*Proceedings of the 2015 Winter Simulation Conference*
*L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.*

# SIMULATING SMOKING BEHAVIORS BASED ON COGNITION-DETERMINED, OPINION-BASED SYSTEM DYNAMICS

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## ABSTRACT

We created a cognition-focused system dynamics model to simulate the dynamics of smoking tendencies based on media influences and communication of opinions. We based this model on the premise that the dynamics of attitudes about smoking can be more deeply understood by combining opinion dynamics with more in-depth psychological models that explicitly explore the root causes of behaviors of interest. Results of the model show the relative effectiveness of two different policies as compared to a baseline: a decrease in advertising spending, and an increase in educational spending. The initial results presented here indicate the utility of this type of simulation for analyzing various policies meant to influence the dynamics of opinions in a population.

## 1 INTRODUCTION

The investigation of health-related behaviors using simulation and analysis is a growing field that integrates behavioral, epidemiological, and computational research. Studies on smoking behavior are of particular interest due to tobacco's large impact on public health. Smoking is linked to a large number of diseases, and has contributed to at least 20 million premature deaths in the United States since 1964. A variety of government programs have been implemented to reduce smoking rates. These rates have dropped substantially in the last 50 years, but almost 42 million American adults and 3.5 million adolescents continue to smoke (U.S. Department of Health and Human Services 2014).

This project looked at the dynamics of smoking tendencies as determined by media influences and communication of opinions. Evidence suggests that peer influence (Kobus 2003) and advertisement (Durkin et al. 2009; Lovato et al. 2003) play major roles in determining smoking rates. We created a system dynamics model of smoking behavior loosely based on a Moore et al.'s (2001) SnapDragon model, an opinion dynamics model that simulates attitudes about smoking. Opinion dynamics models like this one do not generally include detailed assessment of the cognition driving these dynamics. We posit here that the dynamics of attitudes about smoking can be more deeply understood by combining opinion dynamics with more in-depth psychological models that explicitly explore the root causes of behaviors of interest.

To approach this problem we used the Behavioral Influence Assessment (BIA) framework, a cognition-oriented system dynamics modeling approach for simulating decision making and interactions among individuals, groups, and their environments. We simulated communication among groups, as well as media influences on those groups and on their communication tendencies. Initial results are used to indicate the potential effect on smoking rates of different spending rates for pro- and anti-smoking media.

## 2 THE BEHAVIORAL INFLUENCE ASSESSMENT SMOKING MODEL

To simulate smoking behavior, we use a cognition-oriented system dynamics approach with a static population split into three stocks: people who have never smoked, current smokers, and former smokers (figure 1). Each group is modeled in aggregate. People can move between these stocks through the initiation (never smokers becoming current smokers), cessation (current smokers becoming former smokers), and relapse (former smokers becoming current smokers). Opinions about smoking, decisions about whether to smoke, and communication between and within groups are based on communication of negative and positive opinions about smoking from each group, as well as influence from both pro-smoking media (advertising) and anti-smoking media (educational).

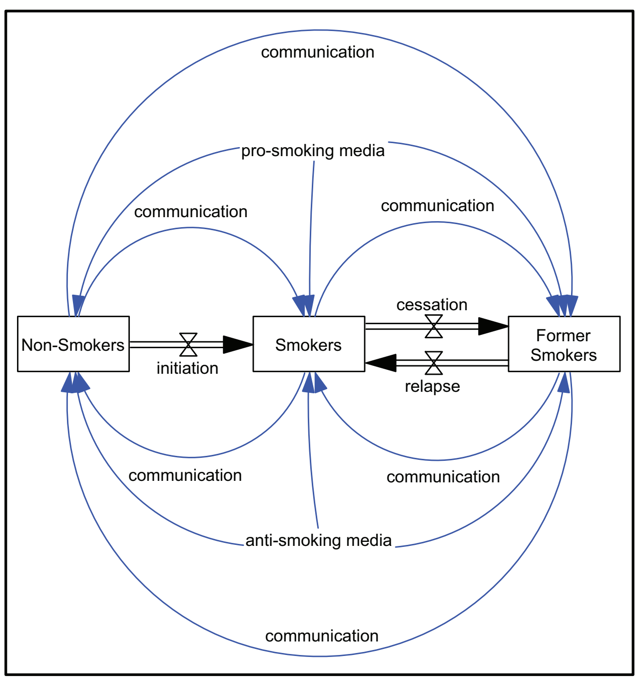


Figure 1: Basic model structure.

