DRAM BALANCES CARE

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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.

This paper describes how the submodel, DRAM (Disaggregated Resource Allocation Model), compares with the Balance of Care (BOC) model which has recently been successfully applied in the Department of Health and Social Security in the UK as an aid to health care planners. It was found that DRAM's performance compared favorably with the BOC model.

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

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ABSTRACT

In many developed countries the problem of allocating resources within the Health Care System is perennial. Health Care planners wish to know the consequences of changing the mix of resources. The Balance of Care (BOC) Model, designed to help Health Care Planners answer this question, has been successfully applied over the past few years in the Department of Health and Social Security, UK. The Disaggregated Resource Allocation Model (DRAM), developed at IIASA, is also designed to help Health Care planners answer the above question.

This paper compares the performance of both models in two respects. Firstly, it indicates that DRAM is likely to be able to cope with problems of the same size and complexity as the BOC model. Secondly, the paper demonstrates that DRAM can more accurately model the use of alternative modes of care within treatment categories. Data collected for the allocation of care for the elderly in Devon, UK are used in the comparisons.

CONTENTS

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1. INTRODUCTION

In many developed countries the problem of allocating resources within the Health Care System (HCS) is perennial. Health Care planners are continually asking what the consequences are of changing the mix of resources. It is therefore not surprising that systems analysts have sought to develop mathematical models which assist the health care planner with this problem. The Balance of Care (BOC) model [MacDonald et al. (1974), Coverdale et al. (1978)] is an example of such a model. This model has been successfully applied over the past few years in the Department of Health and Social Security, UK.

In any health care system, resources are never sufficient to satisfy all the perceived needs of the population. In practice the many agents in the HCS (doctors, nurses, social workers, etc.) must ration resources by:

-- Caring for fewer patients (reducing "cover")
-- Providing less care for patients than is desirable or "ideal" (reducing "quotas")

The size of the reductions is variable since many patients can be cared for in alternative ways ("modes" of care) which require different resources. For example, the same elderly person may in principle be cared for in three different ways:

a. In a geriatric hospital
b. By the patient living at home, making visits to a day hospital, and being supported at home by visits of the home nurse and home help
c. By the patient living at home and being supported by visits (more than b) of the home nurse and home help.

The BOC model can be used to simulate, at an aggregate level, the balance chosen between the various alternatives. Within the model, patients with similar care requirements and for whom similar alternative forms of care are possible, are grouped into "categories".

The model's underlying assumption is that the aggregate behavior of HCS agents can be represented as the maximization of a utility function whose parameters can be estimated from the results of previous choices. If these parameters do not change with time, the model can be used to estimate the consequences of different mixes of resources in the future. An example of the model's application is given by Canvin et al (1978).

In applications of the model, its users have found two drawbacks. The first is in connection with the specialized routines used in the computer program. The optimization of the utility function is carried out by a linear programming package incorporating a piecewise linear approximation routine. The latter routine is not generally available with linear programming packages, thus limiting the transferability of the model from computer to computer. Work is currently being carried out for the Department of Health in London (see Bowen & Royston (1979), Arthur Andersen & Co. (1979) to improve the "portability" of the BOC model. Pursuing another line of attack, Hughes et al (1979) have demonstrated how non-differentiable optimization (NDO) techniques can be used to solve the problem.

The second drawback of the BOC model concerns the case when, for a given treatment category, the model is free to choose any combination of the modes of care available. In such circumstances the model generally allocates resources so that only a small number of the available modes are chosen. (The NDO technique mentioned above also has this property.) This behavior is a consequence of a linear programming (LP) formulation in which there are fewer constraints than variables. However, in the real HCS it is found that a greater mix of modes is used in each treatment category. In practice, this means that examining the consequences of changes in resource mix in terms of changes in the mix of modes is difficult for the BOC model. This is important because each mode (or alternative form) of care is made up of a package of resources, and the numbers of patients allocated to this mode may critically depend on the availability of one resource.

