Introducing System Dynamics Modeling to Health Care in Alberta

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Abstract

Alberta, Canada is going through a period of unprecedented demand for health services, driven by the Province's growth. Problems arising from population growth have led to a gradual realization among health region planners that better tools are needed to help make policy decisions. We discuss our progress to date in introducing systems thinking and system dynamics modeling as tools for evaluating alternative health policy decisions. To date, we have held a workshop to introduce Calgary Health Region opinion leaders to what system dynamics can and cannot do, and have begun model development work in two areas. The first is in emergency care services and the second is in colorectal cancer screening. In this paper we describe the problems being tackled and the preliminary (qualitative) models that have been developed.

Keywords: Health, Emergency Care, Cancer Screening, Strategic Planning

Introduction

Health care in Alberta, Canada is managed by integrated health regions. The Calgary Health Region (CHR) is one of the largest fully integrated, publicly funded health care systems in Canada. It serves over 1.2 million people from the city of Calgary as well as surrounding satellite communities in southern Alberta. More than 23,000 staff and 2,200 physicians provide services in over 100 locations, including 12 hospitals, two comprehensive health centres, 41 care centres and a variety of community and continuing care sites. Services provided by the Region include public health, mental health, home care and palliative care services.[1] Working closely with the CHR and other health regions in Alberta, the Alberta Cancer Board (ACB) manages cancer care on a province-wide basis. The ACB services include cancer prevention, early detection, diagnosis, treatment, research and education.

There has been growing interest in the using system dynamics modeling as a tool to support population health management in Alberta. The working group for the Population Health Measurement Strategy believes that system dynamics could be an important tool for strategic planning, and is one of the groups that sponsored a half-day workshop to raise awareness of system dynamics as a strategic planning tool among opinion leaders in the CHR. This workshop was timely, because two system dynamics projects in the region are just getting underway:

1. In late 2006 the Health Quality Council of Alberta (HQCA) was commissioned by the Alberta Minister of Health to conduct a review of emergency and urgent care services. In part, this study was motivated by the severe overcrowding problems

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[1] www.calgaryhealthregion.ca

in the waiting areas of emergency departments at the three major hospitals in Calgary. As part of its study, the HQCA provided funding to the University of Calgary to develop a qualitative model of the emergency and urgent care system in Calgary for the purpose of informing the effectiveness of improvement options within the broader CHR system.

2. The ACB and the Government of Alberta announced a province wide colorectal screening program on March 23, 2007 (ACB, 2007). A system dynamics model is being developed in conjunction with the development of this program to enable "what-if" testing of alternative policy options.

The driving force for this renewed interest among population health planners and managers is to move beyond the traditional "cost effectiveness" approach of health care economics. The traditional approaches have their place, but the tools of systems thinking and systems dynamics are seen as being better suited to address the dynamic complexity of public health (Homer and Hirsch, 2006).

An Old Tool in a New Era for Strategic Planning

We invited 25 persons "of interest and influence" associated with the CHR and the ACB to attend a three hour workshop entitled *System Dynamics: an old tool in a new era for strategic planning*. Participants ranged from senior health planning consultants to the Medical Officer of Health. We chose to position system dynamics as a modeling technique that had been around for a while but was now coming to the forefront as a leading tool for strategic planners in health care. We positioned the workshop as a "discovery meeting" to provide participants with an opportunity to learn about system dynamics and to discuss its potential value in supporting strategic planning and policy analysis in health care.

The first hour of the workshop was devoted to introducing systems concepts, systems thinking and the dynamic behavior of systems. The first part of the workshop included some simple models to demonstrate the concepts of stocks and flows and how these contribute to system behavior. For example, the "SIR[2]" model for infectious diseases (Sterman, 2000) was particularly helpful as it uses subject matter familiar to the audience to illustrate the concepts of balancing loops, reinforcing loops and tipping points.

The second part of the workshop introduced some applications of system dynamics modeling in the field of health care. Two applications were described in detail. The first was chosen to illustrate the use of systems thinking to understand system/policy interactions at a strategic level, namely how to achieve health care reform in the United States (Hirsch, *et al.*, 2005). The second application was chosen to illustrate the use of system dynamics to model the effect of tactical policy alternatives, in this case how to allocate resources between the hospital sector and the home care sector to cope with a massive surge in demand (Lubyansky, 2005).

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[2] SIR stands for Susceptible, Infectious and Recovered respectively, representing the three population stocks in the model.

The workshop concluded with a very brief review of system dynamics modeling projects just getting underway in Calgary, which will be discussed in the next section. In the discussion at the end of the workshop, participants were asked for feedback on whether system dynamics could support the work that they do and whether they thought it could support strategic planning in the health region. Some participants expressed interest in learning more about how they could learn to do system dynamics modeling themselves.

System Dynamics Projects in Calgary, Alberta Health

We discuss two projects that are at an early stage of problem definition and conceptual modeling. First is the HQCA-funded causal analysis of overcrowding in emergency departments. Second is a project funded by Alberta Health and Wellness to improve capability in health technology assessment, for which we are developing a model to assist in the evaluation of alternative colorectal screening policies.

Understanding Overcrowding in Emergency Departments

Literature

There have been some excellent system dynamics modeling studies of overcrowding in emergency departments in the UK (Royston, *et al.*, 1999; Lane, *et al.*, 2000; Brailsford, *et al.*, 2004).

