



Investigating interventions for increasing colorectal cancer screening: Insights from a simulation model

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ABSTRACT

We develop a discrete-event-continuous simulation model of colorectal cancer screening in North Carolina to examine the impact of six different interventions on the fraction of eligible patients receiving the clinically recommended screening. We find that demand side interventions alone are less effective than using only supply side interventions or a combination of both; the single most effective intervention is implementing a patient reminder system to reduce the number of no-show patients; and that all interventions studied are subject to significant diminishing returns.

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1. Introduction

Colorectal cancer (CRC), commonly referred to as colon cancer, has a major impact on the US population [1]. Although colon cancer is often fatal, it can be prevented by early detection through screening, and it is estimated that tens of thousands of lives could be saved through proper screening and treatment [17]. Increased use of CRC screening is believed to be a major reason for the decline in the number of colon cancer deaths in the US over the past 15 to 25 years [17]. However, the screening level – the fraction of the eligible population actually receiving screening – remains below desired levels, since it is estimated that only 40% of colon cancers are detected at an early stage [20].

A number of barriers to colon cancer screening have been identified by health services researchers [1,18], including lack of awareness, lack of health insurance, general healthcare costs, inadequate healthcare delivery, fear and other emotional barriers, a low level of education, and lack of communication between healthcare providers and patients. Not only does each of these barriers have its own role in hindering access to colon cancer screening and care, but mutually reinforcing interactions between these barriers can create additional difficulty in accessing colon cancer prevention, detection, and care.

Barriers to colon cancer screening can be broadly classified into two categories. *Supply side* barriers, such as lack of screening capacity and the distance a patient must travel for screening, limit the availability of screening to members of the public who are actively seeking it [24]. *Demand side* barriers, on the other hand, prevent patients who should be screened from seeking screening. Lack of communication between patients and providers, fear, and lack of awareness are examples of demand side barriers.

We develop a combined discrete-event continuous system dynamics model of the CRC screening system in North Carolina that can be used to examine the impact of different interventions on the population screening level. The model combines continuous time representations of fast moving phenomena such as population growth with discrete events representing phenomena occurring at much longer time intervals, such as the installation of new screening facilities.

This type of systems dynamics modeling in healthcare is not novel; there have been a variety of other studies which model system wide performance. Ref. [15] gives a good introductory reference for the use of systems dynamics in healthcare, while ref. [9] discusses a variety of system dynamics models of healthcare delivery systems in Europe. Ref. [2] describes a system dynamics model of a city-wide emergency care system. Some of the chronic diseases modeled in healthcare using systems dynamics are breast cancer screening [13], chlamydia control and prevention [12], and mental health treatment [22]. This paper follows the widely accepted approach of modeling a complex healthcare system via

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systems dynamics, and then experimenting on the model to derive insights into the effects of different policy interventions.

Data for the model comes from state-wide information in North Carolina and numerous federal sources. The system dynamics approach allows us to model many different aspects of the CRC screening system and their interactions while maintaining a flexible framework for inexpensive experimentation.

Our paper addresses the following questions:

1. What interventions will lead to meaningful increases in the final screening level?
2. Which of these interventions are most effective when employed individually? What are the limitations of each intervention when employed alone?
3. What is the nature of the interactions between interventions – which are mutually reinforcing, or mutually inhibiting?

In the next section we present the modeling methodology used to address these questions. We then describe the experiments carried out with the model, and discuss the policy implications of the results.

2. Modeling approach

The methodology in this paper can be summarized as follows:

1. Model the CRC screening system as a system of stocks and flows;
2. Identify factors affecting the screening rate;
3. Identify and model potential interventions to increase the screening level;
4. Verify and validate the model; and
5. Analyze interventions with emphasis on their interactions.

Although the description implies that each stage is investigated serially, there was considerable iteration between stages as new information became available. Details of each step are given below.

