System Dynamics Modelling as a Tool in Healthcare Planning[1]

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This paper looks at the use of a System Dynamics model to support the development of a strategy to address diabetes in Manukau, a large multi-cultural city sitting on the southern border of New Zealand's largest city, Auckland. The paper describes the development of the model, from a simple, high-level conceptual framework to a computer simulation used to test a range of policy scenarios. As part of a major project undertaken by the Counties Manukau District Health Board, the model was developed with a team comprising clinicians across the spectrum from public health, through primary and secondary care. The model has been useful to inform thinking and develop a broader, system-wide understanding of diabetes and the strategies needed to address it.

Background

Despite the proliferation of acute care hospitals and the attention given to technological and pharmaceutical innovations, healthcare in the 21st century is far less dramatic. The average patient is increasingly, one suffering from long-term chronic conditions rather than one requiring a rapid emergency response to an acute episode. Chronic care is less dramatic but is becoming the face of the health system (Institute of Medicine, 2001). Obesity, and the type II diabetes, that often results from it, is typical of the chronic conditions that are confronting the health system[2]. Whilst transplants can provide amazing results for some diabetics with acute renal failure, long-term dialysis which confines the patient to four-hour sessions, three times a week is the normal last stage. Furthermore, it is the last stage in a disease that may have begun with childhood obesity and gradually deteriorated over a very long period of time. It may have begun with fatigue, progressed to sore legs, eye problems, eventual blindness or amputation so that by the time dialysis is begun the patient is already suffering from a number of co-morbidities. It is an uncomfortable, often painful, and very expensive way to end one's life. There is very little glamour or excitement in a dialysis ward.

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[1] The authors wish to acknowledge the important roles played by Dr. Kirsten Lindberg in undertaking much of the literature review that supported the model development.

[2] Type II diabetes is the form of diabetes that is of most concern and is the focus of the work discussed in this paper.

The surgeons who undertake the transplants and the nurses and renal physicians who manage dialysis can do nothing to solve the increasing levels of obesity and the increasing number of diabetics. Instead they are continually stretching resources to meet the increasing demand for renal services and, in a macabre twist, are often relieved when a long-term patient dies as it frees up a machine for someone currently desperate to begin dialysis treatment. This problem cannot be solved in hospital wards. It requires a wide range of health professionals and community workers, working together, to have any chance of changing current trends.

The size of this problem in New Zealand was recently documented in a major report by the Ministry of Health (Tobias and Cheung, 2002);

"The diabetes epidemic is forecast to grow rapidly from 1996 to (at least) 2011. The average annual rate of increase in counts over this period is forecast to be 5.8% for diabetes incidence [i.e. new case each year], 3.9% for prevalence [i.e. total number of diabetics] and 2.3% for diabetes attributable mortality for the population as a whole. This growth represents an 80% increase in the number of people known to be living with diabetes from 1996 to 2011 for the total population. For Maori and Pacific people the increase is 130-150%."

In addition to the increasing size of the problem it is recognised that effective responses need to be system-wide (Homer et al 2004). However, health professionals and health planners are often fragmented, working within and seeing only their part of the system and acting alone even though they depend on each other. This paper describes the use of System Dynamics modelling to involve a wide range of health professionals in thinking through the broader 'system of diabetes' and using that thinking to inform a major project designed to address diabetes in the Counties-Manukau District.

Background on Diabetes within the Counties-Manukau District

Manukau, situated on the southern borders of New Zealand's largest city is an area typified by low-socio-economic status, high Maori and Pacific Island populations and above average health needs. Crime rates, poverty levels and health indices are higher than the national average. Diabetes is seen as a critical and growing problem that, in particular, has a significant impact upon the Maori and Pacific populations. The extent of the problem is evidenced by the fact that the dialysis unit at Middlemore hospital, the major hospital in the region, is the largest in Australasia. To address this diabetes issue a major project was initiated and the modeling described in this paper was used to inform the development of the overall project strategy. The project, "Let's Beat Diabetes" was approved by the Board of the Counties Manukau District Health Board (CMDHB) in December 2004 and launched in April 2005[3]. Model outputs were used as part of the presentation to the Board which not only approved the project proposal but agreed to commit funding for a five year period. Such long-term commitment of funding is unique within the New Zealand health scene.

