8  5.4
5-6        76    23     71     13     183  2.8  2.8  3.6  3.6  3.1
> 6       101    30    163     29     323  3.7  3.7  8.2  8.2  5.5
TOTAL    2706   812   1999    362    5879
M/F TOTAL    3518       2361

SENIOR HOUSE OFFICER
********************
<1       2043   824   1022    225    4114 46.3 46.3 35.7 35.7 42.5
1-2      1248   504    681    150    2583 28.3 28.3 23.8 23.8 26.7
2-3       596   241    412     91    1340 13.5 13.5 14.4 14.4 13.8
3-4       252   102    254     56     664  5.7  5.7  8.9  8.9  6.9
4-5       107    43    156     35     341  2.4  2.4  5.5  5.5  3.5
5-6        45    18     96     21     180  1.0  1.0  3.4  3.4  1.9
> 6       118    48    239     53     458  2.7  2.7  8.4  8.4  4.7
TOTAL    4409  1780   2860    631    9680
M/F TOTAL    6189       3491

HOUSE OFFICER
*************
<1       1697   896    164     41    2818 98.5 97.8 89.1 89.7 97.5
> 1        25    20     20      7      72  1.5  2.2 10.9 10.3  2.5
TOTAL    1722   916    184     48    2890
M/F TOTAL    2638        232

JD/TOTAL10758   3998   5519   1144     21419

CONSULTANT
**********
       <25 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69   >70
  GB/M   0.    2.  392. 1368. 1734. 1560. 1366. 1267. 1031.   95.    0.
  GB/F   0.    0.   74.  189.  236.  213.  190.  176.   67.    7.    0.
   O/M   0.    0.   56.  195.  248.  223.  195.  181.  147.   16.    0.
   O/F   0.    0.    8.   21.   26.   24.   21.   20.    8.    1.    0.
TOTAL    0.    3.  530. 1773. 2244. 2019. 1772. 1644. 1253.  116.    0.

GP
**
       <25 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69   >70
  GB/M   0.  809. 2360. 2209. 2425. 2504. 2759. 2194. 1413.  591.  457.
  GB/F   0.  161.  449.  417.  402.  490.  540.  436.  201.  117.   91.
   O/M   0.  143.  417.  390.  420.  441.  408.  300.  250.  104.   81.
   O/F   0.   28.   83.   78.   85.   88.   97.   77.   50.   21.   16.
TOTAL    0. 1141. 3379. 3116. 3420. [illegible] [illegible] 3075. [illegible]  834.  645.
```

```
RUN NO:  24   FLOWS FOR YEAR TO END SEPT  81
*********************************************
WASTAGE OF      C    412.
WASTAGE OF      GP  1112.
WASTE  SR      505.
WASTE  R      1355.
WASTE  SHO    1859.
WASTE  HO      145.
   C JOINERS REQUIRED:    459. EXTERNAL:    192. BY PROMOTION:    447.
PROMOTE     GP FROM   SHO     818.
   GP JOINERS REQUIRED:   1387. EXTERNAL:   277. BY PROMOTION:   1110.
PROMOTE TO SHO     2601.
PROMOTE TO R       2372.
PROMOTE TO SR       688.
*

STOCKS AT END SEPT   81
************************

          <======     TOTAL NO.      ======>
         ---GB+IR---  ---OTHER ---
            M     F      M      F      TOTAL

CONSULTANT
**********
<1       8945  1197   1295    144     11581100.0100.0100.0100.0100.0

GP
**
<1      17867  3432   3141    435     25275100.0100.0100.0100.0100.0

SENIOR REGISTRAR
****************
<1        538    97    128     31     794 27.8 19.1 28.1 34.8 26.5
1-2       513   142    134     23     812 26.5 27.9 29.3 26.3 27.1
2-3       421   117     93     16     647 21.7 23.0 20.3 18.3 21.6
3-4       258    78     63     12     411 13.3 15.3 13.8 13.1 13.7
4-5       102    37     21      4     164  5.3  7.3  4.7  4.2  5.5
5-6        63    23      9      2      97  3.2  4.5  2.0  1.8  3.2
> 6        42    15      8      1      66  2.2  2.9  1.7  1.5  2.2
TOTAL    1937   509    456     89    2991
M/F TOTAL    2446        545

