Stock / Flow models of blood donor restrictions: Why the vCJD problem is worse than expected.

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Abstract

This paper examines the impact of restrictions to blood donations to examine the dynamics of the interactions between the restrictions, on one hand, and the existing donor base and the eligible donor base, on the other. The paper suggests that when the impact of restrictions such as those imposed for the outbreak of vCJD in the US and Australia, are modeled using stock/flow analysis, the results suggest a much greater loss of donations than is suggested in the literature. The paper discusses simulations of both the Australian and UK blood services and suggests that there are similar dynamics in both systems. The required recruitment patterns to recover from the losses were modeled and discussed.

Introduction

The Australian Red Cross Blood Service (ARCBS) is responsible for the all of the collection and distribution of blood products in Australia and the National Health Service (NHS) has a similar role in the UK. Both systems operate on a voluntary donation basis. This means that the supply of blood products to the health system is very much dependent on the nature of the relationship built up between the donors and the ARCBS and NHS. Recruiting and maintaining a donor base consisting of people who regularly give the maximum of four donations the year is therefore, a major concern for both organizations.

Restrictions to eligible donors, such as those associated with HIV, vCJD (Variant Creutzfeldt-Jakob Disease also known as Mad Cow Disease) and Hepatitis all have an impact on the existing donor base and, as a consequence the level of blood stocks. The outbreak of Mad Cow disease raised the possibility of the disease being transferred through blood transfusion. The medical aspects of the threat posed by this have been widely documented (Leikola, (1998), Mitka (2001), Germain et al (2000), Sibbald, (1999), Hoey et al (1998), Payne, (2001) and Jones, (2003). A number of countries imposed restrictions on blood donations imported from European countries affected by the outbreak and on people who had traveled to those countries.

The issue addressed in this paper

This paper examines the output of two System Dynamics models which the simulate the donor losses as a result of the imposition of donor restrictions based on travel to areas considered to place donors at risk of contracting vCJD. The model assumes the loss rate of 7.5% suggested by the *Review of the Australian Blood Banking and Plasma Product Sector March 2001 A report to the Commonwealth Minister for Health and Aged Care* and demonstrates that the estimated losses predicted in the Review significantly underestimate the extent of the problem.

The issue is important for two reasons. First, introducing large step function losses into blood systems will leave the system short of blood for lengthy periods of time because of the boom/bust nature of donor behavior in times of shortage. Second, understanding the impact of such decisions may lead to the examination of different policy options. In the UK, which was worst hit by vCJD, imposing restrictions such as those imposed in the US and Australia would have wiped out the entire donor base, as everyone would have potentially been exposed to the disease. As a result , UK blood authorities adopted a totally different approach.

System Dynamics methodology is important in addressing this issues for two reasons. The separation of the total donor base into stocks defined as annual donation frequency segments. This allows the modeling of the differential impact of the any restrictions on each donation

frequency segment. While a simple distinction, the implications of this are profound. Defining donation frequency segments demonstrates the feedback effect of deferring donors on the recruitment of new donors. It also allows the "feed-forward" impact of the donation rates of new donors to be simulated. The second reason is that it becomes possible to model the feedback of policies designed to recover deferred donors. For example, it is possible to retain a donor deferred under the vCJD restrictions, by placing them in an apheresis donation program.

It is therefore extremely important that blood authorities develop models that increase the accuracy of prediction of donor restrictions.

Background

The Australian and UK systems operate on a voluntary donation basis. Recruiting and maintaining a donor base of people who regularly give the maximum of four donations the year is therefore a major goal for both organizations. The reality falls far short of this, as the donation rate across Australia is 1.9 donations per donor per year. However, this compares favourably with the UK where the rate is 1.2 per year. Donation frequency varies across the donor base. Table 1 shows the numbers in each donor segment

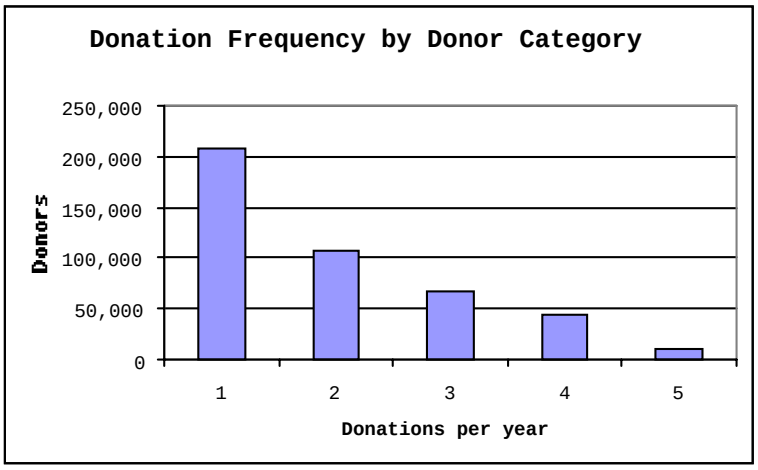

Table 1: Donation frequency by donor segment

Donors who give four and five times a year represent 12% of the donor base but provide 27% of the donations. This means that any donor restrictions that affect these segments have a disproportionately high impact on blood donations and blood stocks.

Australian Red Cross Blood Service

Across Australia, the state divisions of the ARCBS frequently find themselves in a situation where blood supplies reach critical levels. There are a number of reasons for this including increased demands as a result of road trauma over the Easter holiday period, lower donation rates during winter and the "Beer Game" effect of the appeals to cover these shortages. In general, it would be said that the balance between supply and demand is very delicate. Any measures, which restrict the number of eligible donors, can have profound impacts on the supply side of the ARCBS operation. The following discussion of the impact of vCJD restrictions outlines some of the problems of predicting the impact of donor restrictions and the need for modeling and scenario building.

Predicting the impact of restrictions on donor eligibility: vCJD.

There is currently no known screen for vCJD, a disease that is degenerative and terminal. This poses an ethical and practical problem for Blood Agencies. Growing recognition and discussion of the possible danger posed by blood infected by vCJD has led to wide-spread and differing responses to the problem. One response has been restrictions in donor eligibility, most notably on people who have traveled to, or were resident in, Europe. Another has been the use of processing technology, namely leucodepletion, to reduce the risk.

In 1999, the US Federal Drug Administration (FDA) banned donations from people who spent 5 or more years in Europe between 1980 and1996. By June of 2001, the Red Cross, which collects 50% of blood in the USA , had been extended this ban to include a range of people who been in Europe. (see http://www.redcross.org/news/bm/tse/010628madcow.html**)**

The response to the enormity of the impact of the restrictions was an " aggressive donor recruitment campaign". This section of the paper looks at the hypothetical implications of this response in Australia and in Great Britain, where the response had been to use processing methodologies to avoid contamination through vCJD.

In Australia, where the response has been similar to that of the US.

> The ARCBS has estimated that the measure is expected to result in an initial reduction in donations of 5-10 per cent, leading to some 30,000 donors eventually being deferred.
>
> *Review of the Australian Blood Banking and Plasma Product Sector March 2001 A report to the Commonwealth Minister for Health and Aged Care*

The figure of 30,000 is actually predicated on a 7.5% loss. On these figures, and with the 1.9 annual donation rate, the expected loss would be 36,000 donations. If only donors are considered, the answer would appear simple: recruit somewhere around 30,00 new donors. However, the logic is wrong, it is the deferral of donors leads to the loss of donations, not the other way around. The figure of 5-10 % is in line with overseas estimates of 7.5% loss *of donors.* The problems inherent in this mental model are indicative of the problems that arise in estimating, as distinct from modeling, the impact of these restrictions. The first step to an accurate estimation of the problem is to separate the stocks of donors from the stocks of blood and to understand their relationship.

Model history.

The model was developed in response to a move by the Therapeutic Goods Authority (TGA), the Federal authority which legislates all health product standards in Australia, to lift for Hb threshold for blood donors in Australia. Specifically, there was the need to model the impact of two different levels of Hb which were to form the basis for new restrictions on blood donors in Australia. These two standards were known as the Council of Europe and the UK standard respectively. The TGA had a preference for the Council of Europe standard which

was the higher of the two. The simulation showed that the imposition of the standard did such damage to the existing donor base, that the only way to recover would be to impose compulsory blood donations on all adults in Australia. The simulation also demonstrated that the imposition of the UK standard would need to be phased in over a three-year period for there to be any chance that the donor losses could be recovered. The TGA accepted this advice.

This model was originally developed using group modeling techniques. For the last two years, the ARCBS has been developing a Systems Thinking and Systems Dynamics modeling capability which meant that this model was developed with the group of experts who had competence in causal loop diagramming and knowledge of the principles of stocks and flows. The ARCBS also has a policy of building a dispersed Systems Thinking and Systems Dynamics capability in all of its state branches.

The model was originally designed to be able to simulate any form of restriction on donors. Legislated donor restrictions are an important strategic issue for blood donors services. It is therefore important for blood services to have models to advise government on the impact the type legislation. Restrictions related to vCJD are a current example of such legislation, or in the case of the US, self-imposed regulation by the Red Cross Blood Service, being imposed worldwide.

