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Compartmental Models in Tobacco Control Research

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Projecting Future Smoking Rates

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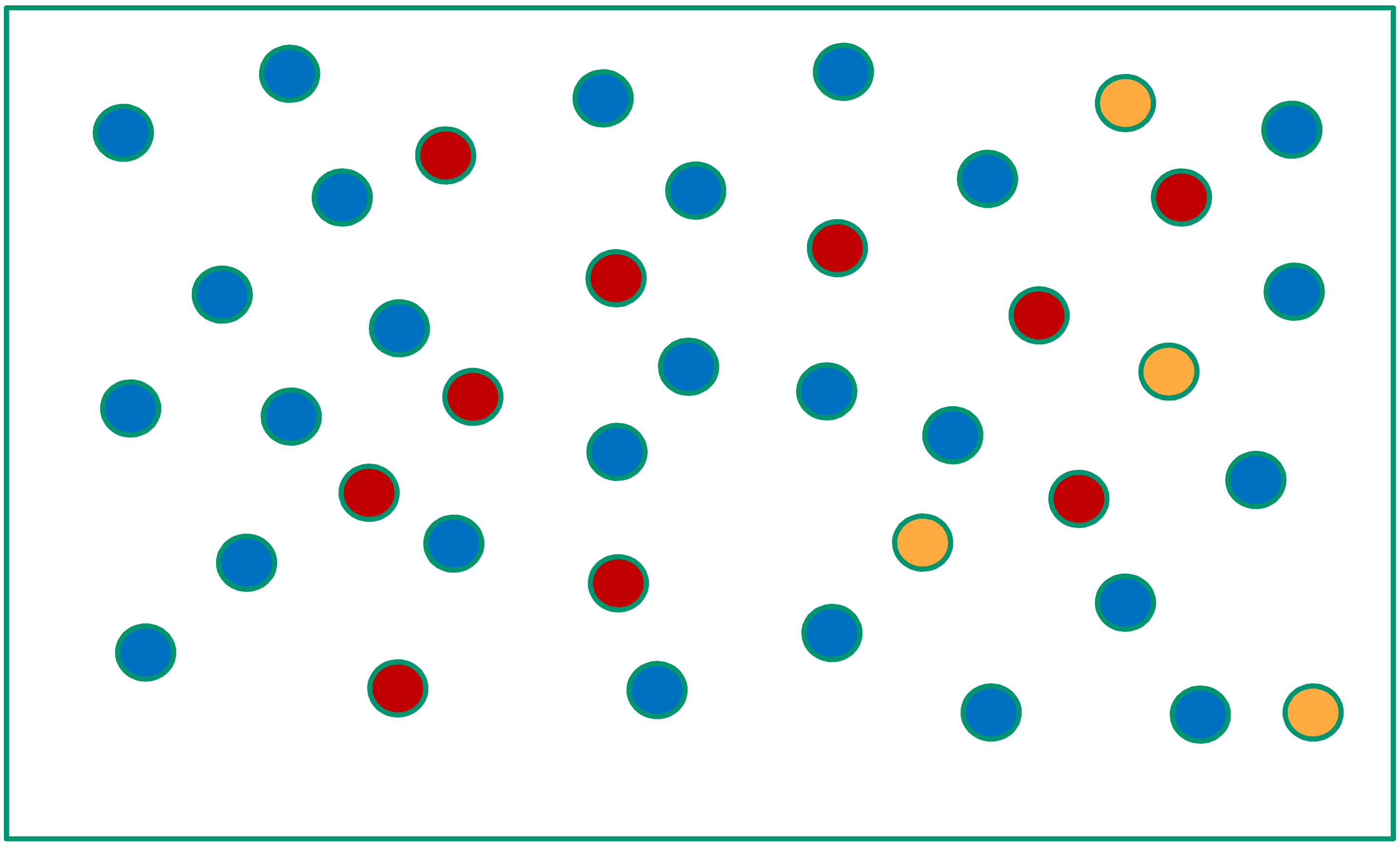
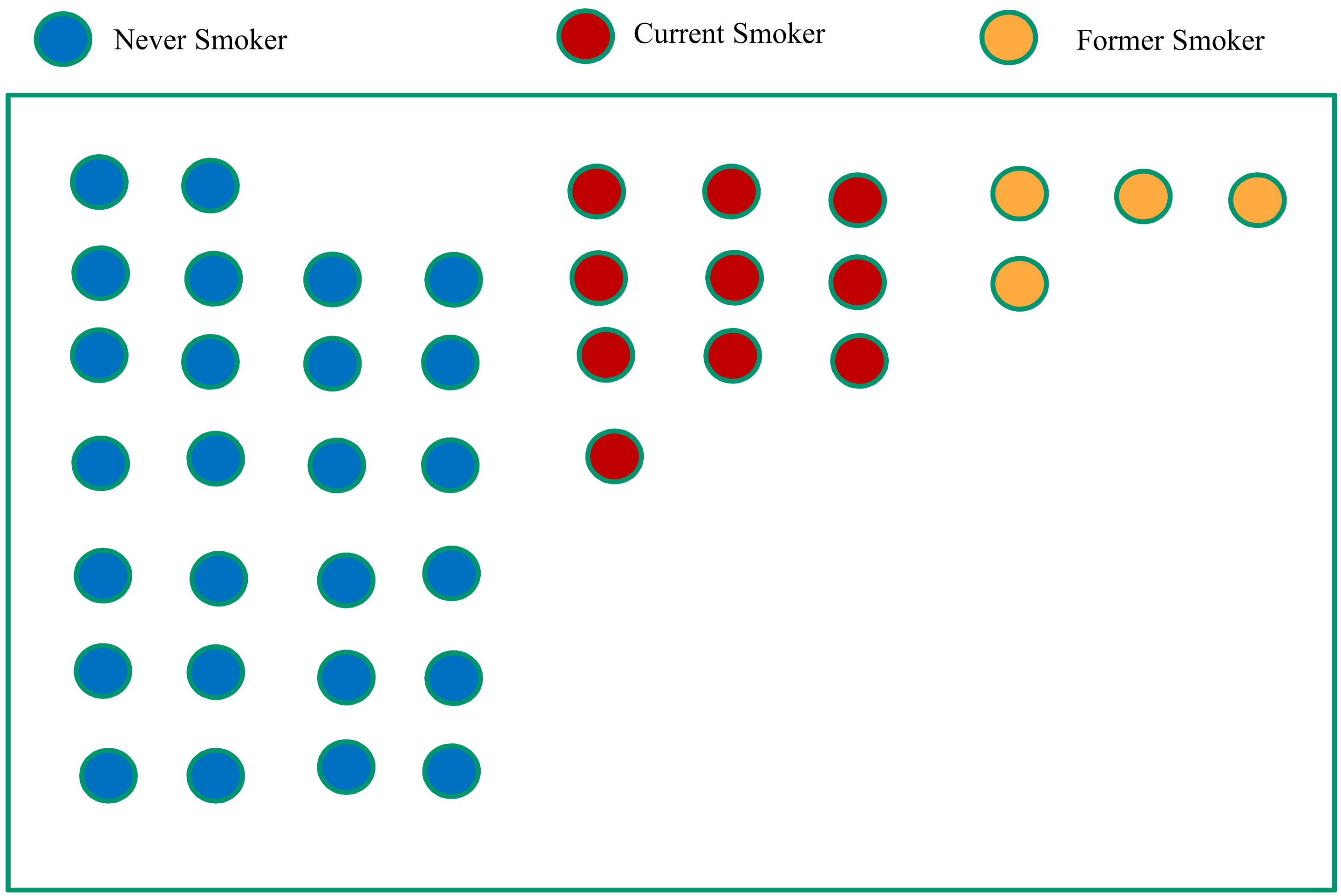
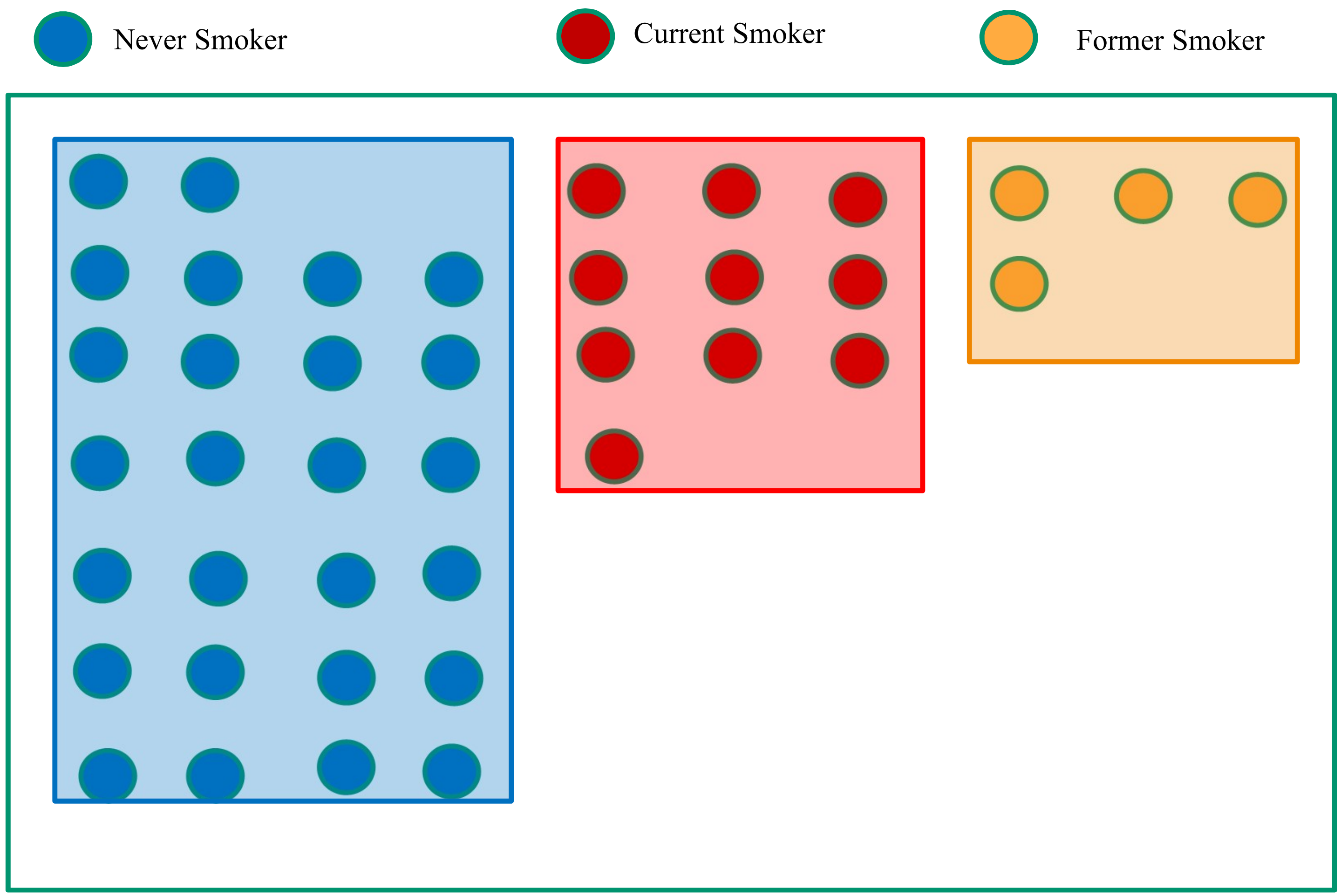
Never Smoker Current Smoker Former Smoker