REGISTRAR
*********
<1       1287   340    721    132    2480 39.8 37.9 36.8 36.4 38.5
1-2       848   207    409     74    1538 26.3 23.1 20.9 20.5 23.9
2-3       525   167    331     65    1088 16.3 18.6 16.9 18.0 16.9
3-4       209    79    177     36     501  6.5  8.9  9.0  9.9  7.8
4-5       139    39    117     21     316  4.3  4.3  6.0  5.8  4.9
5-6       104    26     82     13     225  3.2  2.9  4.2  3.7  3.5
> 6       118    38    123     21     300  3.6  4.2  6.3  5.7  4.7
TOTAL    3230   896   1940    362    6448
M/F TOTAL    4126       2322

SENIOR HOUSE OFFICER
********************
<1       1645   822   1683    365    4515 42.6 49.6 49.8 47.9 46.7
1-2      1288   422    643    145    2498 33.3 25.5 19.0 19.1 25.9
2-3       484   226    369     96    1175 12.5 13.6 10.9 12.6 12.2
3-4       202    81    231     53     567  5.2  4.9  6.8  6.9  5.9
4-5       107    41    153     35     336  2.8  2.5  4.5  4.6  3.5
5-6        61    27    103     23     214  1.6  1.6  3.1  3.0  2.2
> 6        75    38    197     45     355  1.9  2.3  5.8  5.9  3.7
TOTAL    3862  1657   3379    762    9660
M/F TOTAL    5519       4141

HOUSE OFFICER
*************
<1       1615   858    296    128    2897 94.8 95.0 82.1 80.4 92.7
> 1        88    45     64     31     228  5.2  5.0 17.7 19.6  7.3
TOTAL    1703   903    360    159    3125

  M/F TOTAL    2606        519

JD/TOTAL10732   3965   6155   1372     22224

CONSULTANT
**********
       <25 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69   >70
  GB/M   0.    3.  401. 1301. 1740. 1603. 1395. 1276. 1061.   80.    5.
  GB/F   0.    0.   74.  193.  243.  221.  196.  184.   81.    5.    0.
   O/M   0.    1.   64.  205.  251.  230.  200.  182.  152.   11.    1.
   O/F   0.    0.   12.   25.   29.   24.   22.   21.    9.    1.    0.
TOTAL    8.    4.  550. 1804. 2262. 2080. 1813. 1662. 1302.   98.    7.

GP
**
       <25 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69   >70
  GB/M   0.  502. 2401. 2551. 2445. 2470. 2734. 2274. 1419.  628.  444.
  GB/F   0.   99.  497.  520.  510.  504.  552.  455.  281.  125.   88.
   O/M   0.   89.  419.  444.  430.  436.  483.  402.  251.  111.   79.
   O/F   0.   17.   86.   90.   89.   88.   97.   80.   50.   22.   16.
TOTAL    0.  707. 3402. 3605. 3473. 3498. 3866. 3211. 2000.  886.  627.
```

```
AVERAGE TSG OF PROMOTEES TO THE GRADE
*************************************

       GB/M  GB/F GB/AVE   O/M   O/F  O/AVE
C      9.85 11.79  10.82 14.28 14.33  14.31  10.89
GP     4.10  4.74   4.42 10.81 10.55  10.68   5.20
SR     6.34  8.69   7.52 11.48 12.60  12.04   7.45
R      3.38  4.12   3.75  7.95  8.03   7.99   5.09
SHO    1.02  1.02   1.02  4.11  4.11   4.11   1.29

HO TO SHO 1 TIG ON PROMOTION
****************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1   771.  393.   1164.   74.   28.   102.  1266.
   1-2   795.  412.   1207.   94.   34.   128.  1335.
 TOTAL  1565.  805.   2371.  168.   62.   230.  2601.
AVE TIG  1.01  1.01           1.06  1.05          1.01

SHO TO R 1 TIG ON PROMOTION
***************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1   196.   65.    261.   99.   20.   119.   380.
   1-2   398.   99.    497.  193.   33.   226.   722.
   2-3   311.   64.    375.  150.   24.   174.   549.
   3-4   160.   47.    207.   91.   18.   109.   317.
   4-5    69.   24.     93.   57.   11.    68.   160.
   5-6    25.   10.     35.   35.    7.    42.    77.
   6-7    52.   17.     70.   80.   16.    96.   166.
 TOTAL  1212.  326.   1538.  705.  129.   834.  2372.
AVE TIG  2.33  2.39           2.84  2.91          2.52