Within the Health Care Systems Task at IIASA, Gibbs (1978) and Hughes (1978 a, b) have developed the Disaggregated Resource Allocation Model (DRAM). This model is also designed to help Health Care planners answer questions about the consequences of altering the mix of resources. DRAM has many similarities to the BOC model. It simulates the balance between different treatment groups, between different modes of care within the same treatment group, and between quality of care and numbers treated. It also assumes that the aggregate behavior of the many agents within the HCS can be represented as the maximization of a utility function. DRAM, however, has two advantages over the BOC model. Firstly, the computer program to determine the optimum point of the utility function does not require any specialized routines, and therefore can be easily transferred to other computer installations. Secondly, the utility function is designed to penalize solutions which allocate no resources to a particular mode. Thus mixed mode solutions should normally arise.

The question arises, can DRAM cope with the problems the BOC model is designed to handle? In this paper, we describe the replication by DRAM of two BOC runs which are concerned with the allocation of care for the elderly in Devon, UK. In the replication runs, we attempted to determine:

Whether DRAM could handle problems of the same size and complexity as the BOC model
Whether DRAM could more accurately model the use of alternatives in treatment categories

This work is described in sections 4 and 5. Section 2 gives the mathematical formulations of the BOC model and DRAM and section 3 gives some background details about the allocation of care for the elderly in Devon.

2. THE MATHEMATICAL FORMULATIONS OF THE BOC MODEL AND DRAM

In this section we give the mathematical formulations of the BOC model and DRAM. The following variables appear in both models:

x_{jk} = the number of patients in category j who receive care in mode k,
y_{jkl}= the actual levels of resource l given in care mode k for patient category j,
y_{jkl}= the ideal levels of resource l, in care mode k for patient category j,
R_l = the availability of resource type l,
C_l = marginal cost of resource type l when all demands are specified

A frequently used version of the BOC model consists of maximizing the following utility function:

$$Z(\underline{x},\underline{y}) = \sum_j \sum_k \sum_l x_{jk} h_{jkl}(y_{jkl}) \qquad (1)$$

subject to

$$\sum_j \sum_k x_{jk} y_{jkl} = R_l \qquad \forall l$$

and $$x_{jk},\ y_{jkl} \geq 0 \qquad \forall j,k,l$$

where

$$h_{jkl}(y) = \frac{C_l Y_{jkl}}{\beta_l} \left[1 - \left(\frac{y}{Y_{jkl}}\right)^{-\beta_l}\right]$$

and β_l is a parameter measuring the relative importance of achieving the ideal of care for resource l.

For the BOC problems discussed in this paper, there are additional constraints on the x_{jk}'s:

-- "Cover" constraints of the form

$$\sum_k x_{jk} = d_j$$

ensuring that in the model solution a given number, d_j, of patients in category j receive treatment,

-- "Mode" constraints of form

$$L_{jk} d_j \leq x_{jk} \leq U_{jk} d_j$$

where L_{jk}, U_{jk} are lower and upper bounds satisfying $0 \leq L_{jk} \leq U_{jk} \leq 1$. This constraint limits the use of certain modes in accordance with professional advisors' perferences and other system constraints (e.g. the difficulty of moving existing long-term residents out of institutional care).

DRAM maximizes a slightly different utility function:

$$Z'(\underline{x},\underline{y}) = \sum_j \sum_k g_{jk}(x_{jk}) + \sum_j \sum_k \sum_l x_{jk} h_{jkl}(y_{jkl}) \quad (2)$$

subject to

$$\sum_j \sum_k x_{jk} y_{jkl} = R_l \qquad \forall_l$$

where $h_{jkl}(y)$ is as above (normally the β parameter is allowed to vary with treatment category, mode, and resource type) and

$$g_{jk}(x) = - \frac{X_{jk} \sum_l C_l Y_{jkl}}{\alpha_j} \left(\frac{x}{X_{jk}}\right)^{-\alpha_j}$$

where

X_{jk} equals the "ideal" number of patients in category j, to be treated in mode k, and

$\alpha_j (>0)$ is a parameter measuring the relative importance of treating the ideal number of patients in category j and mode k.