Projecting Future Smoking Rates



Projecting Future Smoking Rates



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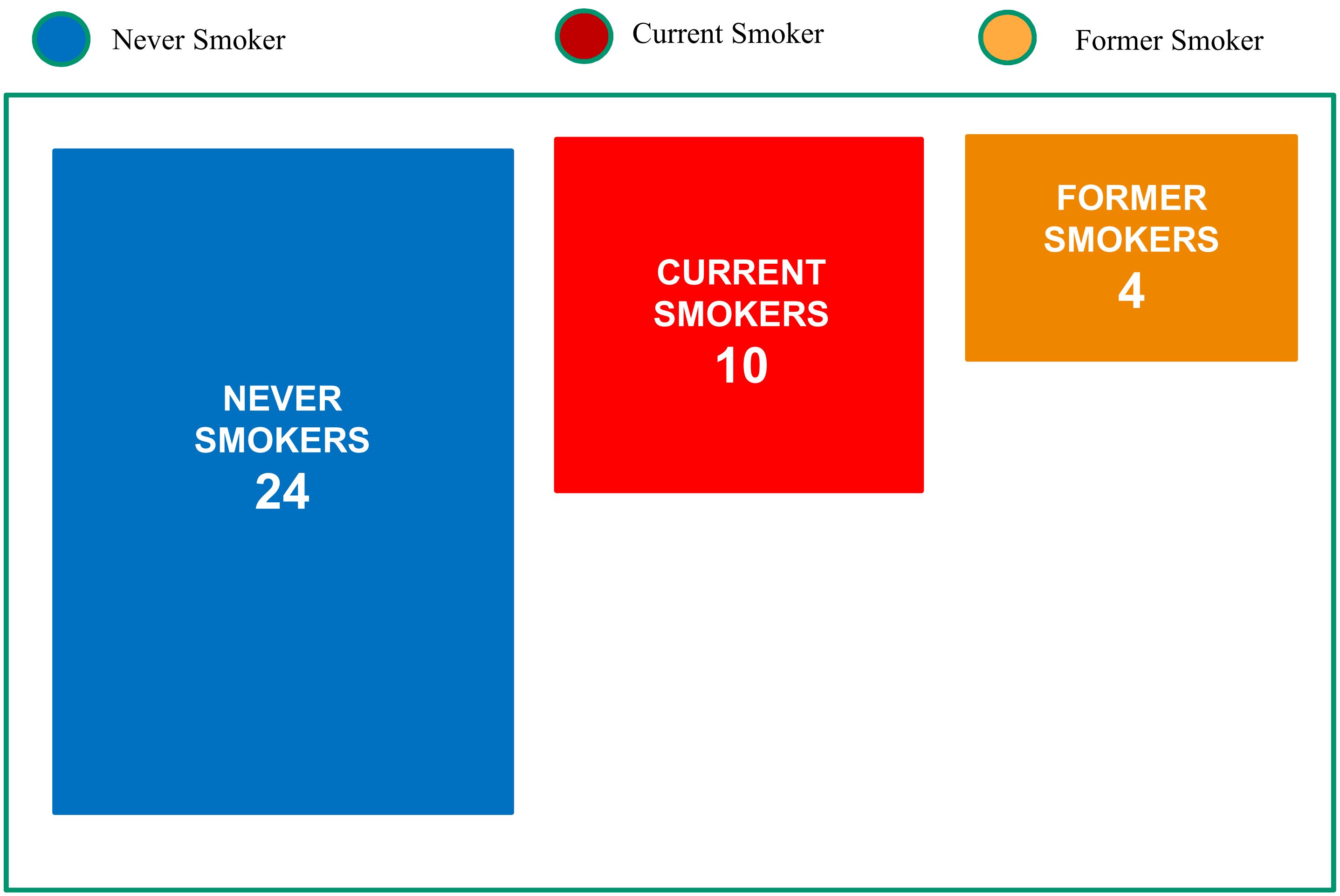

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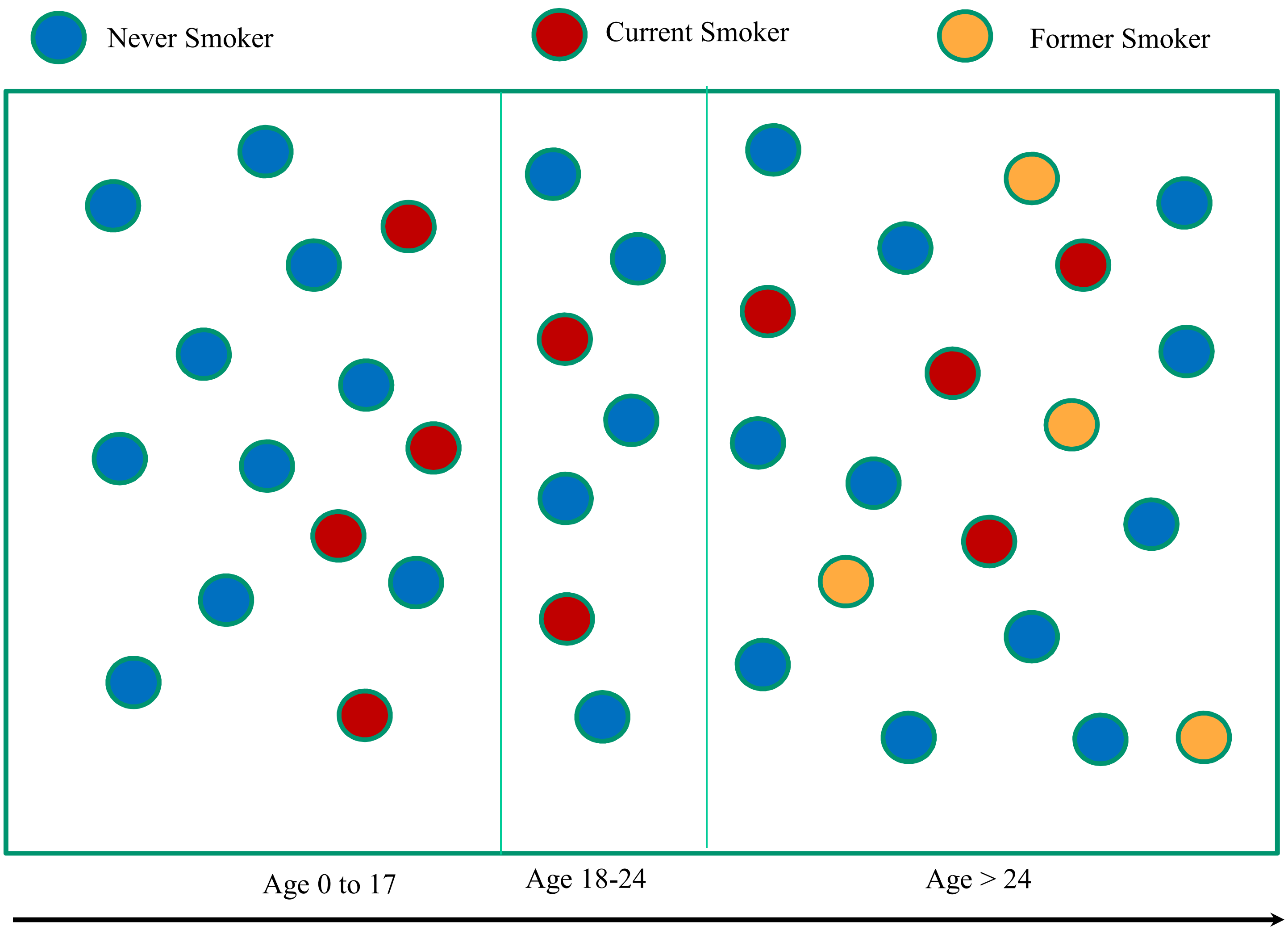

