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System Dynamics Modeling Approach for Manpower Planning and Policy Analysis

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Abstract

The objective of this paper is to demonstrate how System Dynamics Approach may be used to develop new ways of analyzing and projecting manpower requirements and resources. For this purpose, a System Dynamics Model is presented as an example. An examination of the model will show that a System Dynamics modeling approach is an innovative and useful tool for manpower policy analysis and planning. Second, with minor modifications, the model may be used for manpower policy analysis and planning for any skilled personnel in Korea. For example, a similar model may be built for engineers to analyze the effects of alternative policies about engineering education, such as the number of available places in the various institutions of training, scholarships and loans, and the duration of training. An engineer's model may also be used to make the projections of the supply and requirements of engineers in the future according to various alternative assumptions where each assumption represents a policy option.

Introduction

The objective of this paper is to demonstrate how System Dynamics Approach may be used to develop new ways of analyzing and projecting manpower requirements and resources. For this purpose, a System Dynamics Model is presented as an example. The model was originally developed by Pugh-Roberts Associates, a consulting firm in Cambridge, Mass., U.S.A. under a contract with the U.S. Department of Health, Education and Welfare. The writer of this paper evaluated the usefulness and implications of the model for Applied Management Sciences while he was in the U.S.A.. This paper, however, concentrates on describing the model rather than criticizing it. The reason for this is that this paper is written solely to explain a System Dynamics Approach to manpower policy analysis and planning for possible uses here in Korea. The model deals with the health care system of the U.S. in general and the nursing manpower in particular. Although the model is built for the analyses and projections of nursing personnel, it can be applied to any skilled, and trained personnel with minor modifications, if the sufficient data and the knowledge of the system are available.

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System Dynamics Modeling Approach

The Model is being developed with a set of techniques referred to as System Dynamics. These techniques were developed at the Massachusetts Insitute of Technology (MIT) during the 1950's under the direction of Dr. Jay W. Forrester and have been applied to problems in industrial, urban development, public service, and national gevernment settings in the U.S.A. A System Dynamics model describes a set of causal relationships responsible for changes in variables of interest to policy-makers, such as those variables characterizing the supply of, demand for, and distribution of manpower and services. Causal relationships contained in the National Scientist Model describe, for example, the effects of a particular graduation rate on the number of scientists actively employed, or the impact of wage levels on the number of scientists hired during a year to work in a certain employment setting. These relationships are responsible for changes that occur and determine how a system of variables, such as those characterizing scientists, will change.

The pattern of changes that will occur over time in this sort of system is difficult to anticipate because of the large number of relationships usually involved and the complex manner in which changes within the system interact to produce its overall behavior. For this reason, System Dynamics has within its repertoire a computer language called DYNAMO that allows the behavior of a system of causal relationships over time to be simulated. Once the relationships have been represented in DYNAMO's equation format, the computer takes on the work of calculating how the system will respond over time to changes induced in it. "What if?" questions can then be explored by making changes in the Model's relationships to represent the implementation of various policies and programs or the impacts of external forces. A "what if?" question about the impact on scientist requirements of a National Science Development program, for example, might be represented in the Model by revising upward the Model's assumptions about the demand for scientists in various institutions. The computer can then be used to determine how the system would behave as a result of those changes. Many policy and program alternatives and other "what if?" questions can be explored in this manner.

The System Dynamics methodology has several characteristics that distinguish it from other methodologies that have been applied to manpower planning;

1. **Uses Good Data**—System Dynamics modeling uses good data, where available, to quantify causal relationships. When data are not available, estimates of important relationships are used to avoid discarding those relationships from consideration.
2. **Evaluates Policy**—System Dynamics models are used principally for evaluating alternative policies and programs rather than for precisely predicting future developments. Though these models typically simulate a system's performance over future time periods, the emphasis is on comparing simulation results with alternative policies and programs instead of on accurately forecasting system performance.
3. **Involves Non-Technical Participants**—System Dynamics efforts typically involve non-technical participants as sources of "data" on causal relationships. People who are familiar with the system being modeled are likely to be the best sources of information on that

system. They are also more likely to implement policies and programs indicated as preferable by the model if they have had a role in the model's development and use.

4. **Emphasizes Feedback Loops**—These are circular sets of causal relationships that are the focus of System Dynamics analyses. Such sets of relatioships can work to accelerate changes introduced into systems (vicious circles) or to resist those changes. Identifying the feedback loops that principally affect changes in systems is essential for designing any policies and programs for improving those systems' performance.
5. **Takes a Long-Term View**—Interventions in complex systems take a long time to carry out. A decision to make a major change in the mix of scientific personnel available, for example, will not have a significant impact until new programs have been set up, students have been enrolled in and graduated from those programs, and sufficient numbers of graduates have entered the work force, a process that can take many years. Dealing with problems and requirements as they arise is usually not satisfactory because of the long lead times needed to intervene in complex systems, and it results in problems persisting or requirements going unmet much longer than they need to. The long-term view allowed by the System Dynamics approach permits problems and requirements to be anticipated and interventions to be initiated before crises occur.

Together these characteristics make System Dnnamics well-suited to complex problems in manpower planning where limited data exist, many interrelated factors must be considered, and the implications of any decision are far-reaching and long-term in nature.

