A METHODOLOGY FOR ENGAGING MODELING AND SIMULATION TO ASSESS A COROLLARY PROBLEM TO THE OBESITY EPIDEMIC

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ABSTRACT
This paper discusses obesity as a persistent and pervasive epidemic that could easily outpace the medical community's ability to treat its broadening ill-effects. The current approaches to mitigating the epidemic are aimed at changing patient behavior, which is lengthy in duration and dependent upon numerous actors. This paper reframes the problem and medical challenges of caring for this increasing population by juxtaposing patient need with the medical capacity to provide adequate care. Modeling and simulation is engaged, via agent-based modeling and system dynamics, to assess the impact of obesity on both the patient and the medical community. Conclusions are drawn from the simulations of these parallel communities that can serve to mitigate a near-future shortfall of medical providers and patient care.

1. INTRODUCTION

The Obesity Epidemic is confronting public health as a challenge that must be addressed. Like all epidemics obesity has abruptly revealed itself by expanding its human boundaries to afflict segments of the population who had just decades ago been relatively unaffected. A 2007-2008 report by the Centers for Disease Control and Prevention (CDC) showed that obesity is a concern for all ages in the United States. The study examined data from Hispanic, White, and Black races, male and female, noting respectively that 45%, 35%, and 55% female populations are obese; and 37%, 33%, and 38% male populations are obese (Overweight Children 2011). The stark results of the CDC study make clear that the obesity epidemic is experiencing exponential increases in patient numbers. As an epidemic obesity is persistent and pervasive; it could easily outpace the medical community's ability to treat its broadening ill-effects. The current approaches to mitigating the epidemic are aimed at changing patient behavior, an approach that is both lengthy in duration, perhaps generational, and dependent upon numerous actors that include a broader patient community as well as the patient him or herself. Assessing patient need juxtaposed to medical capacity serves as a starting point to ensuring medical capacity to provide adequate care during this epidemic.

This paper discusses obesity as an ongoing threat to the health of the patient and the resources of the medical community. It then makes the case for engaging modeling and simulation as an effective means of assessing the impact of obesity on both the patient and the medical community. Part 2 offers a cursory look at obesity data and the current US governmental efforts to addressing the problem. Part 3 explains why and how modeling and simulation can be used to provide a meaningful assessment. Part 4 provides a use-case and Part 5 presents concluding comments.

2. THE ONSLAUGHT OF OBESITY

Obesity is a national epidemic which is resulting in higher medical costs and a lower quality of life for the patient. Obesity is the result of excess body fat and it is determined by body mass index, or BMI, which is calculated from height and weight. BMI greater than or equal to 30 categorizes the patient as obese.

The widely known facts . . . in the US more than 33% adults (over 72 million) and 17% children are obese. From 1980 through 2008 obesity rates doubled for adults and tripled for children. During the past decades obesity rates for all population groups—regardless of age, gender, race, ethnicity, socioeconomic status, education level, or geographic region—have increased markedly. The overall medical costs of adult obesity have been estimated at $147 billion in 2008. Moreover, obese adults had medical costs that were $1,429 higher than medical costs for people of normal body weight. Obesity also has been linked with reduced worker productivity and chronic absence from work. The data found in Table

1 suggests that the health care requirements of states will vary by virtue of the differing population dynamics of the states. There are also significant obesity and health disparities among sub-populations.

Table 1 – Centers for Disease Control Obesity Rates by State for 2010 (body mass index – BMI - ≥30 based on self-reported weight and height)

State	%	State	%
Alabama	32.2	Montana	23.0
Alaska	24.5	Nebraska	26.9
Arizona	24.3	Nevada	22.4
Arkansas	30.1	New Hampshire	25.0
California	24.0	New Jersey	23.8
Colorado	21.0	New Mexico	25.1
Connecticut	22.5	New York	23.9
Delaware	28.0	North Carolina	27.8
Washington DC	22.2	North Dakota	27.2
Florida	26.6	Ohio	29.2
Georgia	29.6	Oklahoma	30.4
Hawaii	22.7	Oregon	26.8
Idaho	26.5	Pennsylvania	28.6
Illinois	28.2	Rhode Island	25.5
Indiana	29.6	South Carolina	31.5
Iowa	28.4	South Dakota	27.3
Kansas	29.4	Tennessee	30.8
Kentucky	31.3	Texas	31.0
Louisiana	31.0	Utah	22.5
Maine	26.8	Vermont	23.2
Maryland	27.1	Virginia	26.0
Massachusetts	23.0	Washington	25.5
Michigan	30.9	West Virginia	32.5
Minnesota	24.8	Wisconsin	26.3
Mississippi	34.0	Wyoming	25.1
Missouri	30.5		

Data from the National Health and Nutrition Examinations Survey (2005-2008) indicates that 51% of non-Hispanic black women aged 20 years or older were obese, compared with 43% of Mexican Americans and 33% of whites. Among females aged 12–19 years, 24% of non-Hispanic blacks, 19% of Mexican Americans, and 14% of whites were obese (Examination Survey 2011).

