Modeling the Dynamics of Dental Health in Older Adults

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ABSTRACT

As the population of older adults in the United States expands with the aging of the Baby Boom generation, the advantages of developing coordinated and cost effective health policies have become clearer. Co-morbidities between medical and dental health conditions become more prevalent with age. For example, periodontal disease is a risk factor for other chronic illnesses, notably diabetes and cardiovascular disease. Despite this link, medical and dental disorders are rarely screened for and treated as related conditions. Additionally, access to dental care for older adults may be adversely affected by lack of insurance coverage and complex social, cognitive, and physical factors that result in missed opportunities for intervention and prevention of more serious conditions. Developing interventions to improve dental health among older adults is a particular challenge, given the complex set of causal pathways and time delays over the life course that are involved. In this paper, we draw upon the experience of Columbia University's ElderSmile outreach program to inform construction of a dynamic model as part of a larger research endeavor that explores the intra- and inter-personal relationships relevant to oral health in older adults.

1. INTRODUCTION

Oral health has been recognized as a matter of public health concern because it affects a large proportion of the population and is linked with general health status (IOM, 2002). The landmark publication, *Oral Health in America: A Report of the Surgeon General*, highlighted a lack of awareness of the importance of oral health among the general public, and found a significant disparity between racial and socioeconomic groups with regard to oral health and ensuing overall health issues (US DHHS, 2000). According to the Surgeon General's report, the mouth is the gateway of the body, in that it senses and responds to the external world and reflects what is happening deep inside the body. The mouth signals nutritional deficiencies and serves as an early warning system for diseases such as HIV/AIDS, other immune system problems, general infections, and stress. Poor oral health is associated with diabetes, heart disease, and stroke (Allukian, 2006). A comprehensive exam in the mouth is a novel way to study the body as an integrated system, since it is an accessible entry point for the medically complex patient (Glick, 1999).

As the Baby Boom demographic enters retirement, the need for regular and proactive dental care among older adults is becoming ever more acute. The oral health of older adults is influenced by complex medical and social factors including multiple medications for chronic illness, cognitive impairment, social isolation, and/or physical disabilities that interfere both with oral hygiene activity and access to dental care. Early intervention strategies to address oral health problems can prevent illness, diagnose serious conditions early, and maintain optimum overall health. Patient-centered oral health promotion, such as the preventive screening (PS) and referral services offered through Columbia University's *ElderSmile* program in upper Manhattan, provides a way to identify and address conditions that compound oral health problems for this underserved population.

2. CONCEPTUAL FRAMEWORK

Because a systems perspective cannot be gained by studying component parts in isolation, a consideration of cross-scalar relationships is necessary to develop and implement oral health interventions for older adults. Factors at the neighborhood scale (e.g., community access), interpersonal scale (e.g., oral health promotion), and individual scale (e.g., nutrition and chronic illness) are particularly important in influencing dental health outcomes such as tooth retention, dental caries, and periodontal disease. This paper employs a systems perspective to frame oral health in older adults as due to the lifelong accumulation of advantageous and disadvantageous experiences at multiple scales, from the micro-scale of the mouth to the societal scale that involves U.S. federal policy, including lack of routine dental care coverage under Medicare.

Methodological developments in system dynamics, geographic information systems (GIS), agent-based modeling, and social network analysis have enabled a growing body of research on the effects of multiple scales (macro, meso, and micro) and environmental dimensions (geographic, institutional, and social) on health behaviors and outcomes. Intersections of scale and environmental factors on health in general, and dental health in particular, are outlined in Table 1.

Table 1. Multi-level framework for environmental influences on health

	Macro	**Meso**	**Micro**
Geographic Environment	Urban Context	Neighborhood	Individual Activity Space
Institutional Environment	Health Care System	Outreach Programs	Self Care
Social Environment	Socio-economic Structures	Community Relationships	Personal Network

The multiple scales and environmental dimensions outlined in Table 1 represent a multi-level framework for modeling health, where the level of the social environment encompasses a diverse set of mechanisms operating among and within social structures existing at different levels (Northridge et al, 2003; Bachrach & Abeles, 2004). At the *macro* level are structures and processes that involve and affect populations broadly: government, media, economic systems, social stratification, political processes and policymaking, and commonly held cultural values and practices. Some of these processes also operate at the *meso* level, that is, in communities, neighborhoods, and institutions such as workplaces. Processes contributing to social cohesion, social support, social control, social and cultural conflict, and the development and enforcement of social and cultural norms also play a significant role. In families and small groups, interpersonal processes such as conflict and support, socialization, and sharing of resources play a dominant role, at both the meso level and micro level. Characteristics of the individual and biological mechanisms (*micro* level) fill out the multi-level conceptualization for this research.

2.1 CAUSAL DYNAMICS

Modeling with system dynamics enables policymakers to assess the impact of different health interventions to identify ones that yield the greatest leverage in both the short term and the longer

term (Homer and Hirsch, 2006). The difficulty of selecting effective programs and policies that provide the greatest impact may be mitigated by outlining the complex set of causal pathways that links risk factors to dental health. A causal map of the system dynamics is developed to illustrate leverage points for potential health interventions that would reduce the burden of dental health in older adults. Through the process of articulating causal relationships, the research team interacts with dental practitioners and policy scholars in a participatory process of knowledge sharing.