Overview of the Model

This section presents an overview of the Model's structure. The Model's relationships fall into four highly interrelated and interdependent pieces or "sectors":

1. **Nursing education**—representing the factors affecting the number of students in each major type of educational program and the graduation rates from these progras;
2. **Nursing employment**—representing the factors affecting the number of nurses employed in each setting and various characteristics of employment in each setting, such as nurses' wages and nurses' roles;
3. **Demand**—representing the health care provided in each sector of the health care delivery system, the nursing needs, and nursing jobs available in each employment setting;
4. **Demography**—representing key demographic characteristics of the total population that impact on other sectors of the Model, principally the demand sector.

An overview of some of the key relationships in the Model is shown in Figure 1. As shown in that diagram, the number of nursing students being graduated from educational programs, along with other factors, affects the total supply of licensed nurses at each level of educatonal preparation. Numbers of graduates depend on the numbers of places in programs at each level and the numbers of applicants for those programs. Nursing employment in each setting depends on both the number of nursing jobs available and the number of nurses willing to take those jobs (i.e., on both the demand for and supply of nursing personnel). The health care provided in each sector of the health care system, nurses' wages, nurses' responsibilities, and other factors

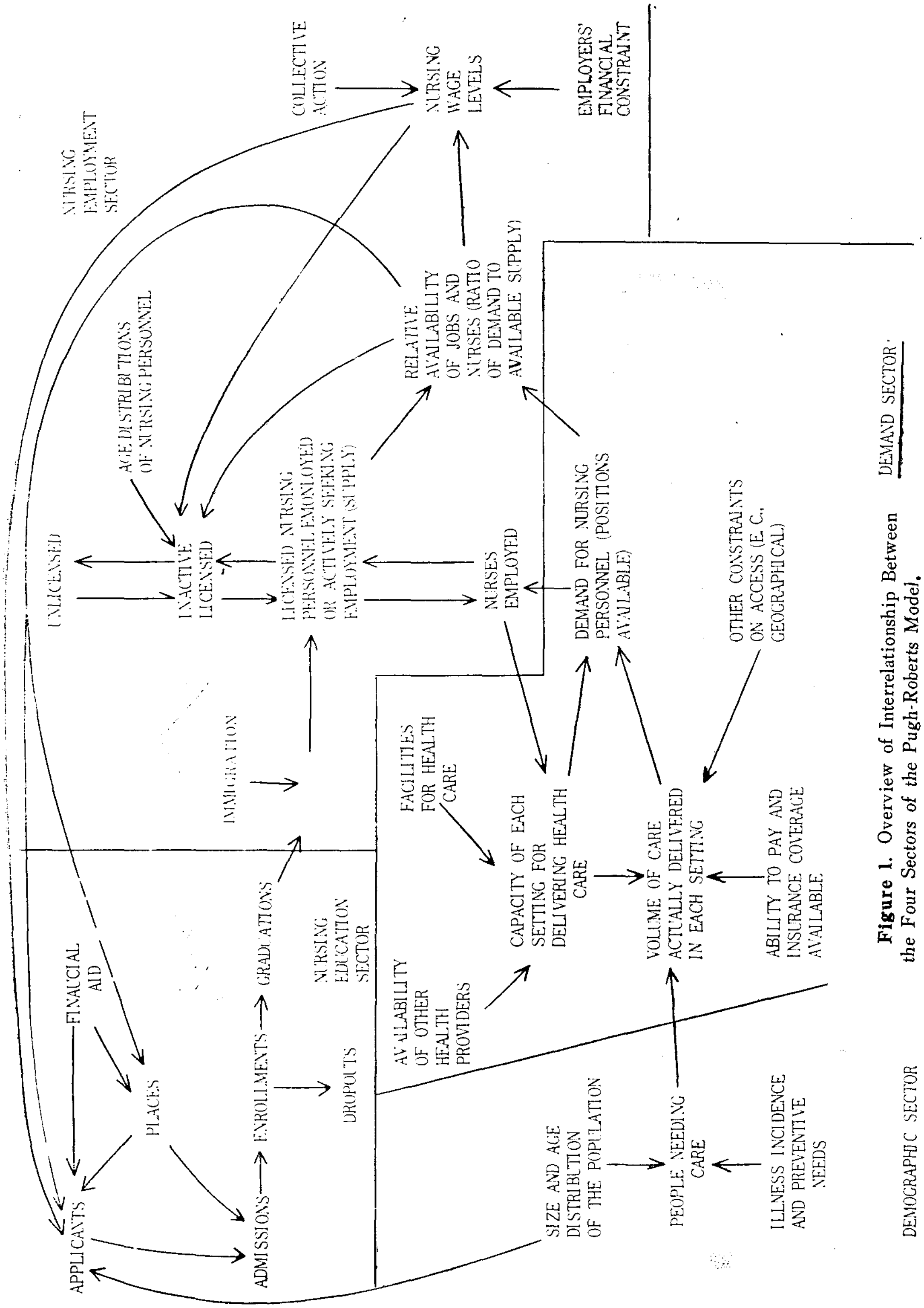

Figure 1. Overview of Interrelationship Between the Four Sectors of the *Pugh-Roberts Model.*

affect employers' desired staffing patterns and the number of nursing jobs available in each setting. Important influences on nurses' willingness to take available jobs include nurses' wages; nurses' roles and responsibilities; the match between qualifications of available nursing personnel and requirements of available jobs; the location of jobs relative to where available nurses live; factors affecting the relative attractiveness of employment in different settings; and demographic characteristics such as nurses' age distribution, the fraction of nurses married, and nurses' childbearing patterns. The volume of health care delivered in each setting is affected by the size and age composition of the total population, care requirements for people in each age group, the financial and geographical accessibility of care, and the attitudes of people toward seeking care.