[3] The five-year plan and other documentation can be found on their web site www.letsbeatdiabetes.org.nz

Overview of the Modelling Process

System Dynamics modelling is an approach that was initially developed by Jay Forrester in the 1950's and articulated in his first major publication, 'Industrial Dynamics' in 1961. It conceptualises the world as a series of flows and accumulations connected together by feedback loops. Understanding the structure that these connections make enables people to develop much deeper insights into the nature of a system and how it behaves under given conditions. Within the health sector the approach has been widely used to explore such issues as wait lists (van Ackere and Smith, 1999), health policy (Rees and Malpass, 1999), antibiotic resistance (Homer et al, 2000), HIV/AIDS (Dangerfield, 2001), chronic care (Homer et al, 2004) and general medical practice (Liddell and Powell, 2004). Most recently the American Journal of Public Health has dedication a completed volume to the application of systems thinking to public health (America Journal of Public Health, March 2006).

The power of System Dynamics lies in the fact that it enables models to be built with, rather than just for, people; bringing together the best scientific knowledge available in a way that supports public discourse and debate (Dietz 2004). The nature of the modelling language and the maths that underpins it provides a rigorous approach yet does not require high levels of mathematical training amongst those involved in the modelling effort. It is a powerful way of bringing together a wide range of people, early in the thinking, thereby facilitating the development of creative and flexible solutions. For example, people can easily understand a basic stock/flow model that depicts the number of people waiting for treatment, as the sum of all those referred for treatment minus all those who have been treated (figure 1).

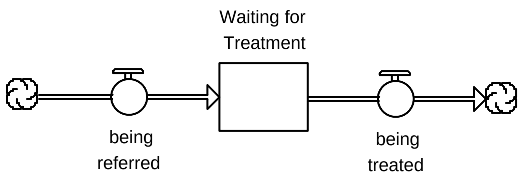

Figure 1. Basic Stock/Flow Model

They can take that simple and powerful concept, work with it and develop a more complex and complete understanding of the system.

Bringing together the best research available on diabetes and doing so in a way that engaged a wide range of people was a key goal of the modelling effort. It required therefore, an approach that brought people along with the project and did not leave them behind because of the complexity of the model. System Dynamics was well suited to this purpose.

Model 1 – Simple Disease Progression Chain (October 2003)

The initial work did not begin with a request for a systems dynamics model. Instead the request was for a framework that would support a broader discussion about diabetes; that took people beyond their particular area of concern and clinical expertise. The initial response was the development of a simple stock-flow structure that provided an overview of the progression of diabetes (figure 2).

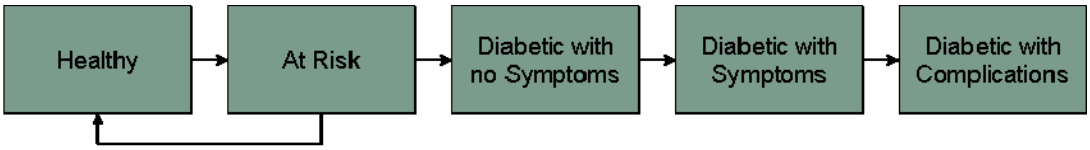

Figure 2. Disease Progression Model

Whilst very simple, this initial structure served to highlight key points about the nature of patient flows within diabetes. For example current interventions, a programme called 'Care Plus' was focusing on people who were heavy users of the health system. This resulted in a focus on 'diabetic with symptoms' and 'diabetic with complications'. increasing the numbers of people with symptoms. This occurs because people are being kept alive longer. In modelling terms the interventions were decreasing the outflow from the stock of 'diabetic with symptoms' but doing nothing to stem the inflow (figure 3).