Adequacy of dental health in older adults requires attention to factors affecting tooth retention, such as periodontal disease and tooth decay. Figure 1 maps the causal dynamics involved in dental health. The reinforcing nature of the feedback loops in Figure 1 reveals their capacity to destabilize the system into one or more vicious cycles. Because health issues tend to compound with age, the reinforcing feedback loops outlined in Figure 1 can trigger vicious cycles of dental health decline among older adults. Our conceptualization of these causal dynamics continues to evolve through an ongoing collaborative and iterative group modeling process (Richardson and Andersen, 1995; van den Belt, 2004).
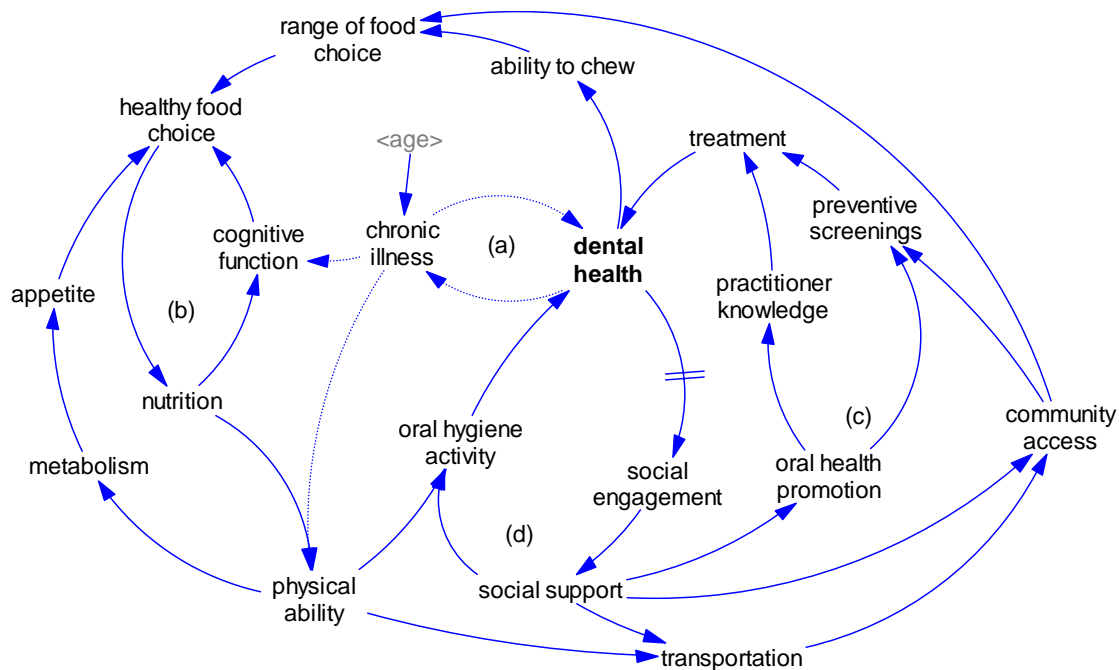

Figure 1. Reinforcing dynamics of dental health in older adults.

The left side of Figure 1 features individual-level factors that influence dental health, whereas the right side reflects the level of dental health care available to the individual. Solid arrows indicate proportional relationships, whereas dotted arrows indicate inverse relationships. Specifically, the central reinforcing loop (a) indicates that *chronic illness* is often implicated in dental disease, furthering the utility of preventive screenings for both medical and dental health purposes. Chronic illness is more likely with increasing age, and frequently affects both physical ability and cognitive function. Resulting impacts may make it harder for individuals to maintain effective levels of oral hygiene activity, worsening dental health. Moreover, the variety of medications used to manage chronic illness may manifest in the oral cavity, such as a dry mouth.

As a key contributor to both physical and mental health, *nutrition* (b) plays an important role in the system dynamics of oral health in older adults. Older adults are particularly prone to have missing teeth, which reduces their ability to chew foods thoroughly. Structural decline of teeth with age also hampers mastication, or ability to chew, limiting the range of foods available for consumption, and thus the capacity to make healthy food choices. Both the structure and content of raw, unprocessed fruits and vegetables are particularly important for the maintenance of dental health. Adequate nutrition enables both cognitive function and physical ability. If nutrition is compromised, a frailty loop is triggered as metabolism slows from reduced physical activity, decreasing appetite and therefore nutrition. At the intra-personal scale, improved physical ability may accompany more diligent oral hygiene activity, self care that (like nutrition) enhances dental health over time through retention of natural teeth and prevention of dental disease. Just as self care improves dental health, certain harmful behaviors such as the use of tobacco and alcohol have been shown to be risk factors for oral pathology.

As implied by the name of the *ElderSmile* program, an incentive to maintain healthy teeth is to sustain the propensity to smile and interact with others. Dental problems such as missing teeth and bad breath can inhibit social behavior. As such, one consequence of healthy tooth retention, disease prevention, and improved overall dental health is self-confidence, which gives rise to an increased propensity for social behavior, the *social engagement* term depicted in Figure 1. The hatched arrow from *dental health* to social engagement indicates a time lag for shifts in social behavior to result from the increased confidence that accompanies improved health.

Social support combines with individual ability to make transportation easier for older adults to access preventive screenings and treatment centers, via a factor termed *community access* in Figure 2. Community access expands the range of food choices available to older adults. *Oral health promotion* (c), such as that made available through Columbia University's *ElderSmile* program, includes activities such as preventive screenings for the population. The *social support* (d) that results from increased social engagement then provides a mechanism for spreading awareness of oral health promotion programs such as *ElderSmile*. Such social support enables opportunities for transportation of older adults who have physical limitations. Social support for older adults is abruptly severed when a partner passes, for example. A loss of social support in the home setting can make it hard to remember effective oral hygiene habits and further restricts community access to nutritious food, especially if cognitive function has been weakened with age, as in the common case of dementia. The latter condition can complicate otherwise routine matters of denture care.