Royston *et al.* (1999) describe several applications of system dynamics modeling to problems in the UK's National Health System (NHS). One of the applications described in detail in the paper uses system dynamics to develop a better understanding of the interactions between the emergency care system and the social care system. This was an even broader study than the later Brailsford *et al*. study (discussed below), encompassing residential care, community care, and primary health care. The main benefit of the model was seen in its use as a learning tool, but it did show that changes in resources such as beds or staffing had less impact than changes in behaviors affecting referral patterns, length of stay, or inter-sectoral flows. Modeling workshop participants found that the solution to a problem in one sector of the system may often lie in another.

Lane *et al.* (2000) use system dynamics to model patient flow through a single emergency department. To a certain extent, a discrete event simulation (DES) model can do a better job of modeling single emergency department (ED) flows because DES allows better characterization of patients through "attributes" that can affect their flow path through the system. Lane *et al.* assume a single flow path but, unlike a DES model, Lane's system dynamics model is able to look beyond the ED to take into account feedback effects from ward occupancy and elective surgery. They calibrated the model's behavior by driving the model with a 24 hour cycle of arrivals and the 24 hour schedule for doctor staffing. The cyclical nature of their arrivals data would superimpose nicely over typical data for emergency departments in the Calgary Health Region - suggesting a similar pattern of human behavior when aggregated over large city populations.

Useful findings from the Lane *et al.* study include the following:

1. The increase in doctor staffing during the day and evening "rush hours" is not sufficient to keep pace with the increase in patient arrivals. This causes an increase in the time from triage to ED physician assessment.
2. The waiting time from decision to admit to actual ward admission is the biggest cause of delay. Patients back up in the ED especially during the 9am to noon period when admitting priority is given to elective patients who have been staying in a hotel unit overnight awaiting admission. Although ED patients ought to get priority over current day elective patients, as the ED gets busy during the day there are fewer nurses and porters available to take patients up to the ward. Thus, ward beds that the ED ought to have priority for are "snapped up" by elective patients, causing an increase in ED delays until elective admissions close and the ED arrivals diminish later in the day.
3. The model proved useful for evaluating different scenarios. Scenarios tested included bed closures, demand increases, a combination of the two, and a crisis event.
4. Increasing hospital beds by 100 from the existing 800 bed capacity caused elective patient cancellations to drop from 16% to 8%. Reducing beds by 100 caused the elective patient cancellations to increase to 30%. Waiting times in the ED did not change because policy requires bed priority to be given to ED patients. Over the range of bed capacities studied, bed occupancy ranged from 90-95% - a natural result of queuing theory - but something that politicians wanting "full utilization of resources" may not appreciate. In fact, 90-95% is indeed full utilization.
5. Increasing demand causes increasing delays in the ED, as expected, with increases of 5% beyond existing demand causing infinite queues. They did not appear to include any Left Without Being Seen or Left Against Medical Advice flows in their model.
6. The system can handle a crisis day surge in demand (13% above normal), but it takes 5 days for the system to return to normal.

The ability of a cluster of hospitals to handle a surge in demand was not reflected in the model presented in the paper, but the authors say that extensions of the model were being discussed.

The Brailsford *et al*. (2004) paper differs from Lane *et al.* because it describes a system dynamics study of a regional emergency and urgent care system, rather than a single emergency department. They constructed a high-level model of patient flows in the Nottingham health region's emergency care system. The model was readily embraced by policy makers who were keen to test various policy scenarios. The model was useful for showing that the system is operating "dangerously close to capacity." Other useful findings include:

1. Interventions aimed at preventing 3-6% of emergency admissions of patients over 60 years made a big difference to congestion, as these patients comprise about half of all emergency admissions. The authors don't comment on how to achieve this sort of reduction.

2. Early discharge (by 2 days) of patients admitted as emergencies to nursing homes hardly made any difference. However, the average length of stay of such patients and their relative importance as a % of admissions was not given.
3. Going to a 7 day a week discharge model also had only a minor beneficial effect.
4. There was a similar small beneficial effect resulting from interventions aimed at patients with specific disease conditions.

In our view, the cumulative affect of many small interventions such as 2, 3 and 4 above, each contributing a 1-2% reduction in capacity utilization, could make a noticeable difference and may meet with less policy resistance. Many small improvements are often more effective than searching for the "silver bullet" of one big innovation (Jamrog, *et al.*, 2006).

The authors also built a small DES model to evaluate the benefits of a "fast track" stream, like the Minor Emergency Treatment (MET) process in Calgary emergency departments. They found that a flexible system in which streaming is only triggered by reaching a wait time threshold would be preferable. Their findings seem to support current MET practices in the Calgary Health Region.

Our Study

We are building a qualitative system dynamics model of the variables affecting patient flow in the Calgary Health Region, to gain a better understanding of factors influencing overcrowding in hospital emergency departments. Concurrently, we are building a discrete event simulation model of the emergency department patient flow at the Foothills Medical Centre, one of the larger hospitals in the region. Our process understanding from the discrete event simulation modeling initiative has been useful in informing the development of the system dynamics model.