The BOC model and DRAM have much in common. The utility functions Z and Z', depict the many agents who control the allocation of health care resources as seeking to attain ideal standards of care (ideal levels of supply (Y) for both models, and ideal levels of service for DRAM). However, Z and Z' have diminishing returns as these ideal standards are approached. When all demands are met ($\underline{y} = \underline{Y}$ for BOC and $\underline{x} = \underline{X}$, $y = \underline{Y}$ for DRAM) the marginal increases in Z or Z' resulting from increasing resource levels equal the marginal cost C_1.

The important difference between the Z and Z' is that in the BOC model the x_{jk} are determined to a large extent by constraints, whereas in DRAM the x_{jk} are determined to a large extent by the parameters of the g_{jk} functions.

3. THE CARE OF THE ELDERLY IN DEVON

In what follows we shall be considering the long-term requirements for care for the elderly (65 years old and above). Thus short-term hospitalizations are excluded. These long-term requirements for care are dependent on such factors as the person's household composition, physical disability, degree of dementia, etc. These requirements can range from long-term care in a geriatric ward to the assistance with house cleaning, shopping, etc. provided by "home helps" for elderly people living at home.

In Devon, as elsewhere in Great Britain, the health and social care of the elderly is provided by two independently administered organizations, the Area Health Authority (AHA) and the Local Authority (LA). The AHA, financed by the central government, provides medical and nursing services via hospitals, clinics, and home visits. The LA, financed by local taxes and the central government, provides personal social services such as residential homes, social workers, home help visits and home meals services.

The BOC work in Devon for the elderly has made two important contributions. Firstly, it has encouraged the two providers of care to work together more closely. Secondly, it has provided a planning framework for the care of the elderly. Discussions between the BOC team and professionals involved in the delivery of care (clinicians, social workers, etc.) have produced a categorization of need, based on the person's mental state, physical disability, degree of incontinence, and social circumstances. For each category of need alternative modes of care have been drawn up. For instance, a person who has no dementia, a moderate physical disability, is incontinent during the night, whose social circumstances are not adverse, may be cared for at a day center together with visits from a nurse and a home help. Alternatively, this person may be cared for by a greater number of nurse and home help visits.

For each mode of care within each patient category, "ideal" (desirable) levels of care have been defined also by the professional advisers. Not surprisingly, the sum total of these levels is greater than the total resources available in Devon for the care of the elderly. Hence, the need to balance care between treatment categories, between quality of care and numbers treated, etc., and the need to assess the consequences of different resource mixes.

The BOC model for the elderly in Devon has used a classification with 32 patient categories, 9 modes of care, and 12 resources. The maximum problem size that the DRAM computer programs could handle at the time of this work was one containing 20 patient categories, 3 modes of care for each patient category, and 5 resources. Fortunately it is possible to scale down the problems that were solved by the BOC model and mentioned in the previous section, while at the same time retaining their most important characteristics. The nine modes of care in BOC can be reduced to three basic types for DRAM with little loss of information:

1. Institutional care: care in a geriatric or psychiatric hospital, or in a residential home
2. Day (+ domiciliary) care: the patient attends a day center, or day hospital, and is supported in his/her home by home nurses, home helps and the delivery of meals
3. Domiciliary care: the patient is supported in his/her home by home nurses, home helps and the delivery of meals

This simplification of the mode structure leads directly to a simplification of the 12 resources in BOC into 5:

1. Institutional bed-days
2. Day care attendances
3. Home nurse visits
4. Home help visits
5. Meals delivered

The 32 patient categories in BOC were reduced to 19 by combining patient categories which had similar ideal resource requirements for each mode. Thus, the BOC problem was scaled down for running on DRAM to one of 19 patient categories, 3 modes, and 5 resources. The patient categories are given in Table 1. The ideal levels of care for each mode and each patient category are given in Table 2.