Consistent with the need for patient-centered (dental and medical) health homes (Glick, 2009), oral health promotion involves dissemination of dental practitioner knowledge regarding the unique considerations of older adults, such as how to treat patients with chronic illness (Lamster, 2004). Importantly, as word of mouth spreads about preventive screening and referral opportunities, community knowledge grows and reinforces social support. The impact of oral health promotion on dental health is mediated through timely treatment of tooth decay. Depending upon the procedures necessary, the affordability of treatment may render it prohibitive for individuals lacking coverage, a significant portion of the overall population of older adults.

2.2 A STRUCTURAL VIEW OF DENTAL HEALTH DECLINE

For many adults, age induces a decreased sensitivity to tooth pain, resulting in longer delays before symptoms of decay compel professional treatment. Figure 2 outlines the process by which healthy teeth become decayed, filled, missing teeth and/or prosthetic teeth. Stocks (boxes) reflect the prevalence of conditions, and flows (arrows with valves) reflect the incidence rates among older adults.
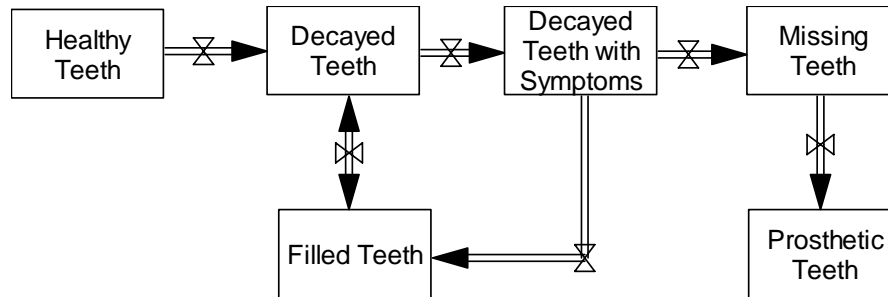

Figure 2. A structural view of dental health decline among older adults.

The stock and flow structures mapped in Figure 2 are appropriate for formalization at the scale of the individual, at the aggregate scale, or at the scale of a population subgroup (e.g., by neighborhood or socioeconomic group). One-way arrows indicate irreversible flows: athough the process of decay can be mitigated with fillings, it cannot be undone. Once decay has begun, teeth cannot return to their original state of health. Moreover, filled teeth are prone to complications and further decay, as indicated by the two-way flow between decayed and filled teeth. A majority of older adults have teeth that are decayed, filled, or missing. Once teeth are missing, prosthetic teeth may be sought, depending upon affordability of treatment as well as cultural attitudes about the importance of prosthetic teeth. A key indicator of oral health among older adults is therefore the retention of natural teeth.

Stock and flow structures inform the modeling at various scales. In addition to those implicated in the diagnosis of dental health decline, stocks and flows are appropriate to simulate age cohorts and anticipate demographic shifts in the population, and to distinguish between levels of risk among subpopulations (Hirsch, 1975). An important factor affecting dental disease progression and tooth loss is frequency and quality of dental care. Adults receiving regular dental care are more likely to have decayed teeth diagnosed and filled before symptoms of pain develop, but underinsured adults are likely to have teeth that progress into the symptomatic state. Consistent with our multi-level conceptual framework, modeling participation in preventive screening and social processes provides a contrast with biophysical processes of tooth decay, enabling intersection of dynamics relevant at different scales of the system.

3. PREVENTIVE SCREENING INTERVENTION

The *ElderSmile* prevention centers are located at senior centers and other locations in which older adults gather in Harlem and Washington Heights/Inwood. The prevention centers host a combination of services, including: general presentations and discussions in both English and Spanish of oral health promotion in later life (e.g., potential oral health problems, how to choose oral health care products, and access to oral health care, including transportation issues);

demonstrations of brushing and flossing techniques and care of prosthetic devices; and oral cancer and oral health examinations for seniors who elect to participate. Services are provided by Columbia University's College of Dental Medicine (CDM) faculty dentists and dental students. Outreach sessions are conducted at community-based prevention centers by *ElderSmile* staff, two of whom speak fluent Spanish. About five *ElderSmile* team members participate in each outreach session, including a program coordinator, a health educator, dentists, and CDM dental students. Numbers vary because of the availability of dental students who volunteer their time and services. Older adults are enrolled in the *ElderSmile* program after participating in the oral health promotion activities and being examined by one of the *ElderSmile* dentists.