Model development methodology.

The model was derived from a series of causal loop diagrams developed with a group of ARCBS experts. The group included specialist haematologists, medical directors, medical scientists and logistics experts drawn from all state offices as well as from the National office. The main-chain of the model was similar in structure to Sterman's aging chain (Sterman, 2000, p. 470). The advantages of using this structure were discussed at length with the group. The cohorts that were used were termed "donor segments" which related to the frequency of annual donations rather than an aging process. Sterman's transition rate was the rate at which donors improve their donation rates. The out-flows from each of the segments were the rates

at which donors were deferred as a result of potential exposure to vCJD during travel to UK, in this specific case, and the normal rate of deferrals associated with the medical screening donors. The inflows to the segments were a result of the recovery of any temporarily deferred donor.

Building the model with this structure allowed the ARCBS managers to examine a range of strategies for dealing with the losses resulting from the vCJD restrictions. The usual method for dealing with shortfalls in the donation levels was to recruit new donors. However, there is a very high attrition rate in new donors, with as many as 75% not returning to give a second donation. This attrition was worsened by the fact that a proportion of new donors were not able to give blood as they were excluded under vCJD restrictions. It was therefore necessary to look at alternative strategies, the use of apheresis donations, increased donation rates, higher retention rates in new donors and the recovery of lapsed and deferred donors, all of which could be stimulated through this model structure.

The development of a working model proved relatively easy. Accessing accurate data was more difficult. The ARCBS is a federal system with each state keeping its own records. The development of a general national model provides indications the impact of high-level strategies. However, in the case of Hb restrictions, there was significant variation between the States in the levels of Hb within the populations. This was thought to be a result of cultural differences in dietary practices arising from the early colonization of various states. In relation to vCJD, where the restrictions are related to travel to the UK, it is not yet fully understood whether there is an interaction between the demographics of those travelers, possibly in older age groups, and the frequency of donations, possibly also higher in older age groups. The result was modeling exercise has been a significant upgrading of the database of ARCBS.

What Stock/Flow models explain about the problem.

There are two stages to understanding why the impact of vCJD could so easily have been underestimated. The first is in understanding the stock- flow structure shown in Figure 1. In this basic model, deferrals of donors drives recruitment efforts, deferred donors are usually replaced by new recruited donors. Sterman's (2000) model of product discard and replacement purchases shows discarded adopters becoming (again) potential adopters. This is partly true of blood donors. Those who are deferred either permanently or temporarily are seen as distinct from potential donors and are treated differently by blood services. In the model these deferred donors are classified according to the reason for deferral, a donor deferred because they have a cold will be classified differently from one who tests positive to HIV. These deferred donors are held in separate databases and specific strategies, such as iron supplementation for iron deficient deferrals, can be used to move then back into the donor bases much as occurs with the Sterman model. A central problem for blood service is the lack of information about potential donors. This is becoming acute with restrictions for vCJD and for haemoglobin levels affecting the potential donor pool (Haslett and Bird, 2002).

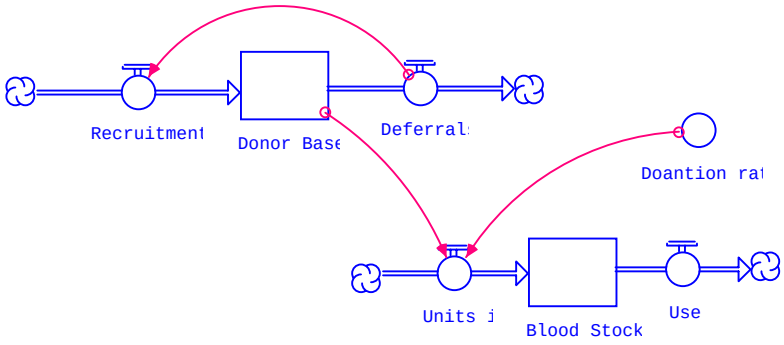

Figure 1: Simple Stock/Flow model of the donor system

Blood stocks are a results of the number of donors and the rate of donation. Losses through deferrals (permanent, in the case of vCJD) are traditionally replaced by recruitment. The problem with this model is that it simplifies the nature of the donor base. The donor base is really a chain (termed a main chain in System Dynamics terminology), as shown in Figure 2.

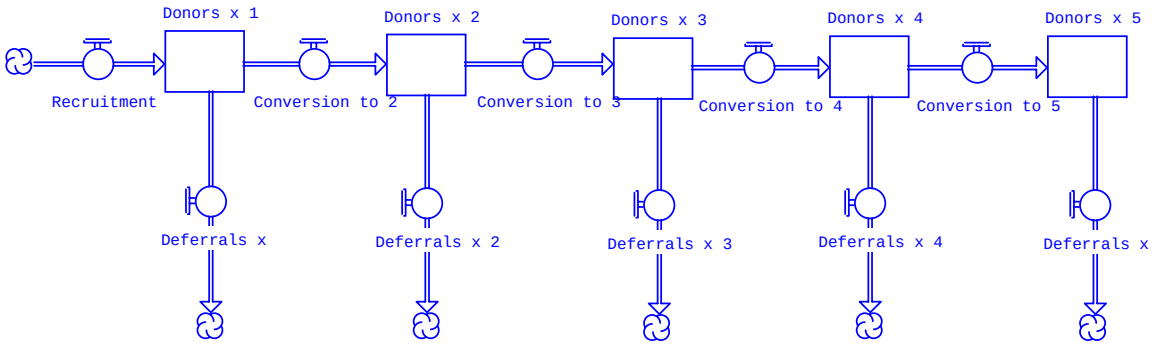

Figure 2: Main chain of donor segments.

This model makes clear that losing a donor from the Donors x 5 stock means a loss of five donations per year, every year from the time of the imposition of the restriction. Using the Australian figures, it is possible to model the impact of a 5% and 10% donor loss from the first year of restrictions. It also highlights an important assumption in the model: that donors improve their donation rates over time.

The models

There were two models used in these simulations. The more complex of the two was used to model the Australian blood service. This model was originally developed to model the impact restrictions of new levels for Hb in donors. However, it was also designed to model of wide range of scenarios, one of which was the restriction in relation vCJD. The model, which is a development of the one shown in Figure 2, is shown in Figure 3.

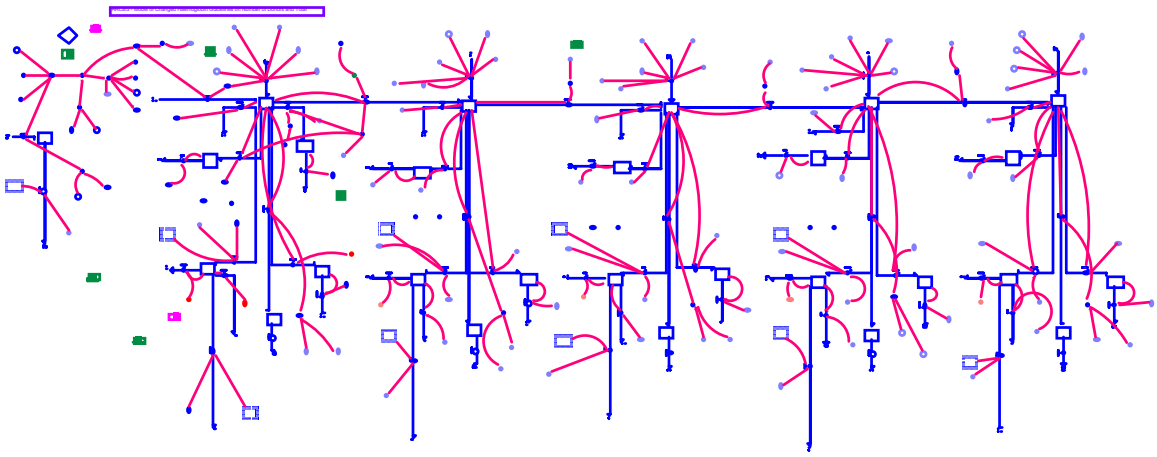

Figure 3: ARCBS model for donor restrictions.

It consists of a main chain of donors segmented by donation frequency. In the top left-hand corner of the diagram are a series of decision nodes representing points at which new donors are deferred before giving blood.

The model assumes that new donors are distributed across the donors segments according to the existing distribution of the donor base. This means that some new donors will begin donating four times year from their recruitment. However, the vast majority of new donors do not return to make second donation. Retention rates of new donors after their first donation are modeled at 40%.

In the main chain, the donors segments are linked by flows. The model assumes improvements in donation rates. These are the rates at which donors increase their annual donation rate. These increases occur either as a natural course of events or in response to appeals when blood stocks run low. The segment improvement rates in the Australian model are shown in Table 2. The rate of 15% for 1 to 2 means that 15% of the 200,000 donors who gave once a year convert to giving twice a year, and that this rate of improvement in donation rates is maintained each year.