SHO TO GP 1 TIG ON PROMOTION
****************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1    63.   21.     84.    5.    1.     6.    90.
   1-2   178.   59.    237.   15.    3.    18.   255.
   2-3   181.   60.    241.   16.    4.    20.   261.
   3-4    86.   29.    115.   10.    2.    12.   127.
   4-5    29.   10.     38.    5.    1.     6.    44.
   5-6    12.    4.     16.    3.    1.     4.    20.
   6-7    12.    4.     16.    4.    1.     5.    21.
 TOTAL   561.  186.    747.   58.   13.    71.   818.
AVE TIG  2.36  2.36           2.85  2.85          2.41

SHO TO ALL 1 TIG ON PROMOTION
*****************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1   259.   86.    345.  105.   21.   126.   470.
   1-2   576.  158.    734.  208.   36.   244.   977.
   2-3   492.  124.    617.  166.   28.   194.   810.
   3-4   246.   76.    322.  101.   20.   122.   444.
   4-5    97.   34.    131.   62.   12.    74.   205.
   5-6    38.   14.     51.   38.    8.    46.    97.
   6-7    64.   21.     86.   84.   17.   101.   187.
 TOTAL  1773.  512.   2285.  764.  142.   906.  3190.
AVE TIG  2.34  2.38           2.84  2.90          2.49

R TO SR 1 TIG ON PROMOTION
**************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1    10.    2.     13.    2.    0.     2.    15.
   1-2    93.    4.     97.   17.    0.    18.   115.
   2-3   173.   12.    185.   33.    2.    35.   220.
   3-4   131.   21.    152.   25.    3.    29.   181.
   4-5    52.   18.     70.   10.    3.    13.    84.
   5-6    18.    9.     27.    4.    2.     6.    33.
   6-7    23.    8.     31.    7.    3.    10.    41.
 TOTAL   501.   75.    576.   99.   13.   112.   688.
AVE TIG  3.01  3.94           3.15  4.37          3.18

R   GP 1 TIG ON PROMOTION
***  ********************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1     8.    2.     10.    2.    0.     2.    12.
   1-2    32.    8.     40.    6.    1.     7.    47.
   2-3    43.   11.     54.    9.    2.    11.    64.
   3-4    32.    8.     39.   10.    2.    12.    51.
   4-5    20.    5.     25.    8.    1.     9.    34.
   5-6    11.    3.     14.    6.    1.     7.    22.
   6-7    15.    4.     19.   36.    6.    42.    60.
 TOTAL   162.   40.    202.   76.   14.    90.   292.
AVE TIG  3.23  3.23           4.81  4.81          3.72

R TO ALL 1 TIG ON PROMOTION
***************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1    18.    4.     23.    4.    1.     5.    27.
   1-2   126.   12.    138.   23.    2.    25.   163.
   2-3   216.   23.    239.   42.    3.    45.   284.
   3-4   163.   29.    192.   36.    5.    40.   232.
   4-5    73.   23.     96.   18.    4.    22.   118.
   5-6    29.   12.     41.   10.    3.    13.    54.
   6-7    38.   12.     50.   42.    9.    51.   101.
 TOTAL   663.  115.    777.  175.   27.   202.   979.
AVE TIG  3.08  3.69           3.87  4.60          3.34
```

```
SR TO C 1 TIG ON PROMOTION
**************************

 TIG     GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL
    <1     5.    1.      6.    1.    0.     2.     8.
   1-2    14.    3.     17.    3.    0.     4.    21.
   2-3    51.   10.     61.   13.    2.    15.    76.
   3-4    90.   18.    108.   22.    3.    25.   133.
   4-5    77.   15.     92.   16.    3.    19.   110.
   5-6    46.    9.     56.    7.    1.     8.    63.
   6-7    23.    5.     28.    6.    1.     7.    35.
 TOTAL   308.   60.    368.   68.   11.    79.   447.
AVE TIG  3.97  3.97           3.84  3.95          3.95