4. THE USE OF DRAM TO CHECK THE BOC CALIBRATION PROCEDURE

It was explained in section 3 how the BOC problems were scaled down because of limitations on the size of the DRAM computer programs. Such scaled-down problems still retain the full complexity of the BOC model. To test whether DRAM could handle these scaled-down probelms, DRAM was used to check the BOC calibration procedure. This procedure is now described.

Before it can be used in a predictive manner the BOC model needs to be calibrated since Y_{jkl} and C_l are supplied

Table 1. Categories of elderly patient

Patient Category	Mental State	Physical Disability	Incontinence	Social Circumstances
	D = Dementia S = Significant behavior disorder	Sev = Severe Mod = Moderate Min = Minor	None Occ = Occasional Night = Regular at night Day = Regular during day	A = Adverse S = Supportive
1	D,S	Sev	Occ, Night, Day	A,S
2	D,S	Mod	Night, Day	A,S
3	D,S D,S D,S	Mod Min Min	Occ Night, Day Night, Day	A,S A S
4	D, No S	Sev	Occ, Night, Day	S
5	D, No S	Mod	Occ, Night, Day	S
6	D, No S No D, No S	Mod Mod	Occ, Night, Day Night	A A
7	D D, No S No D, No S	Min Min Min	Occ Night, Day Night	A A,S A
8	D, No S	Min	Occ	S
9	No S No D, No S	Sev Mod, Min	All Day	A A
10	No D, No S No D, No S	Sev Mod, Min	All Day	S S
11	No D, No S	Mod	Night	S
12	No D, No S	Mod	None, Occ	A
13	No D, No S	Mod	None, Occ	S
14	No D, No S	Min	Occ, Night	S
15	No D, No S	Min	Occ	A
16	No D, No S	Min	None	A
17	No D, No S	Min	None	S
18	No D, No S	None	Occ, Night	A
19	No D, No S No D, No S	None None	Occ, Night None	S A

Table 2. Ideal levels of care needed by the elderly in alternative modes of care.

		Amount of resource needed per patient-year				
Patient Category	Mode	Institutional bed-year	Day care visits	Home nurse visits	Home help visits	Meals
1	1	1	-			
	2	Not applicable				
	3	-	-	700	1500	-
2	1	1	-	-	-	-
	2	-	250	450	800	-
	3	-	-	700	1050	-
3	1	1	-	-	-	-
	2	-	250	350	350	-
	3	-	-	600	700	-
4	1	1	-	-	-	-
	2	-	100	350	950	-
	3	-	-	450	1050	-
5	1	1	-	-	-	-
	2	-	100	125	912.5	-
	3	-	-	225	1012.5	-
6	1	1	-	-	-	-
	2	-	250	350	1050	100
	3	-	-	600	1300	350
7	1	1	-	-	-	-
	2	-	150	100	500	200
	3	-	-	250	700	350
8	1	1	-	-	-	-
	2	-	50	50	200	-
	3	-	-	100	250	-
9	1	1	-	-	-	-
	2	-	250	800	1150	100
	3	-	-	1050	1500	350
10	1	1	-	-	-	-
	2	-	100	250	600	-
	3	-	-	250	800	-
11	1	1	-	-	-	-
	2	-	100	50	750	-
	3	-	-	50	950	-
12	1	1	-	-	-	-
	2	-	100	350	900	250
	3	-	-	350	1100	350
13	1	1	-	-	-	-
	2	-	100	-	600	-
	3	-	-	50	800	-
14	1	1	-	-	-	-
	2	-	100	7	127	-
	3	-	-	13	177	-
15	1	1	-	-	-	-
	2	-	100	-	450	200
	3	-	-	-	500	200
16	1	1	-	-	-	-
	2	-	125	-	350	175
	3	-	-	-	400	200
17	1	1	-	-	-	-
	2	-	100	-	50	-
	3	-	-	-	75	-
18	1	1	-	-	-	-
	2	-	100	-	-	-
	3	-	-	-	100	-
19	1	1	-	-	-	-
	2	-	50	-	-	-
	3	-	-	-	25	-