Our dynamic hypothesis is that over the past decade, as Calgary’s population grew and aged without corresponding increases in health system capacity, a greater proportion of older and sicker patients were sent to EDs. Consultants could not adequately access diagnostic and treatment resources for their patients in a timely fashion and family physicians could not adequately access consultants to see their patients. Over time, for family physicians and consultants, the ED became the safety net to accommodate the demographic push from older and sicker patients. Data from the 1998 to 2006 period showed that the percentage of patients over 50 years old increased from 23% to 30% of ED visits. Data from 2000-2006 showed that higher acuity patients increased from 5% of visits to nearly 25% of visits. The older and sicker patients required more workup time from the ED physicians and more consult time from the consultants, which increased length of stay in the ED. There was a 20% increase in ward admissions from the ED compared to a 5% increase in ED visits during the 1997 to 2005 period, attributed to the older and sicker patients. This increase in hospital admissions from the ED caused increased demand for space in hospital wards at the same time as demand from patients for elective treatments was rising, causing increasing competition for beds. The inability of hospital ward capacity to keep up with increasing demand caused further backup in the ED, further increasing ED length of stay. As the ED length of stay increased, some patients were discouraged from going to the ED. For example, a patient requiring minor emergency treatment might go to a walk-in medicentre. The opening of new urgent care centres in Calgary in 1999 and 2003 encouraged this diversion of lower acuity patients away from the ED. As a result, the reduced number of lower acuity patients offset the increased number of higher acuity patients causing the total annual visits to the ED to stay about the same, causing an illusion of "business as usual."

Our first model of the patient flow through the emergency department process of a single hospital is shown in Figure 1. In the diagram, only the variables affecting flows into and out of the stock of Patients Being Treated in ED are shown. However, we are interested in developing an understanding of the system structures influencing all of the patient flow streams into and out of the system. For example, what effect does the structure and policies for elective patients have on the flow of patients being admitted to hospital wards from the ED? What effect does a shortage of family physicians or consultants have on the stock of Patients Waiting for ED Consult or Discharge?

To answer these and other questions we are using an iterative modeling process, building the structure of the model with input from experts working within the system. For example, Figure 1 shows the model as it existed after interviews with one expert and Figure 2 represents a revised and updated model after input from three experts. One of our challenges has been to keep the model simple enough to be transparent and useful while reflecting enough detail to reflect the experts' understanding of how the system works. In fact, the current version of the model has input from interviews with seven system experts and is too large to be readable in a single view on letter size paper. Figure 3 shows a view of the variables influencing ED flows in the latest version of the model.

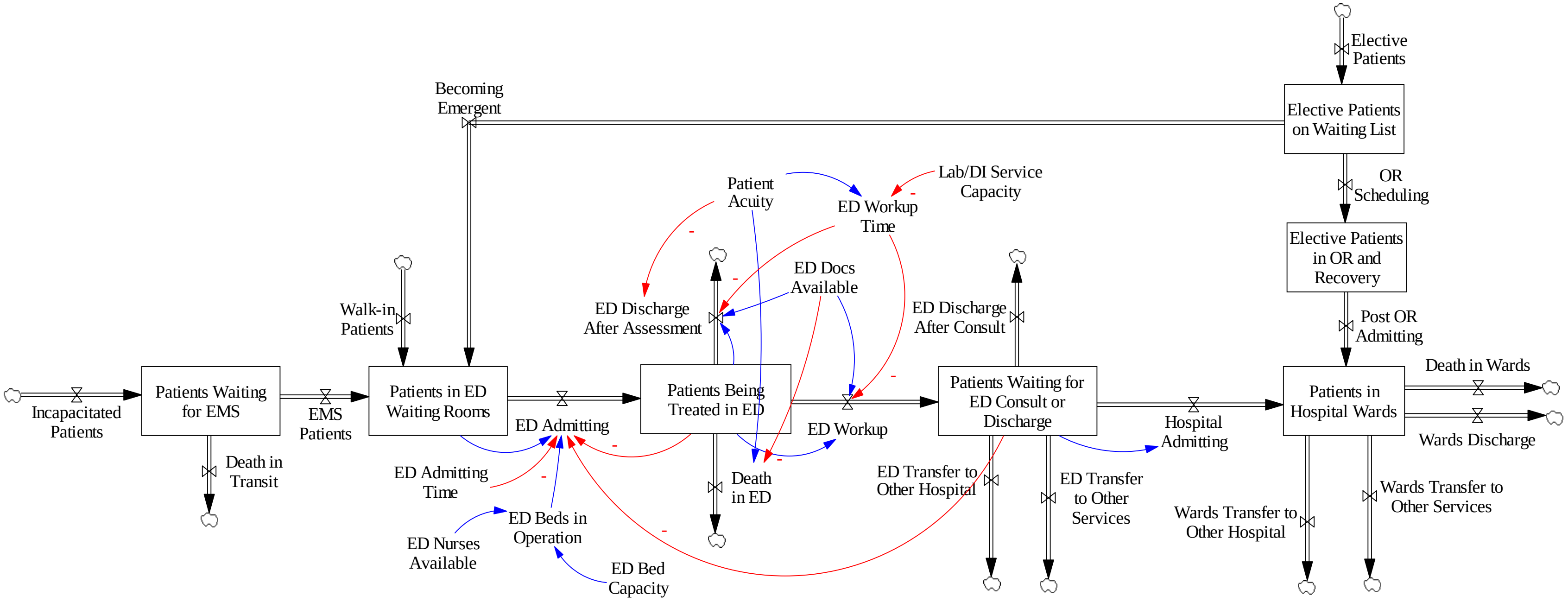
The study as currently envisaged is expected to yield a conceptual model that will support the dynamic hypothesis and help to explain the causes of bottlenecks in the system. The conceptual model will:

- Embody the expert consensus of how the "system works"
- Help to identify feedback loops and shed light on system behavior
- Provide a rigorous basis for further analysis and group discussion
- Put the problem on "one piece of paper"

The next step in the process is to generate a report describing the qualitative model, the implications of the system structure for patient flows in the ED, and a discussion of important variables influencing patient flows. Depending on resources, available funding, and the value seen by participants in the qualitative model building process, we will continue development towards a fully-functioning simulation model. This will allow calibration to historical data and testing of policy alternatives.