2.1. Modeling the CRC screening system using stocks and flows

The continuous or system dynamics portion of our model is best described as a system of interlinked linear differential equations, representing a network of stocks and the flows between them as shown in Fig. 1. The equations are given in detail in Appendices A and B. There are some discrete elements that model events occurring on a significantly longer time scale which we describe in more detail in Section 2.4. While the simulation model is best described as a continuous-discrete hybrid, the continuous elements constitute the dominant components of the model. The primary quantity of interest is the fraction of North Carolina adults aged between 50–75 years who receive the clinically recommended screening for CRC, given by the ratio of the screened population to the total population presented in Fig. 1. Current clinical guidelines [26] recommend that these adults be screened via colonoscopy once every 10 years beginning at age 50, assuming there is no family history or other concerns. Thus the focus of the model is the evolution of the size of this population over time in response to different interventions. This evolution is addressed by considering changes in the population over very short time intervals, which in our case is a day. The different interventions change the values of auxiliary variables that affect the rate at which individuals flow into and out of the screened population through the inflows and outflows represented in Fig. 1. These flows can be summarized as follows:

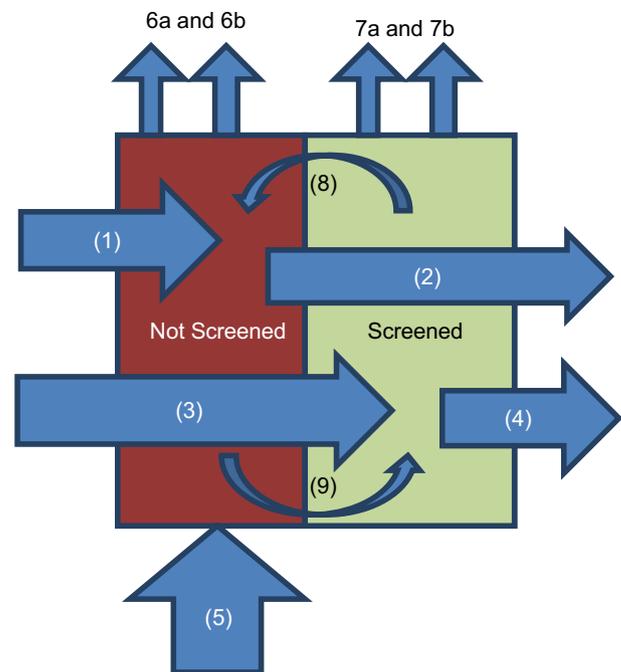


Fig. 1. Tank model of CRC screening levels.

- Flows 1 and 3 represent daily immigration into the screened and unscreened populations from outside the state; we assume that the mix of screened and unscreened individuals in the daily immigration is the same as that in the general state population.
- Flows 2 and 4 represent emigration from each population out of the state; again we assume that the mix of screened and unscreened individuals matches that of the general population.
- Flow 5 denotes the rate at which persons enter the target age group (50–75 years of age) due to aging. We assume these new entrants have not been screened, so they enter the unscreened population.
- Flows 6a and 7a represent the rates at which people leave the target populations because they exceed the upper age limit of 75 years. We again assume that the distribution of screened and unscreened individuals follows that in the general population.
- Flows 6b and 7b represent the rates at which people exit the target age group due to death from any cause. These can be combined with (6a) and (7a) for their respective populations.
- Flow 8 denotes the rate at which the screening an individual has received “expires” due to the passing of more than ten years, causing them to move from the screened to the unscreened population.
- Flow 9 represents the rate at which people get screened, which is the primary focus of the model and is elaborated on in more detail below.

Our model assumes that all populations are homogeneously mixed in status with respect to age, clinical history, and other relevant factors. This assumption may be a cause for concern, but is made for two reasons. First, reliable data at the level of detail needed to model subcategories based on age and past history were not available. Second, modeling subpopulations based on age and history would require significantly more complex modeling structures, complicating both the structure of the model and the analysis of its results, without adding much benefit given the limited data availability.

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