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Agent-Based Modeling
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Final Report

Final Report: A Spatial Agent-Based Model of Tobacco Surveillance for Empirical Investigation

Introduction

While epidemiological modeling of infectious diseases benefits from long and rigorous study, investigations and modeling of chronic illnesses that have complex relationships between individuals and their built and social environments continue to suffer from large gaps, despite calls for additional research. Tobacco use in particular has many complicated relationships between individuals and the built and social environment that are not well understood. Tobacco use is the leading cause of death in the United States, with consumption leading to multiple chronic and terminal illnesses such as cancer, heart disease, stroke, lung diseases, diabetes, and chronic obstructive pulmonary disease, which includes emphysema and chronic bronchitis, in addition to increasing risk for other diseases (Centers for Disease Control and Prevention, 2015). Triggers that challenge cessation efforts in individuals are many and complex *and also* unique to individuals, from commuting behaviors to peer-influenced environments to visual cues from tobacco marketing.

In a public health context, how is an individual practicing cessation from tobacco affected by their environment as they navigate it across space and time? How do changes in that environment, as generated by public health interventions, affect the outcomes of the individual? Public health interventions could be policies (ie. designated tobacco-free zones or strict tobacco marketing regulations), programs (ie. enrollment into cessation training), or individual-based modules (ie. mobile apps or periodic follow-ups after individual calls cessation hotline). Other interventions can be fiscal (ie. higher taxes) as well as clinical (ie. nicotine patches and medication to reduce cravings), illustrating that interventions may have very different and multiple interactions, not all incorporating a human-to-environment interaction.

To more effectively investigate influence peer and built environment effects on smoking cessation across space and time, an agent-based model was developed and implemented for empirical investigation. Smoking cessation and smoking behavior can be influenced by nearby smokers, nearby abstainers, tobacco advertising, public health initiatives, and individual traits. Analysis of these characteristics within an agent-based model provides an ideal setting to explore these relationships further.

Background

Some effects on cessation success and smoking rates are more well understood than others; taxing and certain regulations have had well measured successes, though experiences beneficial to cessation efforts derived between human-environment interaction to support cessation is less understood. Additionally, past research has suggested that as many of 80% of smokers who quit did so without formalized treatment, and that aversion and counterconditioning practices are helpful in that process (DiClemente and Prochaska 1982). For smokers who have chosen to quit, how might their environment shape their cessation processes through the day, and as they traverse across their communities?

Communities also experience tobacco differently. Marketing of tobacco is disproportionately higher in minority, low-income areas (Laws et al 2002). Mentholated brands that pose more risk to smokers, especially in cessation efforts, have a long history of targeted advertising to certain ethnic groups as well as the LGBT community. Health outcomes also are significantly different in many minority, low income areas across the United States, as much research has well documented health inequalities in the country.

Interaction modeling using agent-based methods is still new to public health research, though with promising first starts. One agent-based model looks at effects of segregation on diet choice in low income areas, underscoring the challenges of behavior change in environments that are both segregated and low income (Auchincloss et al 2011). A review in complex modeling of obesity environments found that the complex and rich environment of obesity research with multiple agents, scales, and levels of influence was well matched to agent-based modeling and other simulation environments (Hammond 2009). Tobacco research may also benefit from similar work, as it presents parallel challenges to behavior modifications that promote improved health outcomes.

There have been several agent-based models implemented and tested to evaluate various aspects of tobacco use. Simulations showing effects of smoking in enclosed spaces, specifically cars and housing units, are uploaded for interactive use at SimSmoke.org (2011). A Brookings Institute report from 2006, *Social Influences And Smoking Behavior,* multiple models are described and reviewed studying aspects of smoking behavior. Within this report, the Parker model studies the spread of smoking among teenagers, and the Axtell model considers smoking as addiction among adolescents with peer effects. Decisions to smoke are based on individual biology, individual psychology, social networks, and information (or messages). The report focuses on addictive aspects of smoking and social networks, with policy impacts focused on messaging to reduce the "forbidden fruit" epidemic influencing adolescent smokers (2006).

A more recent spatial ABM on smoking behavior considered cessation behaviors in student populations (Beheshti and Sukthankar 2014). Researchers incorporated multiple surveys of students considering different aspects of smoking behavior and beliefs (individualism, hedonism, achievement, health, and regret), and predicting smoking behavior as a transportation model to and from the campus. Advertising and no-smoking signs on the campus map were located within the model. With surveys informing the model, final ABM results were compared to additional surveys given to students throughout the year. This model raised interesting concepts in integrating individual behavior with built environment factors.

Another extensive overview of simulation modeling of tobacco control was recently published in a report to the Surgeon General (Courtney 2015). In the report, Appendix 15.1 includes multiple types of models and simulation model examples for tobacco control. Two main challenges remain for agent based models for this topic: (1) the availability of the appropriate data for populating the model and (2) the additional uncertainty associated with the stochastic nature of communication and decision-making among the agents (p. 17, Courtney 2015). Additionally, while advertising bans and media campaigns were considered in select model examples, none of the simulation models reviewed considered or compared both social and built environmental aspects within a single model. Integration of empirical data to simulated models and a deeper understanding of agent interactions between other agents and the environment remain essential to modeling effective tobacco control.

Goals and Objectives

With geo-tagged data increasingly available through self-tracking mobile devices and applications, both movement and self-recorded behavior may be available, offering insight into the dynamic behaviors and patterns of individuals across space and time. In this study, a collaboration with a clinical team at the NYU Medical School considers a large sample of data that includes geo-tags and self-recorded smoking behavior (IRB in process). While the data is not used for this phase, an exploration of social and built environment behavior among smokers is an essential first step. By framing a theoretical starting point to generate hypotheses and ground our understanding, incorporating empirical results at a later stage can be effectively compared in response.

A spatial agent-based model is thus implemented to build a conceptual model of human and environment interactions that affect cessation efforts of smokers as they navigate their environments. This agent-based model seeks to investigate the following research questions:

(i) How are smokers and the study population influenced by **peer effects** as they navigate their environment across space and time?
(ii) How are smokers and the study population influenced by aspects of the **built environment** as they navigate it across space and time?

Environmental components are abstracted into built and social environment factors, such as tobacco marketing points or designated tobacco-free-zones or clusters of smokers or dense commuting zones, and further explored to model how public health interventions may affect outcomes. The conceptual model will be later tested with a rasterized grid of an urban environment and sample data that includes paths of smokers who have expressed interest in cessation, and self-recorded locations that they smoked.