exogenously, this means that appropriate values for the parameters β_l are found. This process is normally carried out by fitting the model for a recent time period using the following data:

a. The numbers of patients treated in category j and mode k, d_{jk}

b. The "quotas" of care delivered $q_{jkl} = y_{jkl}/Y_{jkl}$

The quotas are the ratios of actual to ideal levels of care, and are a convenient way of representing the output of the BOC model.

In the BOC model a simplifying assumption is normally made to the effect that quotas, and hence the corresponding β parameters, vary over resource l, but not over category j, nor mode k. Estimates of the β parameters can then be commputed by an analytical method described by Coverdale and Negrine (1978). For the purpose of this exercise, a data set from the Exeter health district, Devon, UK was employed.

To use DRAM to check the BOC calibration procedure, x_{jk} should be made equal to d_{jk}. If the x_{jk} variables are fixed Z and Z' are the same but for a constant term (see equations 1 and 2). Using the β estimates as derived above the DRAM solution should give quotas ($y_{jkl}/Y_{jkl} = q_l$) which reproduce the actual quotas. In the DRAM run the x_{jk} were constrained to be very close to d_{jk} by setting $X_{jk} = d_{jk}$ and setting all α_j equal to a high number (100). The results of running DRAM with this data set come very close to expectation as shown in Table 3. The small differences between the last two columns of Table 3 are attributable solely to the approximations and averaging involved in reducing the BOC problem to the size required for DRAM.

The DRAM program reached the solution in 7 iterations taking about 1 min CPU on the IIASA PDP 11/70 mini-computer with UNIX time-sharing operating system. This suggests that the DRAM solution procedure can easily handle a problem with 19 patient categories, 3 modes, and 5 resource types.

Table 3. Calibration results.

Resource (1)	β_1 Estimated from Devon data	Resource availabilities R_1 in units per annum	Resource coverage (y_{jkl}/Y_{jkl}) DRAM results	Devon data
Beds	100.00	1,150 Beds	1.00	1.00
Day care	1.50	27,000 Attendances	0.75	0.80
Nurses	4.00	232,560 Visits	0.97	0.95
Home help	0.67	297,600 Visits	0.169	0.165
Meals	9.00	204,000 Meals	0.51	0.52

The next step is to see if DRAM can cope with larger problems. The signs are hopeful since the DRAM algorithm searches over the space of Lagrange multipliers associated with the resource constraints. It would thus appear that the number of resources is the most important dimension when considering the size of the problem that DRAM is able to handle. The BOC has been applied with typically 10-12 resource types, i.e. just over twice the number of resource types successfully handled by DRAM.

5. IMPROVED MODELING OF MODAL SPLITS USING DRAM

In its applications to HCS planning issues the BOC model is commonly employed in an "indicative" mode in which it simulates how the HCS will allocate planned amounts of resources. In principle, data is required for the following quantities only:

R_l = planned amount of resource l

d_j = expected number of patients j to be treated

Y_{jkl} = ideal level of resource l for category j and mode k.

C_l = resource costs

β_l = power parameter for resource l

and the model will predict the HCS response in term of the x_{jk} and the y_{jkl}.

In practice, the solution obtained in this type of run is unsatisfactory. For the reasons discussed earlier the model tends to allocate all patients in a category to only one of the several permitted modes, which is in strong contrast to the observed behavior of the real HCS. In order to improve the realism of the BOC solution, it is necessary to add constraints on the x_{jk}, in effect forcing the x_{jk} to take exogenously determined values. This represents a significant weakening of the model's predictive value and leaves only the quotas, y_{jkl}/Y_{jkl}, as effective model variables. (However, by running the BOC model several times with different sets of constraints on the x_{jk}, results are obtained which are useful in showing planners the cost-effectiveness of attempting to change the pattern of modal splits in the HCS.)