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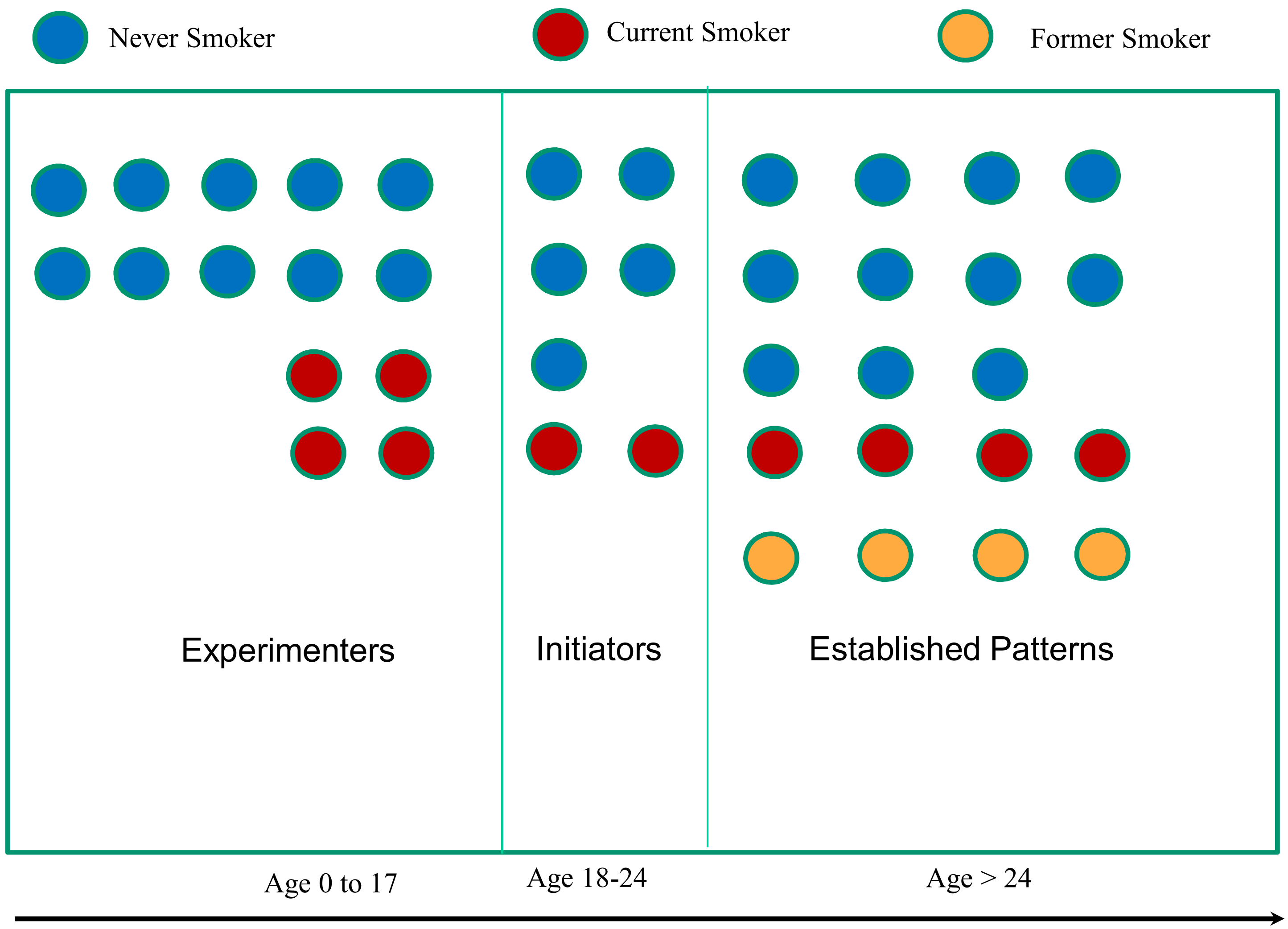

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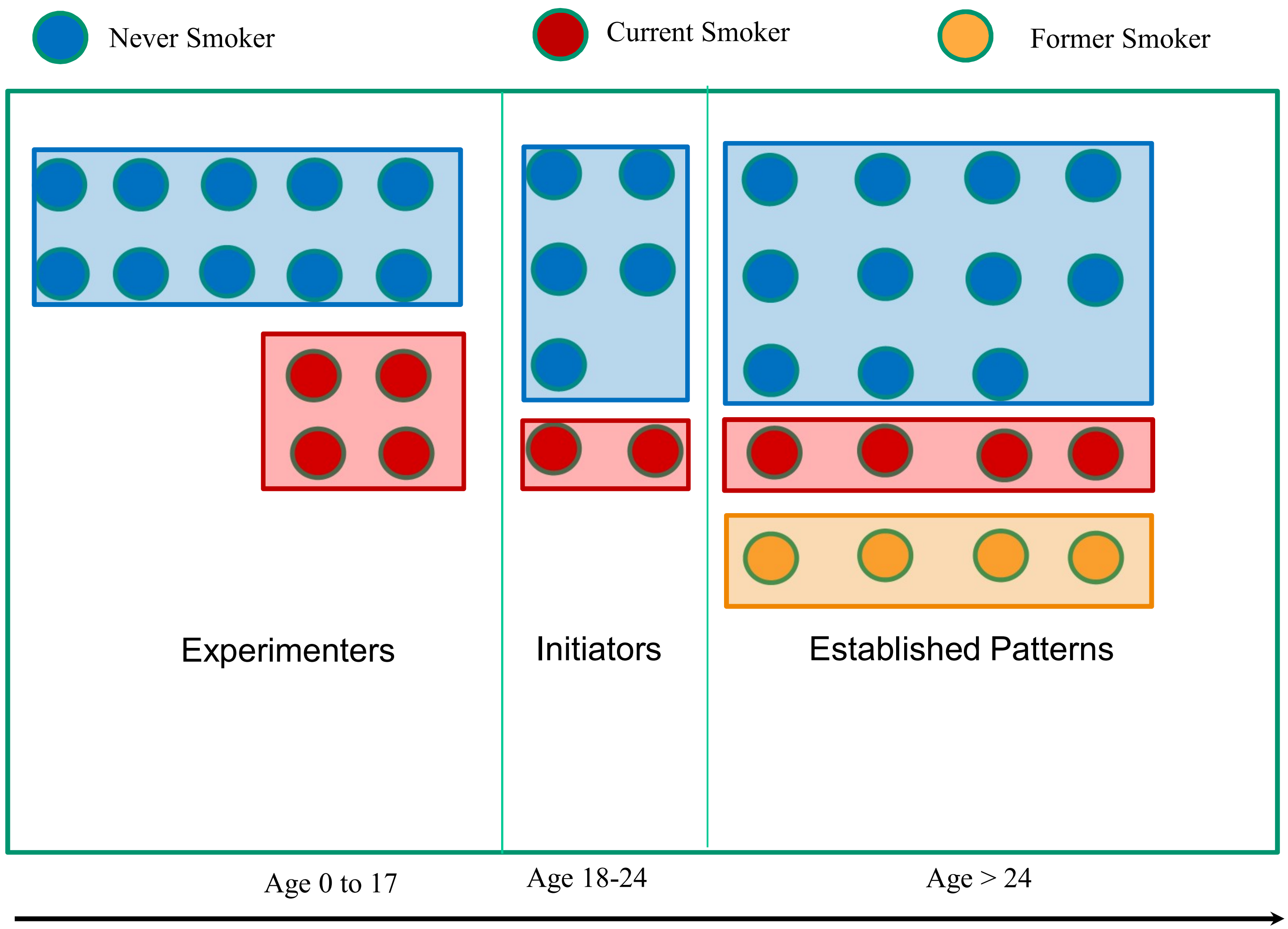