Theoretical Construct of the Model

As mentioned before, the System Dynamics Model contains four inter-connected sectors, three of which comprise the health care system. They are nursing education, nursing employment, nurse demand, and demographic sectors. The theoretical construct of each sector will be discussed initially, with the construct of the entire model then examined in terms of inter-sectoral relationships.

Nursing Education Sector.

The nursing education sector of the model consists of specifying how the selected variables determine: (1) the number of non-nurse applicants to nursing education programs, (2) the number of nurse applicants to nursing education programs, (3) the number of available places in nursing education programs, and (4) the drop-out rate from such programs. The establishment of the above relationship allows the projection of the number of graduates each year, given an age-specific population projection. A schematic view of the nursing education sector of the model is presented in Figure 2.

The total number of applicants is a measure of the demand for nursing education, while the number of available places is a measure of the supply of nursing education. The number of entering students is, then, determined by the interaction of these demand and supply measures. Given the number of entering students, the number of graduates at the end of required years of schooling is determined by applying drop-out rates. Yearly graduates from nursing schools constitute a major source of nurses entering the employment sector. (See Figure 2) In the following, the structure of the nursing education sector is presented in terms of the determinants of the demand for, and the supply of, nursing education, along with the drop-out rates. The demand for nursing education by non-nurses in the model may be expressed as:

$$NAEP=f(NPAE,\ PAJA,\ W,\ CBNR, ASL,\ OFDE) \qquad (1:1)$$

where:

NAEP = number of people without previous training applying to each type of nursing education program;

NPAE = number of places available in each type of educational programs, represented by the ratio of the number of places available at each point in time to that in 1972;

PAJA = perceived availability of jobs in nursing at each level, represented by the ratio of nurses employed and considering employment to available jobs at each level over the 1972 ratio;