In the simulations, these increases in annual average donation rates meant that the annual donation rate increased from 1.95 donations per year to 2.21 per year by the end of the simulation period. In the UK model, a more conservative increase of 1.2 to 1.3 donations per year was assumed. The models demonstrated high levels of sensitivity to changes in donation rates. This is discussed in the sections on the individual models.

The out-flows from the donor segments were modeled underneath the stocks. These out-flows model the donors are lost to the system. They may be permanently deferred, (as result of medical condition such as a positive test to Hepatitis C.), temporarily deferred (as result of having a cold), deferred by restrictions imposed from low Hb levels, deferred under travel restrictions as a result of vCJD, or permanently lapsed (died, left the country). All these

deferrals, with the exception of the permanently deferred, are accumulated in stocks. This allows the modeling of recovery strategies for these deferred groups.

There are in-flows into each donor segment. These are modeled on top of each of the respective stocks. It is at this point that the results of the recovery strategies are flowed back into the donor bases. The model assumes that a reactivated donor donates according to their previous donation pattern.

The UK model, shown in Figure 4, was far a simpler model. The added complexity of the recovery strategies in the Australian model has been left out. Most importantly, the donor base is not modeled in donors segments. However, the UK model produced qualitatively similar results to the more complex and sophisticated Australian. As such, this model can still produce import insights to the dimensions of problems posed by policies relating to travel restrictions and vCJD.

Simulation results for the ARCBS model

A single simulation was run with a loss rate from existing and new donors of 7.5% If recruitment is was held at the rate ARCBS projected of 104,000 new donors per annum the following shortfalls in donations occurred. This is the donation loss a result of the loss of 31,500 donors in going into 2004. . The impact of these losses is shown in Table 4.

Table 2: Donation shortfall with the loss of 7.5% of donors.

These figures look disproportionately high given the donor losses. This is because, as the main chain in Figure 2 showed, one lost donor does not equal one lost donation. It is clear that not analyzing the systems using the Stock/flow structure greatly underestimates the impact of the restrictions.

Whereas non-Stock/Flow thinking suggests a worst case scenario with a loss of 36,000 donations at 7.5% donor losses, Stock/Flow thinking suggests a worst case scenario of 91,000 lost donations by 2004. This suggests that the magnitude of the difference is significant for planning purposes. It is also clear that the simulation model produces markedly different outcomes from those suggested in the Review of the Australian Blood Banking and Plasma Product Sector.

There is a second reason why the simulation figures are much higher. While deferrals have a "once-only" impact on the existing donor base, they have on ongoing impact on the recruitment of new donors. This means that new donor recruitment rates will be down by the deferral percentage for the foreseeable future as the inflow to the donor base is restricted as shown in Figure 4.

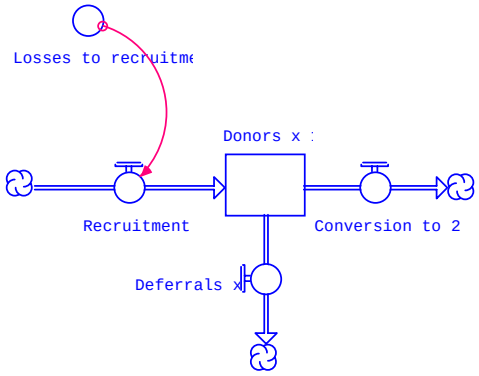

Figure 4: Model with ongoing new donor losses included.

Deferrals are traditionally replaced by recruitment. ARCBS figures show that loss rates of first time donors vary between 40 - 70% in Australia. This means that a large number of people who become donors only ever give blood once. The correct mental model for this process is shown in Figure 5.

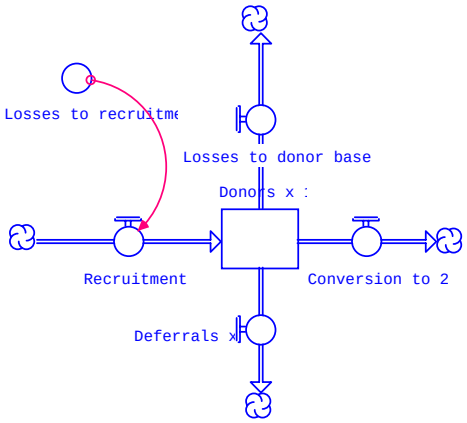

Figure 5: Losses of "once only" donors from donor base.

Recovery by increased recruitment of new donors.

Traditionally the method for the meeting of shortfalls has been to recruit new donors. Figure 5 shows the required recruitment pattern and Table 4 shows the numbers of donors needed to meet a 7.5% donor loss from vCJD.

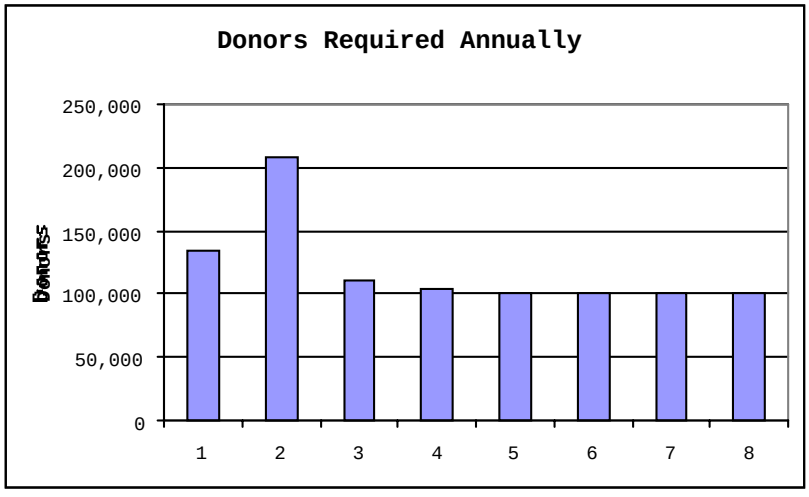

Table 3: New donors required with 7.5% donor loss from vCJD.

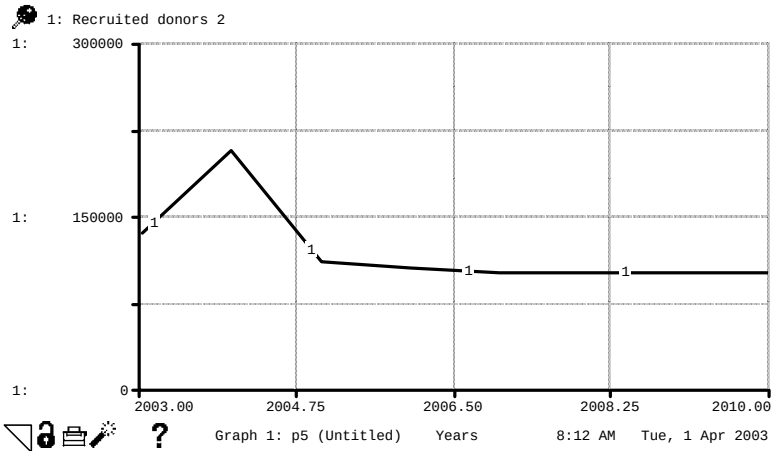

Figure 6: Recovery by recruitment (7.5% loss)

The model suggests that an increase from the projected figure of 104,000 to 134,00 in 2003 would be needed to begin to redress the problem. This figure jumps to 207,600 in the next year when the full impact is felt. This spike, in the first two years, means that the accumulation in the stock of retained donors allows the ARCBS to recruit at a slightly lower level than the projected 104,000 and still meet a 3% growth target.

This strong recovery rate is greatly helped by the improved annual donations rates. These improvements mean that more people give more frequently. If this does not occur the model predicts that the need to recruit will be 50 - 60% higher each year.

Modeling the UK situation.

A simulation of the impact of a hypothetical set of restriction was run on the UK figures as a comparison with the Australian figures. The UK has adopted a different approach, through the use of leucodepletion, to the vCJD problem, so this discussion is hypothetical. This simulation was used to show that problems arising from vCJD restriction are systemic to blood services rather than specific to individual countries.

The findings from the model of the Australian figures were further emphasized by an examination of the UK figures. The National Health Service takes 2.4m donations from 1.9m people at a rate of 1.2 donations per year, less than in Australia. Table 4 shows the fundamental dynamics of the UK system. New donors enrolled are those recruited, however a smaller number (designated by the conversion rate)"attend", and give blood. Enrolling 442,550 donors leads to a 3.7% increase in the donor base of 1.9m. Significant numbers of donors lapse and these numbers are made up from the new donors.

	1998 - 99	1999 - 2000
New donors enrolled	408,043	442,550
New donors attending	279,409	268,739
Conversion rate	68%	60%
Lapsed donors	218,116	196,863
Net gain (attending - lapsed)	61293	71876
% gain to donor base (1.9m donors)	3.2%	3.7%

Table 4: New donors, conversions and gains (UK).