Figure 3 outlines the reference mode for participation in *ElderSmile* preventive screening activities, illustrating monthly participation rates over a 2-year period from 2006-2008.
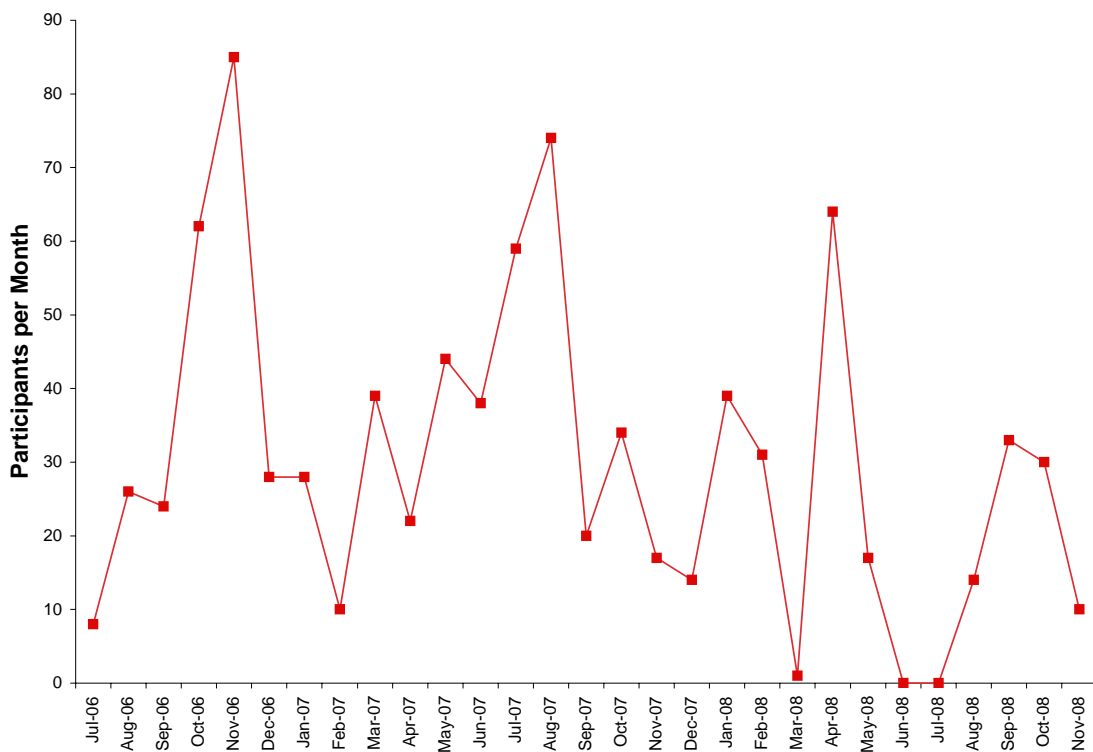

Figure 3. Participants in the ElderSmile preventive screening (PS) outreach program.

The oscillatory dynamic in Figure 3 may be analogous to a problem posed by Arthur (1999) about the *El Farol* bar in Santa Fe, New Mexico. The bar has a weekly Irish night. If the potential Irish bar-goers (such as Arthur) wish to avoid a crowd and anticipate its likelihood based upon recent experiences, oscillatory behavior results from commonly held expectations about the system. However, the capacity for the *El Farol* dynamic is fixed, based upon the size of the bar and the constant (weekly) frequency of the Irish night. For the *ElderSmile* program, workshops are not evenly spread throughout the year, and they are furthermore distributed among the 27 participating senior centers in upper Manhattan. Figure 4 illustrates the relationship between monthly participation and workshop availability between 2006 and 2008. Variation in workshop utilization indicates that resources may be fully utilized or underutilized.

Further analysis will consider the location-specific variation, accounting for differences among senior centers participating in the *ElderSmile* program.
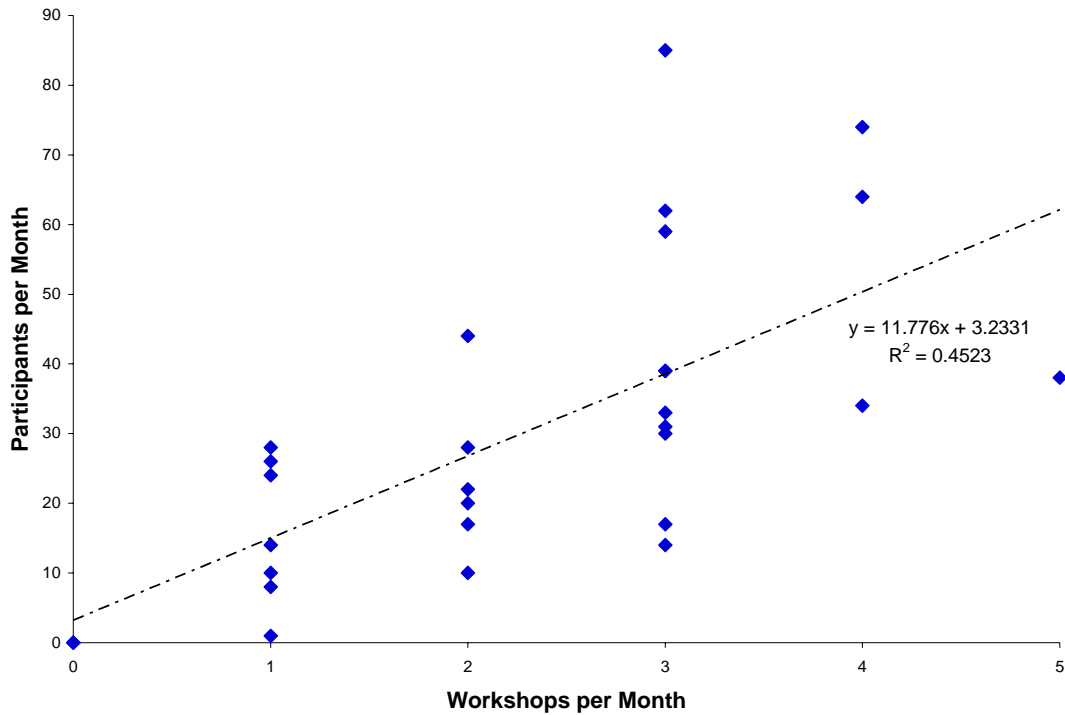

The chart shows data with trend line: y = 11.776x + 3.2331, $R^2 = 0.4523$

Figure 4. Monthly utilization versus availability of *ElderSmile* preventive screenings (PS).

