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USE OF SIMULATION TO DETERMINE RESOURCE REQUIREMENTS FOR END-STAGE RENAL FAILURE

Ruth Davies

Warwick Business School
University of Warwick
CV8 3BT, UK.

ABSTRACT

All Western countries are taking increasing numbers of patients onto their renal programs. Physicians now accept older and sicker patients than they would have done in the past. A discrete event simulation describes patient arrivals and the transfer between three modalities of treatment for different age and risk groups in order to project future demands for treatment. In the UK, at the national level the main uncertainty arises from the expected number of new patients, which is on an upward trajectory and has not yet reached the level of most other European countries or the USA. At a local level the uncertainties are much greater because of the inherent randomness in smaller populations. In these smaller populations, simpler modeling methods that only take account of new arrivals, transplant and death rates may be equally valuable, providing that the standard deviations of the estimates can be calculated.

1 INTRODUCTION

End-stage renal failure is fatal if not treated by renal replacement therapy (RRT) which may be hemodialysis, peritoneal dialysis or transplantation. Hemodialysis and peritoneal dialysis cleanse the blood of unwanted chemicals. Patients requiring hemodialysis must be attached to a hemodialysis machine, at least twice a week, for several hours on each occasion. In peritoneal dialysis, there is an exchange of fluids directly via a catheter from a bag of dialysis fluid to the patient's abdomen. Kidney transplantation is the preferred treatment as it grants the patient freedom from dialysis regimes, and it naturally restores all the kidney's functions. Donor organs come from either cadaver or live donors. Transplanted patients must take anti-rejection therapy, but even so a proportion of kidneys are rejected and the patients, if they survive, will have to return to dialysis.

There is an increasing demand for treatment from elderly and co-morbid patients whilst at the same time there is limited availability of transplanted organs. Hemodialysis is a more successful long term treatment than peritoneal dialysis. There has, therefore, been an ever increasing expansion of hemodialysis programs (UK Registry Report, Ch5 2004). Hemodialysis takes place in hospital or satellite units and patients travel to either for their treatment. Most satellite units are run by nurses, with medical cover from the parent unit or nearest hospital. Satellite units are smaller and more accessible than the hospital units.

At a population level, two factors determine occurrence of renal replacement therapy. First, the incidence of end-stage renal failure rises significantly with age. Second, although there are no studies of the incidence of end-stage renal failure in ethnic minorities, populations from the Indian Sub-Continent and of African Caribbean origin both have higher rates of renal replacement therapy (Roderick et al. 1996) and also higher levels of precursor conditions that lead to end-stage renal failure such as diabetes. The ageing of these ethnic populations are placing a burden on the demand for renal replacement therapy in areas with large ethnic minority populations.

A recent study (Roderick et al. 2004) shows the use of discrete event simulation to determine the increasing demand for treatment. It shows that the patient numbers are unlikely to level off for at least 15 years. Furthermore, the expected increase is mainly in the number of patients on hemodialysis, the most expensive form of treatment.

Clearly all those funding services for end-stage renal failure, want to know the future demand for services, where they should be provided and how expensive they will be. This paper looks at the value in using simulation to make such projections.

2 PROJECTIONS FOR ENGLAND

Our paper (Roderick et al. 2004) estimated the requirement for services throughout England (population approximately 50 million). This study was to inform the Department of Health about the future need for resources for these patients.

The discrete event simulation was constructed in Delphi 3 with a user friendly interface. The flow diagram is shown in Figure 1. New patients with end-stage renal failure usually start treatment with hemodialysis or peritoneal dialysis. A few patients will, however, have an immediate cadaver or live-related transplant. Patients may be transferred between the two forms of dialysis or may be put on a waiting list for transplantation. The simulation can give priority to different age groups and/or other risk factors. Kidneys arrive independently and are allocated to those on the waiting list. The simulation assumes that the selected recipient will accept the transplant (as is usual in the UK). Following transplantation, patients may suffer kidney rejection or may die. Those who suffer rejection, return to dialysis. Patients may die from any state.