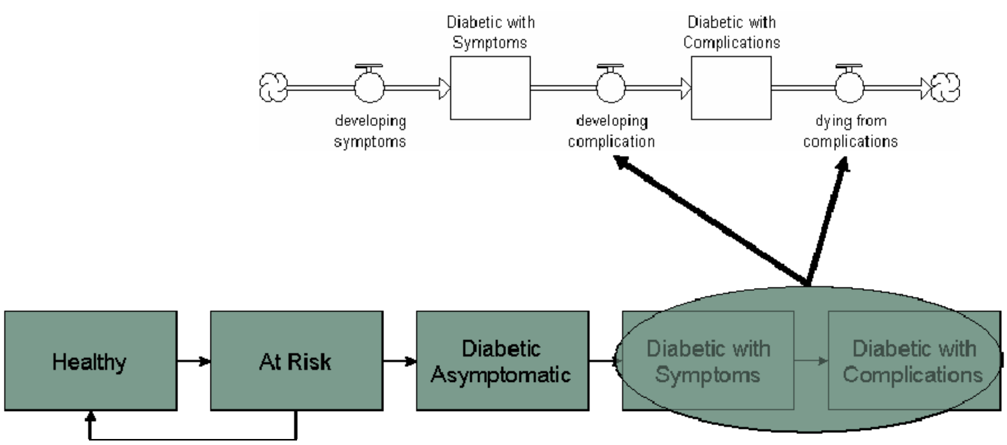

Figure 3. Impact of interventions

Because of this dynamic there is a need to increase resources beyond those needed to meet the current and projected population growth. This is because the population would grow beyond the baseline projections due to the very success of the programme. The more successful the programme is, the greater the numbers there will be in the target population.

This simple insight resulted in people to thinking more carefully about the impact of interventions and how the broader system would be affected. In addition, this simple qualitative stock/flow model showed that it was possible to look at diabetes within a broader systemic framework. Furthermore, it highlighted the fact that in developing interventions one needed to understand the impact on the flow rates into and out of the stocks and that any intervention ultimately had an impact upon the whole system; its effect not being limited to the area of the system at which it was targeted

Model 2 – Population Stocks and Health System Responses (July 2004)

Model 2 was developed, building on the work of Homer et al (2004), to show the types of intervention that were possible and the nature of the resources that would be required to implement them.

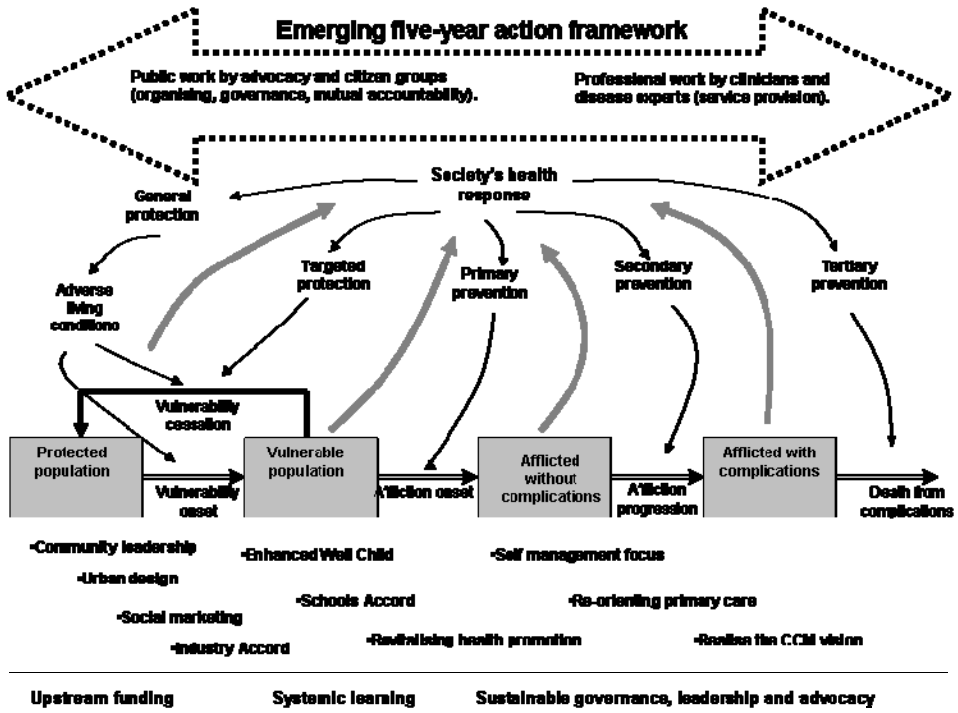

Figure 4. Chronic Disease and Health System Responses

Key points highlighted by this model are that downstream activities are provided by professional clinicians and disease experts – in this case nephrologists and renal nurses. On the other hand the upstream activities are provided by community groups involving a wide range of people and expertise. Any approach to diabetes, from a whole-system perspective, therefore needs to take account of this range and which part of the 'population' it was targeting. Examples of the types of interventions that could be considered are shown at the bottom.