The decision calculus is completed using the Behavioral Influence Assessment (BIA) framework (Backus et al. 2010). BIA is a system dynamics-based modeling framework for simulating systems that involve human behavior and decision making. The theoretical framework of the BIA is based on well-established psychological, social, and economic theories that have been incorporated into a single structure (figure 2) that is both self- consistent and dynamic. Details can be found in Backus et al. (2010). BIA uses a hybrid cognitive-system dynamics architecture. Cognitive models are implemented using system dynamics and embedded into an encompassing system dynamics model, which simulates interactions between people, groups, and physical, economic, or other system components.

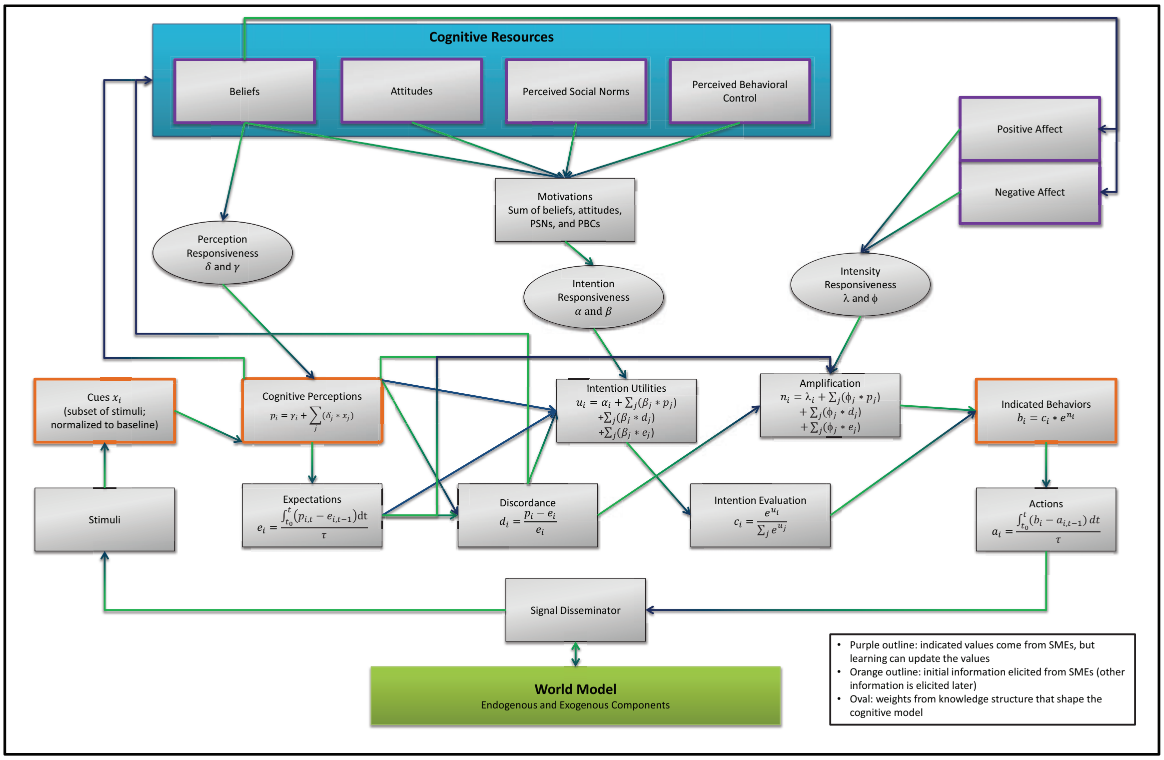


Figure 2: Behavioral Influence Assessment framework

The cognitive portion of the BIA begins with individuals or groups being exposed to cues (stimuli relevant to the decision-maker). These cues are processed to create cognitive perceptions, the decision-maker's assessment of the world or situation. Over time, cognitive perceptions become expectations, which are compared to cognitive perceptions to determine discordance with the current situation. Intentions are calculated using utility functions, and a multinomial logit function (McFadden 1982) compares intentions to determine realized behaviors, which over time become realized actions.

One of these cognitive models is populated for each individual or group being included in the system. These cognitive models are connected to each other and to a world model sector using system dynamics. The world model sector includes all of the non-cognitive components of the system of interest, including physical systems, economics, etc. Outputs from the world model and the cognitive models act as inputs, or stimuli, for the cognitive model in subsequent time steps.

The model described here simulates smoking and related behaviors in a static population. This can be thought of as a cohort model: the people in the group remain the same, with no people entering or exiting the system. Each of the three groups (never smokers, current smokers, and former smokers) decides whether and how much to communicate both negative and positive opinions about smoking. Further, never smokers can decide to start smoker, current smokers can decide to quit, and former smokers can decide to relapse. To make these decisions, each group considers communication from all three groups, the fraction of the cohort represented by each group and moving between groups, and communication from pro- and anti-smoking media.