Figure 1: Preliminary System Model of Patient Flows for a Single Hospital Emergency Department

Note: Only the variables affecting flows in and out of Patients Being Treated in ED are shown.



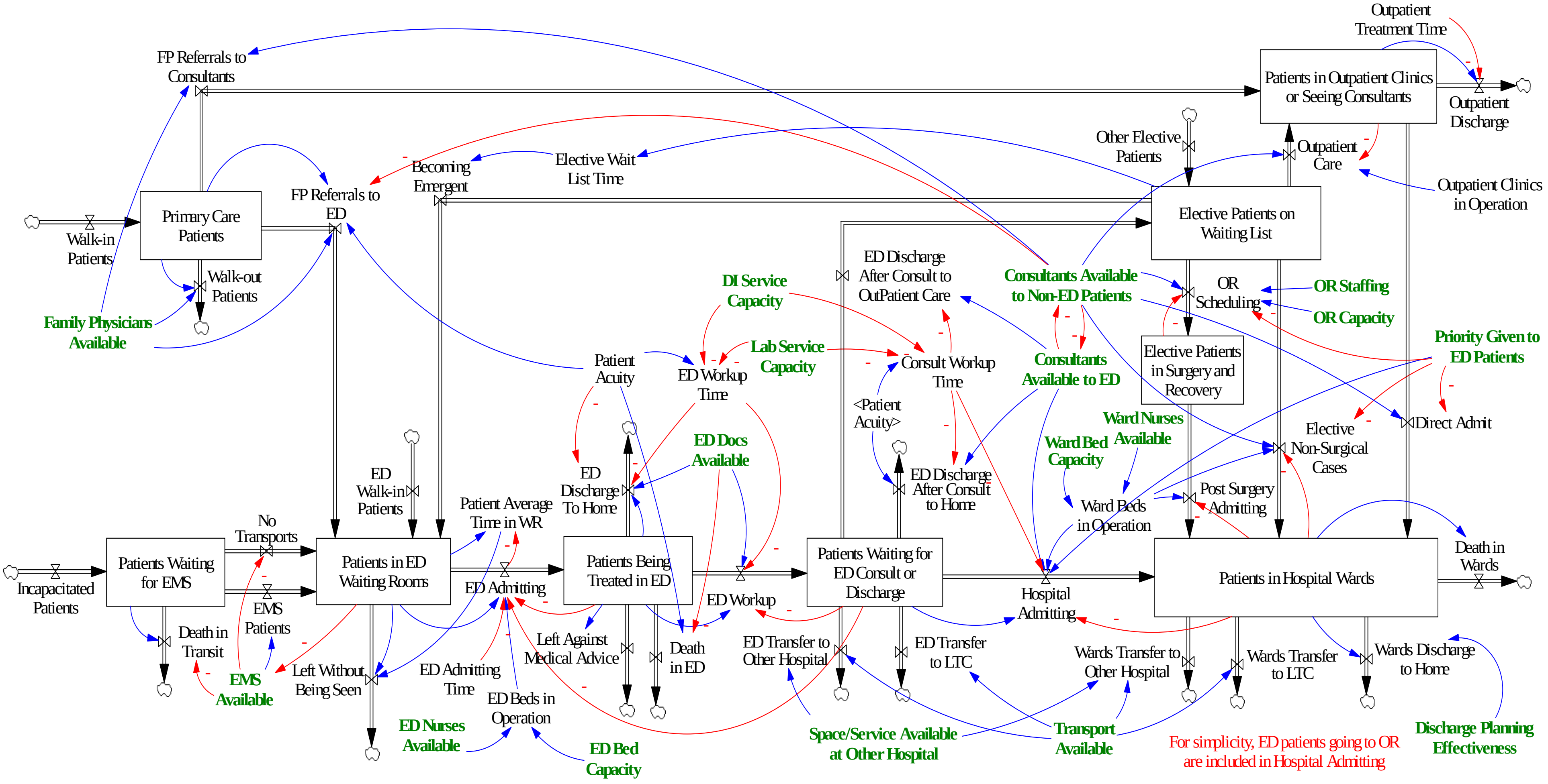
What this diagram says:

The more ED Docs Available, the faster the rate of ED Workup and ED Discharge After Assessment, and the lower the rate of Death in ED. Longer ED Workup Time reduces these flow rates. More Lab/DI Service Capacity reduces ED Workup Time. Increasing Patient Acuity increases Death in ED and Workup Time, but reduces the rate of ED Discharge After Assessment.

The higher the Bed Capacity and the more Nurses Available, the greater the number of Beds in Operation. If Patients Being Treated in ED and Patients Waiting for ED Consult or Discharge falls below Beds in Operation then ED Admitting increases.