A 2009 study on the annual medical spending attributable to obesity compared 1998 data in which the medical costs of obesity were estimated to be as high as $78.5 billion, with roughly half financed by Medicare and Medicaid (Medicaid and Medicare are two governmental programs that provide medical and health-related services to specific groups of people in the United States. Medicare is a social insurance program that serves over 44 million enrollees as of 2008. Medicaid is a social welfare social protection program that serves over 40 million people (Finkelstei200). The study then estimated the cost of obesity in the US across Medicare, Medicaid, and private insurers as payers, distinguishing for in-patient, non-inpatient, and prescription drug spending. The study determined that the increased prevalence of obesity was responsible for almost $40 billion of increased medical spending through 2006 (including $7 billion in Medicare prescription drug costs) projecting that the medical costs of obesity could have risen to $147 billion per year by 2008.

One of the most serious costs, both medically and financially, is the early onset of diabetes as a result of obesity. The prevalence of diabetes in the US is reaching 17.5 million and it is continuing to rise (Figure 1).

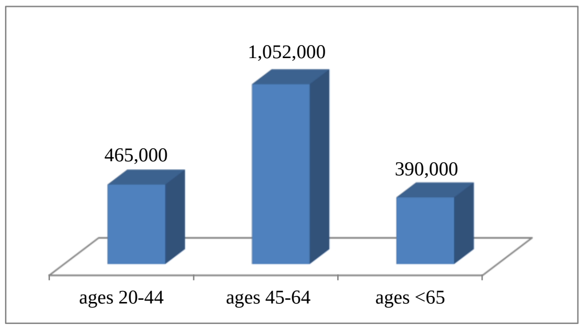

Figure 1 – Statistics from the National Health Interview Survey of New Cases of Diagnosed Diabetes per age range 2010 (Health Interview Survey, 2009).

A 2008 study set out to quantify the economic burden of diabetes caused by increased health resource use and lost productivity by detailing these costs as attributable to diabetes (American Diabetes Association 2008). The findings totaled an estimated cost of diabetes in 2007 of $174 billion, including $116 billion in excess medical expenditures and $58 billion in reduced national productivity. These medical costs included $27 billion to directly treat diabetes, $58 billion to treat the portion of diabetes-related chronic complications that are attributed to diabetes, and $31 billon in excess general medical costs. The largest components of medical expenditures attributed to diabetes are hospital in-patient care (50% of total cost), diabetes medication and supplies (12%), retail prescriptions to treat complications of diabetes (11%), and physician office visits (9%). In short, the study determined that for the cost categories analyzed, approximately $1 in $5 health care dollars in the US is spent caring for someone with diagnosed diabetes, while approximately $1 in $10 healthcare dollars is attributed to diabetes. (Significantly, this study did not include in its analysis expenditure categories such as health care system administrative costs, over-the-counter medications, clinician training programs, and research and infrastructure development.)

2.1 Government Efforts to Manage Obesity

There are a number of government sponsored programs aimed at managing and eventually reversing the obesity epidemic with various levels of financial support: federal, state, local, and the individual (Signs 2001). With a cursory review of what is recommended among these approaches to mitigating the obesity epidemic, one can draw the following conclusions: there are numerous actors, numerous entities, and unrealistic expectations that this change can occur without more stringent requirements and that it can occur in time to head off the full-scale effects of the epidemic on healthcare as a whole. The numerous actors and entities include the individual patient; specific to children are the parents, caregivers, school administrations, local institutions that provide foods. A prominent US government strategy is the *Let's Move* program introduced by First Lady Michelle Obama. As it states in its mission, "this program seeks to eliminate childhood obesity within a generation." Its main points of action are:

- ✓ empowering parents and caregivers
- ✓ providing healthy food in schools
- ✓ access to healthy, affordable foods
- ✓ increasing physical activity