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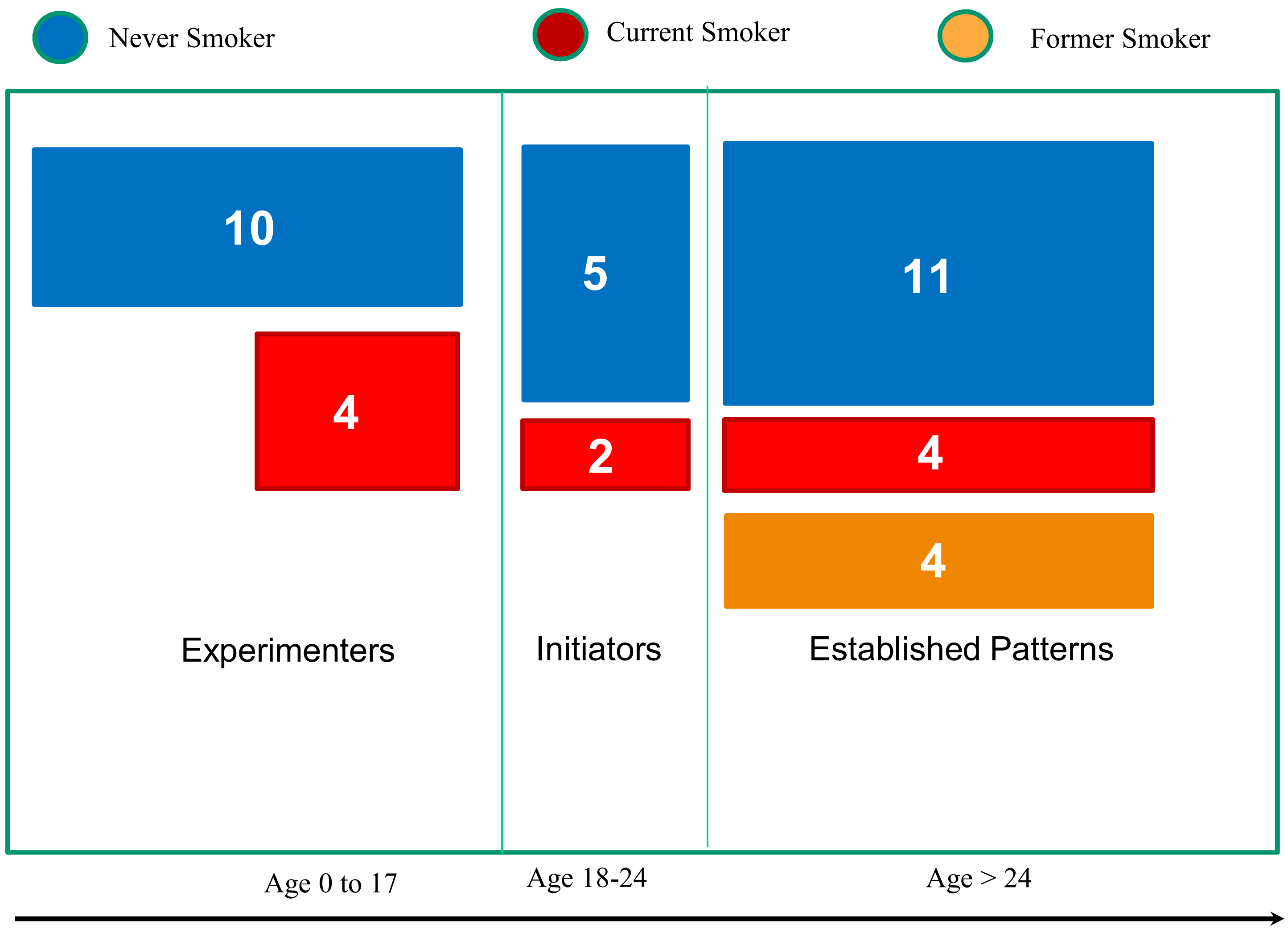
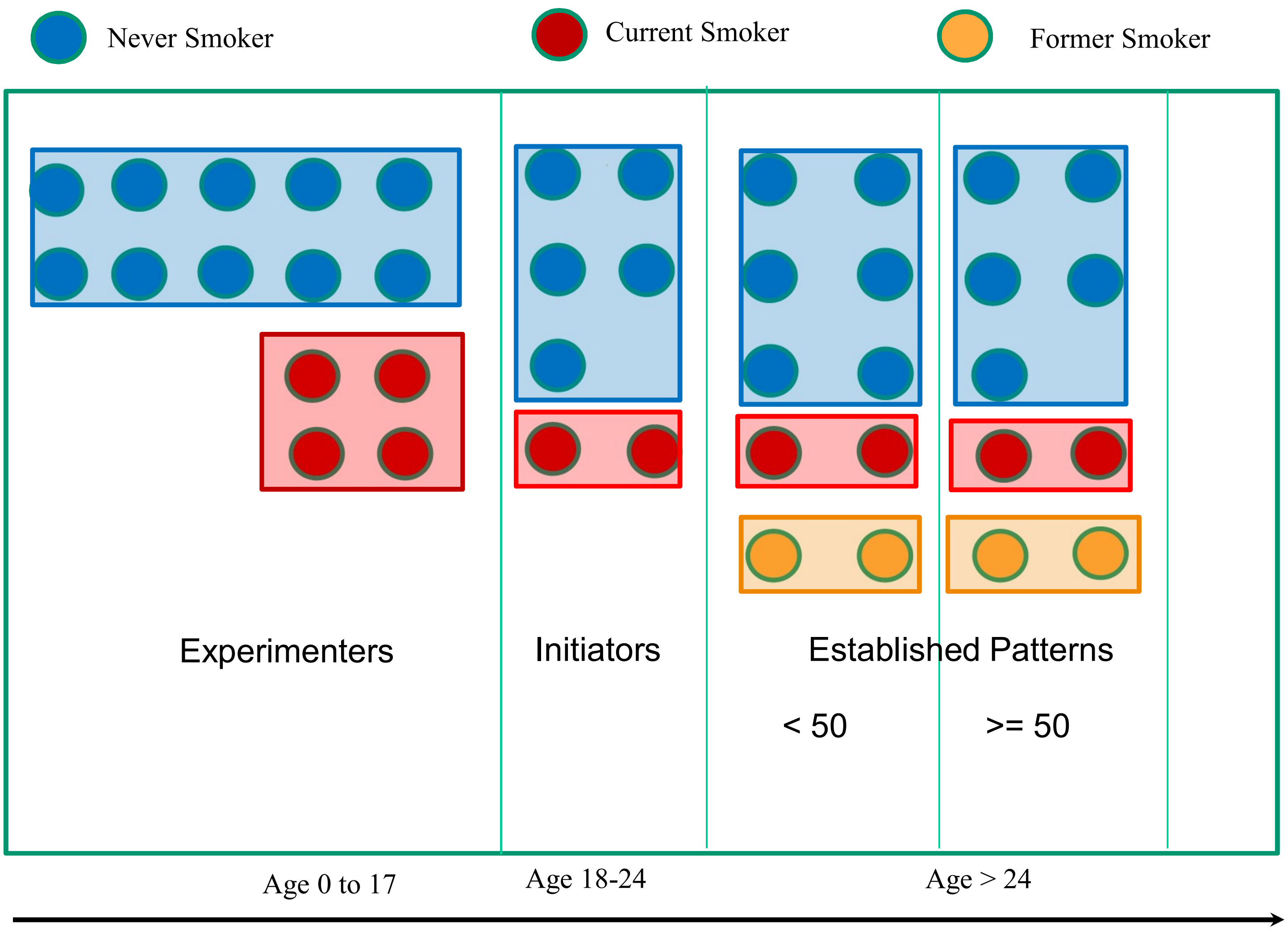