Figure 2: An Early Version of the Emergency Department System Model Showing the Impact of Consultants

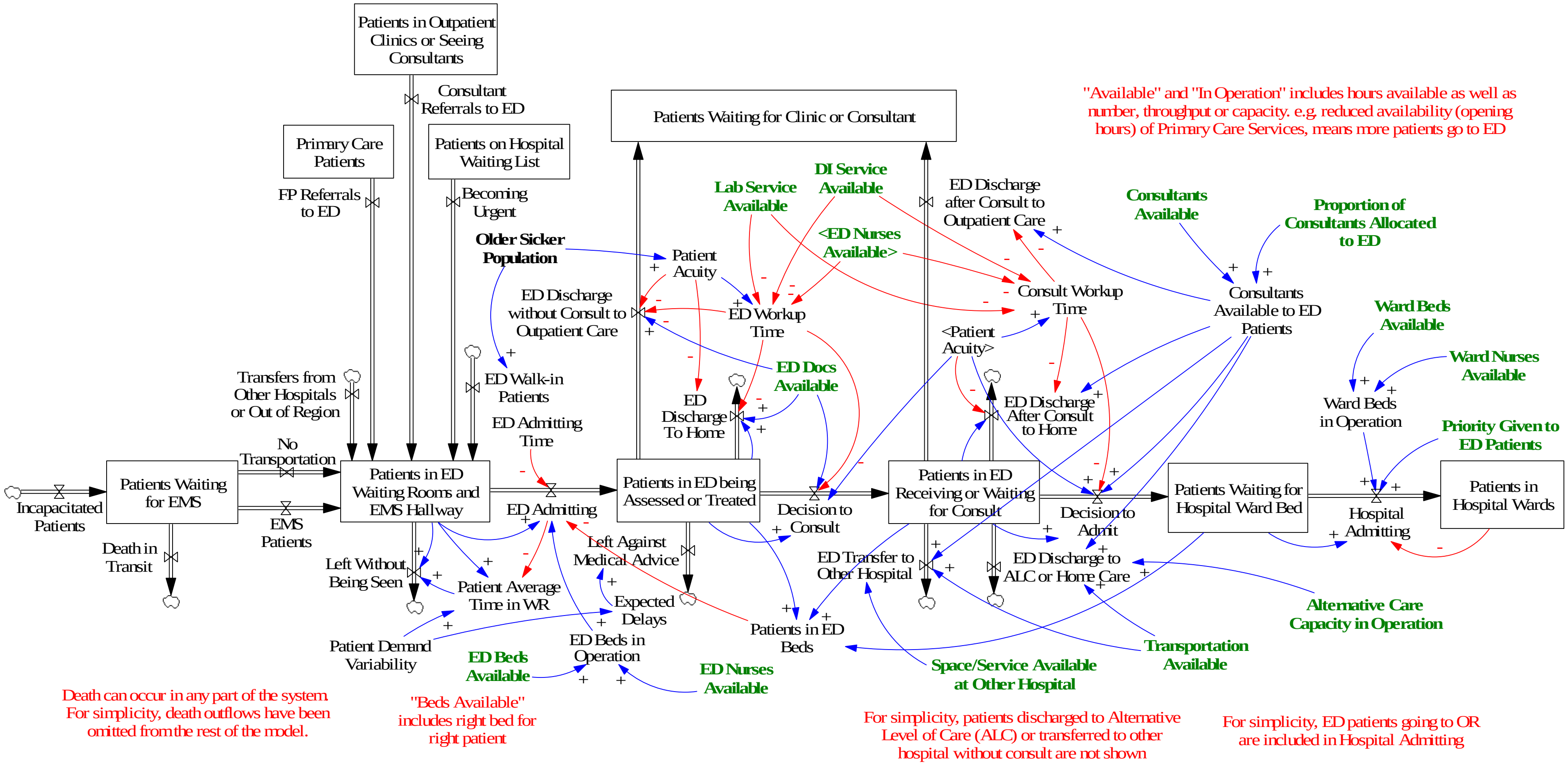
Variables in **bold green** are affected by policies



For simplicity, ED patients going to OR are included in Hospital Admitting

Figure 3: **Part of the Current Model Showing Variables Influencing Flows Inside the Emergency Department**

Note the evolution of the model compared to Figure 2, based on input from four more system experts.



"Available" and "In Operation" includes hours available as well as number, throughput or capacity. e.g. reduced availability (opening hours) of Primary Care Services, means more patients go to ED

Death can occur in any part of the system. For simplicity, death outflows have been omitted from the rest of the model.

"Beds Available" includes right bed for right patient

For simplicity, patients discharged to Alternative Level of Care (ALC) or transferred to other hospital without consult are not shown

For simplicity, ED patients going to OR are included in Hospital Admitting

Evaluation of Alternative Colorectal Screening Policies

Literature

There have been a few reported system dynamics studies involving population health screening: Chlamydia and cervical cancer screening (Royston, *et al.*, 1999); and diabetes screening (Jones, *et al.*, 2006).

Royston *et al.* (1999) used system dynamics models to test alternative policies for cervical cancer and Chlamydia screening. The UK Department of Health found the results to be useful for the development of screening guidelines. Policy questions included what should the screening interval be and what should the coverage be. The results suggested it was more effective to increase the screening coverage than to decrease the screening interval. The model was later used to evaluate the effect of interventions aimed at increasing coverage.

Jones *et al.* summarize a system dynamics study of diabetes sponsored by the Center for Disease Control and the Sustainability Institute in the US. More details of the model and modeling process can be found in an earlier ISD conference paper (Homer, *et al.*, 2004) on the same subject. The core of the Jones *et al*. model is two parallel aging chains, one in which healthy people progress from health through different stages of undiagnosed diabetes to death and the other in which there is the same progression through diagnosed diabetes. This allows the modelers to demonstrate the effect of improved screening on the control of the disease, and to demonstrate the effect of some possible intervention scenarios. These include enhanced clinical management, increased management of pre-diabetes and reduced obesity prevalence. Enhanced clinical management actually leads to an increase in the prevalence of diabetes because deaths from diabetes are reduced. Increased management of pre-diabetes is a more effective strategy for reducing prevalence, but it tends to "back-up" patients who then develop diabetes later in life. The most effective strategy is to reduce the prevalence of obesity. The researchers assume that interventions will be successful in bringing obesity in the population back to 1995 levels, going down from 37% in 2006 to 26% by 2017. Of course, bringing about such behavioral change will be a lot more difficult to achieve in real life than it is to model.