## 3 ILLUSTRATIVE MODEL RESULTS

This model is not final, but illustrative results shown here can help to illustrate the potential for a model such as this one. These results show our assessment of the effects of within- and between-group communication and of pro- and anti-tobacco media campaigns on rates of initiation, cessation, and relapse. The cognitive component of the model allows us to assess which aspects of cognition are important in determining these dynamics, and allows a more detailed determination of why opinion dynamics occur as they do.

The model simulates a static population of 1000 people, and uses the exogenous spending rates based on historical spending (Campaign for Tobacco-Free Kids 2015; Creamer 2012) as a starting point for communication by pro- and anti-smoking media (figure 3). An initial calibration of the model is described here. This calibration can be improved, and should not be considered final.

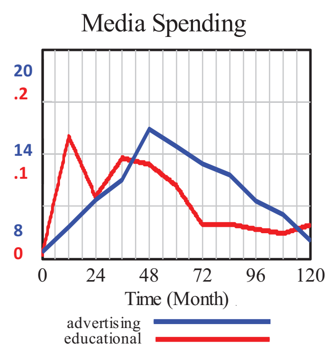


Figure 3: Media spending.

Results from the based case simulation are shown in figure 4. While current smokers and former smokers increase over time, the never smokers drops substantially. This is to be expected, since the cohort structure of the model does not add new people to the simulation, so the never smokers stock cannot grow. Positive and negative communication about smoking is shown, and is based on the cognitive model described above. The utility of positive communication and negative communication about smoking are also shown. These can utilities can be interpreted as general attitudes about smoking. When the utility of positive communication about smoking is high, the group in question has generally high positive opinions about smoking. When the utility of negative communication about smoking is high, the group has more strongly negative opinions about smoking.

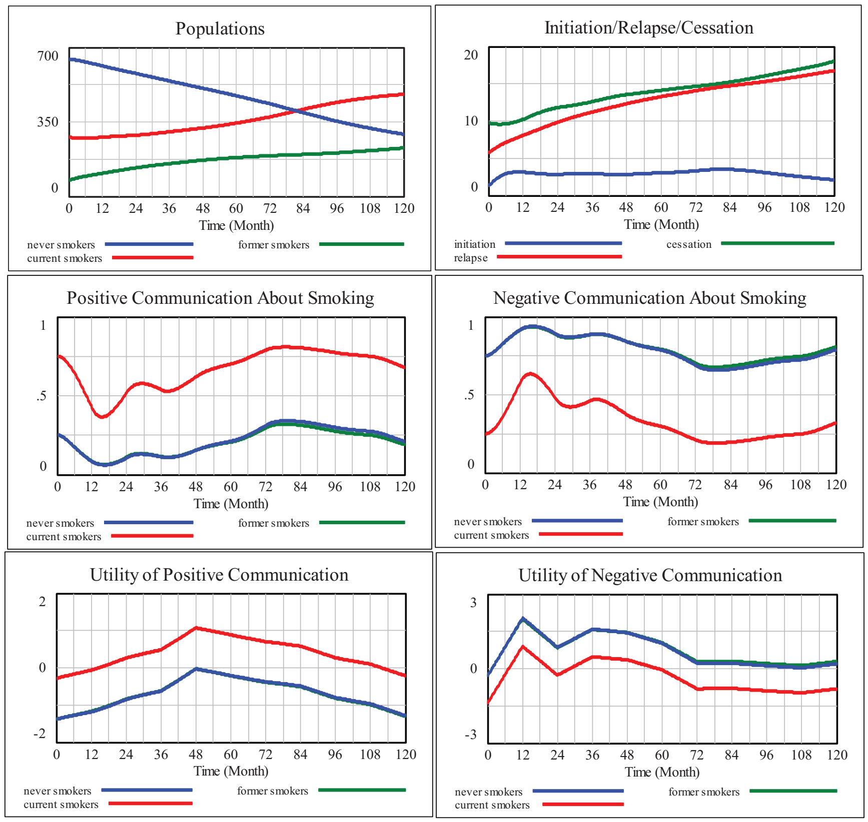


Figure 4: Base case simulation.

Figure 5 shows a simulation in which advertising (pro-smoking media) spending is cut in half. The change takes place at month 24, with all spending after that month half of what is shown in figure 3. Compared to the base case simulation, the advertising cut simulation results in fewer smokers and more never smokers. Positive communication about smoking drops substantially compared to the base case, and negative communication about smoking is visibly higher. While the utility of negative communication about smoking stays about the same as the base case, the utility of positive communication about smoking, which can be interpreted as positive attitudes about smoking, drops very significantly.