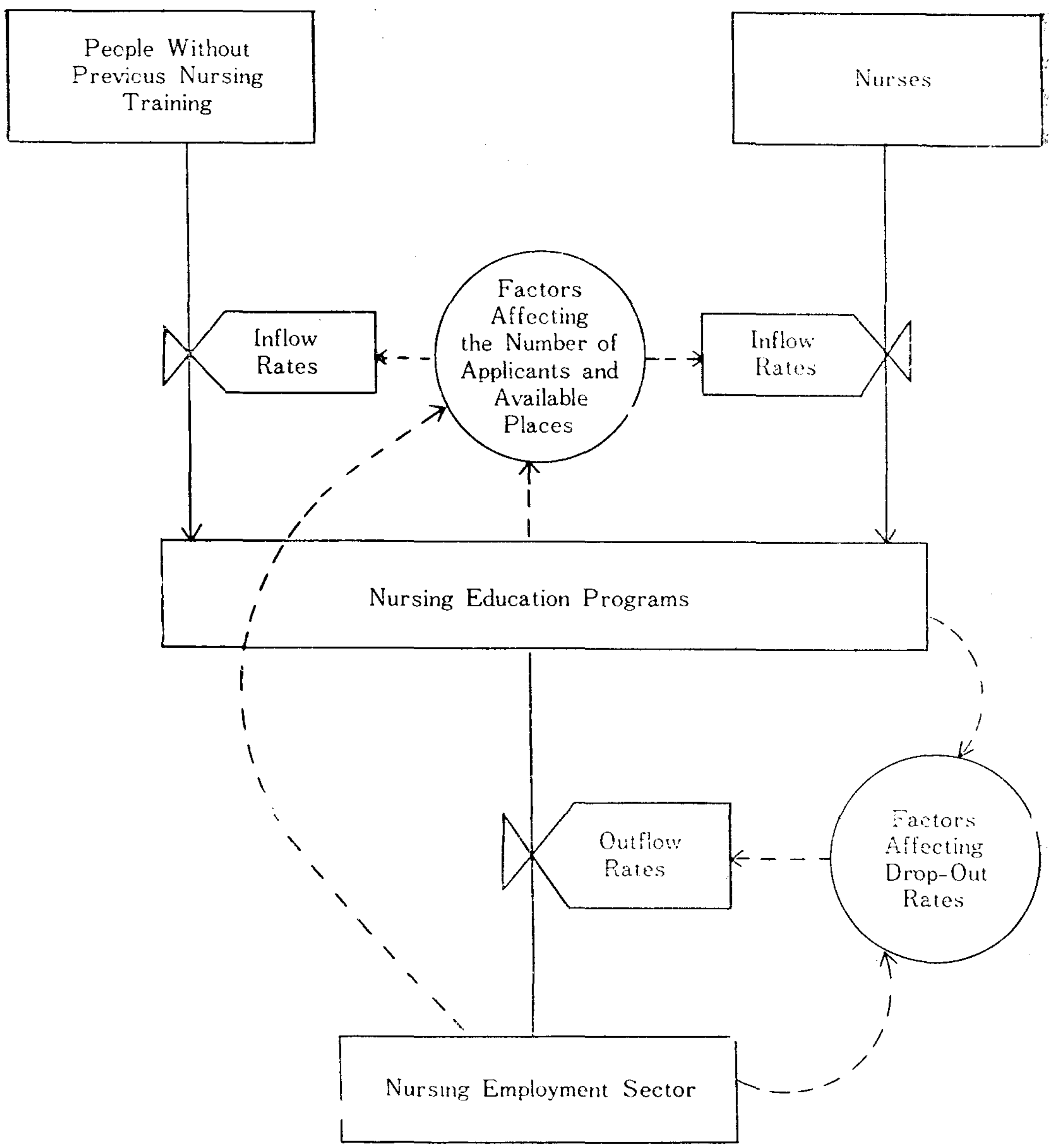

Figure 2. Schematic View of the Nursing Education Sector of the Pugh-Roberts model as Interpreted by Kong-Kyun Ro.

W = nurses' wages as represented by the ratio of real wages at each level to 1972 wages for personnel at that level;

CBNR = changes in the breadth of nurses' responsibilities, as represented by a dimensionless index in which a value of 1.0 represents the breadth of responsibilities of nurses at each level in 1972;

ASL = availability of scholarships and loans, as represented by the fraction of costs covered by scholarships and loans for the average student; and

OPDE = other factors affecting the demand for nursing education, such as perceived availability of jobs in other professions, changes in average tuition levels, and the perceived job satisfaction of nurses.

The effects of these independent variables on the demand for nursing education is expressed by "multipliers" which increase or decrease the value of dependent variables by specified proportion. These multipliers are often determined from the consensus judgment of the Task Group rather than by correlation estimation.[1] Since the values of the multipliers change according to the magnitude of changes in the independent variables in a complicated non-linear and, possibly non-systmatic way, one cannot represent them as the usual demand parameters.

An estimation of multipliers presented in Table 1 indicates that the Task Group considered the perceived availability of nursing jobs as the most important factor affecting the demand for nursing education,followed by nurses' wages, the availability of scholarships and loans, available places in each educational program, and changes in the breadth of nursing responsibilities. The judgment of the Task Group, as expressed by the values given for the multipliers, closely conforms to the results of several past correlation studies of the parameters of demand for professional education which they considered in forming their judgments.

The demand for nursing education by nurses (continuing education) is similar to that exhibited by non-nurses. For obvious reasons, however, there are some variations in the affecting variables used. For example, the relative availability of nursing jobs at higher levels replaces the perceived general availability of jobs in nursing, and wage differentials among levels of nursing positions replaces the general levels of nurses' wages. The total demand for nusing education is then measured by adding the total demand by non-nurses to that of nurses who wish to return to nursing schools.

On the supply side the total supply of nursing education may be expressed as follows:

$$NPAE = f(NAEP_t/NAEP_{72}, PAJA, FPF, OFSE) \qquad (1:2)$$

where;

NPAE = number of places available in each type of nursing education program;

$NAEP_t/NAEP_{72}$ = number of applicants relative to existing places as represented by the ratio of applicants to programs at each level to the 1972 applicants;

PAJA = perceived availability of jobs in nursing, as represented by the ratio of nurses employed and considering employment as each level to jobs available at each level over the

1) In response to a concern that the model be an accurate representation of nursing and its role in healthc are, a National Model Task Force was formed and played a central role in the work. The Task Force consists of nine members and brought with them diverse perspectives.

Table 1. Factors Affecting Numbers of Applicants to Nursing Programs at Each Point in Time

Effect on the number of applicants of:	Determined by the values of these variables:	These values of the variables:	Correspond to these multipliers that increase or decrease the number of applicants:
1. Available places in programs at each level	Number of places available at each point in time/Number of places available at that level in 1972	0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00	0.10 0.40 0.70 0.85 1.00 1.05 1.10 1.12 1.15
2. Jobs available at that level	Number of nurses employed and considering employment/ Available jobs at each level/1972 value of the ratio of available nurses to available jobs	0.5 0.75 1.00 1.25 1.5	1.35 1.20 1.0 0.8 0.6
3. Wages of personnel at each level	Real wages of personnel at each level (adjusted to factor cost inflation)/ 1972 wages for personnel at that level	0 0.5 1.0 1.5 2.0	0.7 0.9 1.0 1.2 1.5
4. Breadth of responsibilities of personnel at each level	Dimensionless index in which a value of 1.0 represents the breadth of responsibilities of nursing personnel at each level in 1972	0 0.5 1.0 1.5 2.0	0.80 0.90 1.00 1.08 1.10
5. Availability of financial aid for students in programs at each level	Fraction of costs covered by scholarships and loans for the average student	0 0.25 0.5 0.75 1.0	0.85 1.00 1.10 1.15 1.20
6. Other factors impacting on numbers of applicants			A multiplier given varying values over time to reflect assumptions about the effects of such factors as perceived availability of jobs in other professions, changes in average tuition levels, and the perceived job satisfaction of nursing personnel

1972 ratio;

FPF = availability of qualified faculty as represented by the fraction of faculty positions filled; and

OFSE = other factors affecting the supply of nursing education, such as financial pressures on schools and constraints on the availability of clinical exposure.