Solution Framework

A detailed description of the model following ODD protocol can be found in the Appendix.

To build on previous work in the modeling community, following a comprehensive review of relevant models, I incorporated code snippets and concepts from these models:

- Social Drinking Model (Fitzpatrick and Martinez 2011): Baseline smoking rate is determined by a distribution to mimic variability of individual rates. Satiation and craving model concepts are also utilized.
- EpiDEM Basic Model (Yang and Wilensky 2011): nearby turtles are "infected" (ie. influenced to smoke) if neighbors are smoking.

The population is made of mainly abstainers with between 5-20% smokers. The rate of smoking for the smoking population is represented with a gamma distribution with the majority having lower individual smoking rates, following that the smoking population being considered strives for cessation.

At each tick, smokers agents consider different aspects of their social and built environment, impacting their smoking rate, and then decide whether or not to smoke. The individual smoking rate gets higher if smoking agents are near other smoking agents, or near tobacco advertising (red patches), and lower if smoking agents are near abstainers or near health zones (green patches). Abstainer influence is chosen by a random number generation. The remaining influences are chosen as rate parameters indicated in a slider controlled by the user. If the smoker is satiated, they remain satiated for 10 ticks, after which they are reset to a baseline smoking rate and craving.

Model inputs are number of people, probability of abstainers in the population, influence of peers, tobacco retailers, and health zones, and sliders to create smoke and health zones. A monitor shows the number of agents on smoke and health zones. Model outputs include the percent of smokers smoking, the value and a histogram range of the mean rD rate of smokers, percent of persons smoking in the world, and hours passed.

To ensure the most effective means of interaction between agents and environment, I used a large space with many agents. The smokers leave traces (pen-down) following a grid so that their movements can be visually inspected during testing. The world is too large to inspect effectively when sized to fit the desktop window, so the final version is zoomed in and used as a backdrop to the plots and monitors. Alternatively, the user could shrink the view and inspect a patch.

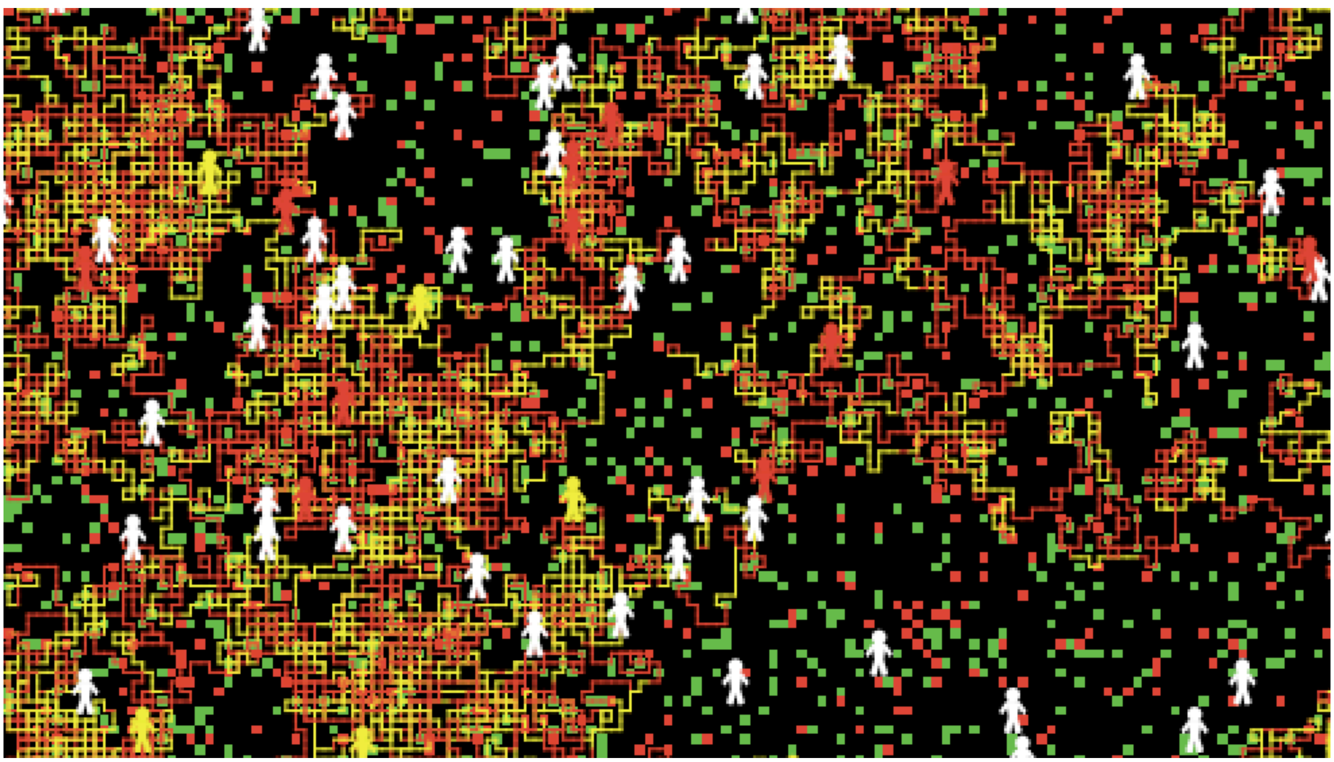

Figure 1 Snapshot of world space after model has run. Green and red patches correspond to different health or tobacco advertising zones, at different percentages. Abstainers are white. Smokers are red, and turn yellow when smoking. Final traces show red and yellow according to history of smoker behavior.

Results

I performed multiple Behavior Space simulations to test impacts of various impacts on the outcomes of the model. I used two reporters to measure impacts: mean rD (or smoking rate for smokers) and percentage of smokers smoking. In the first, simulation, I varied population size while keeping the remaining parameters constant. I wanted to see how the population or sample size may affect the outcome. The results are as follows:

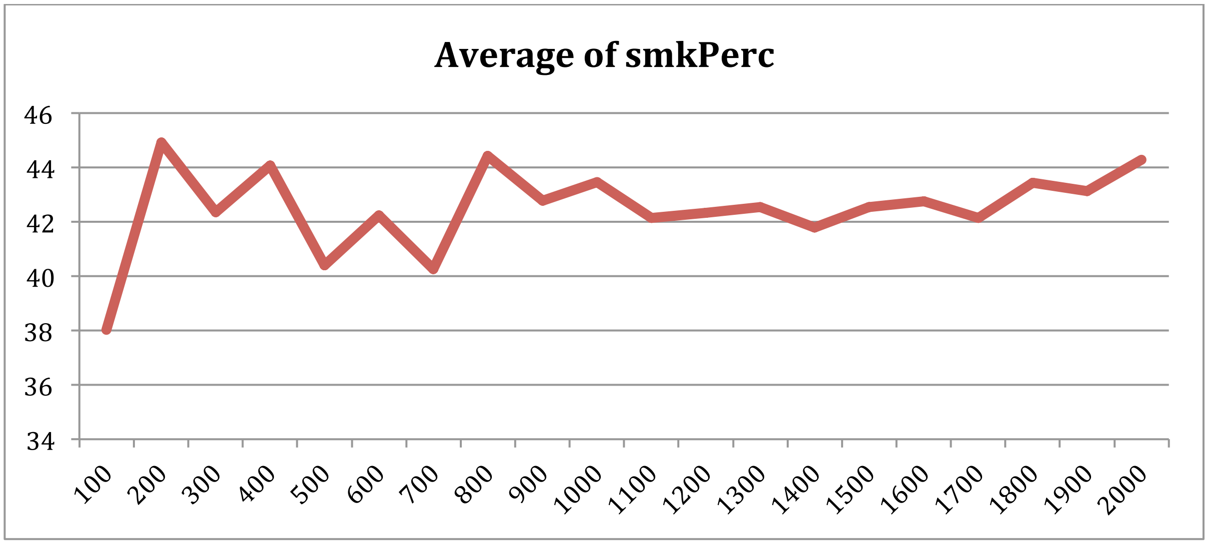

Figure 2 Population Size vs. % Smokers Smoking. (10 repetitions, 1000 ticks, 210 runs)

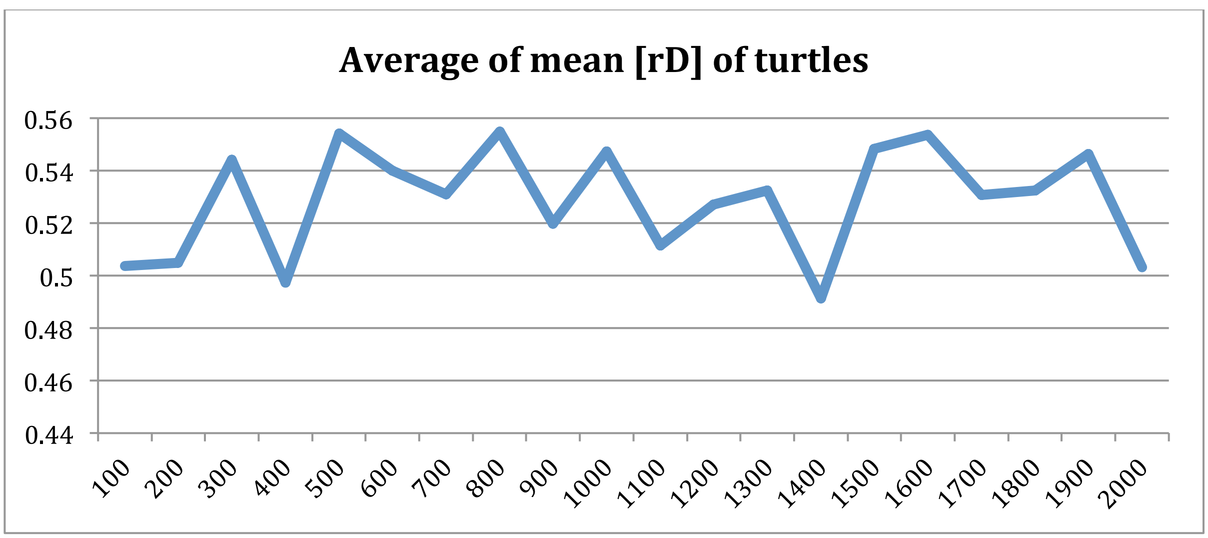

Figure 3 Population Size vs. Average Smoking Rate . (10 repetitions, 1000 ticks, 210 runs)

The average percentages of smokers smoking evens out after about 1,100 persons. The mean rD or smoking rate of individual smokers doesn't seem too be affected too much by the population size. From these results, I chose 1,500 persons as a baseline for following simulations.

In the next simulation, I vary influence parameters (peer pressure, advertising pressure, and health zone pressure) to investigate how different pressures affect smoking rate outcomes.

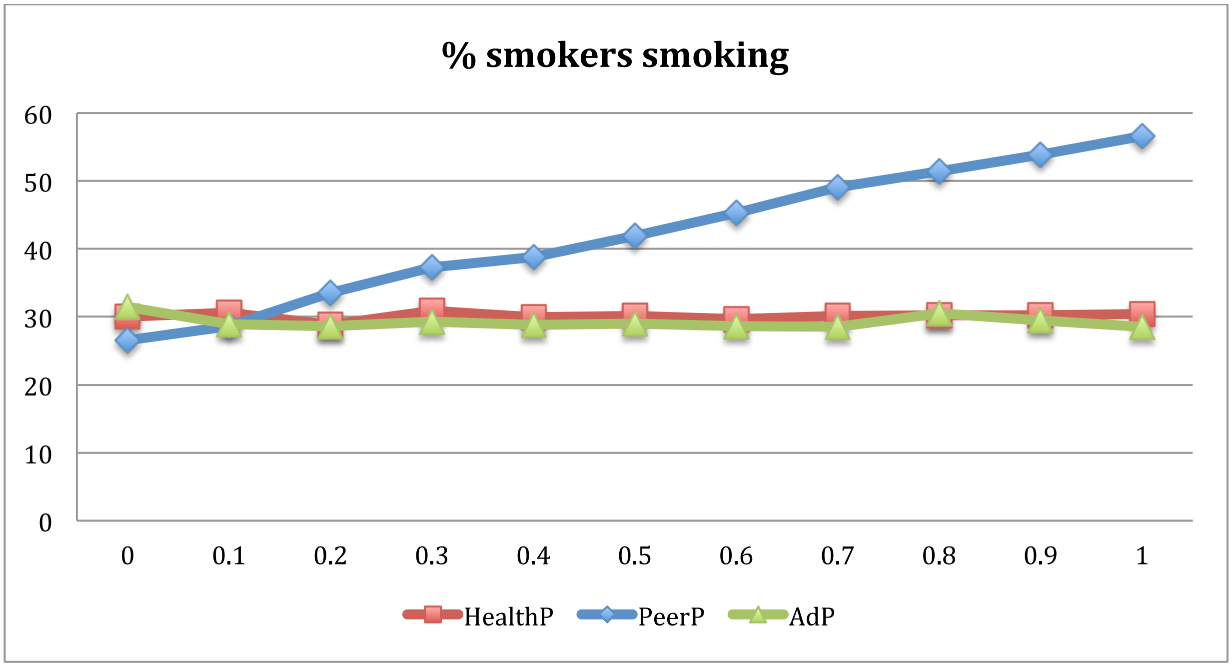

Figure 4 Influence parameters set to 0.1 when not tested. 10 repetitions, 500 ticks, 1500 persons, 0.8 pA