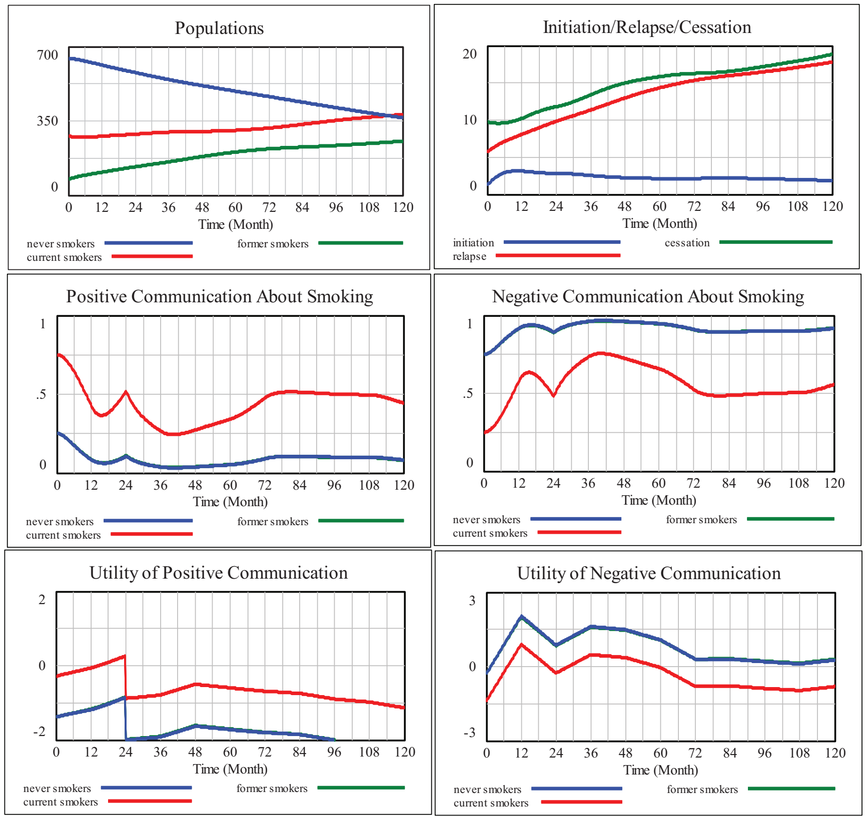


Figure 5: Advertising spending cut in half.

The final simulation discussed here, shown in figure 6, changes educational spending to be increased by half as compared to the base case in month 24. Note that educational spending is substantially less than media spending through all of the simulations, and that this increase is less substantial than the cut to advertising in the previous simulation. While not quite as dramatic as the previous simulation, the number of current smokers drops and never smokers increases as compared to the base case. Positive communication about smoking decreases and negative communication about smoking increases as compared to the base case. The utility of negative communication, which we use as a proxy for negative attitudes about smoking, is higher than in the base case for all groups.