This representation helped move discussion from single intervention points to an appreciation of the larger system and the range of possible interventions.

Model 3 – Exploring the Dynamics through Computer Simulation (July-December 2004)

Once appreciation of the 'systemic' nature of diabetes was well understood a clinical team was brought together to develop a detailed model that would increase understanding of the dynamics of such a system and how it would respond to a range of strategies. The model was developed by a small team supported by an extensive search of the literature[4]. A high level view of the model is shown below:

[4] The literature research was undertaken by Dr. Kirsten Lindberg.

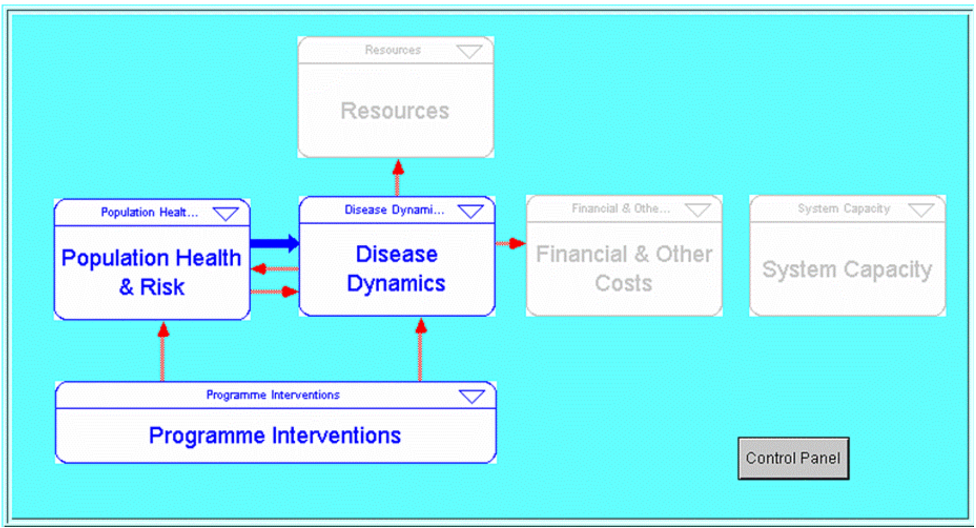

Figure 4. High-Level Map of Simulation Model

Within the model itself the population was split into those who were non-obese and those who were obese. This was done as the major flow into diabetes is through obesity (Deckelbaum and Williams 2001). Whilst there are other causes, obesity is by far the major determinant of diabetes and the clinical team decided that little was to be gained by complicating the model with other factors such as smoking. In addition, both population groups were disaggregated along an ageing-chain so that behaviours of different age groups could be studied; and along ethnic lines so that the different behaviours of Maori, Pacific and European populations within Manukau could be explored.

A number of scenarios were developed within the model to explore the impact of intervening across different parts of the system. The first scenario, 'working with the non-obese population' looked at the impact of working with the healthy population, influencing the rate at which they became obese. The second set of scenarios 'working with the diabetic population' worked with diabetics, influencing firstly how many of them were diagnosed and brought within the system and secondly how many of those that were diagnosed were under effective management programmes. The third scenario, 'working with the obese population' explored the effect of working with the obese population, influencing the rate at which they developed diabetes. Some key results from each of these scenarios are shown below along with a description of the issues that emerged from the model runs.

Scenario 1 – Working with the non-obese population

Working with the non-obese population is the focus of public health initiatives. It encompasses a range of strategies designed to improve diet and exercise within the population and with 'at risk' individuals so as to decrease the rate at which they become obese and therefore at risk of diabetes and other health issues. The following graph shows the impact on the number of diabetics if the rate at which people became obese was reduced by 1% per annum.