The demand for and supply of nursing education, as specified above by equations (1 : 1) and (1 : 2), determine the number of students entering into each type of nursing education program.

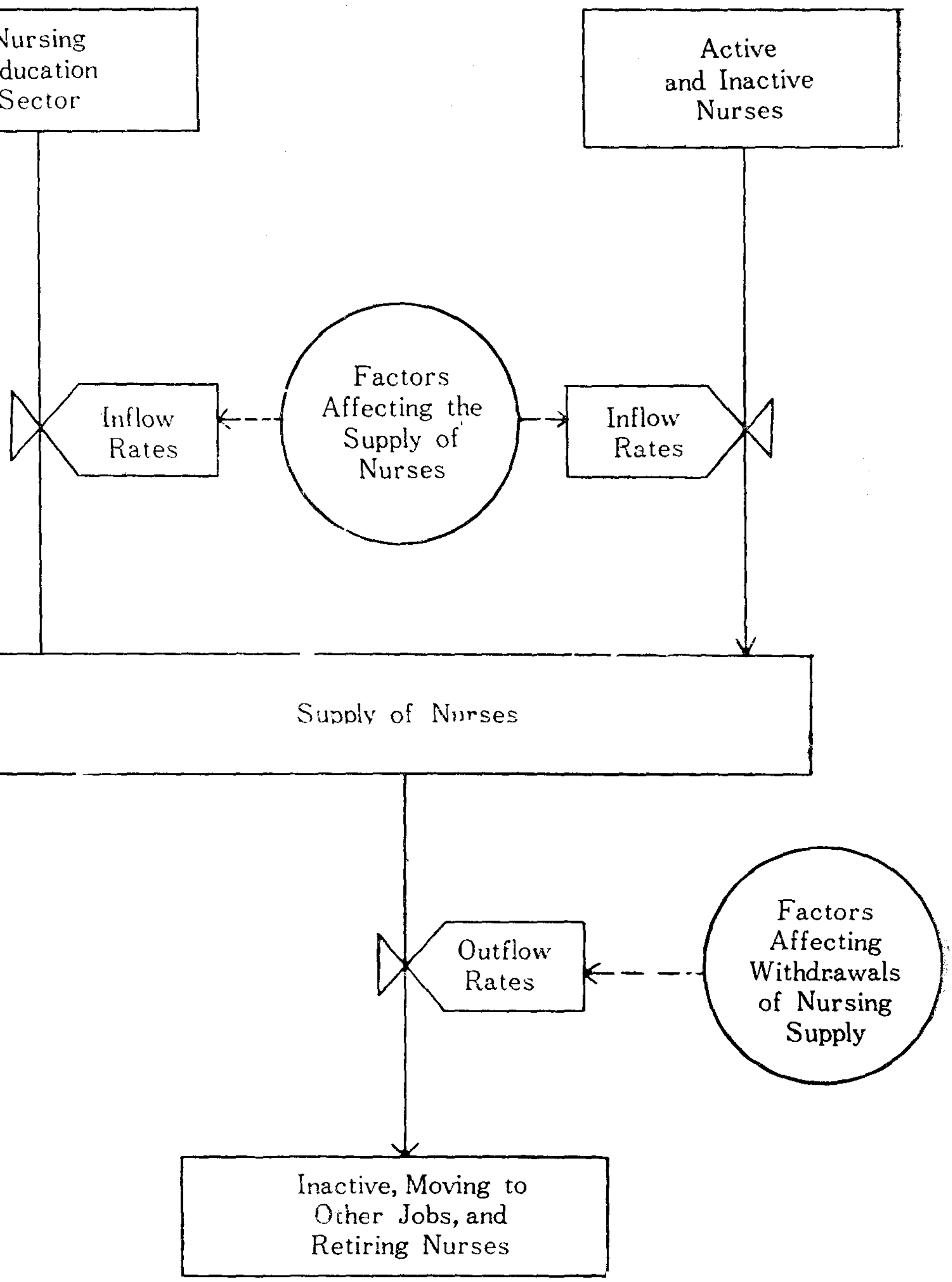

Figure 3. Schematic view of the Supply of Nurses of the Pugh-Roberts Model as Interpreted by Kong-Kyun Ro.

Then, the number of graduates at each type of educational program is determined by subtracting the number of drop-outs from entering students following the required years of schooling. The model projects the number of drop-outs by.

FNSD = f (CSL, OFDR) (1 : 3)

where

FNSD = fraction of nursing students dropping out of each type of educational program;

CSL = changes in the availability of scholarships and loans; and

OFDR = other factors affecting drop-out rates such as more stringent academic standards in some programs.

Thus, the number of yearly graduates is determined as:

$NGS_{t+n} = NSEN_t - (NSEN_t \times FNSD)$ (1 : 4)

where

NGS_{t+n} = number of students graduating from each type of nursing education program at the year t+n, where t denotes the base year and n the number of required years of schooling;

$NSEN_t$ = number of students entering into each type of program at the base year t; and

FNSD = fraction of nursing students dropping out of each type of educational program during the n year of schooling.