Inferred in this agenda is the need for all to participate in the outlined program, *i.e.*, if one fails the entire program can fail because children as patients are dependent on the other actors and entities. The program also sets a goal of eliminating childhood obesity in one generation, which is approximately 22-25 years. Juxtaposed to that goal is the data revealing what has happened to childhood obesity in less than one generation. Significantly, in just two years (2001/2002 to 2002/2003) the percentage of overweight young people ages 2 to 5 rose from approximately 10% of the population to 14%. In five years (1999-2004) the number of obese young people ages 6 to11 increased from 15% to 19%. Those ages 12 to19 increased from 10% to 14% of that population.

Regarding the urgency of adult obesity, these rates doubled for adults and tripled for children for all population groups regardless of age, sex, race, ethnicity, socio-economic status, education level, or geographic region. In 2010, not one state had a prevalence of obesity less than 20%. Thirty-five states had prevalence equal to or greater than 25%; twelve of these states (Alabama, Arkansas, Kentucky, Louisiana, Michigan, Mississippi, Missouri, Oklahoma, South Carolina, Tennessee, Texas, and West Virginia) had a prevalence of obesity equal to or greater than 30% as shown in Table 1 (Stop Childhood Obesity 2011).

This data clearly indicates the outsized implications associated with the increasing number among the obese population. Significantly, the time sequence – less than one generation – indicates the speed in which the epidemic is expanding its reaches among all age groups. It is not reasonable to think that federal programs aimed at behavior change will see their hoped-for results in one generation and undo obesity's effects across the age groups. Programs at the state and local level reflect the same unrealistic expectations.

As such, this cursory review of the approach employed by government programs are employing is not to critique the behavioral / policy and environmental change to curtailing the obesity epidemic, but to note how the obesity epidemic is being addressed and if there are other aspects of the epidemic that need to be assessed. These programs foster behavioral and environmental change *i.e.*, seeking to change patient behavior and improve patient environment be it home, school, and food availability. Significantly, none of the programs aimed at behavioral and environmental change consider a prominent component of managing the obesity epidemic: the medical community. Thus, the purpose of this study is to reframe the problem by analyzing the increasing number of obese patients and the medical community's ability to provide healthcare during the administration of the behavioral and environmental approach programs. To do this a simulation analysis of these two communities, patient and medical is necessary.

3. ENGAGING MODELING AND SIMULATION TO ASSESS A COROLLARY PROBLEM TO THE OBESITY EPIDEMIC

The authors propose that government approaches to mitigating the obesity epidemic are complex with numerous actors and a long-term strategy focusing on lifestyle changes which can take years to effect. These approaches are certainly necessary to reverse the obesity epidemic, but they do not address the escalating and imminent healthcare needs of the patient relative to the medical community's capacity to provide that care. Thus, it is necessary to assess how and if the medical community will be able to provide care juxtaposed to the increasing number of patients afflicted with obesity and obesity-attributable illnesses.

Current analysis on this topic is being done via trending data (Adult Obesity 2011). This analysis is built upon statistical modeling of trend projection based on past history. What is typically used is a *Three-Year Moving Average;* an average that is calculated for a 3-year period on a rolling basis. For example, the 3-year moving average value for 2003 would be based on values for years 2001-2003, the value for 2004 would be based on years 2002-2004, and so forth. A moving average is calculated in order to smooth short-term fluctuations and help identify long-term trends. The deficiency with this type of modeling is that while a moving average is a valid representation of past activity it is not a good predictor of what is to come in the future. To address future outcomes one must take into account the complex relationships among factors that influence those outcomes. To overcome that deficiency, simulation can review the expected trends while incorporating behavioral issues; issues that are integral to this specific study as so much funding and hope has been predicated upon changing behavior. Coupling this existing trending analysis with simulation to assess behavior provides a more accurate representation of likely future outcomes.

As such, modeling begins with looking at both the supply and demand for patient care. The project thus reframes the problem of obesity by including an analysis of the medical community along with the at-large patient community. This type of study serves to proactively prepare for an expanding epidemic by ensuring that the medical community will keep pace or prevail over the public's medical needs.