Figure 2 shows results from running the simulation. The uncertainty about the predictions arises from the randomness of the arrivals and transplants about given averages and from the uncertain survival times. The 95% prediction interval indicates that a new result generated from the simulation will have a 95% chance of lying within that interval. The prediction intervals in Figure 2 are relatively narrow because of the large number of patients. The average input parameter values are assumed to be known but these may also vary.

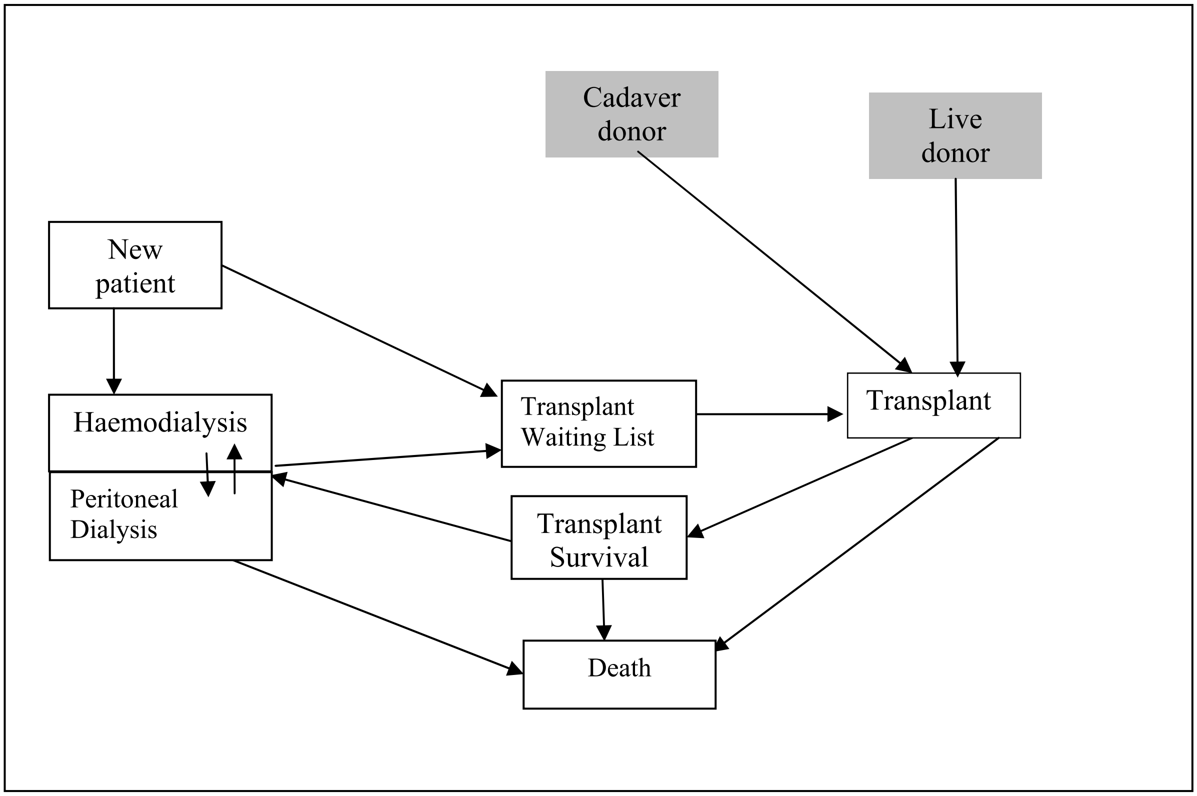

Figure 1: Flow diagram of patient flow showing the structure of the simulation

The average survival times are likely to change very slowly over the period under consideration, if at all, but the average arrival rates of new patients are likely to increase. The arrival rate expanded by 15% between 2000 and 2003 (UK Registry Report, Ch 17 2004). In 2002, the UK acceptance rate was less than half of that reported in the USA. The higher levels in Figure 2 are from the national study (Roderick et al. 2004) in which we assumed that the arrival rates would increase to a level similar to those that were current in Wales or Greece, a 51% increase over the subsequent 10 years. The lower level on Figure 2 assumed that the arrival rates were only going to increase in response to population changes with respect to ethnic mix and age (20% increase).