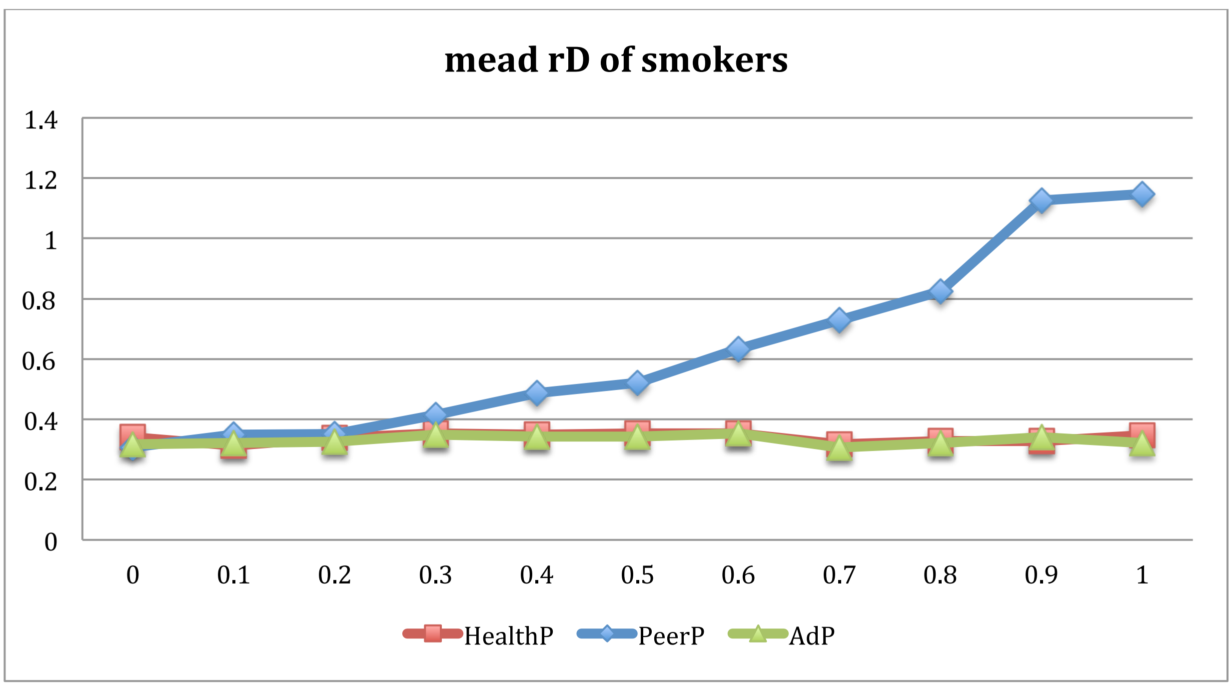

Figure 5 Influence parameters set to 0.1 when not tested. 10 repetitions, 500 ticks, 1500 persons, 0.8 pA

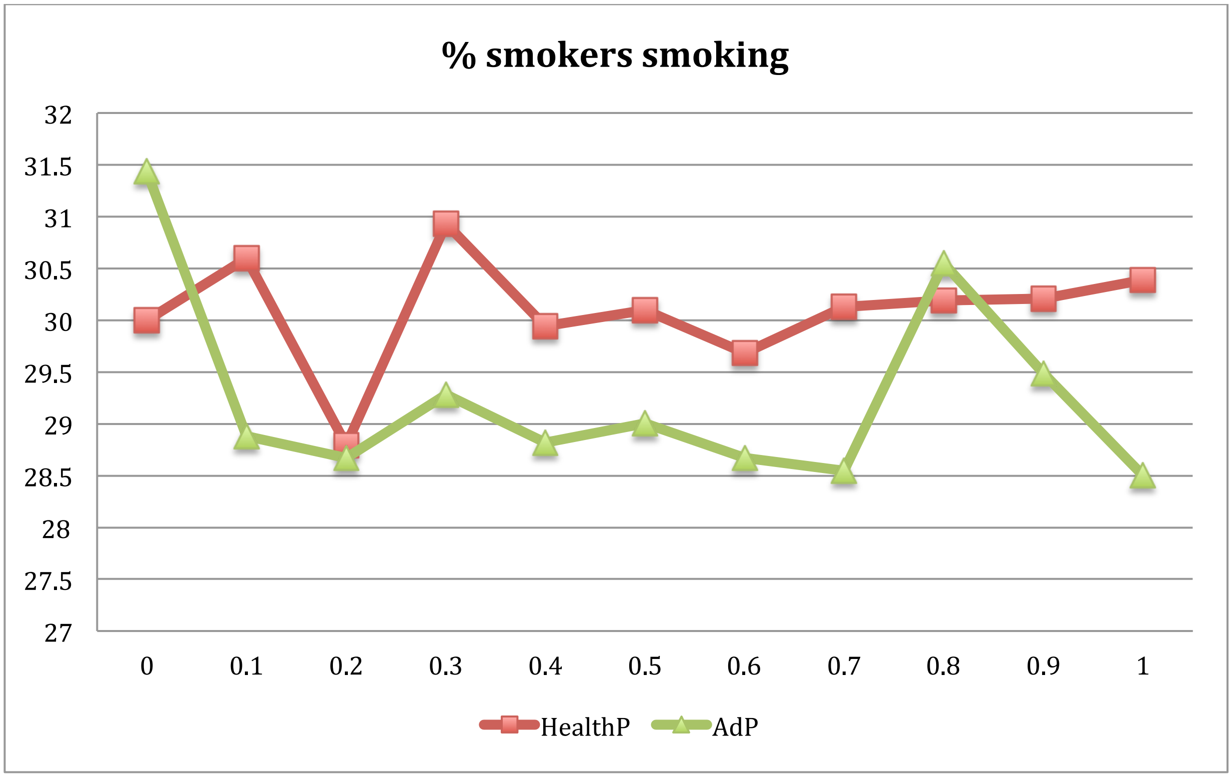

Figure 6 Influence parameters set to 0.1 when not tested. 10 repetitions, 500 ticks, 1500 persons, 0.8 pA