It is clear from this table that, as in Australia, large enrolment numbers only convert to relatively small increases in the donor base as a result of low conversion rates from enrolled to attending and the added impact of lapsed donors.

The following simulations show what the impact of travel based restrictions, such as those imposed in Australia and US, would be in the UK. The model is simplified to a single stock of donors, which does not take into account increased impact of the loss of high frequency donors. The model therefore tends to underestimate the impact of the restrictions. This discussion is based on a hypothetical imposition of the percentages estimated in the US and Australia. Had the UK decided to impose US and Australian level restrictions on donors as a result of vCJD, it would have wiped out the entire donor base.

The model in Figure 6 was used to simulate the potential impact of a 7.5% deferral as a result of vCJD on the UK National Blood Service.

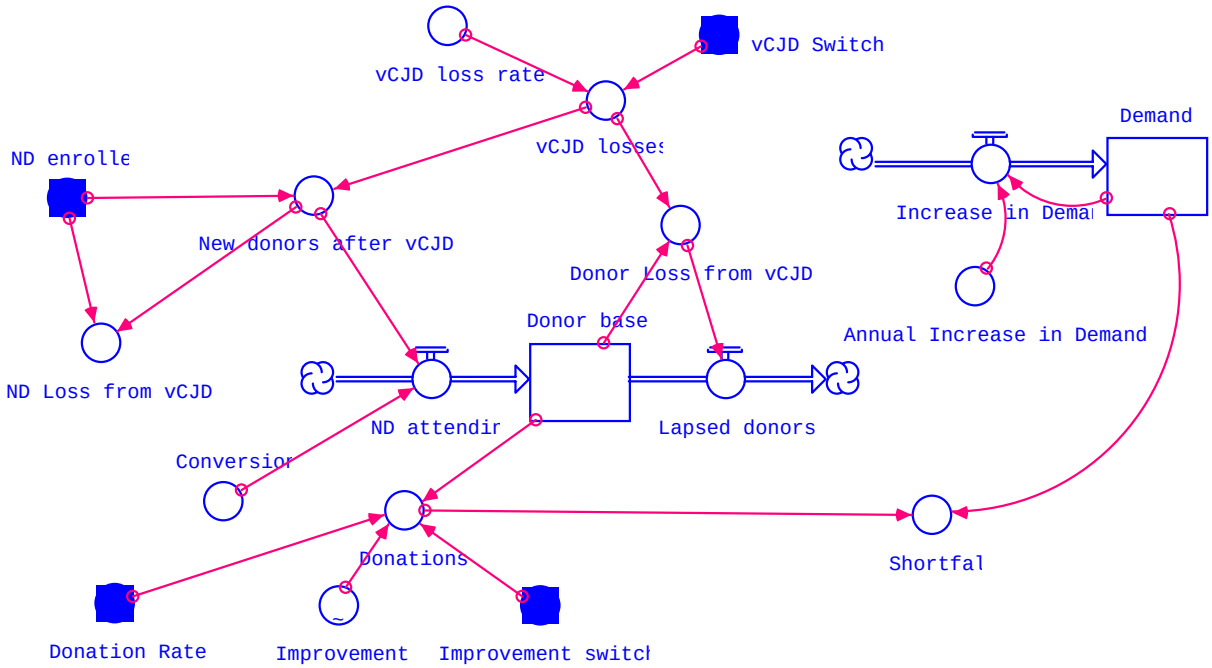

Figure 6: Model of UK donor system

Table 4 shows donor base would decline by 142,000, with a one-off hit in the first year and there is a growing deficit over the next four years as a result of new donor losses

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Year	Donor base	Losses	ND enrolled	ND attending	ND vCJD losses	Donations
1	1,900,000	142,500	442,600	245,643	33,195	2,280,000
2	1,913,155		442,600	245,643	33,195	2,295,786
3	1,961,935		442,600	245,643	33,195	2,354,322
4	2,010,715		442,600	245,643	33,195	2,412,858

Table 5: Hypothetical donor losses in the UK at 7.5%.

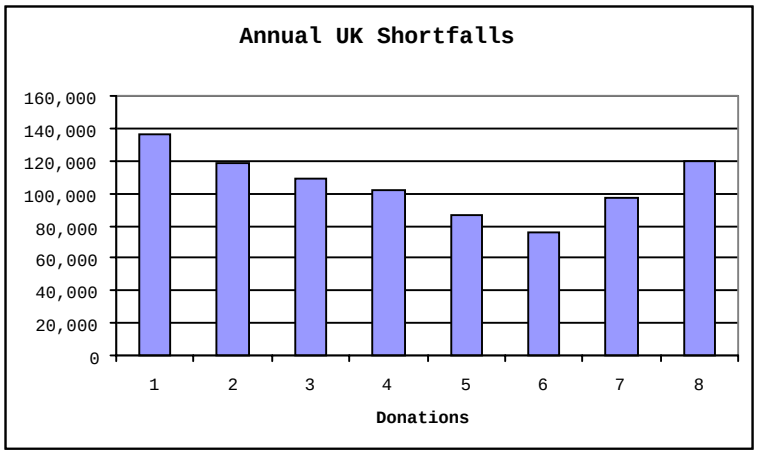

Table 6: UK shortfall figures with the introduction of vCJD restrictions.

To maintain the existing donor base requires an additional 1.8m donors in the first two years of the hypothetical introduction of vCJD, however, as Figure 7 and Table 6 below show, this does not need to be maintained. This scenario constitutes a 39.5 % increase in new donors enrolled over the first two years. The actual increase in new donor enrolled from 1999 - 2000 was 9.2% and this increase is not factored into the figures. This scenario assumes that all donor losses occur and are replaced in the first two years after the imposition of the restrictions. If this is possible, there would be not ongoing need to recruit new donors each year, and still meet growth targets of 3% which currently covers increased demand.

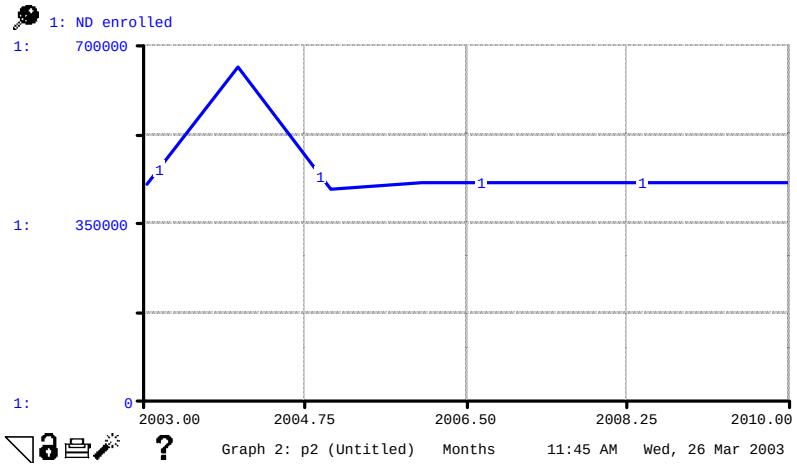

Figure 7: Recovery by recruitment (UK)

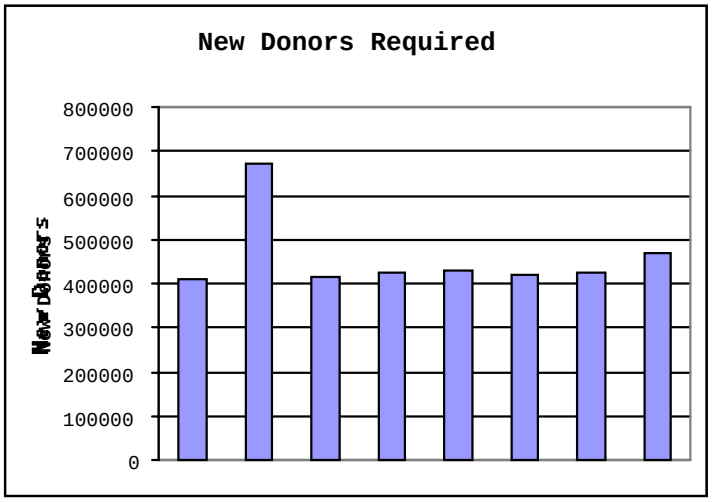

Table 7: Figures for Recovery by recruitment (UK)

The implications of recovery through recruitment.

Figures that are generated by models indicate that the numbers required by recruiting new donors are extremely high in both the UK and Australian. Using Australian figures has an illustration, it is necessary to recruit just under 1 million new donors in an eight year period. Australia has a population of 18 million, of whom roughly 50% are of eligible donation age, with 50% of the age eligible population actually able to give blood. This provides an eligible donor pool of roughly 4.5m. This means recruiting approximately 25% of the eligible donor population. Given that the current participation rate is around 10% of the eligible population, this will be a significant task.

The are two points to be made in relation to this discussion. The first point is that, unless the impact of such restrictions are modeled with appropriate stock/flows structures, it is highly likely that targets of recruitment that are may ultimately be unachievable, will be seen as a solution to the problem.