Projecting Future Smoking Rates



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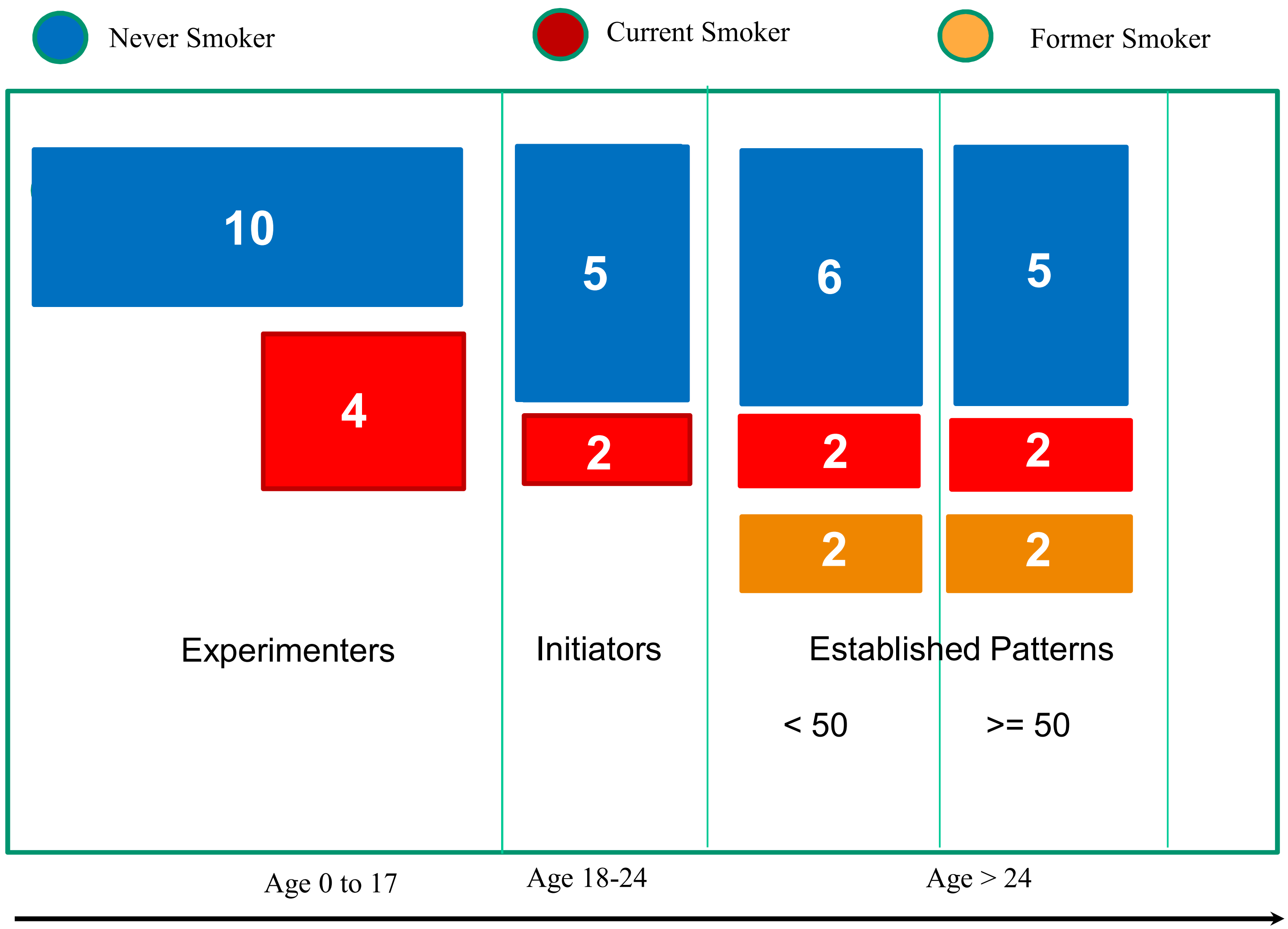

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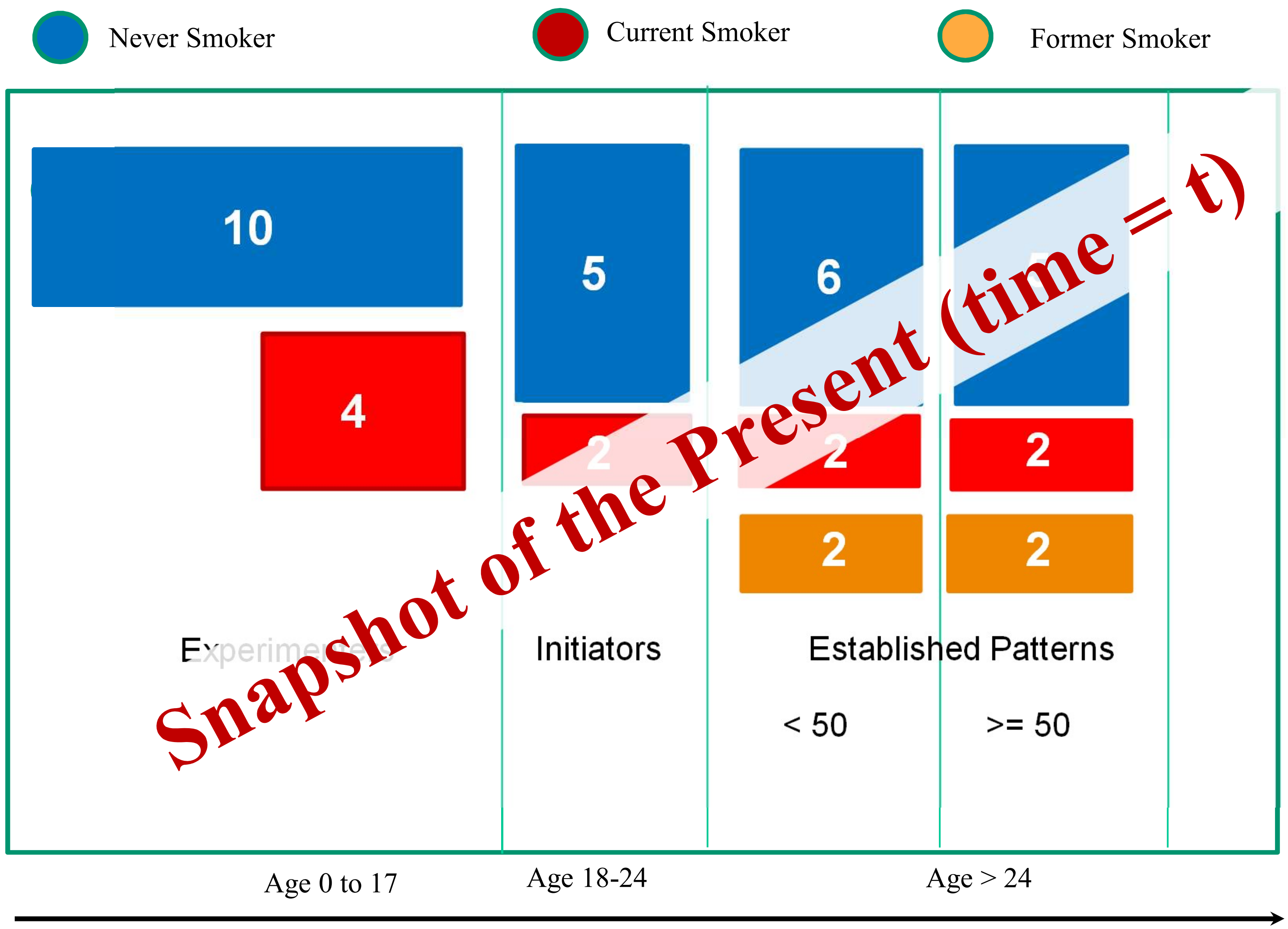