The descriptive statistics in Table 2 for average DMFT (Decayed Missing Filled Teeth) among participant subgroups reveal disparities by age, gender, ethnicity, education, and smoking history. Differences between missing (MT) and filled (FT) teeth reflect accumulations of advantages and disadvantages over the life course, with filled teeth reflecting some degree of access to care.

Table 2. Means and Standard Errors (SE) of Decayed Filled Missing Teeth (DMFT), Decayed Teeth (DT), Missing Teeth (MT), and Filled Teeth (FT) by Age, Gender, Race/ Ethnicity, Education Level, and Smoking History of Older Adults Aged 65 Years and Older (N = 662) Who Participated in Community-Based Oral Health Examinations Conducted by Dentists: The *ElderSmile* Program, New York, NY, 2006-2009

Characteristic	DMFT (SE)	p-value	DT (SE)	p-value	MT (SE)	p-value	FT (SE)	p-value
Age in years								
65-74	20.6 (0.3)	0.19	0.9 (0.1)	0.66	**14.2 (0.5)**	**0.05**	**5.5 (0.3)**	**0.04**
75+	21.2 (0.3)		1.0 (0.1)		**15.6 (0.5)**		**4.7 (0.3)**	
Gender								
Men	20.5 (0.4)	0.14	**1.4 (0.2)**	**<0.01**	**13.9 (0.6)**	**0.04**	5.2 (0.4)	0.66
Women	21.2 (0.3)		**0.7 (0.1)**		**15.4 (0.5)**		5.0 (0.3)	
Race/ ethnicity								
Non-Hispanic White	20.4 (0.5)	0.09	1.2 (0.3)	0.13	**8.9 (0.9)**	**<0.01**	**10.4 (0.7)**	**<0.01**
Non-Hispanic Black	21.2 (0.4)		1.0 (0.1)		**16.4 (0.6)**		**3.9 (0.3)**	
Non-Hispanic Other	18.4 (1.2)		1.3 (0.4)		**10.4 (1.5)**		**6.8 (0.8)**	
Hispanic	21.1 (0.4)		0.7 (0.1)		**16.1 (0.6)**		**4.2 (0.3)**	
Education level								
Less than high school	**21.7 (0.5)**	**0.02**	1.0 (0.2)	0.89	**17.4 (0.7)**	**<0.01**	**3.4 (0.3)**	**<0.01**
High school	**21.0 (0.4)**		0.9 (0.1)		**15.5 (0.6)**		**4.6 (0.3)**	
More than high school	**20.0 (0.4)**		0.9 (0.1)		**11.4 (0.7)**		**7.7 (0.4)**	
Smoking history								
Current smoker	**23.0 (0.7)**	**<0.01**	1.8 (0.5)	<0.01	**18.2 (1.2)**	**<0.01**	**3.0 (0.6)**	**<0.01**
Former smoker	**22.0 (0.4)**		1.0 (0.2)		**15.8 (0.7)**		**5.2 (0.5)**	
Never smoked	**20.0 (0.3)**		0.7 (0.1)		**13.5 (0.5)**		**5.7 (0.3)**	
Total	20.9 (0.2)		0.9 (0.1)		14.9 (0.4)		5.1 (0.2)	

Racial disparities are manifest in the increased prevalence of decayed and missing teeth among African American and Hispanic participants in the *ElderSmile* screenings, at a rate nearly double that of their white counterparts, whereas the latter had more teeth with fillings (Table 2). These disparities reflect accumulations of advantages and disadvantages over the life course, such as insurance coverage and access to quality care. Nearly all of the participants of the *ElderSmile* program required dental treatment at neighborhood sites, and the vast majority (88%) of those referred have followed up with treatment, demonstrating the effectiveness of the program as well as the widespread need for such services (Northridge et al, 2011).

The utilization of preventive care and treatment is driven by the accessibility and affordability of services. The region of northern Manhattan served by *ElderSmile* is a U.S. federally designated manpower shortage area. Disparities in oral health and health care have been documented for seniors in the study region as compared to the U.S. senior population overall. Only 23% of seniors in Harlem and Washington Heights/Inwood visit a dentist annually, compared to 50% of seniors nationally. Among the U.S. population at large, 70% visit the dentist at least once a year, significantly more than those who visit a doctor within the past year. Among the older adults in upper Manhattan participating in the *ElderSmile* program, this relationship is reversed: only 45% visited the dentist during the past year, whereas doctor visits are more frequent. The utilization of dental care tracks strongly with the availability of dental insurance, as only 48% of *ElderSmile* participants had dental insurance (Marshall et al, 2009).

Many adults develop edentulism, or a complete absence of permanent teeth in the mouth. In northern Manhattan, 45% of seniors have no teeth, compared with 25% of seniors nationally. For older adults with missing teeth, prosthetic replacements may not be sought for reasons of affordability. While the Medicaid program in New York State offers dental coverage, only 20% of enrolled *ElderSmile* participants access dental services through Medicaid, and only 10% of private dentists provide over $10,000 in Medicaid dental services (CDM, 2006). The relationship between age and tooth loss is apparent in data from the *ElderSmile* program: 17% of participants aged 65-74 years were edentulous, whereas 22% of adults over 75 years had the condition (Northridge et al, 2011). Among social networks in which the absence of teeth is a norm, the need for prosthetic teeth may be questioned as an unnecessary expense in later life. While the logic that 'you can eat without teeth' is prevalent among many, including some budget-minded policymakers who view dental health as a luxury, a systems perspective reveals the compounding impacts of neglecting oral care.