The second point is that it is necessary to model the resource implications of any recovery strategies. If it is possible to recruit large numbers of new donors, the next important question is whether the system has the capacity to process this number of new donors. The feed-forward and feed-back implications of this, are best understood through model building

Sensitivity of models to improvements in donation rates

Both models show that a spike in recruitment can overcome the loss from vCJD and allow recruitment at lower than projected levels. This is because both models include a continuous improvement in donation rates. The improvement in annual donation rates in the Australian model is from 1.95 to 2.21. International comparisons suggest that this will be extremely difficult to do. The model is very sensitive to these improvements. If the assumption that these rates can be maintained is not correct, the need for new donors increases. It is worth noting that the projected recruitment rate was 104,000 pa. The figures in Table 7 indicate that recruitment would need to double in 2003 and increase by a factor of 2.7 in 2004.

Table 8: Sensitivity of new donors required to improvements in donation rates (Australia). Without improved donation rates on left, with improved donation rates on right

The same was observed in the UK model, where a large increase in donors is needed to meet the initial impact of vCJD. This allows lower levels of recruiting in future years (412,000 v projected 442,000) because of the improvement in donation rates from 1.2 to 1.3 donations a year over 8 years. Table 8 shows the annual improvement rate, the cumulate improvement is 10% over eight years, marginally over 1% per year but the impact on shortfalls and the recruitment required is disproportionate high. The annual donation rate changes from 1.2 to 1.3 over eight years. The cumulative effect of this is very strong. Table 9 compares the differences in donations, with and without the donation improvement rate.

Table 9: Sensitivity of new donors required to improvements in donation rates (UK). Without improved donation rates on left, with improved donation rates on right

Discussion of model outcomes.

The models showed the numbers of new recruits that would be needed to meet losses from the vCJD restrictions. The models illustrate the enormity of the task of using recruitment as a means for overcoming this problem. It is important that targets of 39% increases in new donors in two years in the case of the UK should be modeled against the systems capacity to handle that number.

In addition to the logistics of such a rapid ramp-up of donor supply, there are a number of other complicating factors. The UK figures suggest a 60% conversion of enrolled to new donors. In a study of 14-month study period, 1,000 first-time donors Royse (1999) found that this sample of donors gave an average of 1.89 donations in their lifetime, compared with 1.2 donations annually from continuing donors. This suggests that the on-going commitment of this group may not be high. The importance of ongoing commitment is emphasized by Ferguson and Bibby (2002) who reported a study of 630 donors that past behavior was predictive for regular donors (5 or more previous blood donations), indicating the need to establish patterns of behaviour in the donor base. This problem is compounded by the problem represented by donation frequency profile, which is the number of times a donor gives blood each year.

Restrictions, such as those imposed in response to vCJD, impact across the complete range of the donation frequency profile. The recruitment of new donors may not necessarily replace the losses across the profile. It may well be that new donor recruitment programs may replace losses with lower frequency donors, thus creating an additional problem of lowered overall donation rates. This highlights the importance of establishing high frequency donation patterns with new donors. Evidence of the importance of establishing donation patterns is provided by Koesterich (1983) who reported on the American Red Cross "Donor 17" program which was designed to establish the habit of donating blood regularly in high school age youth. She observed that Donor 17 participants donated significantly more blood and also donated during more years than nonparticipating peers.

The point of this discussion is that unless the assumptions underlying the mental models of decision-makers are surfaced and modeled, recovery strategies may be suggested and implemented, that are unsustainable in the long run.

Directions for future research

As noted earlier in the paper, the ARCBS exercise identified areas where there was incomplete or no data. Much of the research will need to be in developing data bases to support the models. The lack of information linking travel patterns to donation frequency has been noted. The relationship between frequency of blood donation and Hb levels needs to be understood. It is suspected that the attrition for the Hb restrictions will have a disproportionate affect on higher frequency donors. There is little useful information on the causal factors relating to donation frequency, with some suggestion that the patterns are best established when the donor is (a) young and (b) a new donor. Given that the ideal donor makes a long-term commitment of frequent donation understanding this dynamic is critical.

In terms of model development within Australia, the ARCBS is currently developing state-based models of all aspects of blood collection. In Australia, blood collections are geographically dispersed across a country roughly the size of the US but with 10% of the population. Collection is logistically complicated and expensive and there is increasing

scrutiny by the Federal government, which funds the ARCBS, of the costs of blood collection. Further work is needed developing models that simulate the complex social, logistic and economic factors in blood collection.

Conclusion.

The aim of this paper was to demonstrate that the application of System Dynamics modeling to the problems of international blood services provides insights that are not currently available to senior decision-makers. The ARCBS is currently using this technology to model the impact of Hb restrictions and gaining new insights into the dynamics of this process (Haslett and Bird, 2002).

This paper has demonstrated the insights that can be generated from the use of modeling and also the sensitivity of the blood donation systems to variations in certain assumptions, in this case, improvements in donation rate. It is highly likely that similar sensitivity in demonstrated in relation to other variables in the model, for example, the retention rates of new donors. The use of System Dynamics modeling not only allows the decision-makers to test the sensitivity of the these assumptions, but also to create scenarios that model one or a combination of recovery strategies.

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Appendix 1 Equations for UK model

Demand(t) = Demand(t - dt) + (Increase_in_Demand) * dt
INIT Demand = 2280000

INFLOWS:
Increase_in_Demand = Demand*Annual_Increase_in_Demand
Donor_base(t) = Donor_base(t - dt) + (ND_attending - Lapsed_donors) * dt
INIT Donor_base = 1900000

INFLOWS:
ND_attending = New_donors_after_vCJD*(Conversion)
OUTFLOWS:
Lapsed_donors = 196863 + Donor_Loss_from_vCJD
Annual_Increase_in_Demand = .03
Conversion = .6
Donations = (if Improvement_switch=1 then Improvement else Donation_Rate)*Donor_base
Donor_Loss_from_vCJD =
(if time =2004 then Donor_base*vCJD_losses else 0)
Improvement_switch = 0
ND_Loss_from_vCJD = ND_enrolled-New_donors_after_vCJD
New_donors_after_vCJD = ND_enrolled*(1-vCJD_losses)
Shortfall = Demand-Donations
vCJD_losses = if vCJD_Switch = 1 then vCJD_loss_rate else 0
vCJD_loss_rate = .075
vCJD_Switch = 0
Donation_Rate = GRAPH(TIME)
(2003, 1.20), (2004, 1.20), (2005, 1.20), (2006, 1.20), (2007, 1.20), (2008, 1.20), (2009, 1.20), (2010, 1.20)
Improvement = GRAPH(TIME)
(2003, 1.20), (2004, 1.22), (2005, 1.23), (2006, 1.25), (2007, 1.26), (2008, 1.27), (2009, 1.29), (2010, 1.30)
ND_enrolled = GRAPH(TIME)
(1.00, 442550), (2.00, 442550), (3.00, 442550), (4.00, 442550), (5.00, 442550), (6.00, 442550), (7.00, 442550), (8.00, 442550)
New_donors_No_IDR = GRAPH(TIME)
(2003, 458000), (2004, 724000), (2005, 464000), (2006, 467000), (2008, 470000), (2009, 473000), (2010, 479000), (2011, 481000), (2012, 484000)
New_donor_IDR = GRAPH(TIME)
(2003, 411000), (2004, 671000), (2005, 414000), (2006, 427000), (2008, 432000), (2009, 419000), (2010, 427000), (2011, 471000), (2012, 474000)

Appendix 2 Equations for Australian model

Cumulative_New_WB_Recruit_Hb_loss(t) = Cumulative_New_WB_Recruit_Hb_loss(t - dt) + (Recruit_Hb_loss_rate - Conversion_of_new_WB__to_Apheresis) * dt
INIT Cumulative_New_WB_Recruit_Hb_loss = 0

INFLOWS:
Recruit_Hb_loss_rate = Recruited_donors*uk_haemoglobin_loss_A
OUTFLOWS:
Conversion_of_new_WB__to_Apheresis = Cumulative_New_WB_Recruit_Hb_loss*Rate_of_conversion_to_Apheresis_Donors
Total_Lapsed__donors_x4(t) = Total_Lapsed__donors_x4(t - dt) + (Lapsed_donor_x_1__4 - Recovery_of_Lapsed__Donors_x4) * dt
INIT Total_Lapsed__donors_x4 = 3000

INFLOWS:
Lapsed_donor_x_1__4 = WB_Donor_Base_x_4*Lapsed_Donor_Rate
OUTFLOWS:
Recovery_of_Lapsed__Donors_x4 = Total_Lapsed__donors_x4*Recovery_rate_of__Lapsed_Donors
Total_Lapsed__donors_x5(t) = Total_Lapsed__donors_x5(t - dt) + (Lapsed_donor_x5 - Recovery_of_Lapsed__Donors_x_5) * dt
INIT Total_Lapsed__donors_x5 = 1000