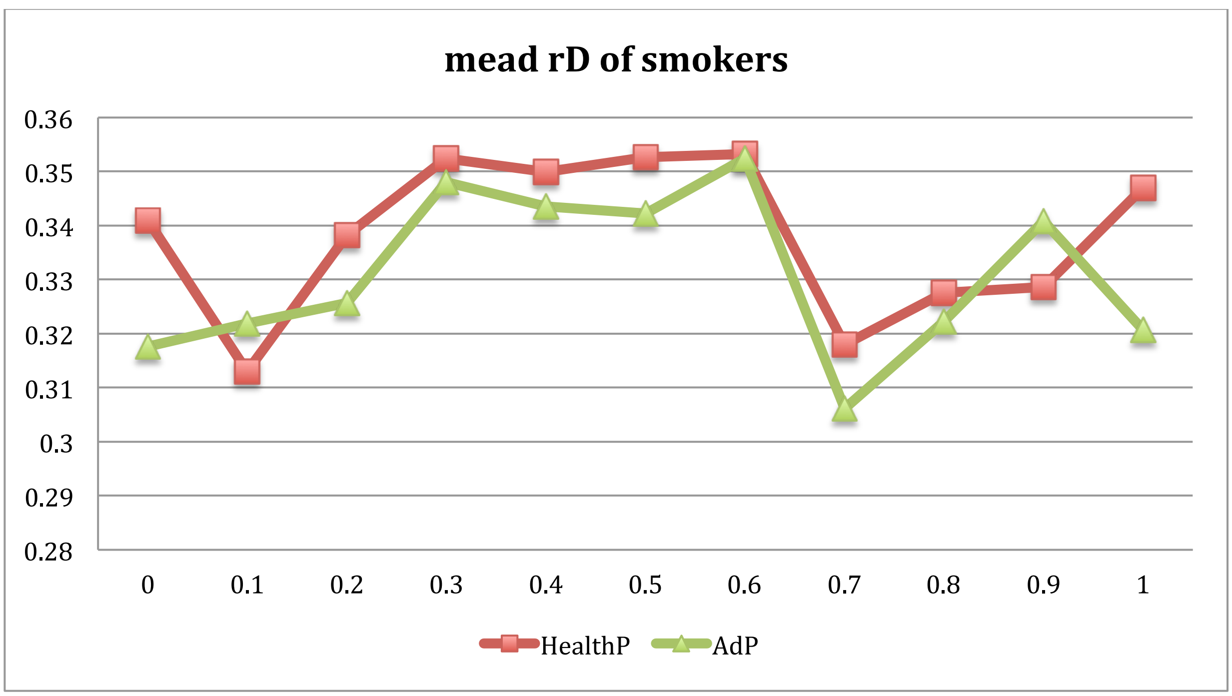

Figure 7 Influence parameters set to 0.1 when not tested. 10 repetitions, 500 ticks, 1500 persons, 0.8 pA

Finally, I run a simulation for starting the world with different proportions of red and green patches, corresponding to tobacco-advertising (or pro-smoking) and tobacco-free (or health) zones. The total percentage of both these can only add up to ten percent of the world space, though the user can choose how many each exists in proportion. The first set looks at influence of Health Zones (green patches) on smoking rates and smoking behavior:

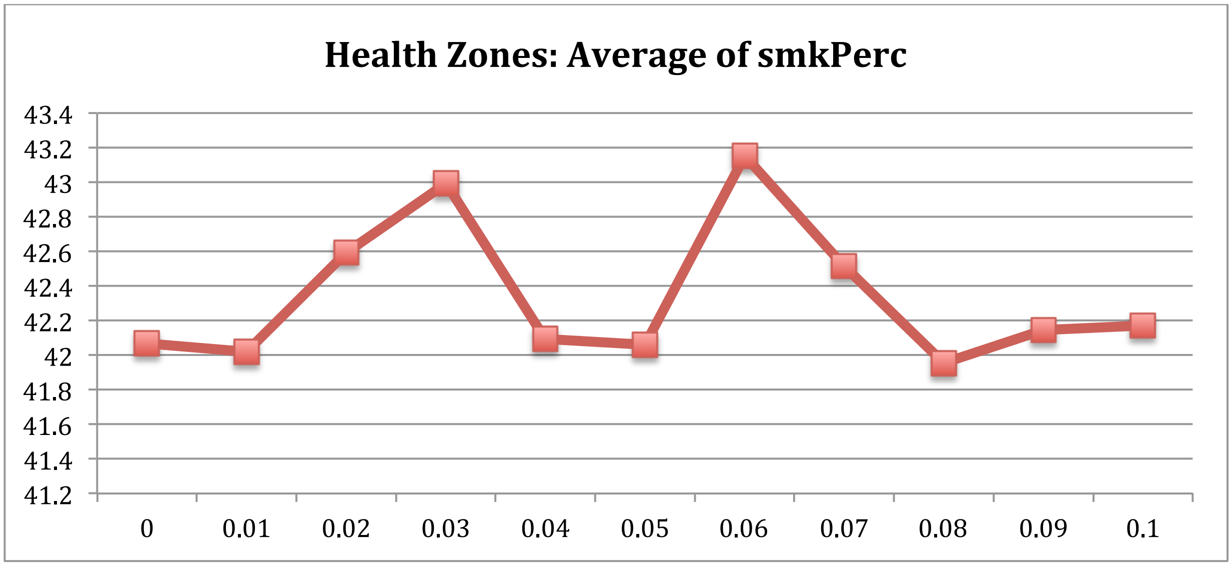

Figure 8. Variation of Health Zone patch percentage at the setup of the model. Other parameters of BehaviorSpace are Number of people: 1500, pA=0.8, adP=0.6, healthP=0.6, peerP=0.5, SmokeZone=0.1