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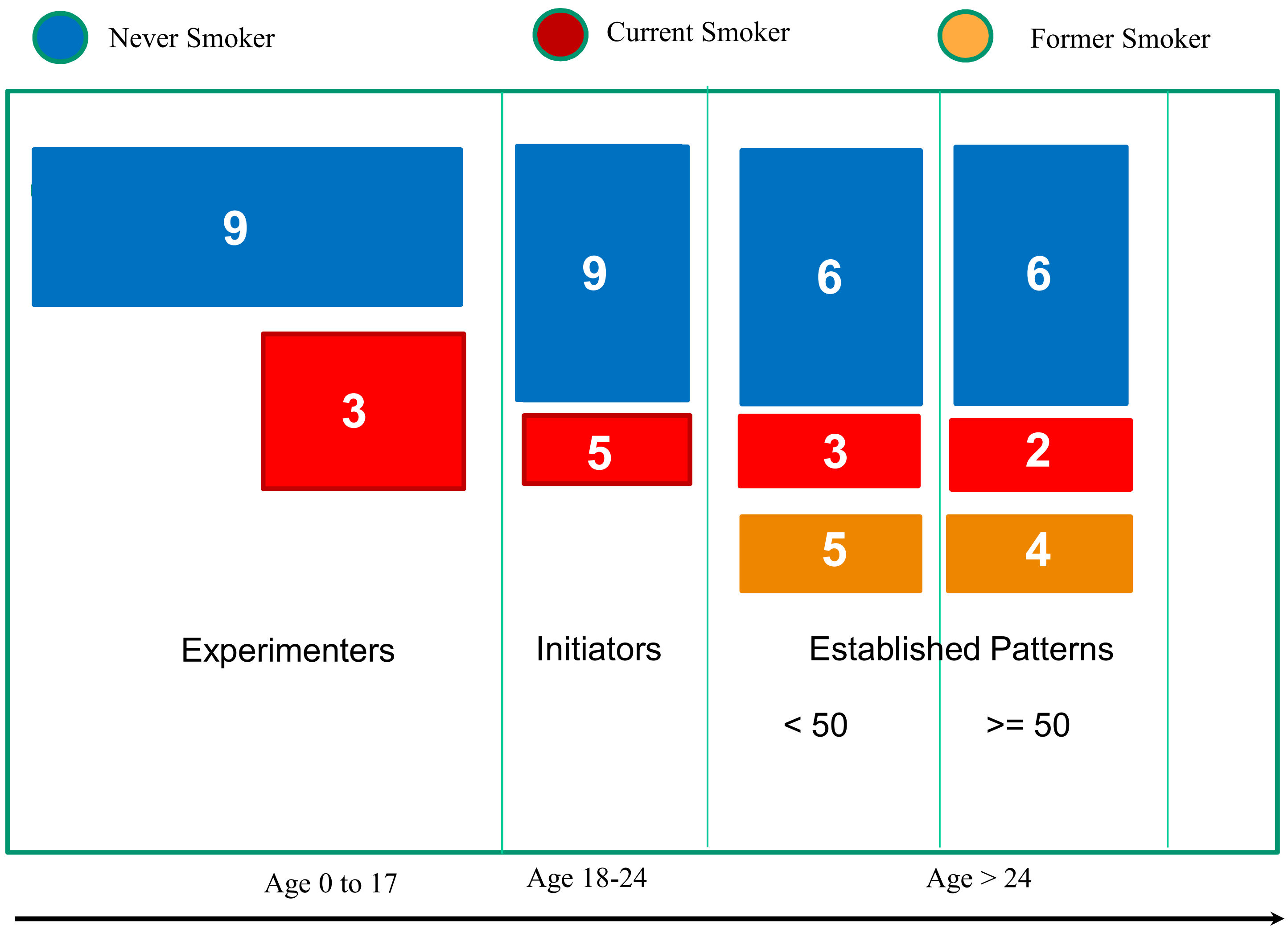

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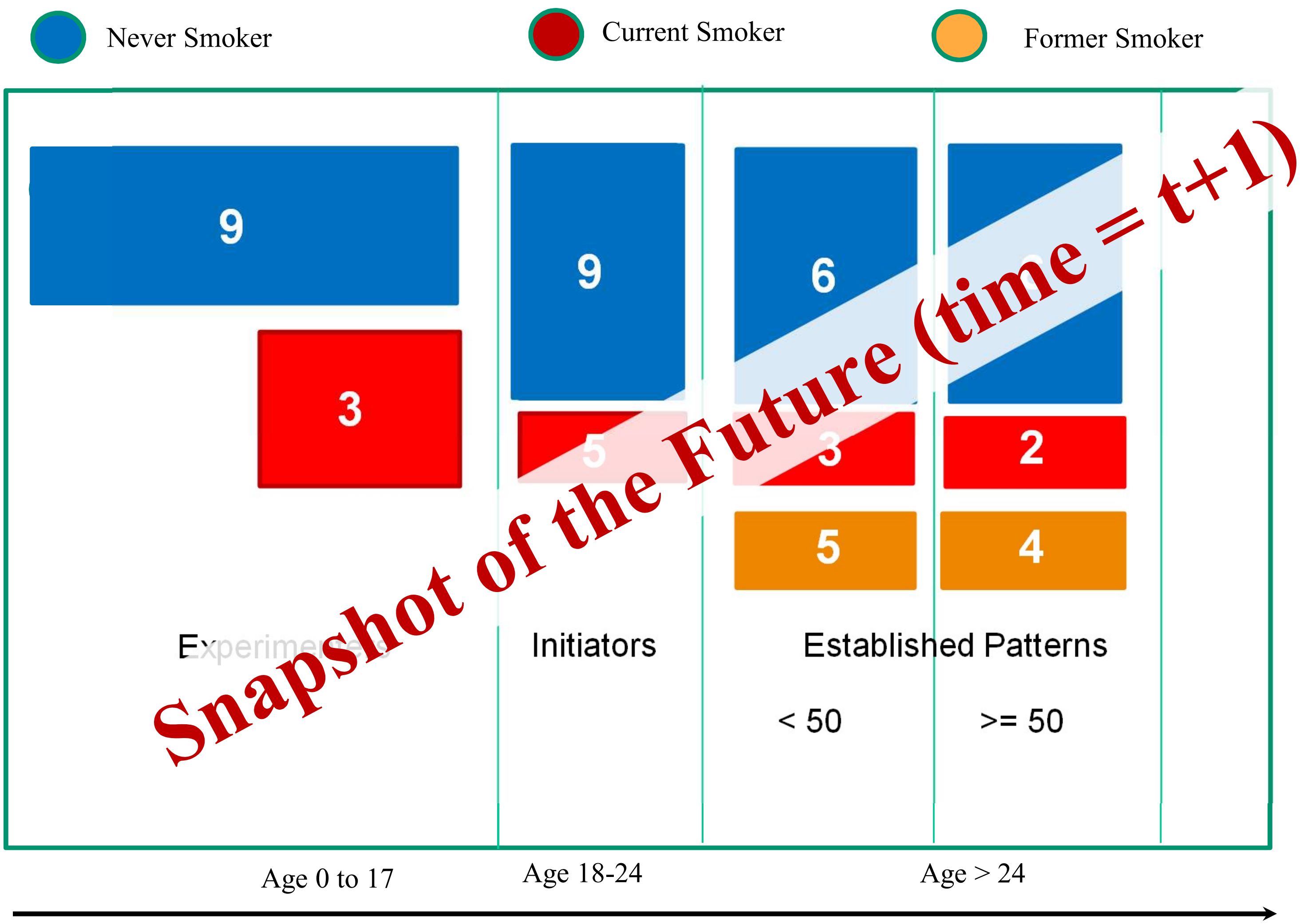


Model Dynamics

Future = Present + Change

$Smokers\ (t+1) = Smokers(t)$ + Change

Model Dynamics

Future = Present + Change

Smokers (t+1)= *Smokers(t)* + Change

Model Dynamics

Future = **Present** + Change

Smokers (t+1)= ***Smokers(t)*** + Change

Model Dynamics

Future = Present + **Change**

Smokers (t+1)= Smokers(t) + **Change**

Model Dynamics

Present

Smokers(t)

10

Model Dynamics

+ Change

-5

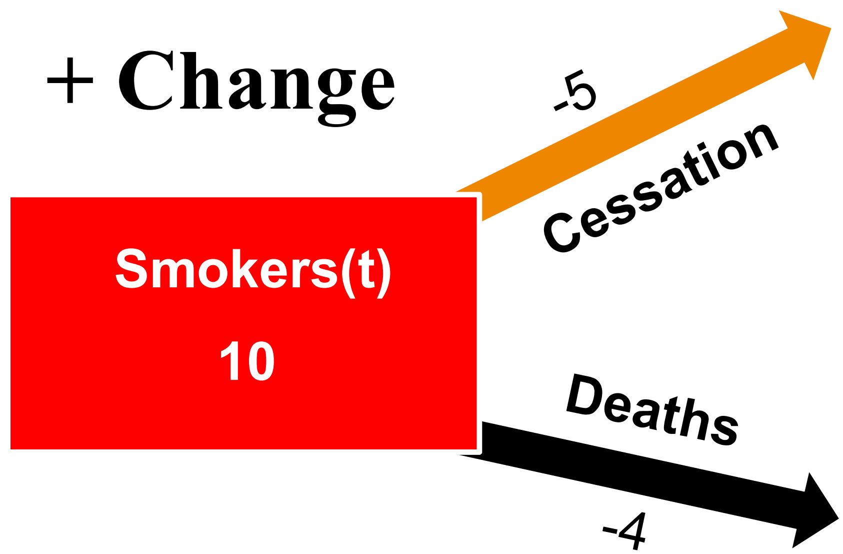
Cessation

Smokers(t)