TSG DISTRIBUTION OF PROMOTEES TO CONSULTANT
*******************************************

TSG      GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL GB/O/ALL
 3- 4      1.    0.      1.    0.    0.    0.       1.     0.2   0.0   0.0   0.0
 4- 5      2.    0.      2.    0.    0.    0.       2.     0.8   0.0   0.0   0.0
 5- 6      9.    0.      9.    0.    0.    0.       9.     2.9   0.2   0.0   0.0
 6- 7     22.    1.     22.    0.    0.    0.      22.     7.1   1.0   0.0   0.0
 7- 8     37.    2.     39.    0.    0.    0.      39.    12.0   3.0   0.0   0.0
 8- 9     49.    4.     53.    0.    0.    0.      53.    15.9   6.9   0.1   0.1
 9-10     52.    7.     59.    0.    0.    0.      59.    16.9  11.6   0.6   0.5
10-11     46.    9.     55.    1.    0.    2.      56.    14.8  15.0   2.0   1.8
11-12     34.   10.     44.    3.    0.    4.      48.    11.1  16.0   4.9   4.5
12-13     23.    9.     31.    6.    1.    7.      38.     7.4  14.4   8.4   8.0
13-14     14.    7.     21.    8.    1.    9.      30.     4.5  11.2  11.4  11.1
14-15     03.    8.     20.   27.    4.   31.      51.     4.1  12.6  39.4  40.1
15-16      7.    5.     12.   23.    4.   26.      38.     2.4   7.9  33.1  33.9
TOTAL    308.   60.    368.   68.   11.   79.     447.

TSG DISTRIBUTION OF PROMOTEES TO GP
***********************************

TSG      GB/M  GB/F  GB/ALL   O/M   O/F  O/ALL GB/O/ALL
 1- 2     63.    7.     70.    0.    0.    0.      70.     8.7   3.1   0.0   0.0
 2- 3    181.   34.    214.    0.    0.    0.     214.    25.0  14.9   0.0   0.0
 3- 4    196.   60.    256.    0.    0.    0.     256.    27.1  26.5   0.0   0.0
 4- 5    113.   52.    165.    0.    0.    0.     165.    15.6  23.1   0.1   0.1
 5- 6     59.   28.     87.    5.    1.    6.      94.     8.2  12.2   3.9   4.4
 6- 7     41.   15.     55.   15.    3.   18.      74.     5.6   6.6  11.1  12.3
 7- 8     27.   10.     37.   18.    4.   21.      59.     3.7   4.6  13.1  14.4
 8- 9     17.    7.     25.   13.    3.   16.      41.     2.4   3.3   9.7  10.4
 9-10     11.    5.     16.   10.    2.   12.      28.     1.5   2.2   7.6   7.7
10-11      7.    3.     10.   10.    2.   11.      22.     0.9   1.4   7.1   7.0
11-12      4.    2.      6.    9.    2.   10.      17.     0.6   0.7   6.5   6.3
12-13      2.    1.      4.    9.    2.   10.      14.     0.3   0.6   6.5   6.1
13-14      1.    1.      2.   10.    2.   11.      13.     0.2   0.3   7.1   6.5
14-15      1.    1.      1.   21.    4.   25.      26.     0.1   0.2  15.4  14.1
15-16      0.    0.      1.   16.    3.   19.      19.     0.0   0.1  11.8  10.8
TOTAL    722.  226.    948.  135.   27.  161.    1110.