INFLOWS:
Lapsed_donor_x5 = (WB_Donor_Base_x_5*Lapsed_Donor_Rate)
OUTFLOWS:
Recovery_of_Lapsed__Donors_x_5 = Total_Lapsed__donors_x5*Recovery_rate_of__Lapsed_Donors
Total_Lapsed__donors_x_1(t) = Total_Lapsed__donors_x_1(t - dt) + (Lapsed_donor_x_1_ - Recovery_of_Lapsed__Donors_x1) * dt
INIT Total_Lapsed__donors_x_1 = 20000

INFLOWS:
Lapsed_donor_x_1_ = WB_Donor_Base_x_1*Lapsed_Donor_Rate
OUTFLOWS:
Recovery_of_Lapsed__Donors_x1 = Total_Lapsed__donors_x_1*Recovery_rate_of__Lapsed_Donors
Total_Lapsed__donors_x_2(t) = Total_Lapsed__donors_x_2(t - dt) + (Lapsed_donor_x_1__2 - Recovery_of_Lapsed__Donors_x_2) * dt
INIT Total_Lapsed__donors_x_2 = 12000

INFLOWS:
Lapsed_donor_x_1__2 = WB_Donor_Base_x_2*Lapsed_Donor_Rate
OUTFLOWS:
Recovery_of_Lapsed__Donors_x_2 = Total_Lapsed__donors_x_2*Recovery_rate_of__Lapsed_Donors
Total_Lapsed__donors_x_3(t) = Total_Lapsed__donors_x_3(t - dt) + (Lapsed_donor_x_1__3 - Recovery_of_Lapsed__Donors_x_3) * dt
INIT Total_Lapsed__donors_x_3 = 5000

INFLOWS:
Lapsed_donor_x_1__3 = WB_Donor_Base_x_3*Lapsed_Donor_Rate
OUTFLOWS:

Recovery_of_Lapsed__Donors_x_3 =
Total_Lapsed__donors_x_3*Recovery_rate_of__Lapsed_Donors
Total_Once__only_losses(t) = Total_Once__only_losses(t - dt) + (Once_only_loss -
Once_only_recoveries) * dt
INIT Total_Once__only_losses = 150000

INFLOWS:
Once_only_loss = Once_only__to_1*Cv_to_Base
OUTFLOWS:
Once_only_recoveries = Total_Once__only_losses*Once_only_recovery_rate
Total_x1_Donors_UK__Hb_Loss(t) = Total_x1_Donors_UK__Hb_Loss(t - dt) +
(UK_Haemoglobin__Loss_x_1 - Reentry_from_X1__UK_Hb_Loss -
Conversion_of_x1_to_New_Apheresis_Donor - Venous_Hb_x1) * dt
INIT Total_x1_Donors_UK__Hb_Loss = 0

INFLOWS:
UK_Haemoglobin__Loss_x_1 = IF uk_haemoglobin =1 THEN
(WB_Donor_Base_x_1*Hb_implementation___%_rate_2) ELSE 0
OUTFLOWS:
Reentry_from_X1__UK_Hb_Loss = Total_x1_Donors_UK__Hb_Loss*Reentry_Rate_of__Hb_Loss
Conversion_of_x1_to_New_Apheresis_Donor =
Total_x1_Donors_UK__Hb_Loss*Rate_of_conversion_to_Apheresis_Donors
Venous_Hb_x1 = Total_x1_Donors_UK__Hb_Loss*Venous_Hb_Recovery_rate
WB_Donor_Base_x_1(t) = WB_Donor_Base_x_1(t - dt) + (flow_to_x1 + Returns_to_x! -
Lapsed_donor_x_1_ - flow_to_x_2 - vCJD_Deferral__V2_x_1 - UK_Haemoglobin__Loss_x_1 -
X1_T_D - Once_only_loss - x1_PD) * dt
INIT WB_Donor_Base_x_1 = 207605

INFLOWS:
flow_to_x1 = Once_only__to_1
Returns_to_x! =
Recovery_from_X1_vCJD__V2_Loss+Recovery_of_Lapsed__Donors_x1+Reentry_from_X1__UK_
Hb_Loss+Venous_Hb_x1+x1_TD_recoveries+x1_TD_recoveries+Once_only_recoveries
OUTFLOWS:
Lapsed_donor_x_1_ = WB_Donor_Base_x_1*Lapsed_Donor_Rate
flow_to_x_2 = (WB_Donor_Base_x_1*Cv_x1)
vCJD_Deferral__V2_x_1 = vCJD_from_x1*WB_Donor_Base_x_1
UK_Haemoglobin__Loss_x_1 = IF uk_haemoglobin =1 THEN
(WB_Donor_Base_x_1*Hb_implementation___%_rate_2) ELSE 0
X1_T_D = WB_Donor_Base_x_1*Temp_Deferral_Rate
Once_only_loss = Once_only__to_1*Cv_to_Base
x1_PD = WB_Donor_Base_x_1*Perm_Deferral_Rate
WB_Donor_Base_x_2(t) = WB_Donor_Base_x_2(t - dt) + (flow_to_x_2 + Returns_to_x2 -
flow_to_x3 - UK_Haemoglobin__Loss_x_2 - vCJD_Deferral__V2_x_2 - Lapsed_donor_x_1__2 -
x_2_P_D - X2_tT_D) * dt
INIT WB_Donor_Base_x_2 = 107100

INFLOWS:
flow_to_x_2 = (WB_Donor_Base_x_1*Cv_x1)

Returns_to_x2 =
Recovery_from_X2_vCJD__V2_Loss+Recovery_of_Lapsed__Donors_x_2+Reentry_from_X2__UK_Hb_Loss+Venous_Hb_x2+x2_TD_recoveries+Once_only__to_2
OUTFLOWS:
flow_to_x3 = WB_Donor_Base_x_2*Cv_x_2
UK_Haemoglobin__Loss_x_2 = IF uk_haemoglobin =1 THEN (WB_Donor_Base_x_2*Hb_implementation___%_rate_2) ELSE 0
vCJD_Deferral__V2_x_2 = vCJD_from_x2*WB_Donor_Base_x_2
Lapsed_donor_x_1__2 = WB_Donor_Base_x_2*Lapsed_Donor_Rate
x_2_P_D = WB_Donor_Base_x_2*Perm_Deferral_Rate
X2_tT_D = WB_Donor_Base_x_2*Temp_Deferral_Rate
WB_Donor_Base_x_3(t) = WB_Donor_Base_x_3(t - dt) + (flow_to_x3 + Returns_to_x3 - flow_to_x4 - UK_Haemoglobin__Loss_x_3 - vCJD_Deferral__V2_x_3 - Lapsed_donor_x_1__3 - x3_P_D - x3_T_D) * dt
INIT WB_Donor_Base_x_3 = 67700

INFLOWS:
flow_to_x3 = WB_Donor_Base_x_2*Cv_x_2
Returns_to_x3 =
Recovery_from_x3_vCJD__V2_Loss+Recovery_of_Lapsed__Donors_x_3+Reentry_from_x3__UK_Hb_Loss+Venous_Hb_x3+x3_T_D_recoveries+Once_only__to_3
OUTFLOWS:
flow_to_x4 = (WB_Donor_Base_x_3 * Cv_x_3)
UK_Haemoglobin__Loss_x_3 = IF uk_haemoglobin =1 THEN (WB_Donor_Base_x_3*Hb_implementation___%_rate_2) ELSE 0
vCJD_Deferral__V2_x_3 = vCJD_from_x3*WB_Donor_Base_x_3
Lapsed_donor_x_1__3 = WB_Donor_Base_x_3*Lapsed_Donor_Rate
x3_P_D = WB_Donor_Base_x_3*Perm_Deferral_Rate
x3_T_D = WB_Donor_Base_x_3*Temp_Deferral_Rate
WB_Donor_Base_x_4(t) = WB_Donor_Base_x_4(t - dt) + (flow_to_x4 + Returns_to_x4 - flow_to_x5 - UK_Haemoglobin__Loss_x_4 - Lapsed_donor_x_1__4 - vCJD_Deferral__V2_x_4 - x4_T_D - x4_P_D) * dt
INIT WB_Donor_Base_x_4 = 43700

INFLOWS:
flow_to_x4 = (WB_Donor_Base_x_3 * Cv_x_3)
Returns_to_x4 =
Recovery_from_X1_vCJD__V2_Loss_4+Recovery_of_Lapsed__Donors_x4+Reentry_from_x4__UK_Hb_Loss+Venous_Hb_x4+x4_TD_recoveries+Once_only__to_4
OUTFLOWS:
flow_to_x5 = (WB_Donor_Base_x_4 *Cv_x_4)
UK_Haemoglobin__Loss_x_4 = IF uk_haemoglobin =1 THEN (WB_Donor_Base_x_4*Hb_implementation___%_rate_2) ELSE 0
Lapsed_donor_x_1__4 = WB_Donor_Base_x_4*Lapsed_Donor_Rate
vCJD_Deferral__V2_x_4 = vCJD_from_x_4*WB_Donor_Base_x_4
x4_T_D = WB_Donor_Base_x_4*Temp_Deferral_Rate
x4_P_D = WB_Donor_Base_x_4*Perm_Deferral_Rate
WB_Donor_Base_x_5(t) = WB_Donor_Base_x_5(t - dt) + (flow_to_x5 + Returns_to_x5 - vCJD_Deferral__V2_x_5 - UK_Haemoglobin__Loss_x_5 - Lapsed_donor_x5 - x5_P_D - x5_T_D) * dt
INIT WB_Donor_Base_x_5 = 10900