3.1 MODELING WORD OF MOUTH

Because this project is designed to inform oral health interventions, the model centers on the role of preventive screening (PS) outreach programs in assisting seniors with securing dental treatment. The stocks in Figure 5 distinguish broad subgroups of the population by whether or not older adults have participated in the preventive screenings and treatment opportunities offered by the *ElderSmile* program. In this representation, a reinforcing word-of-mouth mechanism (R1) enables knowledge diffusion about preventive screening events. Although desired PS participation grows rapidly, it is tempered by perceived availability (B1) when screening sessions are at capacity. Although PS capacity constrains participation (B2), it is adjusted (R2) to accommodate increasing interest.
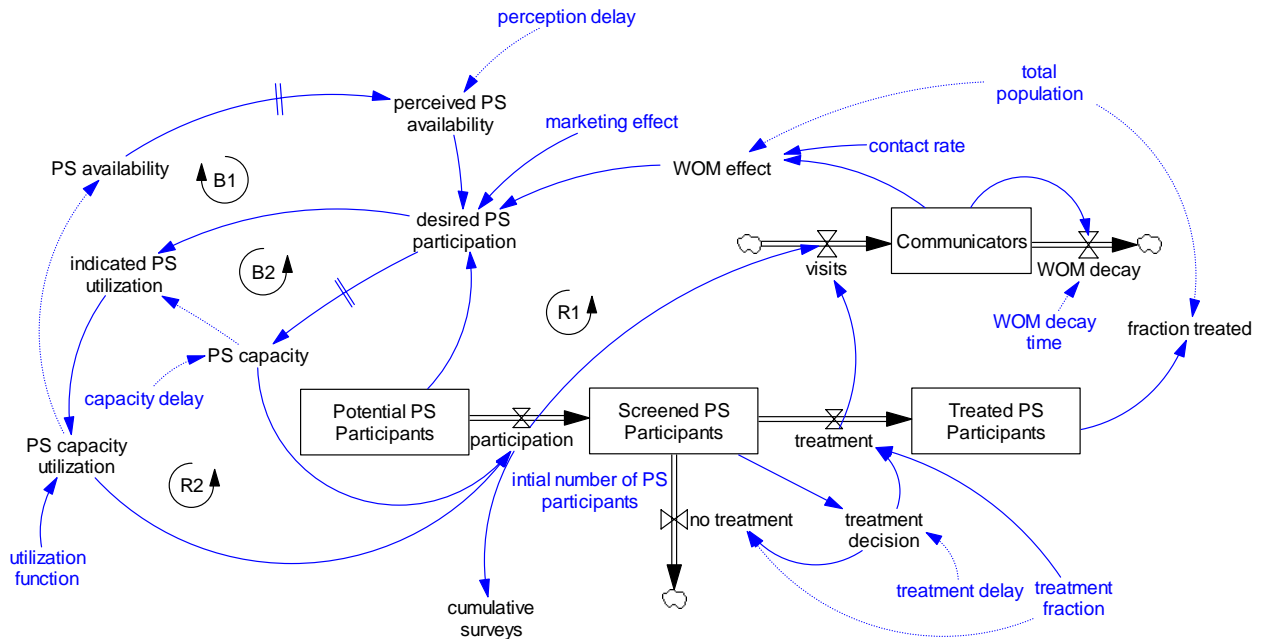
Figure 5. Structural dynamics of preventive screening (PS) intervention.

The model structure in Figure 5 accommodates the *El Farol* dynamic described above through the use of delayed adjustment of capacity and perceived availability via B1 and B2. Desired participation is diminished with perception of unavailability, as with the crowd deterrent on attendance at *El Farol*'s Irish night. Balancing feedback with delays can induce such oscillation. Figure 6 illustrates a range of weekly participation outcomes induced by variation in the perception and capacity delay times relative to the base run, which has a capacity delay of 24 weeks and a perception delay of 4 weeks. Using a minimum 2-week delay for both, capacity adjustment time is varied to 48 weeks (doubling the base run delay), and perception adjustment time is varied to 16 weeks (quadrupling the base run delay). These delays induce a range of transient behavior before weekly participation rates approach a constant equilibrium.
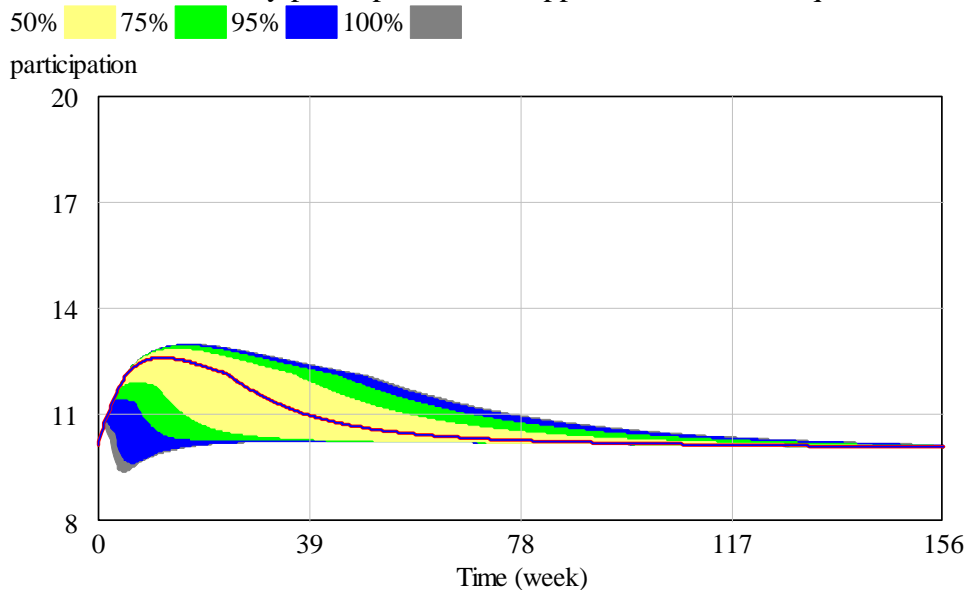