WASTAGE OF      C    442.
WASTAGE OF      GP  1114.
*

STOCKS AT END SEPT   82
************************
            GB/M   GB/F     O/M     O/F   TOTAL
     C           9069.   1256.   1327.   157.  11811.
     GP         18014.   3737.   3143.   647.  25541.
     SR          2005.    521.    423.    87.   3035.
     R           3479.    923.   2018.   384.   6804.
     SHO         3521.   1508.   3345.   824.   9277.
     HO          1602.    957.    345.   159.   3063.
WASTAGE OF      C    473.
WASTAGE OF      GP  1118.
```

Figure A4. A typical output file, corresponding to the input file of Figure A2.

the title, with each line of title in inverted commas.

Lines 110-170: The *DEF operator is used to specify abbreviations, full names and type (A or T) for each state in the network. A state is referred to in the input data file by its abbreviation, but full names appear in the output (Figure A4) to make this more immediately intelligible. For T-states, the number of years-in-state bands into which the population is to be split is given by the number immediately preceding the T.

Lines 180, 185, 190: The *DIM operator is used to split up ("dimension") the population in each state into population subgroups. Line 185 specifies that the population is to be split up according to origin (doctors who are natives of Great Britain and Northern Ireland, and doctors who are foreign). Line 190 specifies a further split according to sex.

Lines 210: The *TRACE operator ensures that error messages, if necessary, appear in the output -- a useful facility when a new data file is being constructed.

Line 220: This line specifies the projection period -- 15 years in this example.

Lines 240-597: In this part of the file, base-year stocks data for 1980 are specified. The order in which states are dealt with is unimportant. Line 242 specifies that GP data are to be input in M7 format (which indicates to the program that GP is an A-state). Lines 243-246 specify, for native male doctors, age-specific numbers (TN), whole-time equivalents (WTE), wastage rates (LR) and the external entrant (JD) distribution. There are eleven age bands for TN, WTE and JD data: <25, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70+ years. There are 22 age bands for LR data: <29, 29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, >70. One of the program's subroutines converts all data into single-year distributions, before wastage rates are applied to stocks data. Single year wastage rates are necessary above age 58, because rapid changes from year to year occur in retirement rates at these ages. Lines 247-258 contain data for the other three population subgroups: native female doctors, foreign male doctors, foreign female doctors. All the JD lines also calibrate T flows into A-states -- see section 3.1. of the main paper. Line 300 specifies that SR data are to be input in M6 format, which tells the program that SR is a T-state. There are 28 entries for numbers and whole-time-equivalents (lines 301, 302). The first seven in each line are for the *seven* years-in-state bands (see line 140) of the native male doctor population subgroup. The next three sets of seven entries are for native female doctors, foreign male doctors, and foreign female doctors, respectively. Lines 303 and 304 relate to an algorithm which has been included in the program to allow the user to input raw data which are not in the exact form needed by the model. Data may often be in the form of years *since first entry* to a particular state, and not years actually spent *in* the state. Line 303 contains 28 percentage figures, and these specify the percentages of each (TN) number who have spent time out of a state after first entering that state. Line 304 gives the corresponding average numbers of years spent out of the state. The program uses the information in lines 303, 304 to convert the input stock distributions (lines 301, 302) to the correct years-in-state form. If the raw data are in the correct form already, *zeros* are input in lines 303, 304. Stocks data for the C-state (an A-state) are input in the same as the GP data; data for all other states (T-states) are input as for the SR state. To be concise, the description of these lines is omitted from this example.

Lines 580-597: The *TSQ operator introduces the data which allows the program to calculate Time-Since-Qualifiying for T-states. Line 582 contains four pairs of entries, one for each population subgroup. The first number in each pair specifies the percentage of doctors who have joined the grade from outside the network, not from promotion within. The second number gives the TSQ "band" (sixteen are available) in which the joining doctors are placed. For House Officers, 100% of doctors join from outside the network, because HO is the lowest grade. (Lines 586, 591, 595 should be interpreted in a similar way, for the SHO, R, and SR grades.) Numbers in lines 583, 587, 592, 596 are used to calculate the TSQ distribution of those doctors who enter each grade from some other grade in the network. See for instance, line 583: this line contains eight entries. The first two entries are for native male House Officers who have been promoted to SHO. Those promoted from the upper band of the HO grade have had a 9-times greater chance of being promoted than those from the lower band. Lines 587, 592, 596 carry similar information for the other T-grades, all of which have seven years-in-state bands. The order in which the states are input under *TSQ is important. The SHO distribution is needed to calculate the R distribution, and this in turn is needed to obtain the SR distribution.

For the purpose of calculating the TSQ distribution of the starting stocks, all the external joiners to grades (see the J lines) are assumed never to have been in those grades before. They therefore enter the lowest years-in-state band. This is important, because it is the ageing "flow" from one years-in-state band to the next which generates the TSQ distribution of the entire grade.