Clearly the uncertainty about the *average* arrival rate has a considerable effect on the number of patients on dialysis but has little effect on those with functioning transplants because the provision of transplants is heavily constrained. At national level, therefore, there is considerable uncertainty arising from doubts about the future demand for treatment, but there is very little inherent uncertainty arising from random arrivals and departures.

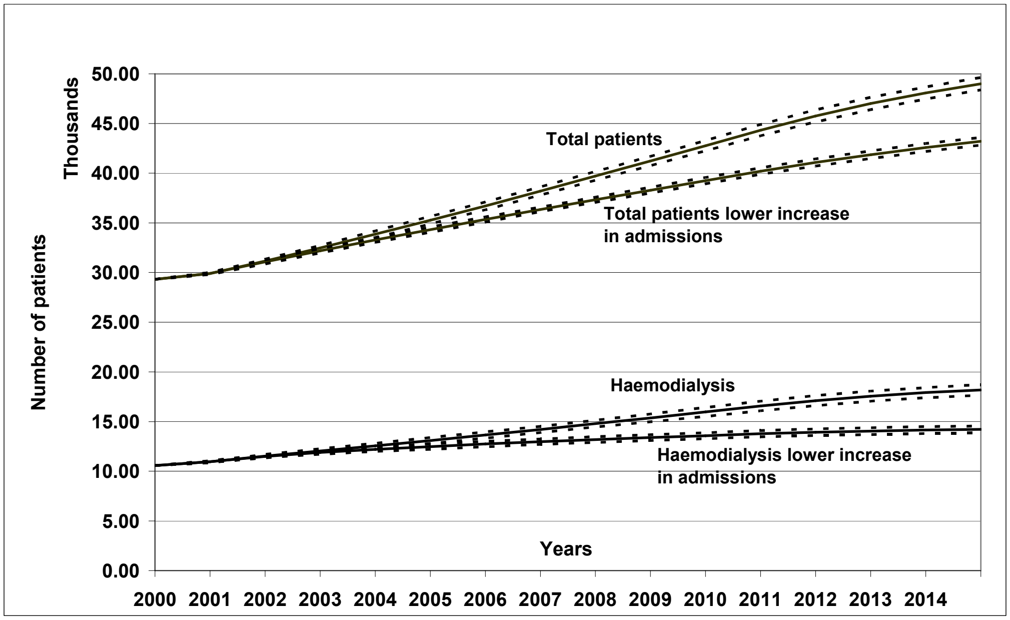

Figure 2: Projections of patient numbers for England showing the 95% prediction intervals

3 LOCAL POPULATION STUDY

Those supplying services at a local level were anxious to know how the demand for dialysis services would increase and what services they should provide and where. The patients in a region of interest were distributed across 13 primary care trusts (PCTs) with populations between 100,000 and 275,000.

The populations for 2004 are shown in Table 1. Whereas some of the more densely populated areas (D, J and L) were found to have high rates of treatment and the most remote and sparsely populated area, E, had a rate well below the national average; there was not a consistent gradient from urban to rural.

Table 1: PCT populations

PCT	Total population	% Ethnic Minorities
A	116,471	0.8
B	81,683	0.8
C	137,274	2.9
D	59,923	30.5
E	107,974	2.1
F	112,788	6.1
G	110,097	1.7
H	111,787	3.4
I	161,785	5.0
J	98,181	1.5
K	106,273	1.1
L	266,988	14
M	105,599	3.6
Total	1,576,823	5.7

The main purpose of this part of the study was to project the demand for services for hemodialysis, by PCT. A further stage in which we considered the current and possible future supply of facilities, is not covered in this paper. The assumption in both parts of the study was that because this was a clearly defined disease, the location of the services would not affect the underlying need. The analysis used the simulation model (Roderick et al. 2004) breaking down the population into those under and those over 65 years old. The data required for input were as follows:

- Survival and transfer probabilities by modality;
- Proportion of new patients starting each modality;
- Proportion of patients suitable for transplantation;
- Transplant rates;
- Current number on renal replacement therapy by modality;
- Acceptance rates by year.