INFLOWS:
flow_to_x5 = (WB_Donor_Base_x_4 *Cv_x_4)
Returns_to_x5 =
Recovery_from_x5_vCJD__V2_Loss+Recovery_of_Lapsed__Donors_x_5+Reentry_from_x5__UK_Hb_Loss+Venous_Hb_x5+x5_TD_recoveries+Once_only__to_5
OUTFLOWS:
vCJD_Deferral__V2_x_5 = vCJD_from_x5*WB_Donor_Base_x_5
UK_Haemoglobin__Loss_x_5 = IF uk_haemoglobin =1 THEN (Hb_implementation___%_rate_2 * WB_Donor_Base_x_5) ELSE 0
Lapsed_donor_x5 = (WB_Donor_Base_x_5*Lapsed_Donor_Rate)
x5_P_D = WB_Donor_Base_x_5*Perm_Deferral_Rate
x5_T_D = WB_Donor_Base_x_5*Temp_Deferral_Rate
X1_Donors_VCJD_V2_Loss(t) = X1_Donors_VCJD_V2_Loss(t - dt) + (vCJD_Deferral__V2_x_1 - Recovery_from_X1_vCJD__V2_Loss) * dt
INIT X1_Donors_VCJD_V2_Loss = 0

INFLOWS:
vCJD_Deferral__V2_x_1 = vCJD_from_x1*WB_Donor_Base_x_1
OUTFLOWS:
Recovery_from_X1_vCJD__V2_Loss = 0
x1_T_Deferred(t) = x1_T_Deferred(t - dt) + (X1_T_D - x1_TD_recoveries) * dt
INIT x1_T_Deferred = 20000

INFLOWS:
X1_T_D = WB_Donor_Base_x_1*Temp_Deferral_Rate
OUTFLOWS:
x1_TD_recoveries = x1_T_Deferred*T_D_Recovery_rate
x2_Donors_UK__Hb_Loss(t) = x2_Donors_UK__Hb_Loss(t - dt) + (UK_Haemoglobin__Loss_x_2 - Reentry_from_X2__UK_Hb_Loss - Conversion_of_x2_donors_to_Apheresis - Venous_Hb_x2) * dt
INIT x2_Donors_UK__Hb_Loss = 0

INFLOWS:
UK_Haemoglobin__Loss_x_2 = IF uk_haemoglobin =1 THEN
(WB_Donor_Base_x_2*Hb_implementation___%_rate_2) ELSE 0
OUTFLOWS:
Reentry_from_X2__UK_Hb_Loss = x2_Donors_UK__Hb_Loss*Reentry_Rate_of__Hb_Loss
Conversion_of_x2_donors_to_Apheresis =
x2_Donors_UK__Hb_Loss*Rate_of_conversion_to_Apheresis_Donors
Venous_Hb_x2 = x2_Donors_UK__Hb_Loss*Venous_Hb_Recovery_rate
X2_Donors_VCJD_V2_Loss(t) = X2_Donors_VCJD_V2_Loss(t - dt) + (vCJD_Deferral__V2_x_2 - Recovery_from_X2_vCJD__V2_Loss) * dt
INIT X2_Donors_VCJD_V2_Loss = 0

INFLOWS:
vCJD_Deferral__V2_x_2 = vCJD_from_x2*WB_Donor_Base_x_2
OUTFLOWS:
Recovery_from_X2_vCJD__V2_Loss = 0
x2_T_deferred(t) = x2_T_deferred(t - dt) + (X2_tT_D - x2_TD_recoveries) * dt
INIT x2_T_deferred = 12000

INFLOWS:
X2_tT_D = WB_Donor_Base_x_2*Temp_Deferral_Rate
OUTFLOWS:
x2_TD_recoveries = x2_T_deferred*T_D_Recovery_rate
x3_Donors_UK__Hb_Loss(t) = x3_Donors_UK__Hb_Loss(t - dt) + (UK_Haemoglobin__Loss_x_3 - Reentry_from_x3__UK_Hb_Loss - Conversion_of_x3_donors__to_Apheresis - Venous_Hb_x3) * dt
INIT x3_Donors_UK__Hb_Loss = 0

INFLOWS:
UK_Haemoglobin__Loss_x_3 = IF uk_haemoglobin =1 THEN
(WB_Donor_Base_x_3*Hb_implementation___%_rate_2) ELSE 0
OUTFLOWS:
Reentry_from_x3__UK_Hb_Loss = x3_Donors_UK__Hb_Loss*Reentry_Rate_of__Hb_Loss
Conversion_of_x3_donors__to_Apheresis =
x3_Donors_UK__Hb_Loss*Rate_of_conversion_to_Apheresis_Donors
Venous_Hb_x3 = x3_Donors_UK__Hb_Loss*Venous_Hb_Recovery_rate
x3_Donors_VCJD_V2_Loss(t) = x3_Donors_VCJD_V2_Loss(t - dt) + (vCJD_Deferral__V2_x_3 - Recovery_from_x3_vCJD__V2_Loss) * dt
INIT x3_Donors_VCJD_V2_Loss = 0

INFLOWS:
vCJD_Deferral__V2_x_3 = vCJD_from_x3*WB_Donor_Base_x_3
OUTFLOWS:
Recovery_from_x3_vCJD__V2_Loss = 0
x3_T_Deferred(t) = x3_T_Deferred(t - dt) + (x3_T_D - x3_T_D_recoveries) * dt
INIT x3_T_Deferred = 5000

INFLOWS:
x3_T_D = WB_Donor_Base_x_3*Temp_Deferral_Rate
OUTFLOWS:
x3_T_D_recoveries = x3_T_Deferred*T_D_Recovery_rate
x4_Donors_UK__Hb_Loss(t) = x4_Donors_UK__Hb_Loss(t - dt) + (UK_Haemoglobin__Loss_x_4 - Reentry_from_x4__UK_Hb_Loss - Conversion_of_x4_donors_to_Apheresis - Venous_Hb_x4) * dt
INIT x4_Donors_UK__Hb_Loss = 0

INFLOWS:
UK_Haemoglobin__Loss_x_4 = IF uk_haemoglobin =1 THEN
(WB_Donor_Base_x_4*Hb_implementation___%_rate_2) ELSE 0
OUTFLOWS:
Reentry_from_x4__UK_Hb_Loss = x4_Donors_UK__Hb_Loss*Reentry_Rate_of__Hb_Loss
Conversion_of_x4_donors_to_Apheresis =
x4_Donors_UK__Hb_Loss*Rate_of_conversion_to_Apheresis_Donors
Venous_Hb_x4 = x4_Donors_UK__Hb_Loss*Venous_Hb_Recovery_rate
x4_Donors_VCJD_V2_Loss(t) = x4_Donors_VCJD_V2_Loss(t - dt) + (vCJD_Deferral__V2_x_4 - Recovery_from_X1_vCJD__V2_Loss_4) * dt
INIT x4_Donors_VCJD_V2_Loss = 0

INFLOWS:
vCJD_Deferral__V2_x_4 = vCJD_from_x_4*WB_Donor_Base_x_4
OUTFLOWS:
Recovery_from_X1_vCJD__V2_Loss_4 = 0

x4_TDeferred(t) = x4_TDeferred(t - dt) + (x4_T_D - x4_TD_recoveries) * dt
INIT x4_TDeferred = 2000

INFLOWS:
x4_T_D = WB_Donor_Base_x_4*Temp_Deferral_Rate
OUTFLOWS:
x4_TD_recoveries = x4_TDeferred*T_D_Recovery_rate
x5_Donors_UK__Hb_Loss(t) = x5_Donors_UK__Hb_Loss(t - dt) + (UK_Haemoglobin__Loss_x_5 - Reentry_from_x5__UK_Hb_Loss - Conversion_of_x5_donors_to_Apheresis - Venous_Hb_x5) * dt
INIT x5_Donors_UK__Hb_Loss = 0

