AGENT BASED MODELING AND SYSTEM DYNAMICS IN HEALTHCARE
Modeling Two Stage Preventive Medical Checkup Systems

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Abstract: Modeling preventive medical checkup systems (PMCS) is an important part of predicting future healthcare coverage. In this paper we show how to model a two stage interdependent System as it applies to basic cancer prevention. Starting with a short introduction of the two used modeling techniques we show the basic principle of the preventive cancer checkup process (PCCP) and how it was modeled with these opposing approaches. We then extract the key benefits from each technique and also their shortcomings when applying it onto the PCCP. Furthermore we show at what level of detail which method should be used to gain the most valuable insight into those complex checkup systems.

1 INTRODUCTION

In medical science, especially health care, computer simulation is still a relatively young field. In contrast to that social sciences use computer simulation as a well-established domain of research, to gain insight to a system and make predictions for the future. Troitzsch (1997) divided prediction into two parts: (1) qualitative prediction, which is prediction of behavior modes, and (2) quantitative prediction, which is to predict a certain system state in timeline. Currently there are two major schools, System Dynamics and Agent Based Modeling, which use computer simulation to gain insight into non-linear social and socio-economic systems (Milling and Schieritz, 2003). Both approaches have a broad overlap in research topics, but have been quite unnoticed by each other. (Phelan, 1999)

There are only a few publications about health care systems concerning prevention frameworks. The health care system itself is complex and large and it is quite hard to understand all the dependencies and influences in this system. Because of the constantly growing demand for preventive cancer checkups the main purpose of this paper is to show how to model those systems with both approaches.

Western industrial countries are facing an over aging of their population. This makes it necessary to model future health care scenarios to get valid answers to problems arising from these systems because media seems to continuously bombard us with one horror scenario of health care issues after the other. For example the amount of people in Austria above the age of 60 will grow till 2030 by 54% although the whole population will just grow by 8% (Statistik Austria, 2007). Is this significant increase in older people an indication requiring 50% more medical specialists to cope the demand of preventive medical checkup in this age group? This is just one pressing question concerning preventive medical checkups for the future. In this paper we will discuss the main modeling differences of the two approaches based on the preventive cancer checkup process (PCCP) and give a first short answer to the question above.

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1.1 The System Dynamics Approach

System Dynamics is an approach that has been developed by Jay W. Forrester, an electrical engineer, in the mid 1950s and was originally called Industrial Dynamics since the initial applications, which he described in the book of the same title, were all in private industry (Forrester, 1961). Later works focused on urban dynamics (Forrester, 1969) and on social systems, with the probably most popular publication "Limits to growth". (Meadows et al). In 1983 the International System Dynamics Society (SDS) has been established, and within it a special interest group on health issues was organized in 2003 (Homer and Hirsch, 2006). Although many papers dealing with health care systems have been published, in a variety of journals worldwide, since then very few of them focused on prevention frameworks. (Koelling and Schwandt, 2005)

The basic concept behind System Dynamics is that the complex behaviors of organizational and social systems are the result of both reinforcing and balancing feedback mechanisms. The central observation point when modeling a system in SD is to describe its feedback loops, which consist of the real-world processes, called stocks, and the flows between these stocks. These generated computerized models can then be used to test alternative scenarios and policies in a systematic way to answer both "what if" and "why" questions. (Borshchev and Filippov, 2004), (Sterman, 2001).

1.2 The Agent Based Modeling Approach

Agent Based Modeling (ABM) is a relatively new computational modeling paradigm. Although it had been developed in the late 1940s, it did not become widespread until the 1990s, because compared to SD significantly more computational power is required. The increase of available and powerful computational resources in the last years and the inherent parallel nature of ABM approaches contributed to their popularity. There are three different fields of research for ABM: (1) artificial intelligence, (2) object oriented programming and concurrent object-based systems, and (3) human-computer interface design (Jennings and Wooldridge, 1998). The concept of agents can be tracked through many different disciplines, but using agents on designing simulation models is mainly applied in complexity science and game theory (Milling and Schieritz, 2003). In contrast to SD there is no universally accepted definition of ABM and this makes it much more difficult to identify the basic concept and assumptions underlying this paradigm. An Agent is basically an independent component that has individual rules and is able to interact with its environment or not. The behavior can range from primitive reactive decision rules to complex adaptive intelligence (Macal and North, 2005). The global System behavior emerges as a result of the agents following their rules and doesn't need to be known at the beginning of the modeling session.

That's why ABM is often called bottom-up modeling (Borshchev and Filippov, 2004). Agent Based Modeling is used in a wide range in medical health care but mostly to simulate patient scheduling and workflow management (Nealon and Moreno, 2004). Estimating the medical demand of equipment and specialists for the future is quite a new area for ABM.