The projection of the number of yearly graduates from each type of nursing education program, as determined by equations (1 : 1) though (1 : 4), completes the function of the nursing education sector of the model.

Nursing Employment Sector

As shown in Figure 3, the nursing employment sector of the model consists of specifying how the chosen variables determine: (1) the number of licensed nurses including new graduates, who are employed or seeking employment, and who are willing to take available jobs at each job settings, (2) the number of nurses not employed or inactive but willing to take available jobs, (3) the number of nurses quitting to take other nursing positions, (4) the number of nurses retiring or becoming inactive, and (5) the number of nurses immigrating into the country. Determination of the above would enable model users to project the effective rate of nurses' supply at each point in time.

The model's specification of the factors affecting the supply of nurses from both the nursing education sector and active nurses may be expressed in the following way:

FNWECE = f(PAJAS, W, BNR, EFOT) (1 : 5)

where

FNWECE = fraction of nurses at each educational level who are employed or are willing to consider employment;

PAJAS = perceived availability of jobs at each level, as presented by the ratio of the number of jobs available for nurses at each level to the total number of jobs for nurses at each level;

W = nurses' wages, as represented by the ratio of wages personnel at each level to 1972 wages for personnel at that level;

BNR = breadth of nurses' responsibilities represented by a dimensionless index in whch a value of 1.0 represents the breadth of nurses' responsibilities in 1972; and

EFOT = changes in overal economy over time.

In terms of the values of impact multipliers given by the Task Group, by far the most important factor influencing the supply of nurses is nurses' wages. (See Table 2) Other factors are judged to exert relatively insignificant impacts on the nurses' supply. In the model, the movements of nurses between employment settings are determined by the differences between employment settings in the factors influencing the willingness of nurses to take employment in a particular setting. The factors affecting the willingness of nurses to take employment in a particular setting are relative availability of jobs in each setting, relative wage rates, and relative inherent attractiveness that reflects the relative breadth of responsibilities of nursing personnel.

As mentioned above, the model also considers the factors affecting the withdrawal of nurses from the supply. The model assumes that the decision of nurses to quit nursing employment, either to take jobs outside of nursing or to become inactive, are influenced by the availability of jobs in the nursing sector vs. those in other sectors, and by changes in the demographic statuses of nurses.

In addition to specifying what variables and how they influence the supply of nurses, the model considers how these variables are determined. For example, the model specifies the

Tabe 2. Effect of Various Factors on the Fraction of Licensed Nurses at each Educational level who are Employed or Willing to Consider Employment

Effect on nurses willing to consider employment of:	Determined by the values of these variables:	These values of the variables:	Correspond to these multipliers that increase or decrease the fraction of those employed or considerin employment
1. Average nurses' wages for each educational level	Real wages of personnel at each level (adjusted to factor cost inflation)/1972 wages for personnel at that level	0.50 0.75 1.00 1.25 1.50	0.90 0.95 1.00 1.05 1.10
2. Breadth of nurses' responsibilities	Dimensionless index in which a value of 1.0 represents the breadth of nurses' responsibilities in 1972	0.0 0.5 1.0 1.5 2.0	Effect varies: greater impact on higher educational levels, e.g.: LPN Advanced degree 0.98 0.90 0.99 0.95 1.00 1.00 1.01 1.04 1.02 1.08
3. Effect of changes in overall economy over time	Projected effect over time	1972 1977 1982 1987 1992	1.00 1.02 1.01 1.00 1.00
4. Other exogenous factors	Projected effect over time		No changes due to other factors assumed in most simulations

variables influencing the spread of collective bargaining in hospitals, changes in nurses' wage rates, and the relationship between the two.

Demand (for Nurses) Sector

Given the supply of nurses as determined in the nursing employment sector, the demand for nurses needs to be determined in order to arrive at projections of nursing requirements. The model determines the demand for nurses at each educational level, for each of the seven major employment settings in its "demand sector." Factors that affect the demand for nurses differ somewhat sccording to the employment settings. Since the majority of nurses are employed in hospitals, and because a set of factors that influence the demand for nurses in hospitals approx imates the general set of factors that influence demand in most of employment settings, the determinants of the demand for nurses in hospitals are discussed here as representing the demand sector of the model.

Factors affecting the demand for nurses in hospitals, as represented by the number of jobs available in hospitals, may be expressed as:

$$NEDH = f(WH, FSH, CBH, BNRH, INPNH, TCEFH) \quad (1:6)$$

where

NEDH = number of nurses at each educational level demanded in hospitals;

WH = nurses' wages, represented by he ratio of average wages of nurses in hospitals adjusted for inflation to 1972 average wages.

FSH = hospital's financial situation, as represented by an index measuring the degree of difficulty hospitals have in passing along increased costs;

CBH = collective bargaining, as represented by the fraction of hospitals with collective bargaining aggrements;

BNRH = breadth of nurses' responsibilities in hospitals, as represented by a dimensionless index for which a value of 1.0 represents the breadth of responsibilities of nurses in 1972;

INPNH = average intensity of patient needs for nursing services as represented by a combined index reflecting average length of stay and pre-admission screening; and

TCEFH = technological change and other excgenous factors.