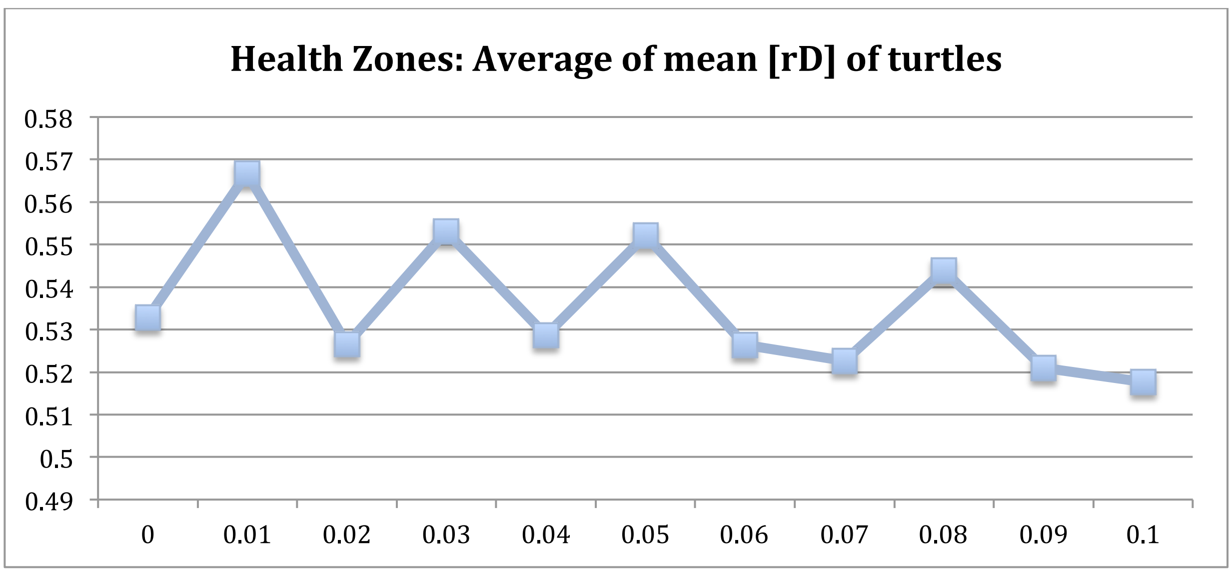

Figure 9 Variation of Health Zone patch percentage at the setup of the model. Other parameters of BehaviorSpace are Number of people: 1500, pA=0.8, adP=0.6, healthP=0.6, peerP=0.5, SmokeZone=0.1

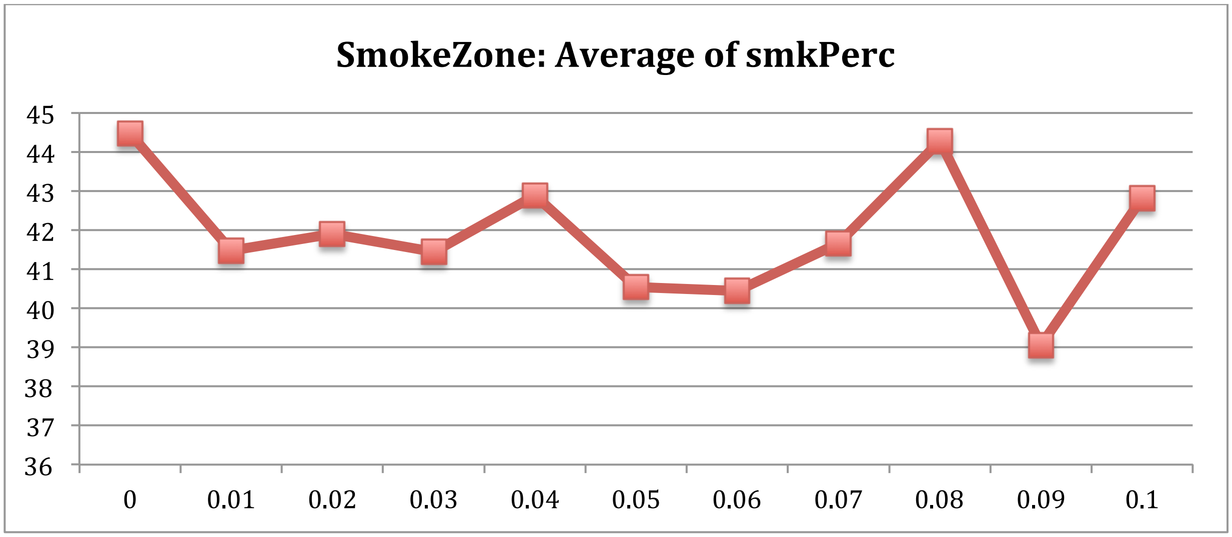

Figure 10. Variation of Smoke Zone patch percentage at the setup of the model. Other parameters of BehaviorSpace are Number of people: 1500, pA=0.8, adP=0.6, healthP=0.6, peerP=0.5, HealthZone=0.1

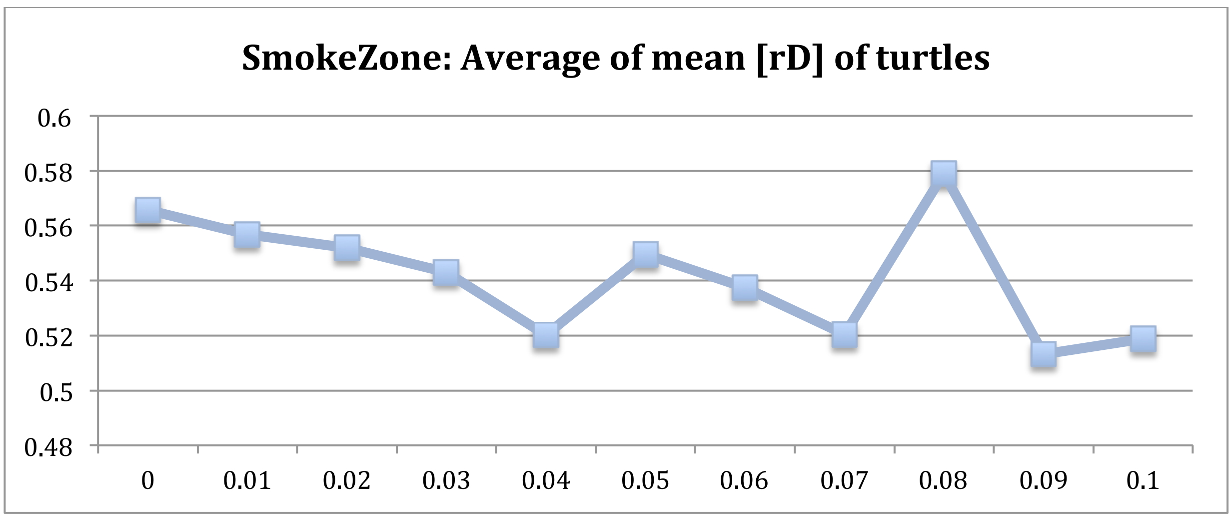

Figure 11. Variation of Smoke Zone patch percentage at the setup of the model. Other parameters of BehaviorSpace are Number of people: 1500, pA=0.8, adP=0.6, healthP=0.6, peerP=0.5, HealthZone=0.1