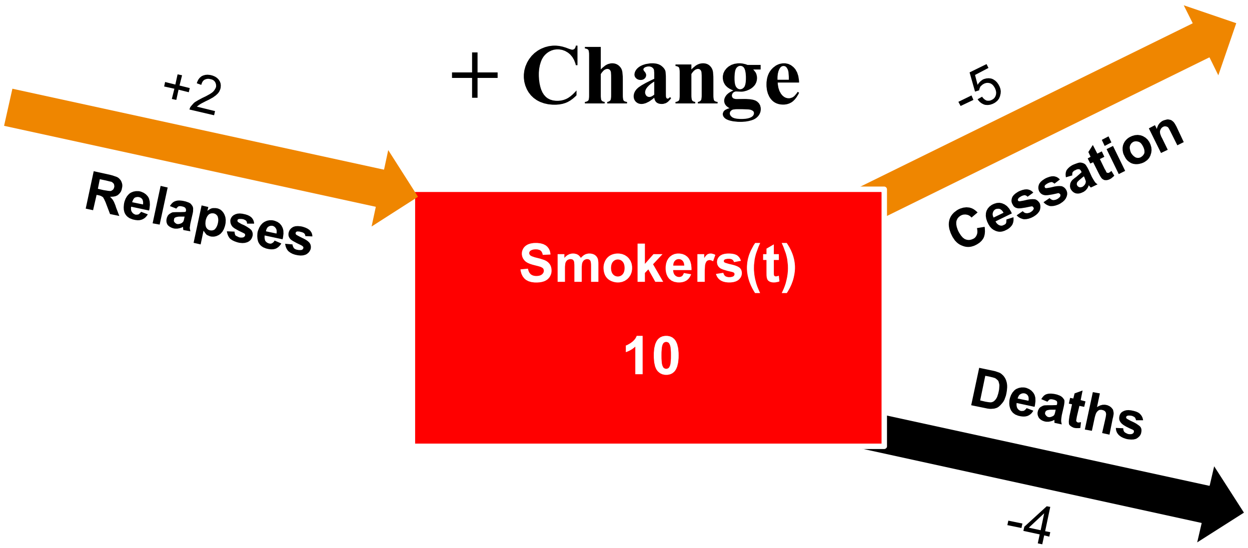
10

Model Dynamics

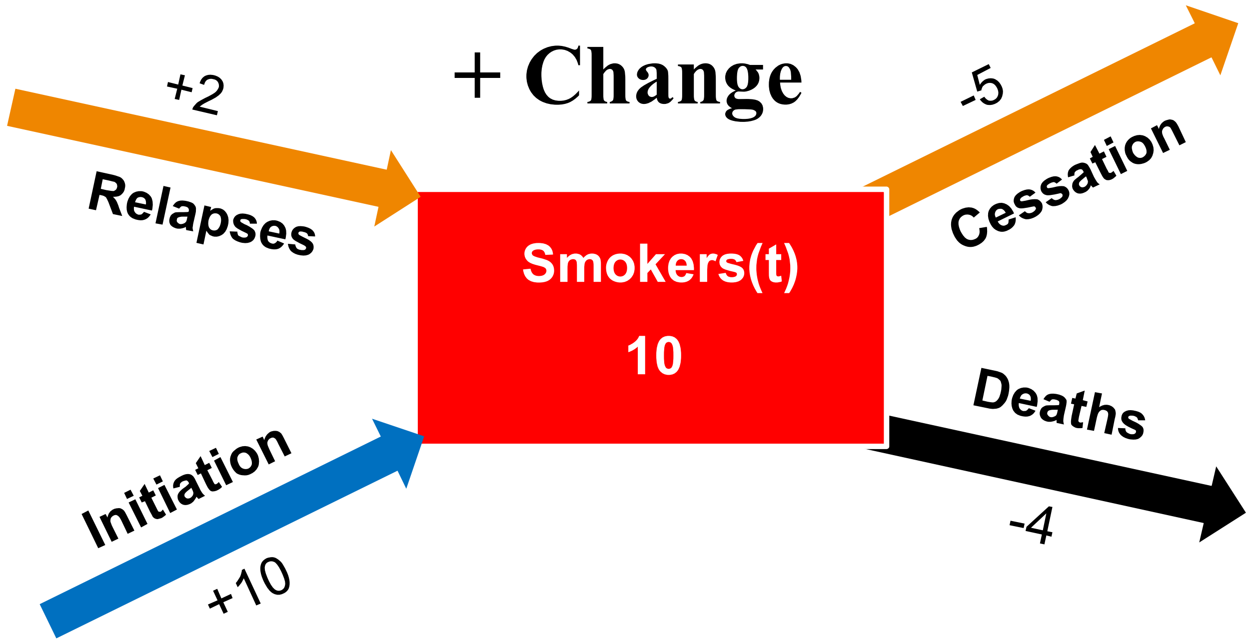
+ Change



Model Dynamics



Model Dynamics



Model Dynamics

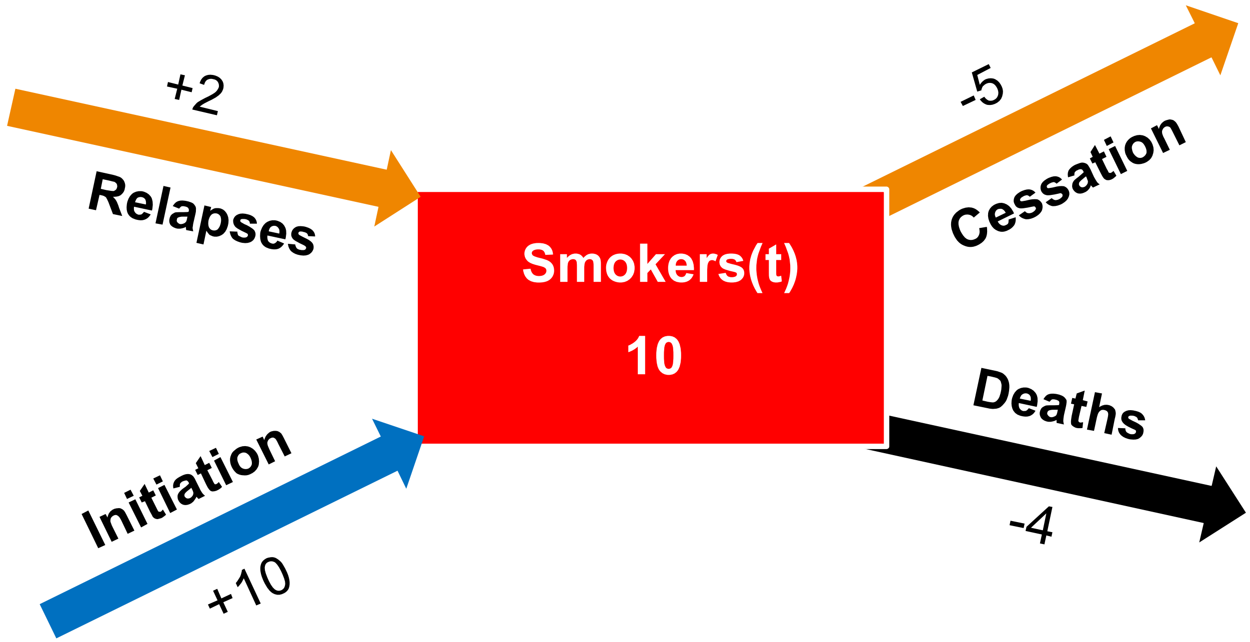
= Future

Smokers(t+1)