According to the values assigned to the multipliers, the Task Group considered the intensity of patient needs for nursing services and nursing wages, as the two most important factors influencing the demand for nurses in hospitals. (See Table 3) It projected a 20 percent decrease in the number of jobs available in hospitals with a 40 percent increase in nursing wages. On the other hand, the Task Group projected a decrease in the demand fcr nurses of five percent with an increase in the patient need intensity index of ten percent. It is also interesting to note that the Task Group expected technological changes and other exogenous factors to increase the demand for nurses by 20 percent by 1992.

Demographic Sector

The demographic sector of the Pugh-Roberts model estimates the nation's population in terms of both total size and the distribution amorg ten age categories, as well as the fertility rates and death rates for members of each age category. The number and age distribution of those

Table 3. Factors Affecting Total Nursing Staffing Levels in Hospitals

Effect on staffing levels of:	Determined by the values of these variables:	These values of the variables:	Correspond to these multipliers that increase or decrease the number of staff
1. Nursing wages	Average wages of nursing personnel in hospitals (adjusted to factor cost inflation)/ Average wages of nursing personnel in hospitals in 1972	0.8 0.9 1.0 1.1 1.2 1.3 1.4	1.05 1.02 1.0 0.97 0.93 0.87 0.80
2. Hospital financial pressures	An index measuring the degree of difficulty hospitals have in passing along increased costs	Low High	1.0 1.0 0.96 0.92 0.80
3. Collective bargaining agreements between hospitals and nurses	Fraction of hospitals with collective bargaining agreements	0 0.5 1.0	1.0 0.8 0.5
4. Breadth of nurses' responsibilities in hospitals	Dimensionless index for which a value of 1.0 represents the breadth of responsibilities of nursing personnel in 1972	0 0.5 1.0 1.5 2.0	0.75 0.90 1.0 1.10 1.20
5. Average intensity of patient needs for nursing services	Combined index reflecting average length of stay and pre-admission screening	0.8 0.9 1.0 1.1	1.24 1.12 1.0 0.95
6. Technological change and other exogenous factors	Projected effect over time	1972 1977 1982 1987 1992	1.00 1.08 1.13 1.17 1.20

*This effect eliminates part of the reductions in staffing that would otherwise tend to occur if financial pressures increase or wages increase faster than the rate of inflation.

immigrating into the country is also included in the model.

Given the ten age groups, the rates of change of the population (per month) due to births, deaths, and immigration for each age category are derived from the "Series E" censue projections of the U.S.A. The rate of immigration is held constant at 400,000 peopleper year, and is distributed among various age categories. The model automatically "ages" the population each month by moving a fraction of each age group to the next-older age group. Female death rates, which are somewhat different from those reported for the total population, are used in computing the rates of deaths of nurses in each age category for each educational lAeel.

The objectives of demographic sector are twofold. One is to provide a basis to calculate the age-specific incidence of illness in the population and, thereby, the magnitude of the population's need for health services. This enables the model to project the demand for nurses in the demand sector. The other is to provide a basis for projecting the number of applicants for each nursing education program. This, in turn, provides a basis for projecting the supply of nurses from the nursing education sector.

Integration of the Four Sectors

For each of the four sectors of the model (nursing education. nursing employment, demand, and demographic), the model construct is separately described above. This subsection discusses how these four sectors fit together to make projections of the demand for, and supply of, nurses.

The interrelationship between the four sectors of the Pugh-Roberts model is explained by Figure 1 on page 54. As shown in this figure, the primary role of demographic sectors is to provide a basis for estimating the prevalence rate of illness and, thereby, the need of the nation's population for health services. This enables the demand sector to project the demand for health services and, subsequently, the demand for nurses. The secondary role of the demographic sector is to provide the nursing education sector with a basis for projecting the supply of the applicants to nursing education programs.

The role of nursing education sector is to consider the demographic factors, along with other factors, affecting the supply of applicants (or the demand for nurse education) on one hand, and the factors affecting the demand for students (or the supply of nursing education) on the other. Then, it projects the number of the yearly new graduates at each level of education for the nures employment sector.

The role of the demand sector is to provide projections of the magnitude of the demand for health services based on the estimates of the need for health services provided by the demographic sector and other factors affecting the demand for health services. Then, it considers, along with other factors, how the demand for health services affects the demand for nurses and thereby, provides the employment sector with a basis for projecting the number of nurses demanded in each employment setting.

The role of the nursing employment sector is to consider and synthesize projections of the demand for health services provided by the demand sector with the projections of the yearly new graduates provided by the nursing education sector. Then on the basis of these and other factors affecting the demand for and the supply of nurses, it projects nursing employment in each setting.

Validation Test

As a part of building and refining the model on a trial and error basis, four types of model validation tests were undertaken by the model builders. The first type consisted of checking the simulation results for their face validity or plausibility. Face validity checks of initial simulations with the model revealed a number of inconsistencies between model relationships, and aspects of model behavior, that appeared unrealistic. This is to be expected in any complex system during the process of development which relies heavily on a priori data as in a System Dynamics model. The necessary modifications were, of course, made. Then the results of simulations conducted following these modifications were further examined for plausibility by a Task Force. This examination revealed some additional structural inconsistencies and unrealistic behaviors in the model, which were subsequently corrected.