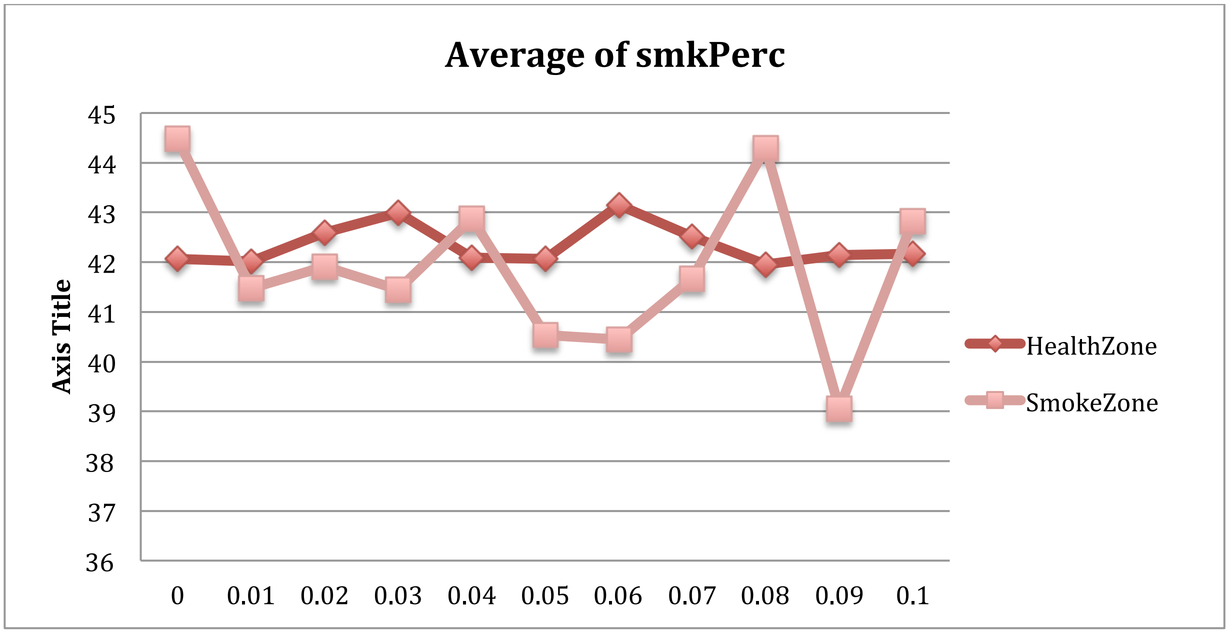

Figure 12. Includes both datasets from above zone starting parameter figures.

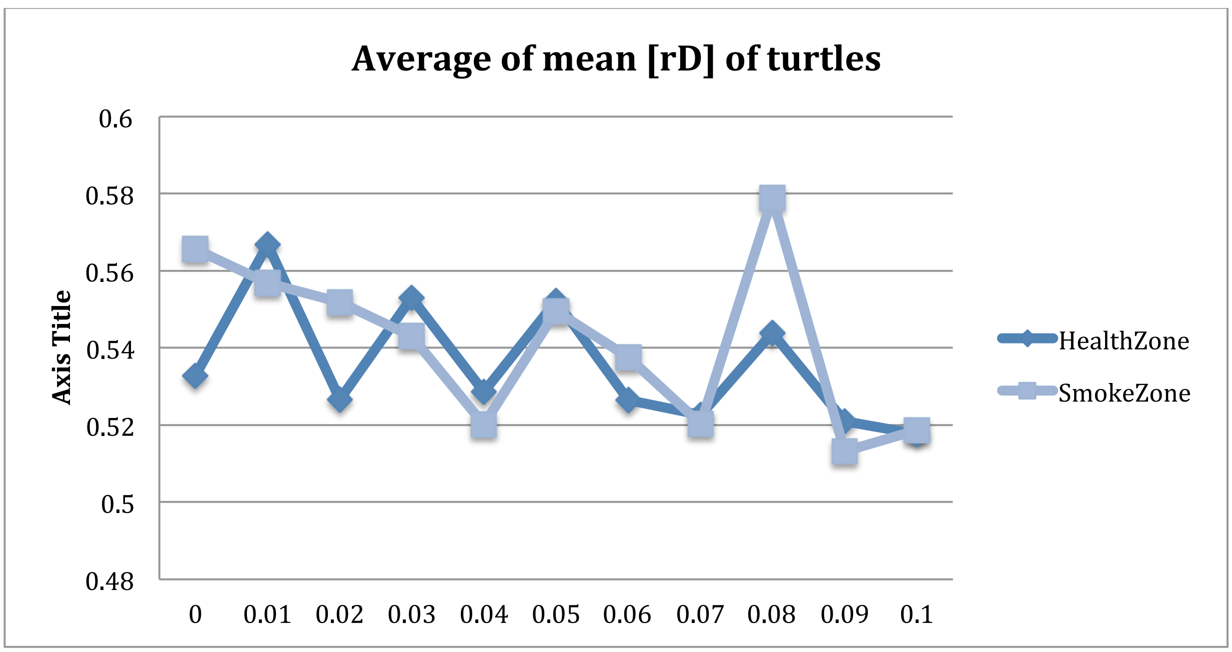

Figure 13 Includes both datasets from above zone starting parameter figures

Discussion

In the first section of the results, an increase in the number of persons in the world made a distinct impact in smoking behavior overall. After about 1,100 persons were initialized in the world, the smoking rate remains high and relatively level. This suggests that more dense environments increase probability of smokers interacting with each other, and so influence as a support or peer pressure will impact the population as there is a greater chance of being within a radius of someone else. Relating this finding to our research questions, the model suggests that **increased population density influences smoking behavior.** After a threshold is reached, it increases slightly and then levels off.

Next, several influences were considered and reported in the results section. When considering peer pressure, **there is a proportional relationship in increasing the influence factor of peer pressure and how many smokers choose to smoke,** even when smoking rates level off. Peer influence affected smoking rates more than any other influence considered, furthermore, with rates reaching nearly 60% of smokers smoking within the model (as compared to a base rate of about 42% from the population BehaviorSpace simulation).