We now wish to examine whether DRAM can be used in a way which allows sensible predictions to be made of <u>both</u> the x_{jk} and the y_{jkl}/Y_{jkl}. We will attempt to use DRAM to replicate the Devon data on modal splits, d_{jk}, and quotas q_l. In this we must give DRAM a fair test. We must not provide so much information in the input data that the variables are effectively constrained and the solution is a foregone conclusion (as in the calibration test described above). Nor must we provide too little information; the model must have some basis for allocating patients to modes in a manner which replicates the real HCS. What we choose to do is to employ the input data required for BOC described above <u>without</u> the constraints on the x_{jk} but <u>with</u> a method for setting the additional DRAM parameters that employs a minimum of information on the attributes of the patient categories.

To be more precise, we set the following input quantities exactly as in BOC: R_l, Y_{jkl}, C_l, β_l. There is no direct equivalent in DRAM to the input data d_j used in BOC. Accordingly, we arranged for a combination of parameter values X_{jk} and α_j that would approximately produce an equivalent effect, i.e. to ensure that in the DRAM solution the values x_{jk} should satisfy:

$$\sum_k x_{jk} \doteq d_j \qquad \forall j.$$

As a first approximation we found by trial and error, that this could be achieved by setting all $\alpha_j = 2$ and subjecting the X_{jk} parameters to the condition:

$$\sum_k X_{jk} = 2\, d_j \ .$$

Subject to this condition we now have to obtain values for the X_{jk} parameters that take reasonable account of those attributes of the patient categories that would be considered *a priori* relevant to their model split. We start from the rather unsurprising observation, frequently made in the UK literature - Harris (1971), that patients with the greatest degree of disability and dependency are the ones for whom the proportions in institutional care are highest; correspondingly the proportions in day and domiciliary care are greatest for the least disabled patients. Accordingly, we constructed a simple dependency score based on the 4 attributes that were used in Devon to categorize patients. The scoring system is shown in Table 4. It can be seen that the maximum possible score, 11, is for a patient who has dementia with significant behavior disorder, severe physical disability, regular incontinence day and night, and adverse social circumstances; the minimum score is 3. With this system, we calculate a dependency score for each of the 19 patient categories as shown in Table 5.

We now employ this dependency score to determine, for each category j, the <u>ratios</u> $X_{j1}:X_{j2}:X_{j3}$ which describe the ideal <u>proportions</u> of patients in each mode. With these ratios and the aforementioned condition:

Table 4. Table of dependency scores.

Mental State

1.	Dementia with significant behavior disorder	Score 3
2.	Dementia without significant behavior disorder	Score 2
3.	No dementia and no significant behavior disorder	Score 1

Physical Disability

1.	Severe	Score 3
2.	Moderate	Score 2
3.	Minor	Score 1

Incontinence

1.	Regular during day and night	Score 4
2.	Regular during day and night	Score 3
3.	Occasionally	Score 2
4.	None	Score 1

Social Circumstances

1.	Adverse	Score 1
2.	Supportive	Score 0

Table 5. DRAM results compared with Devon data.

Number of patients treated predicted by DRAM (x_{jk})
(Devon data in brackets)