Figure 6. Effects of varying capacity and perception delays on weekly participation.

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In Figure 7, the same sensitivity analysis is performed as in Figure 6, with the inclusion of a marketing boost after one year (52 weeks). Doubling the marketing effect ultimately results in a doubling of participation rate (note the shift in scale on the y-axis). The shape of the plot indicates that the marketing effect thereby crosses a bifurcation threshold, enabling an approach toward a higher equilibrium rate of participation in preventive screenings.
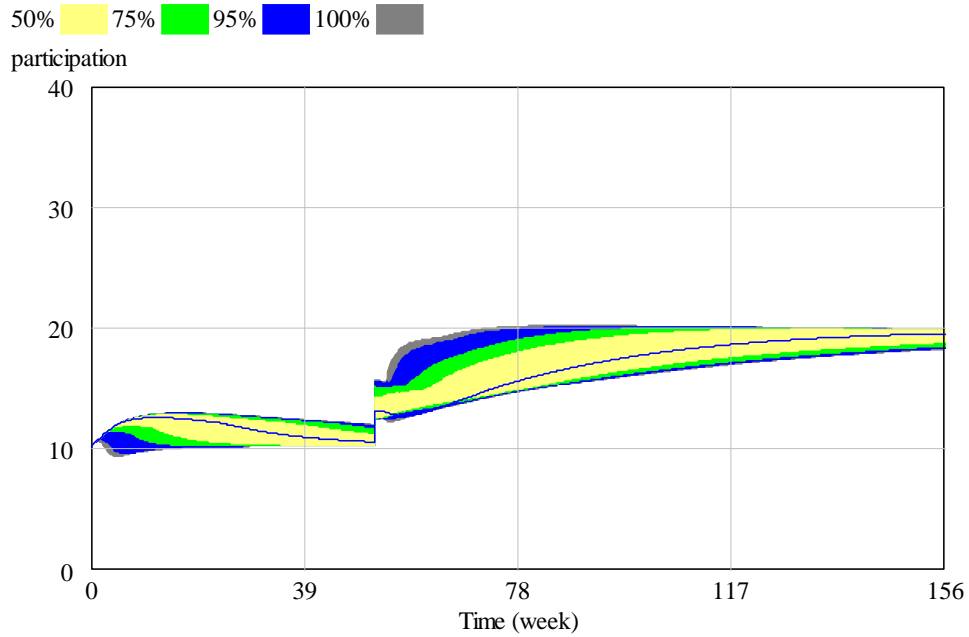

Figure 7. Participation effect of a marketing boost at one year while varying delays.

Figure 8 reveals a range of outcomes from varying contact rate, and therefore the amplitude of the word of mouth effect, from zero to four times the base run setting (0.04/week).
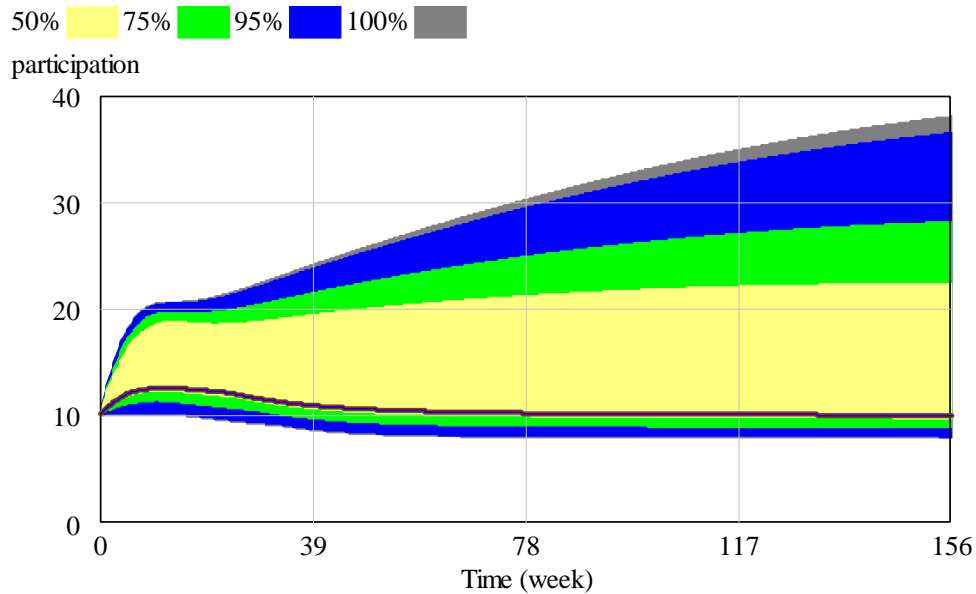

Figure 8. Effects of varying contact rate on PS participation.