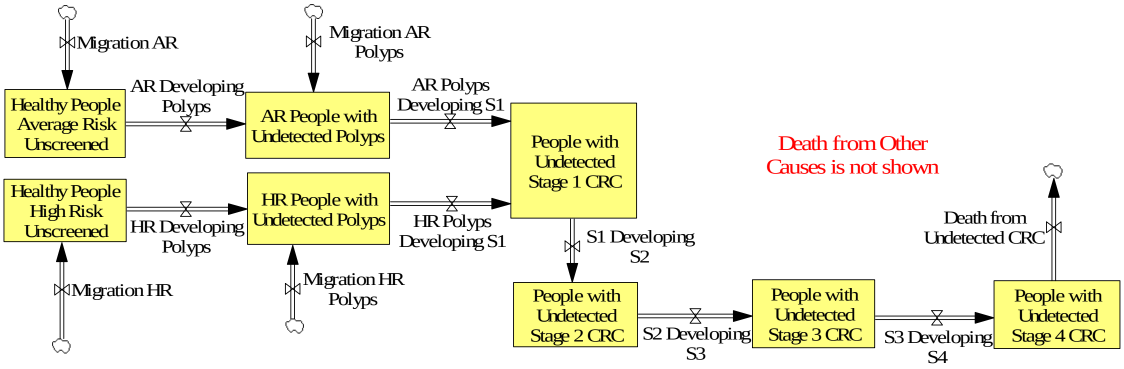
Our Study

A new targeted colorectal screening program was recently announced by the Alberta Cancer Board (ACB, 2007). We expect this new program will reduce morbidity and death from colorectal cancer (CRC), assuming increased capacity for colorectal screening and colonoscopies will be made available to support the program. We have an excellent opportunity to model the expected impact of the program and to use this model to explore different policy alternatives.

Our dynamic hypothesis is that the colorectal screening program will increase costs, but detection and removal of pre-cancerous polyps will inhibit progression of the disease to morbidity and death, thereby improving quality of life and reducing the need for late-stage treatment. As public awareness of the benefits of colorectal screening increases, utilization of the program will increase over time.

The basic structure of the model is a disease progression chain, similar to the diabetes disease chain described in Jones *et al.*, with patients progressing through the various stages of colorectal cancer as shown in Figure 4. We assume two population classes: Average Risk and High Risk. Clinicians typically classify patients as "high risk" based on factors such as family history, hereditary conditions, and some previous medical conditions. The risk and initiation rate of pre-cancerous polyps is assumed to be higher in the high risk group, but cancer progression is assumed to be the same in both groups. We understand this assumption to be valid for 90% of cases.

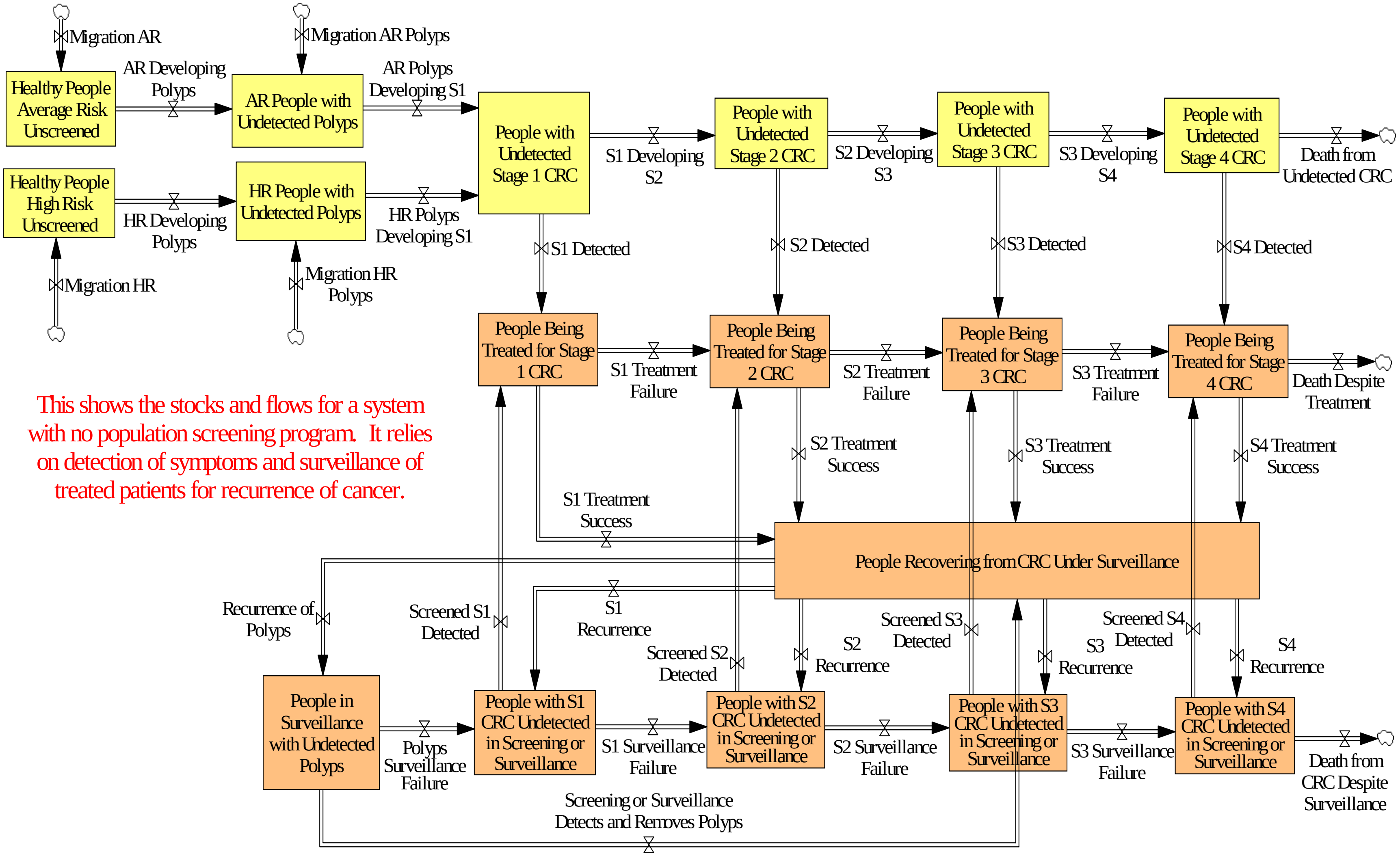
Figure 4: Colorectal Cancer Disease Progression