Patient category	Dependency score	Institutional care	Day care	Domiciliary care
1	9.5	60 (69)	3 (Θ)	4 (Θ)
2	9.0	107 (104)	4 (15)	8 (Θ)
3	7.8	48 (45)	2 (10)	4 (Θ)
4	8.0	68 (27)	3 (12)	5 (40)
5	6.8	63 (35)	12 (44)	95 (82)
6	7.5	136 (139)	6 (4)	8 (12)
7	6.4	94 (83)	16 (10)	110 (147)
8	5.0	12 (84)	9 (22)	267 (134)
9	7.4	125 (119)	6 (2)	8 (22)
10	6.5	104 (11)	20 (26)	161 (229)
11	6.0	34 (2)	7 (7)	47 (77)
12	6.0	61 (89)	10 (Θ)	76 (67)
13	5.0	37 (43)	27 (28)	354 (283)
14	4.8	5 (15)	5 (2)	111 (100)
15	5.0	3 (24)	2 (2)	50 (36)
16	4.0	82 (166)	53 (16)	1226 (1511)
17	3.0	47 (58)	41 (39)	930 (854)
18	5.0	58 (30)	54 (42)	1167 (1132)
19	4.0	36 (8)	34 (31)	731 (716)
Total		1177 (1151)	314 (312)	5364 (5442)

Resource Quotas

	Devon data	DRAM predictions
Beds	1.00	0.98
Day care places	0.75	0.80
Nurses	0.97	1.00
Home helps	0.169	0.178
Meals	0.51	0.59

$$\sum_k X_{jk} = 2d_j \qquad \forall_j,$$

the X_{jk} parameters will be completely determined. Here again we must be careful not to draw so much information about these ratios from the Devon data that we cannot fairly use the data afterwards to test the model's predictive power. Accordingly, we choose to employ a very simple procedure for determining these ratios that uses a minimum of information. We split the 19 patient categories into 3 groups:

High dependency: score > 7

Medium dependency: 7 $\geq$ score $\geq$ 6

Low dependency: score < 6

and we employ the following ratios:

	Institutional Care:		Day Care:		Domiciliary Care
Dependency	X_{j1}	:	X_{j2}	:	X_{j3}
High	0.92		0.03		0.05
Medium	0.42		0.06		0.52
Low	0.05		0.03		0.92

These ratios were derived from a combination of *a priori* reasoning (e.g. that high dependency categories should have a high institutional care ratio) and a process of trial and error-runs of the model in which we "tuned" the ratios so that the totals of patients, over all categories, allocated to each of the 3 modes agreed closely with the corresponding totals in the Devon data. These ratios complete the determination of the X_{jk}.

We are now, able at last, to test DRAM's ability to replicate the model splits in the Devon data. The results of running DRAM with the aforementioned parameter values are shown in Table 5. It will be seen that most of the solution values for x_{jk} are in reasonable agreement with the Devon data. The resource quotas are also in good agreement. We therefore conclude that DRAM has been successful in producing a more realistic solution than would be possible for the BOC model employing equivalent data.

In all the trial runs mentioned above, DRAM converged in 7 to 9 iterations, using 1 to 2 mins of CPU time on the IIASA PDP 11/70 mini-computer with UNIX time-sharing operating system.

Our procedure for employing a measure of dependency to determine the values for the X_{jk} parameters is crude and simple. The values of the X_{jk} parameters cannot as yet be interpreted as "ideal levels" of care. We would expect that our procedure could be considerably refined with the help of health planners, clinicians, social workers etc., so that the model can reproduce improved modal splits and the X_{jk} parameters could be interpreted at ideal levels of care. For instance, not all high dependency patient categories are given a high proportion of institutional care (see category 4) and it is possible there are *a priori* grounds for producing a better grouping of patient categories. Again, it would be expected that all (or nearly all) high dependency patients should receive some form of care. This can be modeled by reducing our original estimates for X_{jk} and raising the relevant α_j. However, the authors think it would be appropriate to stop here, as they have achieved what they set out to do; namely, to demonstrate that with a suitable choice of parameters DRAM can reproduce realistic modal splits.

6. CONCLUSION

We have demonstrated that DRAM can solve problems of the size 19 patient categories, 3 modes of care, and 5 resources, and can reproduce realistic modal splits. DRAM's performance compares favorably with that of the Balance of Care model, which is used to assist health care planning in the UK, and in this important respect it produces more realistic results. With the advantage of low operating costs, good transferability and realism, we therefore commend the model for use in planning the provision of health care resources.

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