3.1 Developing a Conceptual Model

The first step in model development is to capture how people gain weight to unhealthy levels. The model is based on the premise that obesity is due to the imbalance of caloric intake and energy expenditure. In other words, calories people consume through meals are greater than the ones burned through exercising. These two parameters are contingent in the environment where people live: access to different types of food (high calorie or low calorie) and access or lack thereof to exercising facilities (bike lanes or gyms). The second step is to understand how people with obese related illnesses affect the demand on the medical system. We will then apply the model to a real world demographic to validate its predictive capability. The medical community's ability to provide care will be measured by the number of Primary Care Physicians (PCP), Specialists (physicians trained specifically to care for diabetes and obesity). Essentially, the purpose of the model is to provide an assessment of population, population needs, and medical care available as a means to mitigate a potential shortfall of medical professionals trained specifically to provide adequate healthcare vis-à-vis the obesity epidemic.

Modeling and simulation will be engaged to reframe the problem by: 1) reviewing the demographic data from the perspective of patient community and the medical community and its ability to provide care; 2) calibrating data to reflect the patients striving to maintain good health and those less concerned. Those less concerned impact availability of health-care as they enter the health-care arena at later periods and with more complex medical needs (by virtue of not seeking and maintaining proper health-care to avoid emergent situations). The use-case will yield a baseline assessment simulation which can then be modified to study any community, state, or region.

3.2 Case Study: Norfolk, Virginia USA

The purpose of this paper is to show the value of modeling and simulation in assessing the obesity epidemic in a way that represents two communities, a pre-defined patient community and a pre-defined medical community. The case study for this research was Norfolk, Virginia - USA. Included in the model are patient population data and medical practitioner data. The data was drawn from federal agencies like the Centers for Disease Control and state agencies like the Virginia Department of Health. The goal is to assess the impact of obesity-attributable illness on the availability of health-care. This is done by modeling the current status of the patient community juxtaposed to the medical community. Modeling the patient community calls for characterizing the medical needs of the patient; modeling the medical community calls for characterizing its ability to provide care to the patient community via trained general medical practitioners (PCP) and specialized physicians.

The data needed to develop the simulation analysis will include the following:

- overall population of each city workplace
- housing
- recreation facilities
- restaurants
- medical capacity PCP
- medical capacity Specialized physicians

The following tables display data used for this model (Table 2). Note that the data was scaled to a size that was computationally tractable given the complexity of the system being modeled.

Table 2 – Norfolk Demographic Data Norfolk

	Real Data	Scaled Data
Population (Adult)	177,000	10,000
Workplaces	14,436	800
Housing Units	85,000	4,800
Rec Facilities	22	2
Restaurants	530	30
Primary Care Physicians	322	33
Number of Specialists	433	43

3.3 Modeling Paradigms

Unique to this use-case are two facts: 1) the two communities, patient and medical, are better described as *parallel systems* as they are independent and operating in dissimilar modes; yet, they both exact an immense impact on each other; 2) the obese population is growing and the care this population requires is complex (multi-medical care concerns) while the medical community is much more static in terms of growth and stove-piped in terms of ability to provide care. This stove-piped nature is due to expertise-constraints, administrative limitations (patient insurance, financial deficits), and length of turn-around time toward expert care provider.

A multi-paradigm approach that combines agent-based and discrete-event modeling was chosen. The agent-based model captures the patient community while the discrete-event model captures the medical community. Agents account for the behavior of individuals in both the demand side and supply side of the problem. It will facilitate a micro look at the system being modeled via a representation of the patient as an autonomous decision-making entity or agent. Each patient/agent can assess his situation and make decisions and execute various behaviors appropriate for the system he is representing, in this case the propensity to remain as a member of the obese population. The specialists and primary care physicians which are part of the medical system are also modeled as agents. The patient agent goes to a primary care agent if they are health conscious and have medical insurance. The primary care agent directs the patient to one or more specialists agent based on their disease. If the patient agent does not have insurance, they go to the emergency room where they are kept for a time and then released. The patient agent's life expectancy increases or decreases based on whether they access to adequate care or not.

In addition to the agent based paradigm, we add a discrete event paradigm to model daily schedules of individuals, patients, and care providers. The discrete event paradigm allows us to track queues within the medical system and thus provide us a mean to measure the burden of obesity related diseases on the system.

4. CASE STUDY NORFOLK SIMULATION OUTPUTS

The data for Norfolk was scaled down in order to speed up the execution of the model. The population of Norfolk was scaled down to 10,000 people. The starting values of the other parameters listed above were scaled in a manner to maintain the same ratio to the population that the original values had. The primary care physicians and other physicians were scaled down to keep the same physician to person ratio.