1.3 Short Comparison of the Approaches

To characterize both approaches, the major differences are summarized in Table 1 and described below (Milling and Schieritz, 2003) (Stotz and Größler, 2004).

Table 1: System Dynamics versus Agent Based Modeling.

	System Dynamics	Agent Based Modeling
Basic building Block	Feedback loop	Agents
Level of modeling	Macro	Micro
Mathematical formulation	Differential equations	Logic, Differential equations
Perspective	Top-down	Bottom-up
Unit of analysis	Structure	Rules

The core building blocks:
The main behavior of a System Dynamics model is generated by its interacting feedback loops that consist of Stocks and Flows. In Agent Based Models the behavior emerges from the interaction rules of the Agents. These elements can therefore be considered as the basic building blocks of their approaches.

Level of modeling:
In macro simulations, individuals are viewed as a structure that can be characterized by a number of variables, whereas in micro simulations the structure

is viewed as emergent from the rules and the interacting individuals. (Davidson, 2002)

Mathematical formulation:
The basic principle behind SD is to couple non-linear first-order differential equations. This is done by Levels that accumulate the difference between the Flows (in- and outflows). In ABM there are many diverse methodologies from logic-based to emergent equations and that's why no universally accepted formalism for the mathematical description of a model exists. (Milling and Schieritz, 2003)

Perspective:
In SD the structure of the basic system phenomenon is modeled and in ABM this evolves in the simulation.

Unit of analysis:
SD models behavior is determined by the structure that is fix and has to be defined before simulation. In ABM the focus lies on the rules an agent obeys to, to interact with other ones.

2 THE BASIC PREVENTIVE CANCER CHECKUP PROCESS (PCCP)

Modern preventive cancer checkups can diagnose cancer risks at a very early stage making necessary treatment easier, more effective, and more efficient. Most of the common malignant diseases, if detected in an early stage, can successfully be cured, due to tremendous progress in treatment possibilities. That's why regular checkups can prolong a healthy life.

The basic preventive cancer checkup process that is shown in Figure 1 can be applied to all of the malignant diseases for example (colon cancer, prostate cancer, gynecological tumors, skin tumors, etc.). There is always a risk group in a population, normally being addressed by age and gender. This group can then be divided into two parts (percentage R1 and R2): the ones that will never go to a preventive medical checkup and the other ones that go to a preventive medical checkup at least once in their lifetime after entering the specific risk group. Once entering the prevention path there will be a medical checkup. If an indication for the specific cancer is found during the checkup an intervention will be performed and the patient will be send back to regular preventive medical checkup after some years (indicated by X2). If no indication is detected the patient will also be sent back to regular preventive medical checkup after some years (indicated by X1). Once being in the prevention cycle the normal mortality for the specific cancer will decreases with a given percentage (indicated by PI). The basic PCCP will now be applied onto the colon carcinoma one of the most common cancer type of men and women.

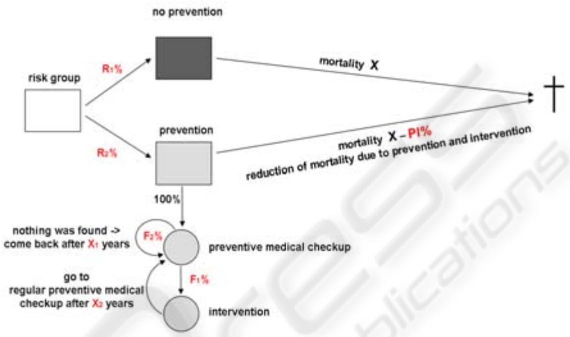

Figure 1: Basic principle of a preventive cancer checkup process (PCCP).

To demonstrate both principles we assumed the following standard values, taken from literature (Citarda et al. 2000) (Barclay et al. 1993) (Barclay et al. 2006) for the colon carcinoma prevention:

Table 2: System parameters for simulating a preventive cancer checkup process (PCCP).

R1	R2	F1	F2	X1	X2	PI	X
60 %	40%	10%	90%	7	3	80%	0,45 $* 10^{-3}$

With this given values the average year a patient comes to the preventive medical checkup is 6.6 according to equation (1).

$$\text{average year} = X1 * F2 + X2 * F1 \qquad (1)$$

2.1 Modeling PCCP with System Dynamics

Based on the basic PCCP process we designed a first Causal Loop Diagram (CLD) of the system and simulated it in Powersim Studio 2005. We split up populations age groups into those within the risk group and those outside. Because of the intuitive user Interface of Powersim the model was quickly built but the output did not quite match real systems data because SD averaged all the Stocks representing the age groups. Population distributions in Western industrial countries are more like bulbs or apples than rectangles and because of the two world wars and the baby boom generation Austria's population distribution has two abnormal spikes. And these two spikes are completely filtered in the standard SD model.