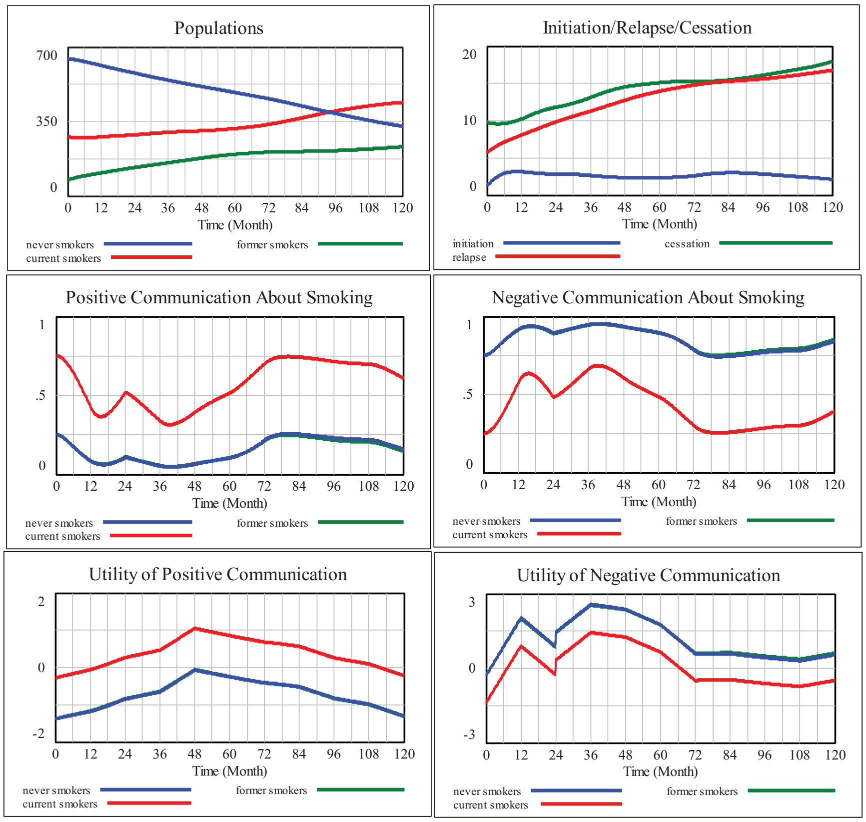


Figure 6: Educational spending increased by half.

## 4 CONCLUSIONS

This project looked at the dynamics of smoking behaviors in a static population. We emphasized the dynamics of opinions, but rather than using a typical opinion dynamics model, we used a detailed cognitive model that allowed explicit simulation of the root causes of various behaviors. To implement the model, we used a cognition-oriented system dynamics approach called Behavioral Influence Assessment. Results showed relative effectiveness of two different policies as compared to a baseline: a decrease in advertising spending, and an increase in educational spending. Both of these policies resulted in reduced smoking rates in the model.

These results should be caveated. First, this is an initial calibration, and can be improved with further data and expert elicitation. Second, the two scenarios are comparing multiplicative changes to substantially different spending rates. Base case advertising spending is substantially higher than base case educational spending. The higher decrease in smoking in the advertising cut scenario is thus not an indication that cutting advertising spending is more effective than increasing educational spending. Further analysis would be needed to directly compare these two types of policies, and to fully understand the likely effects of specific reductions or increases in media spending.

This model represents a very simple case, with a static population with no interaction with outside groups except through media. Regardless, the initial results shown here indicate the utility of this type of simulation for analyzing various policies meant to influence opinion dynamics in a population. The inclusion of cognition in this system dynamics model allowed for understanding of opinion, communication, and behavior, as well as assessment of how each of these might change under different policy or other scenarios. This gives a deeper understanding of why a policy might be effective than traditional opinion dynamics might give. Future work should be done to compare the results of these two types of models (cognition-oriented system dynamics and opinion dynamics), and to assess the potential for combining these paradigms to create deeper understanding of potential effectiveness of policies of interest.

## REFERENCES

Backus, G., M. Bernard, S. Verzi, A. Bier, and M. Glickman. 2010. "Foundations to the Unified Psycho-Cognitive Engine." SAND2010-6974, Sandia National Laboratories, Albuquerque, New Mexico.

Campaign for Tobacco-Free Kids. 2015. Trends in Tobacco Industry Marketing. Accessed July 9, 2015. http://www.tobaccofreekids.org/research/factsheets/pdf/0156.pdf.

Creamer, M. 2012. Anti-Smoking Campaigns Work, So Don't Quit Now*ge*. Accessed July 9, 2015. http://adage.com/article/news/funding-anti-tobacco-ads-fell-quitting-rate/232111/.

Durkin, S. J., L. Biener, and M. A. Wakefield. 2009. "Effects of Different Types of Antismoking Ads on Reducing Disparities in Smoking Cessation Among Socioeconomic Subgroups". *American Journal of Public Health.* 99 (12): 2217-2223.

Kobus, K. 2003. "Peers and Adolescent Smoking". *Addiction*. 98 (1): 37-55.

Lovato, C., G. Linn, L. F. Stead, and A. Best. 2003. "Impact of Tobacco Advertising and Promotion on Increasing Adolescent Smoking Behaviours". *Cochrane Database System Review.* 2003 (4): 1-45.

McFadden, D. 1982. Qualitative Response Models. In *Advances in Econometrics*, edited by Werner Hildenbrand, Cambridge University Press, New York.

Moore, T. W., P. D. Finley, J. M. Linebarger, A. V. Outkin, S. J. Verzi, N. S. Brodsky, D. C. Cannon, A. A. Zagonel, and R. J. Glass. 2011. "Extending Opinion Dynamics to Model Public Health Problems and Analyze Public Policy Interventions". SAND2011-3189C, Sandia National Laboratories, Albuquerque, New Mexico.

U.S. Department of Health and Human Services. 2014. "The Health Consequences of Smoking – 50 Years of Progress: A Report of the Surgeon General". Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health.

## ACKNOWLEDGEMENTS

This research was possible in part by funding from the United States Department of Defense. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly-owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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