4.1 Run 1: Maintain Health

The initial conditions for this run are shown below. All of the people were set to adjust their eating and activity habits (Health Conscious) if they moved outside of a healthy range and to adjust their habits based on the type of people who live near them (Peer Pressure) who are obese, average weight, etc. (Table 3). People were also set to seek treatment as soon as it was determined that they had contracted an obesity-related disease (Health Response). The simulation was run for 10 years and the effects on the queues of the medical facilities by the people were observed.

Table 3: Initial Conditions for Run 1

% Health Conscious	100
% Health Response	100
% Peer Pressure	100

The percent of the initial population that is obese is considered as already having an obesity-related disease. Therefore, at the start of the simulation all of the people who start obese are sent into the primary care queues if they meet the requirements to be treated. For this simulation, it was assumed that everybody was able to enter the medical facilities and that they would utilize the medical facilities as soon as they needed to. This results in a slight overflow on the queues at the start of the simulation as the entire obese population is entering the system for the first time. The first year of the simulation is considered a warm-up period and allows for the total appointments of all the people seeking treatment to be spread out evenly. Only queue lengths after the first year are considered significant for the simulation. It was also assumed that all the specialists in the area were able to treat obesity-related diseases. This likely resulted in a slightly larger number of available specialists in the area then should have been seen.

At the end of the simulation just over 52 percent of the population was classified as obese and placing a burden on the medical community. However, this did not cause an overflow in any of the medical queues in Norfolk over 10 years. Figure 2 shows the total queue lengths from all of the medical facilities over the course of the simulation. The only time that any of the queues overflow is at the beginning of the simulation during the warm up period. Norfolk has a high number of physicians for its population (311 physicians per 100 thousand residents), so this result is not surprising.

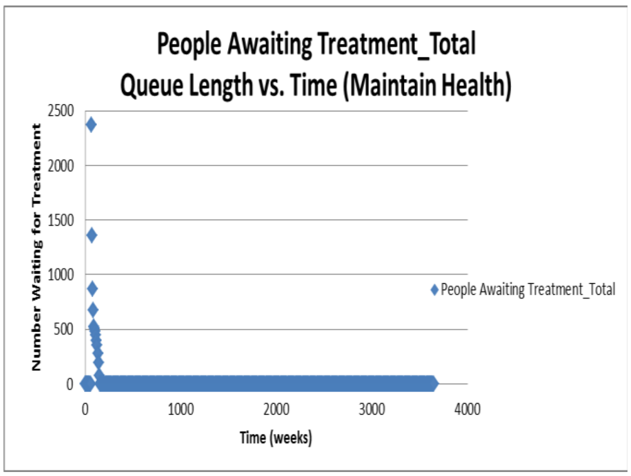

Figure 2: Total People Waiting for Treatment over Time – Maintain Health

The total number of people who died during the simulation was just under 10 percent over the 10 year period. The plot of total deaths over time is displayed in Figure 3.

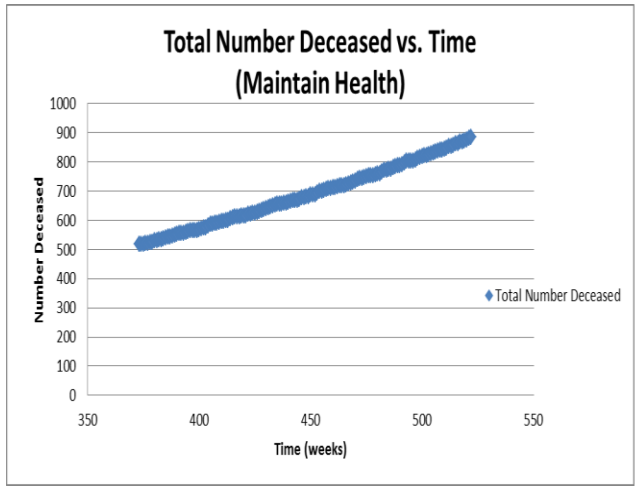

Figure 3: Total Number Deceased over Time - Maintain Health

4.2 Run 2: Ignore Health

Initial conditions for this run are outlined in Table 4. The people were set to not adjust their eating and physical activity habits if their BMI levels went outside of the healthy range. This means that people will not attempt to improve their diet or exercise practices even after they attract a disease. The people were also set to not go to the medical facilities unless absolutely necessary. This means that the people will enter medical queues through the emergency department instead of the primary care facilities.