When considering the influence of health and smoke zones by fluctuating rate parameters healthP and adP, and likewise adjusting proportions of initialized pixels with SmokeZone and HealthZone, trends were less clear. Peer pressure clearly had more of an impact, though there seems to be a technical reasoning behind the lack of effective influence of these zones. For example, while highest rates correspond to a few smoke zone areas, the health zone seems to influence more smoking in the population overall than the smoke zone in some Behavior Space results (see figures 4 through 7). Additional testing and debugging is required. Perhaps this was due to the transportation aspect of the population. Agents do not travel far, and wander in paths that do not stretch great distances. This may prevent interaction with patches across the space.

Regardless of additional testing and troubleshooting to be done, it is clear that **population density, population movement, and built environment factors all impact smoking behavior in differing ways**. I was surprised to see the density impact behavior at a certain threshold, and further surprised to see how important individual locomotion through the space can change relationships with both peer interaction and environmental impact. While preliminary, the model demands additional consideration when considering the complex relationships of social and built environment in population smoking behaviors.

Appendix

ODD Protocol

Overview

Purpose

This spatial agent-based model builds a conceptual model of human and environment interactions that affect cessation efforts of smokers as they navigate their environments. This agent-based model seeks to investigate how smokers and the study population are influenced by peer effects and aspects of the built environment as they navigate it across space and time.

Environmental components are abstracted into built and social environment factors, such as tobacco marketing points or designated tobacco-free-zones or clusters of smokers or dense commuting zones, and further explored to model how public health interventions may affect outcomes.

Entities, state variables, and scales

The model has two kinds of entities: persons and zones. Persons are abstainers or smokers, and smokers have different rates of smoking with most having low rates (or seeking to quit). Zones correspond to patch variables that are either green or red, and serve as abstractions of a built environment. Green patches correspond to "health zones" or areas that influence cessation efforts, and red patches correspond to "smoke zones" that influence smoking. Locations of both agents and patches are randomly places in the model. There may be up to 2000 agents. Up to ten percent of patches can be either red and/or green, depending on the slider selection. Temporal aspects of the model correspond to approximately a minute per tick, with cravings reset after ten ticks (or ten minutes). A condensed overview is as follows:

Agents:

- Individuals (that smoke >5 cigarettes a day, have expressed interest to quit, with phone)
- Environment (abstractions of built and social environment)

Actions:

- Smoke
- Do not smoke

Individual-Environment interactions across space and time, with outcome testing:

High risk of relapse/smoking:

- Storefront tobacco advertising (built environment)
- Nearby individuals are relapsing/smoking (social environment)

Low risk of relapse/smoking:

- Designated tobacco-free zones (built environment)
- Anti-tobacco marketing (built environment)

Landscape:

- Representation as 2D Euclidean space with different types/patches:
  - Tobacco vendors, high risk marketing (single red pixel)
  - Anti-tobacco marketing, low risk (single green pixel)
  - Tobacco-free zones (multiple red pixels)
  - Green spaces, such as parks (multiple green pixels)

Process overview and scheduling

For every tick, smokers go through the following process. First, the decay rate for craving is increased by one. Then, the go through multiple influences: support of nearby abstainers (reduce craving); peer-pressure of nearby smokers (increase craving); peer-pressure of tobacco advertising (increase craving); and support of health zones or public health advertising (decrease craving). Then, if smoker is craving, they make a decision to smoke or not. After several ticks or 10 minutes and not smoking, the smoker will start craving and have their rate reset. This process is repeated until 1440 ticks are reached, and then the model is stopped.

```
to go
  if ticks > 1440 [stop]

  ask turtles with [rD > 0.0]

     [set decays decays + 1

      support

      peer-pressure

      advertiseSmoke

      noSmokeZone

      if satiation? = 0              ;; if craving,
make a decision
      [  decide  ]

      if decays > maxdecay          ;; after 10
minutes, start craving
        [ set satiation? 0
          set rD random-gamma 2 0.25
          set color red
          set decays 0] ]
```

```
        ask turtles [ walk2 ]
      tick
    end
```

Design Concepts

Basic principles

This model specifically tests aspects of two effects: social and built environment influence on smoking behavior. It seeks to answer: (i) how are smokers and the study population influenced by peer effects as they navigate their environment across space and time? and (ii) how are smokers and the study population influenced by aspects of the built environment as they navigate it across space and time?

Adaptation

Individuals can respond to changes in the environment based on social and spatial components; once craving, nearby agents and friends influence their decision to go out smoking or not.

Sensing

In this model, agents who are smokers can sense agents that are nearby. The nearby agents behavior, whether smoking or abstaining, can influence the agent's willingness to smoke. In addition, the agent can also sense aspects of their patch and nearby patches that may have positive or negative messaging that would impact their smoking decision. After assessing neighboring agents and patches, the agent decides on whether or not they should smoke.

Interaction

Interaction between agents influences their smoking behaviors. Interactions between patches and agents, following their movement through the environment, can also impact agent behavior. Interactions occur at minute-level scales as agents walk through the space.

Details

Intitialization

Data is initialized to the following parameters:

number-people	number of agents	1500	*above 1100 recommended*
pA	probability that individual abstains from smoking	0.80	*0.75-0.95 recommended*
peerP	rate parameter affecting influence of nearby smokers	0.5	
adP	rate parameter affecting influence	0.5	

	of nearby advertising	
healthP	rate parameter affecting influence of nearby healthy zones	0.5
SmokeZone	proportion of red patches (abstracted) that increase smoking behavior	0.05
HealthZone	proportion of green patches (abstracted) that decrease smoking behavior	0.05

Input Data

In this phase, no input data is included for the model. A more advanced model will incorporate geotagged transects through a rasterized city grid, as a comparison to the simulated data.

Submodels

There are multiple submodels, summarized as follows:

Social Network

Within a tick, agents have a decision to smoke or not, depending on their satiation score and unique smoking rate. They can be influenced by peer pressure of those smoking around them, or to not smoke by being near abstainers. This influence contributes to their unique smoking rate.

Advertising Influence

Agents can also be influenced to smoke by aspects of the built environment that may encourage them to smoke, such as (abstracted) media campaigns or retail stores. This influence contributes to their unique smoking rate by increasing it.

Health Zone Influence

Agents can alternatively, or additionally, be influenced to not smoke by aspects of the built environment that may encourage them *not to smoke*, such as (abstracted) smoke-free zones or public health advertising. This influence contributes to their unique smoking rate by decreasing it.

Walking Mode

While preliminary, various forms of simulated walking are included in the model for further analysis. There are three forms of random walking through the space, with two versions of each, one moving a single step in a tick, and the other moving 10 steps to show increased speed in travel. These form the basis for future study in how transportation through the environment affects smoking behavior as agents interact with the built environment differently depending on transportation mode.

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