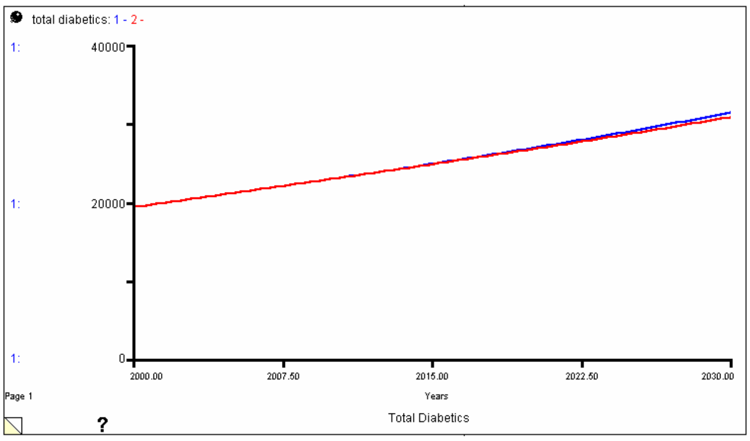

Figure 6. Scenario 1 – Total Diabetics

The graph shows public health initiatives have little impact on the number of people with diabetes, referred to as 'prevalence', over the 25 years of the simulation. This is largely due to the inertia already in the system created by the people who are already obese, already diabetic. The model highlights the fact that change within a chronic condition such as diabetes is a long slow process in which the path of our future is largely written in our past.

The picture is not so bleak however when you explore the rate at which people are developing diabetes. Public health measures can have a significant effect here and this is an important issue. The flow rates, in this case the rate at which people develop diabetes, are early indicators of a future state. Whilst public health measures, on their own, will have little impact upon the numbers of diabetics over the next 25 years such work is crucial as it does slow the rate of developing diabetes, what epidemiologists refer to as 'incidence rates'.

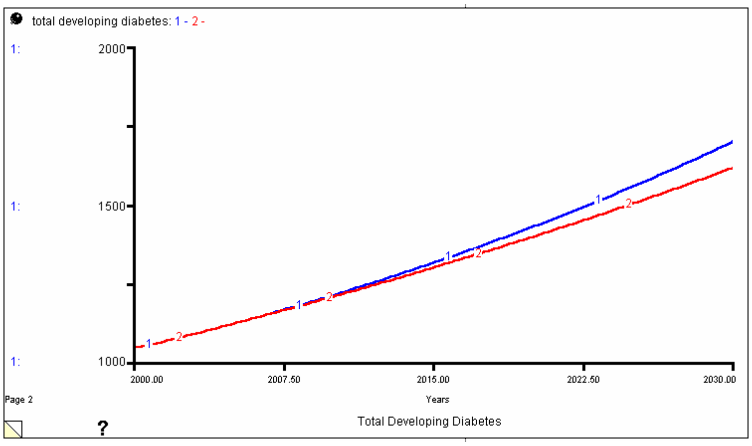

Figure 7. Scenario 1 – Total Developing Diabetes

Scenario 2 – Working with Diabetics

The other area that has been the focus of diabetes programmes is working with the diabetics themselves. The focus here has been firstly on trying to diagnose them and secondly having undertaken a diagnosis place them on effective management programmes. Whilst the data is not conclusive the model assumes that within Counties-Manuaku only 50% of diabetics are diagnosed and of those only 50% are on an effective management programme. Whilst there is very little data on the number of undiagnosed diabetics the clinical team, based on their own understanding of the literature, and their everyday clinical experience considered that 50% was a reasonable approximation. This figure is also consistent with recent Australian research (Dunstan et al 2001).

In scenario 2 the model explored the consequences of having all diabetics diagnosed and all of them on effective management programmes. This is the ideal health professionals are working towards. Whilst this is not likely to be achieved it does allow the exploration of the consequences of success; what would happen if we could be that successful. The model does however accept that achieving such levels would not happen overnight so it has an in-built 5 year delay. The results of this second scenario are shown below.