INFLOWS:
UK_Haemoglobin__Loss_x_5 = IF uk_haemoglobin =1 THEN (Hb_implementation___%_rate_2 * WB_Donor_Base_x_5) ELSE 0
OUTFLOWS:
Reentry_from_x5__UK_Hb_Loss = x5_Donors_UK__Hb_Loss*Reentry_Rate_of__Hb_Loss
Conversion_of_x5_donors_to_Apheresis =
x5_Donors_UK__Hb_Loss*Rate_of_conversion_to_Apheresis_Donors
Venous_Hb_x5 = x5_Donors_UK__Hb_Loss*Venous_Hb_Recovery_rate
X5_Donors_VCJD_V2_Loss(t) = X5_Donors_VCJD_V2_Loss(t - dt) + (vCJD_Deferral__V2_x_5 - Recovery_from_x5_vCJD__V2_Loss) * dt
INIT X5_Donors_VCJD_V2_Loss = 0

INFLOWS:
vCJD_Deferral__V2_x_5 = vCJD_from_x5*WB_Donor_Base_x_5
OUTFLOWS:
Recovery_from_x5_vCJD__V2_Loss = 0
x5_T_Deferred(t) = x5_T_Deferred(t - dt) + (x5_T_D - x5_TD_recoveries) * dt
INIT x5_T_Deferred = 1000

INFLOWS:
x5_T_D = WB_Donor_Base_x_5*Temp_Deferral_Rate
OUTFLOWS:
x5_TD_recoveries = x5_T_Deferred*T_D_Recovery_rate
Conversion = Once_only_donors*First_tme_retention
Cv_of_once_only = 1 - First_tme_retention
Cv_to_Base = 1-First_tme_retention
Cv_x1 = (if Segment_conversion=1 then .15 else 0) * Segment_Conversion_Rate_Improvement
Cv_x_2 = (if Segment_conversion=1 then .12 else 0) * Segment_Conversion_Rate_Improvement
Cv_x_3 = (if Segment_conversion=1 then .06 else 0) * Segment_Conversion_Rate_Improvement
Cv_x_4 = (if Segment_conversion=1 then .035 else 0) * Segment_Conversion_Rate_Improvement
Lapsed_Donor_Rate = 0
ND_vCJD_losses = Recruited_donors-Once_only_donors
Noname_29 = flow_to_x_2+Once_only_loss+X1_T_D+Lapsed_donor_x_1_
Once_only_donors = (Recruited_donors - (Recruited_donors*vCJD_New_Donors))
Once_only_recovery_rate = 0
Once_only__to_1 = Cv_of_once_only*Once_only_donors
Once_only__to_2 = .246*Conversion
Once_only__to_3 = .155*Conversion
Once_only__to_4 = .1*Conversion
Once_only__to_5 = .025*Conversion

Perm_Deferral_Rate = 0
Rate_of_conversion_to_Apheresis_Donors = 0
RD_1 = 1
Recovery_rate_of__Lapsed_Donors = 0
Recruited_donors = if RD_1 = 1 then Recruited_donors_1 else Recruited_donors_2
Segment_conversion = 0
Segment_Conversion_Rate_Improvement = 1
uk_haemoglobin = 1
uk_haemoglobin_loss_A = IF uk_haemoglobin =1 THEN Hb_implementation___%_rate ELSE 0
vCJD_deferral_rate = .031
vCJD_from_x1 = if vCJD_switch = 1 then (if time = 2004 then vCJD_deferral_rate else 0) else 0
vCJD_from_x2 = if vCJD_switch = 1 then (if time = 2004 then vCJD_deferral_rate else 0) else 0
vCJD_from_x3 = if vCJD_switch = 1 then (if time = 2004 then vCJD_deferral_rate else 0) else 0
vCJD_from_x5 = if vCJD_switch = 1 then (if time = 2004 then vCJD_deferral_rate else 0) else 0
vCJD_from_x_4 = if vCJD_switch = 1 then (if time = 2004 then vCJD_deferral_rate else 0) else 0
vCJD_New_Donors = if vCJD_switch = 1 then vCJD_deferral_rate else 0
vCJD_switch = 0
Venous_Hb_Recovery_rate = 0
First_tme_retention = GRAPH(TIME)
(2003, 0.39), (2004, 0.39), (2005, 0.39), (2006, 0.39), (2007, 0.39), (2008, 0.39), (2009, 0.39), (2010, 0.39), (2011, 0.39), (2012, 0.39), (2013, 0.39)
Hb_implementation___%_rate = GRAPH(TIME)
(2003, 0.00), (2004, 0.046), (2005, 0.035), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_implementation___%_rate_2 = GRAPH(TIME)
(2003, 0.00), (2004, 0.046), (2005, 0.035), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_X1_Females = GRAPH(TIME)
(2003, 0.00), (2004, 0.301), (2005, 0.229), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_X1_Females_2 = GRAPH(TIME)
(2003, 0.00), (2004, 0.323), (2005, 0.246), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_X1_Females_3 = GRAPH(TIME)
(2003, 0.00), (2004, 0.329), (2005, 0.251), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_X1_Females_4 = GRAPH(TIME)
(2003, 0.00), (2004, 0.368), (2005, 0.281), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_x1_Males = GRAPH(TIME)
(2003, 0.00), (2004, 0.125), (2005, 0.095), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_x1_Males_2 = GRAPH(TIME)
(2003, 0.00), (2004, 0.176), (2005, 0.133), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_x1_Males_3 = GRAPH(TIME)
(2003, 0.00), (2004, 0.215), (2005, 0.161), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Hb_x1_Males_4 = GRAPH(TIME)
(2003, 0.00), (2004, 0.34), (2005, 0.26), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)

Recruited_donors_1 = GRAPH(TIME)
(2003, 108000), (2004, 108000), (2005, 108000), (2006, 108000), (2007, 108000), (2009, 108000), (2010, 108000), (2011, 108000), (2012, 108000), (2013, 108000)
Recruited_donors_2 = GRAPH(TIME)
(2003, 0.00), (2004, 0.00), (2005, 0.00), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Reentry_Rate_of__Hb_Loss = GRAPH(TIME)
(2003, 0.00), (2004, 0.00), (2005, 0.00), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00)
Stored_values = GRAPH(TIME)
(2003, 130000), (2004, 175000), (2005, 108000), (2006, 101000), (2007, 99000), (2008, 97000), (2009, 98000), (2010, 98000), (2011, 98000), (2012, 98000), (2013, 98000)
Temp_Deferral_Rate = GRAPH(TIME)
(2003, 0.09), (2004, 0.09), (2005, 0.09), (2006, 0.09), (2007, 0.09), (2008, 0.09), (2009, 0.09), (2010, 0.09), (2011, 0.09), (2012, 0.09), (2013, 0.09)
T_D_Recovery_rate = GRAPH(TIME)
(2003, 0.25), (2004, 0.25), (2005, 0.25), (2006, 0.25), (2007, 0.25), (2008, 0.25), (2009, 0.25), (2010, 0.25), (2011, 0.25), (2012, 0.25), (2013, 0.25)
Calculations

Demand(t) = Demand(t - dt) + (Increase_in_Demand) * dt
INIT Demand = 854000

INFLOWS:
Increase_in_Demand = Demand*Demand_%_
Total_New_Donors(t) = Total_New_Donors(t - dt) + (Increase_to_Total_Donors) * dt
INIT Total_New_Donors = 0

INFLOWS:
Increase_to_Total_Donors = Recruited_donors
Total_Recruited_Donors(t) = Total_Recruited_Donors(t - dt) + (Increase_in_Total_Recruited_donors) * dt
INIT Total_Recruited_Donors = 0

INFLOWS:
Increase_in_Total_Recruited_donors = Recruited_donors
Annual_Hb_loss = UK_Haemoglobin__Loss_x_1+UK_Haemoglobin__Loss_x_2+UK_Haemoglobin__Loss_x_3+UK_Haemoglobin__Loss_x_4+UK_Haemoglobin__Loss_x_5
Donation_rate = Total_WB__Donations/Total_Donor_Base
Donor_losses_vCJD = vCJD_Deferral__V2_x_1+vCJD_Deferral__V2_x_2+vCJD_Deferral__V2_x_3+vCJD_Deferral__V2_x_4+vCJD_Deferral__V2_x_5
Rate_of_RBC_per_WB = 0.85
RBC_production = Rate_of_RBC_per_WB*Total_WB__Donations
Shortfall = Demand-Total_WB__Donations
Total_Donor_Base = WB_Donor_Base_x_1+WB_Donor_Base_x_2+WB_Donor_Base_x_3+WB_Donor_Base_x_4+WB_Donor_Base_x_5
Total_WB__Donations = (WB_Donor_Base_x_1*1)+(WB_Donor_Base_x_2*2)+(WB_Donor_Base_x_3*3)+(WB_Donor_Bas

e_x_4*4)+(WB_Donor_Base_x_5*5)+Venous_Hb_x1+(Venous_Hb_x2*2)+(Venous_Hb_x3*3)+(Venous_Hb_x4*4)+(Venous_Hb_x5*5)
Demand_%_ = GRAPH(TIME)
(2003, 0.03), (2004, 0.03), (2005, 0.03), (2006, 0.03), (2007, 0.03), (2008, 0.03), (2009, 0.03), (2010, 0.03), (2011, 0.03), (2012, 0.03), (2013, 0.03)

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