Table 4: Initial Conditions for Run 2

% Health Conscious	0
% Health Response	0
% Peer Pressure	0

The results of the simulation are shown in Figure 4. As expected, all of the medical queues remained empty at the beginning of the simulation. However, just over 8 years into the simulation, the queue for the In-Patient care drastically started to increase and the size of the queue rose linearly until the simulation stopped at year 10. This most likely represents a large number of people suddenly being admitted to an emergency department. People are redirected from the emergency to the in-patient facilities for checkups and re-evaluations after being seen at the emergency department. The large number of people admitted combined with a lower availability of physicians for in-patient care resulted in a sudden and drastic backup of available treatment.

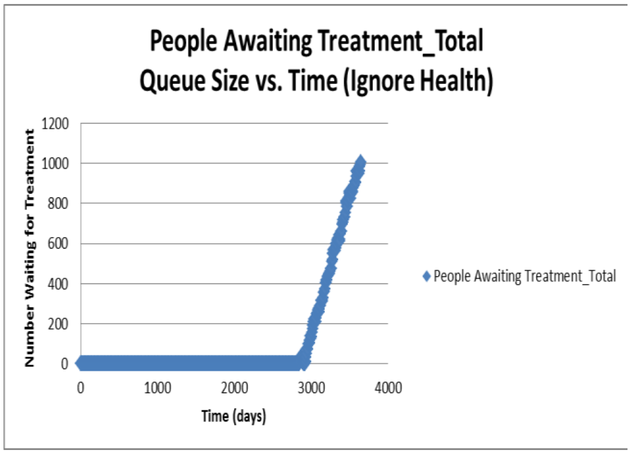

Figure 4: Total People Waiting for Treatment over Time – Ignore Health

This is an extreme case and it is unlikely in practice that 100 percent of a given population would wait to be treated until they were in critical condition. The total number of deaths experienced during this simulation almost doubled the previous simulation. The total deaths in the simulation reached just over 14 percent. Total deaths over the 10 year period are displayed in Figure 5.

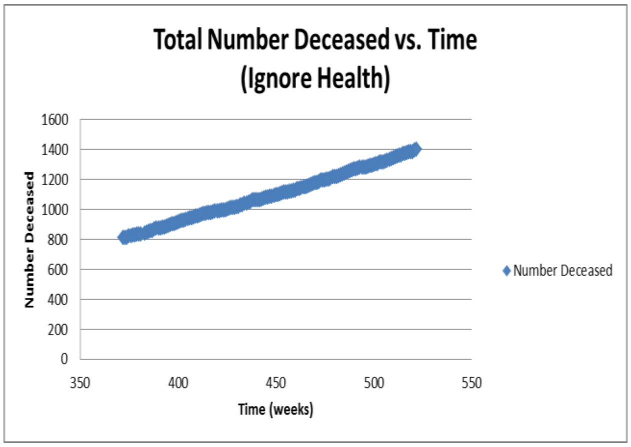

Figure 5: Total Number Deceased over Time - Ignore Health

5. CONCLUSION

The intent of this methodology paper is to suggest a means of analyzing the obesity epidemic using modeling and simulation to provide a broader, yet more inclusive look at the obesity epidemic and its impact on the medical community's ability to provide care. Reframing the problem to include both major actors – patient and medical community – facilitates representing a significant corollary problem of the epidemic. This approach provides a for health-care providers to make adjustments to the medical community. Findings of the simulation outputs can be geared to assessing when an over-burdened tipping point will be reached. The methodology drawn from the use-case can be used as a baseline assessment which can be re-populated with data to represent any size / model of patient community and medical community.

The model showed significant queue lengths of medical facilities for the two types of patients on a weekly basis. These queues reached differing tipping points per urban area, per the ratio of patient to physician, and per individual degree of concern. The model also indicated tendencies of each community to become more or less obese based on the environmental conditions such as availability of healthy food, the availability of wellness centers and recreational facilities, and the types of workplaces within the area.

If obesity trends continue unchecked or if the trends are not mitigated over the course of long-term behavioral change approaches, such as those discussed in this paper, the negative effects on the health of the population will increasingly outweigh or overburden the capacity of many medical communities. As such, the authors encourage a holistic approach to assessing the impact of the epidemic by engaging modeling and simulation. This type of assessment may mitigate a health-care shortfall.

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