So we split up the age groups into one year groups and added both prevention cycles to the simulation to get a more detailed output. A simplified version of the extended basic Causal Loop Diagram (CLD) is shown in Figure 2.

The implemented model now was an "Array Model" with all the different probabilities for each group and the output was qualitatively quite near to real data.

To look at the consequences of another cancer prevention model, for example prostate cancer, we added a second cycle for this disease. This was really a challenging problem because of the arrays and global death rates and at the end we weren't able to complete it because of cyclic references. Both prevention models affect the death rate of the population and are also affected by this rate. When you think in stock and flows you get cyclic references between these rates. Our basic SD model can only capture the qualitative behavior well but lacks realistic quantitative output. The extended model is able to produce a realistic quantitative output but is due to the specialization not able to handle more than one prevention model.

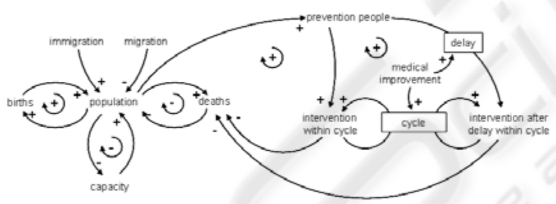

Figure 2: Extended basic Causal Loop Diagram (CLD).

2.2 Modeling PCCP with Agent based Modeling

In the ABM solution we first had to decide what defines an agent to produce an output like the real data. So we decided to model an agent with the basic attributes like number, age and gender and some medical attributes we needed for the preventive checkup process as shown in Figure 3. In this first solution we modeled non interacting agents, because it was not necessary for the concerning question.

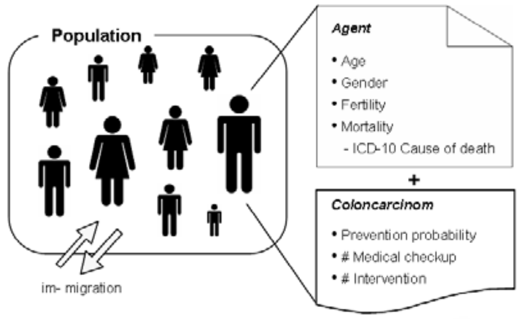

Figure 3: Population of agents with migration effects.

Before implementing the PCCP into our agent framework we had to calibrate our agents to build up a population that was quite similar to the real one in each age group. That's why we had to add immigration, migration and fertility data to each agent. In this case we took statistical data rates from the past decades and added them to the framework. This data can now be loaded from several input files into the framework. Furthermore this attributes can be changed in time to get a similar characteristic as data from the past. Mortality is divided into the main parts of the ICD-10 (International Classification of Diseases endorsed by the WHO in 1990) code and can also be changed in time. Due to this classification the framework is able to handle all different types of classified diseases. To add a specific prevention model one first has to define the ICD-10 category it belongs to and then add the needed attributes to an agent. In our case this new "disease data sheet" that is connected to an agent contains the number of performed interventions, the waiting period till next check is performed, the new death probability, and so forth. Depending on the input data that is linked to the agents they act on probabilities each simulation period. Because this paper is about how to model a PCCP and not about the whole ABM framework we will not go into deep detail this time.

Since we are looking for population effects the number of agents that make up this population has to be sufficiently high. There is obviously a tradeoff between accuracy and computational effort. Agent Based simulation can be seen as a numerical solver to Dynamic System's system of differential equations. The more agents the smoother is the integration.

In the following we will show the first results from the ABM model to illustrate the great level of detail our framework is able to handle. We used 1.5

million agents and 50 simulation runs to get a robust estimate of mean and standard deviation.

The output for the PCCP with the given values for the colon carcinoma was really astonishing for us and is shown in the Figures 3 and 4. Although more people are entering than leaving the risk group the demand for preventive checkup will not grow when we assume that the same percentage of people as today will go to checkup in the future. This is because most of the demand is already generated by the people in this two stage cycle. The demand will not grow until the prevention percentage is set up to more than 60% and this is in fact a relatively unrealistic scenario for the future. In Figure 4 we see the absolute difference of people dieing from colon cancer per year. The absolute amount of people that could be saved due to more preventive checkups will not dramatically fall just by doing 55% more of these checkups. This output is really crucial when we think about investing more money in these preventive checkups or advertisement to increase the amount of people going to cancer prevention.