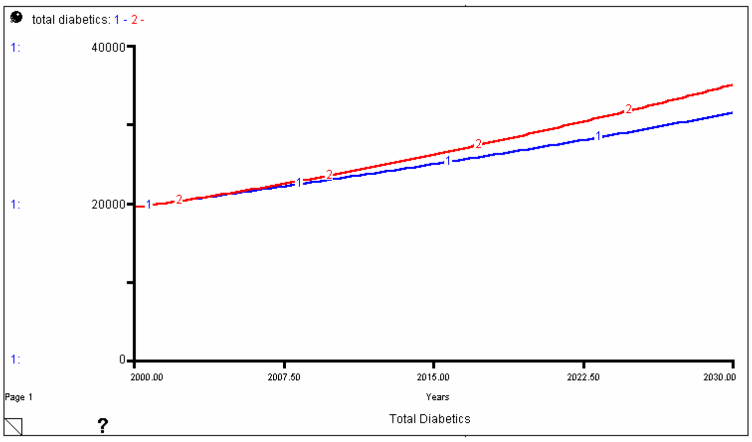

Figure 8. Scenario 2 – Total Diabetics

As can be seen, effectively diagnosing, treating and managing diabetics increases the number of diabetics. This is simply because they are being kept alive longer. With good treatment and chronic care management the progression of the disease can be slowed significantly. Whilst this seemingly produces unwelcome results for the health system – simply more people to deal with – a closer look at the data reveals a different picture. One of the key insights that emerged from the modelling effort is the danger of 'lumping' all diabetics together. Diabetics without symptoms are fundamentally different from those with complications such as end-stage renal failure. Their state of well being is different and so are the resources required to care for them. Whilst effective diagnosis and management increases the number of diabetics it also makes a significant change to the nature of the diabetic population. This is shown in the following graph:

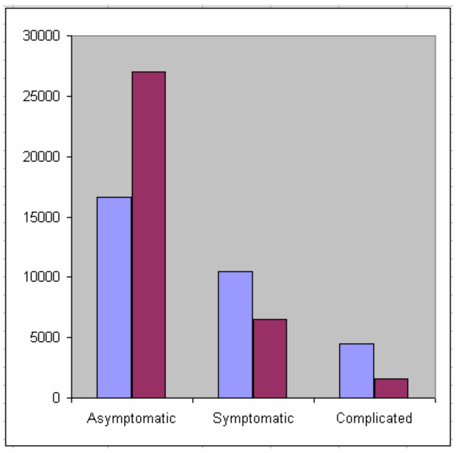

Figure 9. Scenario 2 – Nature of Diabetic Population

As the graph shows, effective diagnosis and treatment programmes, whilst increasing the total number of diabetics, slow the rate of disease progression resulting in significantly more diabetics with no symptoms and a decrease in those with symptoms and complications. This scenario showed that effective diagnosis and treatment of diabetics will increase the number of diabetics – however it will also change the profile of the diabetic population. This changed profile has significant implications for resourcing and programme design.

Scenario 3 – Working With the Obese Population

Scenario 3 - 'working with the obese population' has provided some interesting insights. Most of the literature and most of the health effort has gone at the two 'ends' of the system; public health on the one hand and secondary treatment on the other. The model allowed the team to explore the implications of working in the middle – with the obese population. Whilst the research data is much more scarce the model did show that the effects of changing the rate at which obese people developed diabetes are significant. The graph below shows the impact of reducing this rate by 1% per annum.

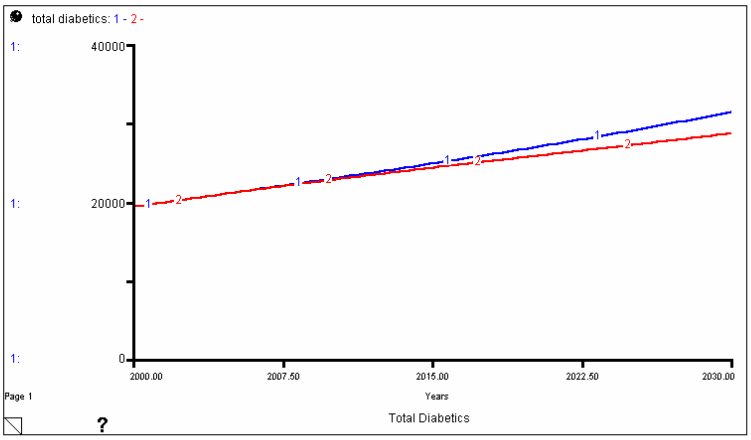

Figure 10. Scenario 3 – Total Diabetics

As can be seen this produced a reasonable decline in the number of diabetics, as measured against the base run. When one looks at the impact upon the numbers of people developing diabetes the results are even more significant;