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Significantly greater contact rates induce participation beyond the rates implied to be feasible via analysis of *ElderSmile* workshop offerings and utilization (as per Figure 4 above). Because the range of simulation outcomes indicated in Figure 8 varies significantly with contact rate, a consideration of heterogeneity among social networks of older adults is warranted.

Social networks may be empirically specified or simulated to test alternative mechanisms for developing social ties and communicating. Agent-based representation is appropriate in cases where a particular social network structure deviates from the random mixing implied by a continuous stock-flow structure (Rahmandad and Sterman 2008). Figure 9 maps a simulated proximity-based social network across residential locations of the *ElderSmile* participants, using AnyLogic software to integrate GIS data within an agent-based model.
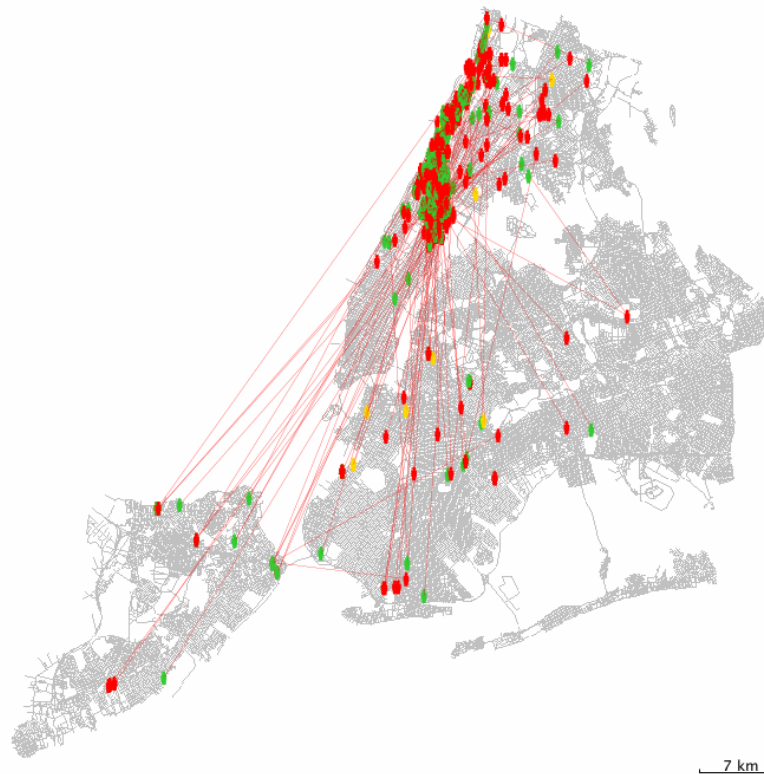

Figure 9. Simulated agent-based network among *ElderSmile* participants.

The network structure in Figure 9 is used to explore the relationship between social and physical distance among participating older adults. By virtue of their presence at senior centers, *ElderSmile* PS participants exhibit a greater physical and social mobility than that of the broader population of older adults in upper Manhattan. Such activity may explain why the dental health of participants is better than national averages in terms of tooth retention, as indicated by lower levels of edentulism (Northridge et al, 2011). Questions about social mobility and geographic distance include: Do participants who come from farther away have greater influence on others? Do they reflect the outcome of a strong word of mouth dynamic? Is the *El Farol* capacity and perception dynamic actually experienced in the *ElderSmile* program? We continue to explore these questions using the process of participatory systems modeling. Extensions of this research will explore the variability of social dynamics in both agent-based and stock-flow formulations, and will examine the utility of individual-level representations of dental health decline.

4. CONCLUSION

Ongoing efforts to refine and reform systems of health care for older adults may be meaningfully abetted by modeling that explicitly links dental health to chronic illness, community access, oral health promotion, and nutrition. Education and outreach programs help promote effective oral hygiene practices and routine care, so as to retain natural teeth as long as they are functional, and to keep them healthy. Oral health promotion also enables health education and early identification of tooth decay and co-morbid conditions. Once the progression of dental decay has started, it can be mitigated or reinforced, but not reversed. This intrinsic irreversibility underscores the importance of regular preventive dental care throughout the life course.

Coordinated intervention efforts minimize the impact of oral diseases and conditions prevalent among older adults so as to improve their quality of life. A systems perspective for oral health in older adults helps to identify interventions as leverage points that are effective and cost-saving. Use of the system dynamics methodology has enabled the research team and project stakeholders to explicitly recognize, discuss and modify feedback relationships relevant to treatment of oral health among older adults. A number of reinforcing dynamics that deteriorate oral health are induced with age, and yet inadequate insurance coverage, cultural beliefs and daily routines often preclude preventive community care.

Outreach programs such as evaluative preventive screenings generate useful opportuities to share critical information between participants and public health providers seeking to mitigate deterioration of dental health. Modeling to address dental health should consider educational incentives to enhance resource capacity for dental hygienists and dentists to improve quality of life for older adults as a growing and underserved population. With the benefit of system dynamics, policymakers and program managers sharpen their sense of how to allocate resources and time interventions for improving oral health and health care for older adults. Our ongoing analysis centers on preventive screening interventions that provide a range of services including transportation, education and instruments for effective oral hygiene, and referrals for full dental treatment.

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