Lines 584, 589, 593, 597 contain sets of weighting factors called End Weights. In a case where the highest year-in-state band of a T-state contains all the population who have been in a state for m+ years, it is not valid to say that the TSQ distribution for this band should simply be the "aged" version of the one for band [(m - 1) - m]. The End Weights facility allows the user to specify the proportions of the 'm + years' population which have been in the state for (m + 1), (m + 2) etc. years. A TSQ distribution can then be calculated for each of these proportions of the 'm + years' population. The distributions are aggregated to produce an overall TSQ distributions for the m + years-in-state band. Ten End Weights can be used. It must be stressed that these End Weights cannot be used to extend the number of years-in-state bands.

The TSQ distribution facility is appropriate only for hierarchical systems. For non-hierarchical systems, each grade's J line should contain percentage values equal to 100%. All other entries should be dummy values of unity. This is simply a device for by-passing the TSQ calculation.

The simulation of a TSQ distribution uses the historic flows pattern. Any completely different flows behavior can be specified for the projection period.

Lines 600-672: This section of the data file contains wastage flows data. Consultants and GPs are wasted in accordance with the age-specific wastage rates input earlier (LR lines under >M7 operators). Wastage from SR and HO is expressed as an overall rate with a percentage annual increment (equal to zero). For the R and SHO grades, a wastage rate for each population subgroup (native males, native females, foreign males, foreign females) is input (the first four numbers in each of lines 650, 660). Accordingly, four percentage increments, one for each rate, are input (all zero). The T2 lines give the weighting factors which represent each year-band's relative contribution to the flow. The first set of numbers are for the years-in-state bands of the native male population subgroup. The remaining numbers are similar sets for the other population subgroups.

Lines 680-705: Pull flows are specified in this section of the data file. Line 680 instructs the program to pull stocks from SR to C each year, so that the C-grade stocks grow at 2% per year. The final entry in line 680 is a zero increment on this 2% rate. Lines 690 and 700 specify pulls from the R, SHO grades to GP, so that the GP grade grows at 1.1% per year. Lines 681, 612 specify percentages of vacancies allocated to joiners from outside the network, by population subgroup, together with the corresponding annual percentage increments. The T2 lines specify the years-in-state weighting factors for the flows from the SR, R, SHO grades.

Lines 710-752: These lines specify push flows. The format is identical to that for wastage flows.

Lines 760-790: These lines instruct the program to advance by one year the age distribution of the stocks of certain grades. (In these cases "age" is years-in-state.) States which are not pull flow destinations have to have their stocks aged in this way.

Lines 800-924: These lines specify entrants to each grade from outside the network. Eight lines are input for House Officers under the >JT operator. The first line specifies, for native males, the numbers who enter the lowest years-in-state band. Fifteen numbers are input, one for each year of the projection period. The next three lines deal with entrants into the lowest years-in-state band for the other three population subgroups. The following four lines specify corresponding information for the second (i.e., highest) years-in-state band.

For the next three states, SHO, R and SR, numbers for individual years-in-state bands are not input. Instead, a distribution over years-in-state is input for each population subgroup. Thus, for Registrars (R), 300 native male doctors enter the grade from outside the network every year. They are distributed over the years-in-state bands according to the declining distribution. (If there are N bands, then external entrants are allocated to them in the ratio: N:N-1:N-2:....... 2:1.) The two other available distributions are the FT (flat), in which all years-in-state bands receive equal numbers of entrants, and the FY (first year), in which all entrants join the lowest years-in-state band. If a distribution is used (under the >JS operator), it is not necessary to input a number for every year in the projection period, if a succession of years have the same number of entrants. For example, in lines 903, 904, 908, 909, 913, 914, 923, 924 numbers remain the same after the sixth year of the projection period. Any state can have external entrants input under either a >JT¯ operator or a >JS operator. In addition, distributions can be input which are the sum of DE, FT or FY (e.g., the entrants to the SHO grade: lines 900-909).

Line 940: This line instructs the program to make projections for 15 years.

The Output: Figure A4

Figure A4 should be largely self-explanatory. (The form of the results is specified in line 10 of the input file -- see also Figure A3.) A few points may, however, be worth mentioning. For conciseness, the results for all 15 years are not shown, merely the base year stocks data (1980) and the reusuts for 1981 (full results) and a summary for 1982. The columns of numbers for T-states are as follows:

-- The first four columns are <u>numbers</u> by population subgroup by years-in-state

-- The fifth column contains totals of the first four

-- The sixth to ninth columns contain the information of the first four expressed as percentages

-- The tenth column contains the information of the fifth column expressed in percentage form

TIG means years-in-state; this appears in the interstate flow results (TIG ON PROMOTION). The final column in these tables contains overall numbers of the grade. The TSQ distribution tables contain in the final four columns, population subgroup -- specific numbers in percentage form. The table headed "AVERAGE TSQ OF PROMOTEES TO THE GRADE" contains overall numbers for the grade in the final column.

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