To the model in Figure 4 we can add the stocks and flows representing the progression of patients through different stages of treatment, depending on the stage of advancement of the disease when it is detected. This extended model, shown in Figure 5, assumes that if the treatment is successful, and people recover, then they remain under surveillance for recurrence of the cancer. Arguably, the system shown in Figure 5 is a crude model of the real system as it exists in Alberta today, ignoring the limited amount of proactive screening being carried out.

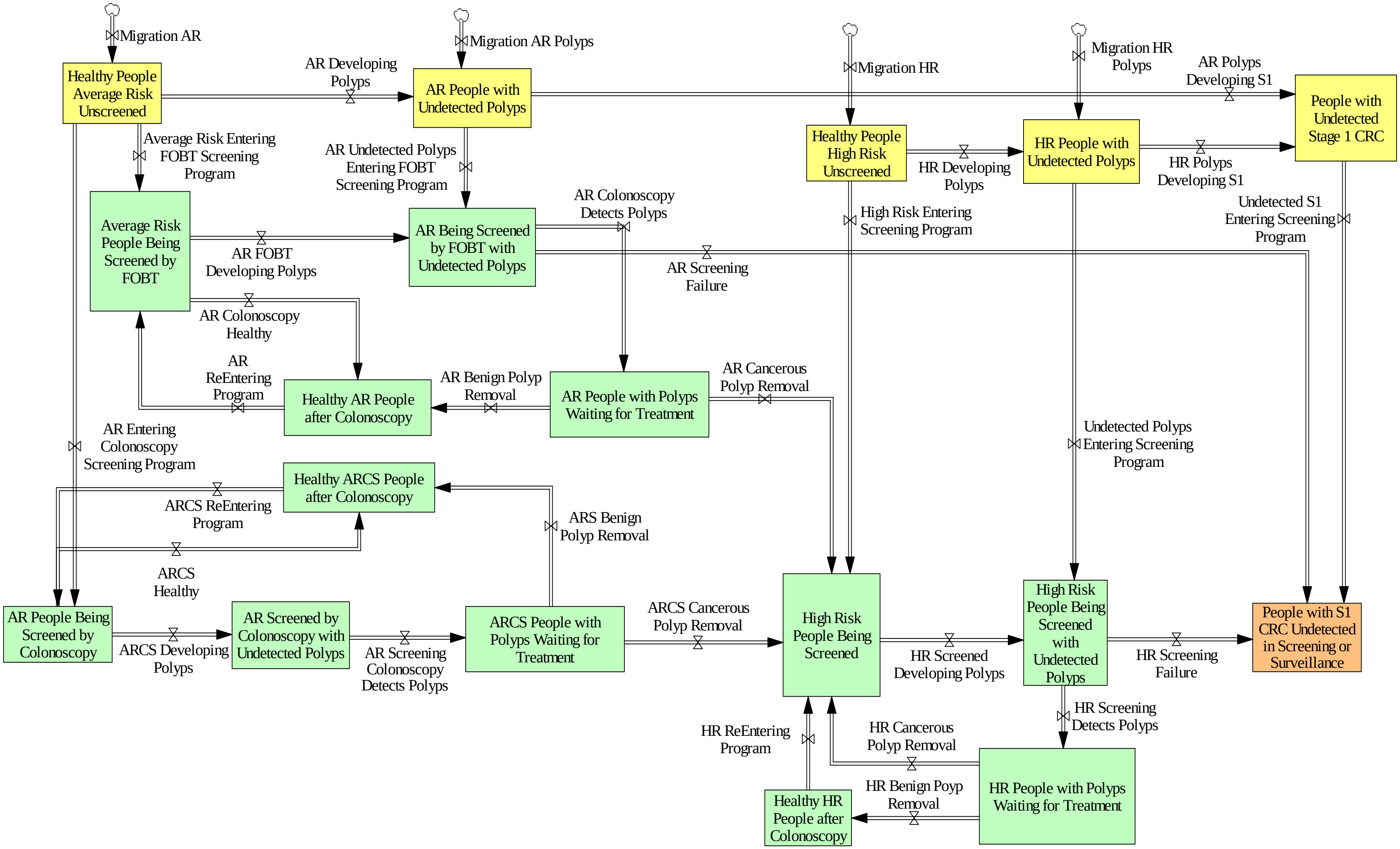
In Figure 6 we model the stock and flow structure of the proposed screening program. The screening program for people with average risk involves a Fecal Occult Blood Test (FOBT) every year. People at high risk of colorectal cancer, about 20% of the population, will enter a colonoscopy screening program. Our model allows for the possibility that some average risk (AR) people will elect to have screening colonoscopies. For example, we assume that people will leave the stock of Healthy People Average Risk Unscreened and enter either a stock of Average Risk People Being Screened by FOBT or AR People Being Screened by Colonoscopy.