Data availability was limited and so the first four sets of parameters were derived from the data used for the national study.

Transplants are administered by hospital transplant centers each of which serves several PCTs. In the model, an average transplant rate, weighted by the proportion of ethnic minorities in the population, was "allocated" to each PCT. These were on average 22 per million for cadaver grafts and 5 per million for live grafts and held constant over the simulation duration. The initial numbers on renal replacement therapy were derived from data supplied by the UK Renal Registry in July 2004.

The future acceptance rates by year were the most difficult and uncertain parameters to predict. The acceptance rates were calculated in similar way to those in the national study. Based on the increase in demand over the past 10 years, we assumed that the PCTs would achieve a rate of 110 pmp for the non-ethnic minority population by 2011. The rate for the ethnic minority population was assumed to be 4 times that value for those under 65 and 7.5 times the value for those over 65 (Roderick et al. 1996). The projected "need" by PCT at 2011 was assumed to be independent of the current supply.

4 RESULTS FROM LOCAL POPULATION STUDY

The results show an overall 30% increase in the need for hemodialysis facilities. Figure 3 shows that these vary from a 15% increase in population F to a 126% increase in A. The increase depends on the starting point and assumes that demand will even out between the PCTs over time.

Figure 4 shows considerable uncertainty in these results for Population D and this is typical of all the PCTs. Figure 3, which shows the haemodialysis predictions for all the PCTs, with in many cases, the lower levels being below the current provision .

The detailed breakdowns between the PCTS must be treated with caution for the following reasons. First, there may be other factors which determine the distribution of patients which have not been taken into account. For example, those who are ill may gravitate to the towns and the proximity of hospitals. Second, the distribution of transplants depends on the characteristics of the waiting patients and is unlikely to retain a constant average value by PCT over time.

5 CONCLUSIONS

Simulation is able to predict resource use using information about risk groups, transfers between different modalities and death by risk group. It provides information about the uncertainty of these projections based on random arrivals and probability survival distributions based on known average demand. The prediction intervals of the projections at national level are small but at PCT level very wide.

Transplants are constrained by the availability of donors and the numbers have remained relatively stable for a number of years. Other patients are kept alive on dialysis. Hemodialysis is a more successful long term treatment than peritoneal dialysis but is expensive. The simulation assumes that dialysis facilities are unconstrained. In reality, they are constrained but grow slowly in response to demand.

The projections at all levels are greatly influenced by the assumptions made about the future demand from new patients. Following an international trend, numbers have been increasing because doctors are now more willing to treat older and co-morbid patients. This creates a demand for new facilities which, once provided, enables doctors to be more relaxed about admission criteria. This positive feedback loop is constrained by health service finances and, ultimately, by the supply of patients.