The second type of validation test conducted for the Pugh-Roberts model consisted of forecast consistency checks. This was done by carefully scrutinizing simulation results for the first four years of the forecast (1972~76), and comparing them with data available for those years. In addition, these forecasts were compared with similar projections made by the Research Triangle Institute and the Interagency Conference on Nursing Statistics. As a result of these comparisons, some major adjustments or calibrations were made to the model.

As the third type of validation tests, the model builders checked the historical tracking ability of the model. This was done by running a series of simulations for the period between 1962 and 1972, under a variety of assumptions. The results of the initial simulation were carefully examined to see how closely the model could duplicate real-world behavior buring the period. The results diverged somewhat from the real-world behavior as indicated bythe historical data. It was discovered, however, that this was because the assumptions made with respect to the exogenous variables in the simulation runs were not applicable to the conditions actually affecting nursing in these years. A new set of simulations was run after correcting the assumptions about the external factors affecting the supply of hospital and nursing home beds, and the results conformed more closely to actual behaviors observed during 1962~72 period.

Clearly then, the face validity tests, forecast consistency tests, and the tests of historical tracking ability were undertaken by the modelers as logical steps to refine the model. As the final step of refining the model through the vaildation tests, policy/assumption impact forecasts were generated by the model builders as a part of a set of sensitivity tests, Sensitivity tests conducted with the model must also be considered as validation tests, because the model's projections involve various assumptions about the possible changes in health care systems most of which are expected to be induced by specific policies.

Seven sets of simulations were conducted as sensitivity tests with the model. Each simulation involved limited changes from the baseline assumptions. The changes incorporated into each of the seven sets of simulations were:

1. a doubling in the size of educational program and of applicants to those programs;
2. a decline in diploma programs that results in a complete elimination of diploma programs during the first half of the simulation;
3. more rapid growth in the total population than in the baseline; and a death rate that is 3 percent lower for all age categories than the rates used in the baseline;
4. a large, rapid shift in the demand for nursing personnel in hospitals especially during the first five years of the simulation;
5. a complete eliminalion of all effects that cause changes to occur in education, other factors aflecting supply such as labor force participation, and demand as a result of supply-demand mismatches;
6. a complete elimination of the effects of supply and demand mismatches (simulation 5) combined with a sharp, rapid increase in hospital's demand for nurses (simulation 4) that helps to create a significant mismatch: and
7. assumption of no change during the course of the simulation in breadth of nurses' responsibilities, fraction of the hospitals that have collective bargaining agreements with nurses, and fraction of the hospitals that pay different wages to R.N.'s at different levels of preparation.

The results of the seven sets of simulation are presented in Table 4, where for each simulation the percentage differences between values of variables in 1990 are displayed. The larger percentage changes shown in column 1 relative to other columns indicates a greater sensitivity of various aspects of the model's behavior to the assumptions of doubling the size of educational programs and the number of applicants to those programs. The next largest changes from baseline values are predicted when there is a rapid increase in hospitals' demand for nurses with no market adjusting process due to supply and demand mismatches (simulation assumption 6).

Concluding Remarks

The above discussion clearly has revealed two things. First, a System Dynamics modeling approach is an innovative and useful tool for manpower policy analysis and planning. Second, with minor modifications the Pugh-Roberts model may be used for manpower policy analysis and planning for any skilled personnel in Korea. For example, a similar model may be built for engineers to analyze the effects of alternative policies about engineering education, such as the number of available places in the various institutions of training, scholarships and loans, and the duration of training. An engineer's model may also be used to make the projections of the supply and requirements of engineers in the future according to various alternative assumptions whereeach assumption represents a policy option.

Table 4. Results of Sensitivity Simulations: Percentage Changes from Baseline Values

	Simulation Numbers						
	1	2	3	4	5	6	7
Total R.N.'s	30	−3	1	3	3	3	−1
R.N. demand	−10	0	3	9	0	20	−10
R.N.'s employed	−10	−2	2	5	0	6	−10
Inaceive considering employment	4	−19	−10	−15	44	−15	35
Total LPN's	45	1	2	−12	10	10	−1
LPN employment	−1	0	2	−32	10	−17	−3
Employment in hospitals	−10	−1	3	9	0	14	−13
Ambulatory care	−13	−20	−4	1	−10		−3
Nursing home	−10	−1	0	−5	0	−15	−1
Home care	−23	0	0	0	−9	−31	0
Nursing schools	33	−14	0	1	13	2	−7
Public health	−14	0	3	−1	1	−8	−1
Private duty	−11	−1	0	−1	1	−7	−1
R.N.'s at lhe A.D. level	51	7	2	8	8	8	−1
Oiploma	18	−14	1	1	0	0	−1
Baccalaureate	31	2	1	3	4	4	−9
Advanced	39	0	1	2	1	1	0
Enrollments in LPN Programs	66	−2	7	−28	39	39	−7
A.D.	38	15	4	11	16	16	−5
Diploma	83	−100	1	4	2	2	−2
Baccalaureate	29	9	2	6	8	8	−15
Advanced	47	0	1	3	2	2	0
Nursing pers/pt-short-term hosp	2	0	0	2	−1	6	−6
long-term	1	0	0	2	−1	6	−6
Frac. of pers. who are aides	0	2	0	19	0	−1	13
LPN's	0	0	0	−18	0	−18	1
R.N.'s	0	−1	0	8	0	18	−7