Figure 5: Colorectal Cancer Progression and Treatment



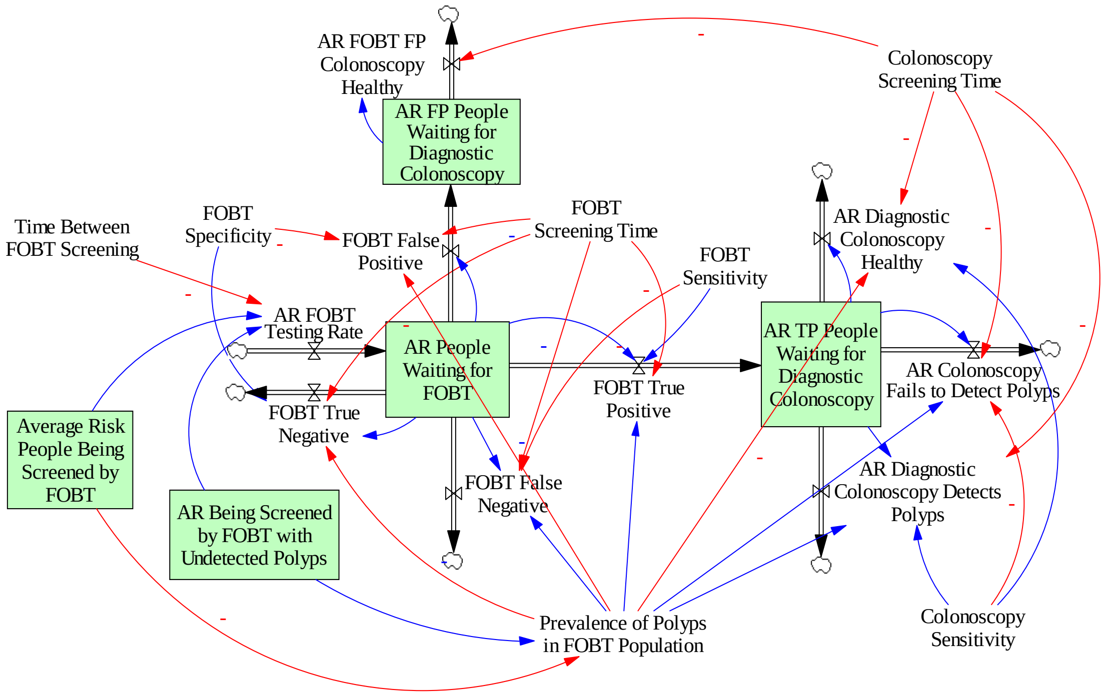
This shows the stocks and flows for a system with no population screening program. It relies on detection of symptoms and surveillance of treated patients for recurrence of cancer.

Figure 6: Colorectal Cancer Screening



Our model assumes that colonoscopy capacity is expanded to cope with increased "positives," including "false positives" from the FOBT primary screening tool. The colonoscopy test is more accurate, and it is expected that FOBT testing will recommence after 10 years for healthy people with average risk who have been declared healthy after completion of this test. If a colonoscopy reveals the presence of pre-cancerous polyps, these can be surgically removed at the time of the colonoscopy. The model assumes that these people will move into the high risk group and continue to be screened by colonoscopy. The screening test for each of the three groups of people (AR, HR and AR electing colonoscopy) is modeled by a co-flow structure. For example, the structure of the screening model for average risk people is shown in Figure 7.

Figure 7: Screening Model for Average Risk (AR) People



Figures 5 and 6 together represent the integrated disease progression, treatment and screening model. We currently have a working prototype and are continuing to refine this model. For example, we intend to add a population model so that age-varying parameters and risk factors can be included. This enhancement will also allow us to model high risk people in the screening program receiving first colonoscopies at an earlier age. Another possible enhancement is to have more than one group of *High Risk People Being Screened* – for example, smaller or "low risk" adenomas would lead to repeat colonoscopies every 1-3 years, whereas higher grade adenomas would lead to repeat colonoscopies every 0.5-1 year. The value of such enhancements can only be assessed by knowledgeable clinicians. Thus, while model enhancements will continue, we expect that the focus of our work will now switch from model building to model testing, data gathering, and model validation with a wider audience of system experts.

Conclusions

We have made a promising start to introducing systems thinking and system dynamics modeling to the Calgary Health Region and to the Alberta Cancer Board. Already we are seeing benefits in terms of promoting discussion of system relationships in the two projects currently underway. The perceived success of these projects will play a major role in whether or not the system dynamics methodology will gain traction among health care strategic planners in Alberta over the next few years.

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