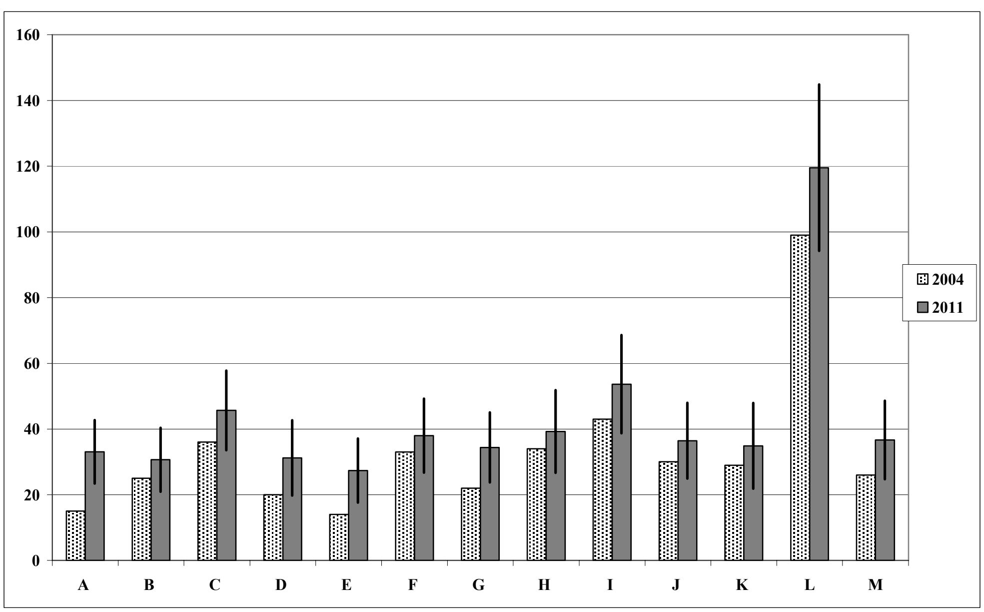

Figure 3: PCT hemodialysis numbers in 2004 and predicted for 2010 showing prediction intervals

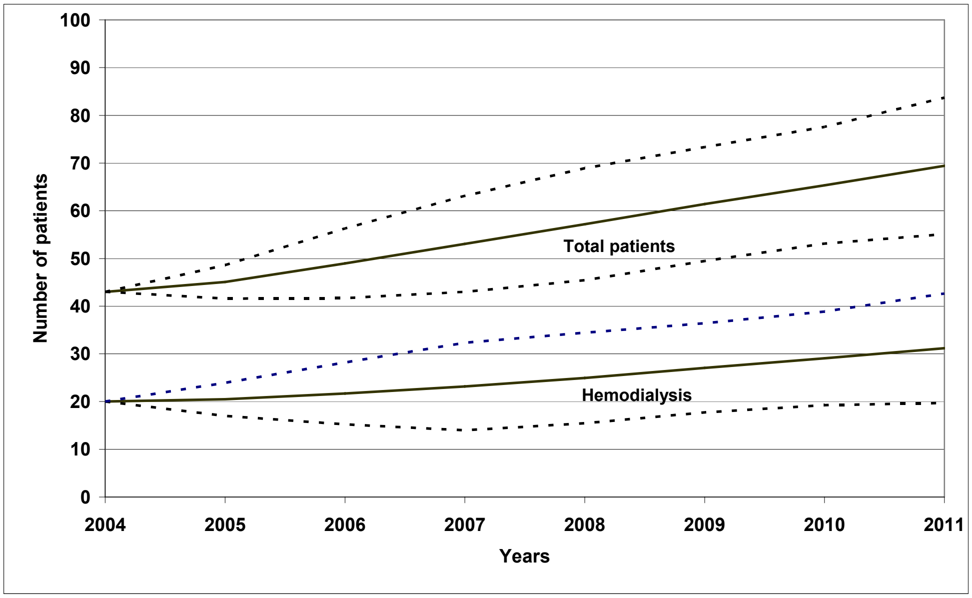

Figure 4: Patient projections and confidence limits for population D

At a national level the increasing demand by new patients may be estimated with reasonable confidence by past rates of increase and current practices in other European countries. At a local level, this is more difficult because the hemodialysis facility provision is patchy and there may be local influences that are not immediately apparent to the modeler.

By linking and projecting the available data, simulation can provide useful information to the clients at the local level. Simpler modeling techniques that only take account of new arrivals, transplant and death rates might be equally effective in providing clients with approximate average values for patient numbers in different modalities or age groups. It is important, however, that the clients are aware of the degree of uncertainty about the predictions. These are not usually present in the spreadsheet models and aggregate Markov models that are commonly used in health service planning. Simulation has the advantage that it can readily provide estimates of the degree of uncertainty surrounding the projections.

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AUTHOR BIOGRAPHY

RUTH DAVIES is a Professor of Operational Research in Warwick Business School, University of Warwick and is head of the Operational Research and Information Systems Group. She was previously at the University of Southampton. Her expertise is in modeling health systems, using simulation to describe the interaction between the parts in order to evaluate current and potential future policies. Over the past few years she has run several substantial projects funded by the Department of Health, in order to advise on policy on: the prevention, treatment and need for resources for coronary heart disease, gastric cancer, end-stage renal failure and diabetes. Her email address is <ruth.davies@wbs.ac.uk>.