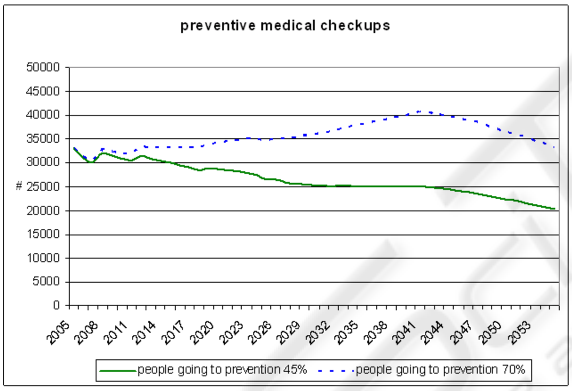

Figure 4: ABM-Framework output for the PCCP, showing medical checkups as a consequence of different policies.

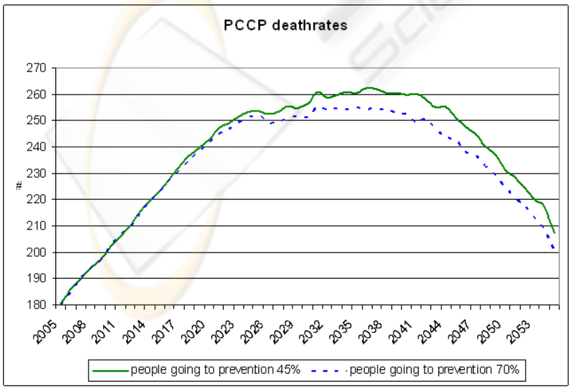

Figure 5: ABM-Framework output for the PCCP, showing PCCP death rates as a consequence of different policies.

3 DISCUSSION

During our modeling sessions we were able to produce the needed output data with both modeling techniques. Building a SD model with realistic real life behavior was really a hard challenge, because of the averaging effect within stocks. Despite all difficulties we found a solution by transferring the initial model into an "Array Model". Due to the specialization of this model it is not possible to simulate more than one PCCP as mentioned above. That's why we had to switch the modeling approach to implement the given PCCP with ABM. After defining the attributes and rules of an agent we implemented our own arbitrary extendable framework. Because of the astonishing answers for the future demand in specialists for colon carcinoma the framework will now be object of further research. Integrating more cancer prevention models, interactions between the agents like transmissibility of diseases, word of mouth advertising for preventive medical checkup, are just a few work packages for the future.

In general both techniques can not be differentiated just by modeling size because both are capable to model small and large-scale systems. They can rather be classified by the problem or perspective and the required output information. One fact that should be considered when deciding for one technique is that with today's modeling tools it is much more complicated to implement a solution in an ABM Framework, when you are not experienced in programming, than implementing a model in one of the intuitive graphic oriented SD tools. Quantifying the parameters of a model is the main difficulty both approaches have in common. In ABM it is tough defining the rules for the agent's behavior and their attributes and in SD it is sometimes quite hard to quantify or find the correlation function between the connections of variables. In contrast to SD ABM allows increasing the level of detail as long as relevant data is available but will not work when this required data does not exist at that level of detail. The next factors to be concerned with are computational effort, memory management, and simulation time. SD provides the output within a few runs lasting only seconds depending on the method that is used to solve the differential equations. When trying to solve the same problem with agents one first has to define the width of the confidence interval and then calculate the needed runs to hit that spread. The simulation time with our model in SD is just a few seconds on an ordinary office computer and there is no need to worry about memory management contrary to our ABM solution.

In general picking one or the other modeling approach depends on the system to be simulated. There are lots of applications where it is much easier and efficient to solve given problems with SD but if you want to capture more realistic real-life phenomena you have to choose the ABM approach. A general decision for one of the two techniques always deals with a trade-off between efficiency and significance.

4 CONCLUSIONS

As we could see from our simulation System Dynamics is useful to model the basic system's behavior. With the causal loop diagram SD provides a powerful tool for modeling, to describe a model and its interactions. Combined with Vesters sensitivity analysis (Vester, 2005) one can easily extract the different kinds of elements in the system (active, reactive, buffering, critical, and neutral) to make steering actions more efficient. A substantial advantage of SD is the big number of available Simulation Software and their intuitive and easy use, when needing quick answers about a systems behavior. Generating realistic quantitative output data was quite a challenging problem with SD and we could just manage it by transferring the original model into an "Array Model" but due to the specialization of this model it is not able to cope with more details or other preventive checkups and therefore we had to switch the modeling approach to ABM.

The ABM approach took much more time to implement, but now agents, the primary building block, can easily be extended with more and more details. That is why the ABM approach and our framework can get beyond the limits of SD, especially when the system contains active objects. However it is difficult to decide on attributes and rules of agents in order to get a behavior that is sufficiently similar to the real system and it is much more difficult to get all the data at the needed level of detail for the simulation than just modeling the structure of the system which is where SD ends. Memory management restrictions still become a big issue for the future of our framework when simulating with millions of agents as we experienced it in our simulation.

With the existing framework we are now able to answer questions for the future demand of several preventive checkup systems and we will extend the model as mentioned above to address more crucial questions concerning futures healthcare management.

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