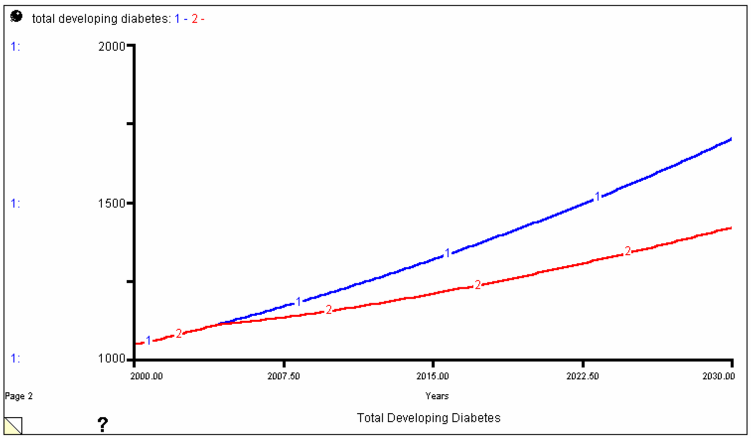

Figure 11. Scenario 3 – Total Developing diabetes

What was Learned

Perhaps the most significant impact of the modelling work so far has been that it has altered the perspectives of those working in the field and responsible for developing an effective strategy to combat it. As one clinician put it;

"I now look at my work differently. It has given me a better perspective of diabetes in its broader context"

Far more important than the numbers themselves has been the fact that it has enabled people to explore the whole system, test out their assumptions and at times, be surprised by the results.

A second impact of the modelling effort has been that, the process of mapping out the system has revealed very clearly where information is available and sound and where it is either non-existent or poor. The model provides a framework in which the best knowledge within the field is captured. As a result it provides a good research agenda, highlighting where more research is needed. Furthermore it provides a framework within which the 'Let's Beat Diabetes' project team are able to continue building and refining their knowledge and using it as a repository to capture what is known. At the time of writing the model is being used to help direct the focus of a research and evaluation programme that has been commissioned alongside the 'Let's Beat Diabetes' project.

A third impact has been that it has re-directed the investment focus within the Let's Beat Diabetes Strategy. The model has allowed people to test different strategies resulting in a more concrete and specific understanding of the consequences of various policy options. Specifically more investment is new being made in the 'pre-diabetes' phase, working with high-risk individuals with the aiming of delaying the onset of the disease. Secondly, research is now underway to look at the implementation of a comprehensive screening and post-diagnosis management programme. The model has shifted the perspective from 'we can't do anything about the number of diabetics, they are just going to keep on increasing' to 'we can influence the nature of the diabetic population for the benefits of the patients and for the broader health system resource requirements'.

At the time of writing a number of related developments are underway. The first is the extension of the model to look more closely at planning options within the Pacific Island community. This model, which is now completed, is exploring the policy levers in more detail, looking at interventions to improve diet and nutrition and also to differentiate between programmes that are population focused as opposed to those that focus on 'at risk' groups and individuals. The second is a refinement of the original model, to explore the financial implications, and to extend the model to include more detail of the resource requirements for each of the policy options.

Summary

Epidemiological research and clinical trials provide us with the basic building blocks of knowledge and means to identify risk, provide management advice and monitor response in health and disease. However, the picture they provide is far from complete. For example, epidemiological cohort studies inform us of rates of developing a condition, event or complication within that cohort but usually will not be able to describe the wider demographic drivers which are influencing patterns of disease: these are often external to the cohort and include population bulges, immigration, lifestyle changes and so on. Intervention studies rightfully focus on the intervention, but usually shed little light on the implementation, generalisability (from a highly selected population), or resource requirements to reproduce the results in the real world clinical environment. Intervention studies tend to concentrate on a single intervention, or strategy compared with routine care or no intervention (placebo), and yet the effect of combinations of interventions and the model of care to promote and provide care are seldom examined.

System modelling provides a tool to describe a "lifecourse" progression, integrating population dynamics, environmental and personal health determinants assembled from existing research and literature. It allows examination of future trends of current care paradigms, and can explore the impact of new interventions (theoretical or proven), be they changes in implementation, new therapeutics, or changes in population structure. Both the structure and content (e.g. rules of flow or influence) can be built based on population demography, medical research, local survey and funding and capacity considerations. The explicit structure of the model, the ability to embed modules within it detailing interventions or other influences, the ability to have complex interrelationships (positive, negative, linear, non-linear, constrained etc), and the possibility to explore the sensitivity of variables to the performance of other parts of the model (e.g. disease progression) provides insights for planning decisions, workforce development and program design and implementation.

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