13

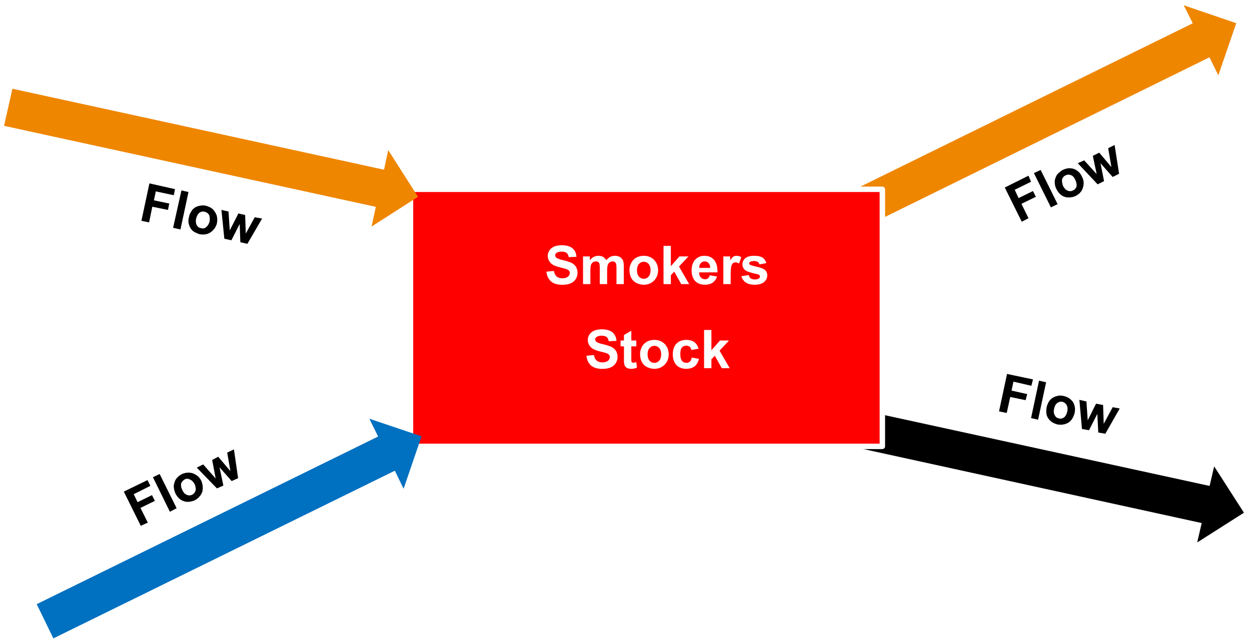
Model Dynamics

Stocks and Flows



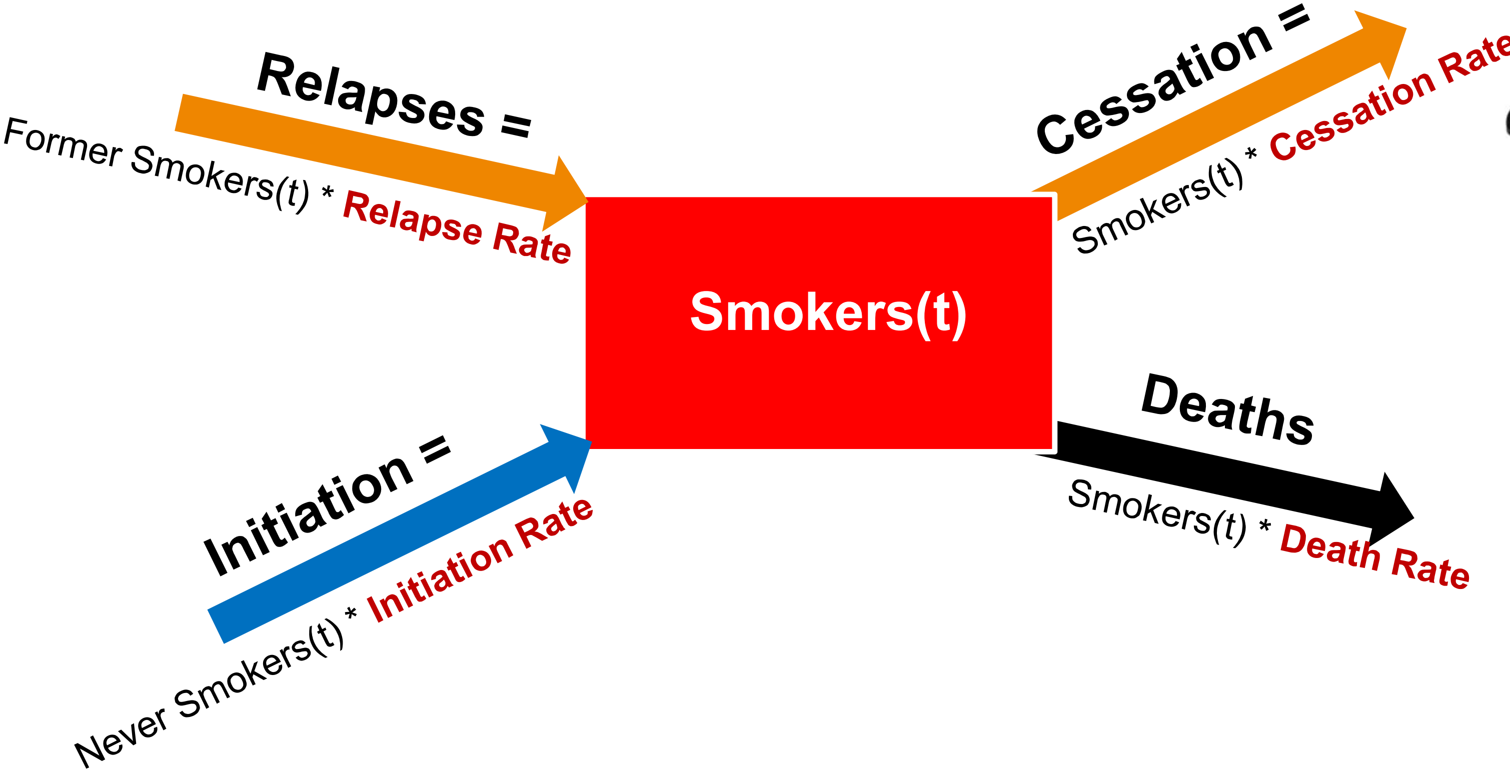
Model Dynamics

Stocks and Flows



Model Dynamics

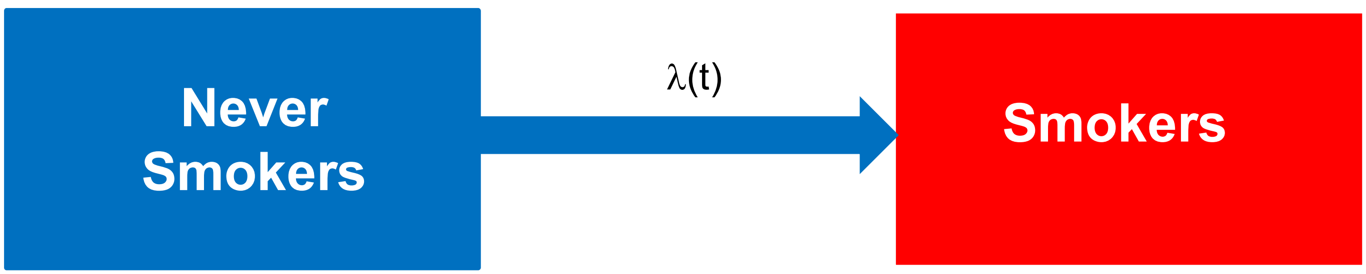
Stocks and Flows



Model Dynamics

Stocks and Flows

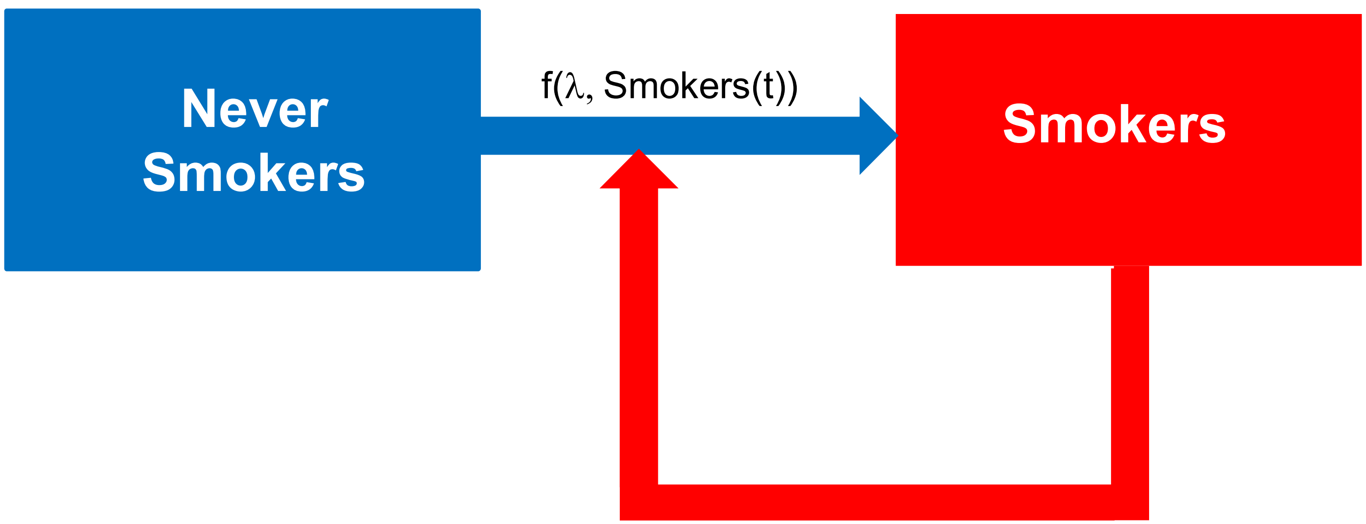
$\lambda(t)$ = Initiation Rate due to Exogenous Causes



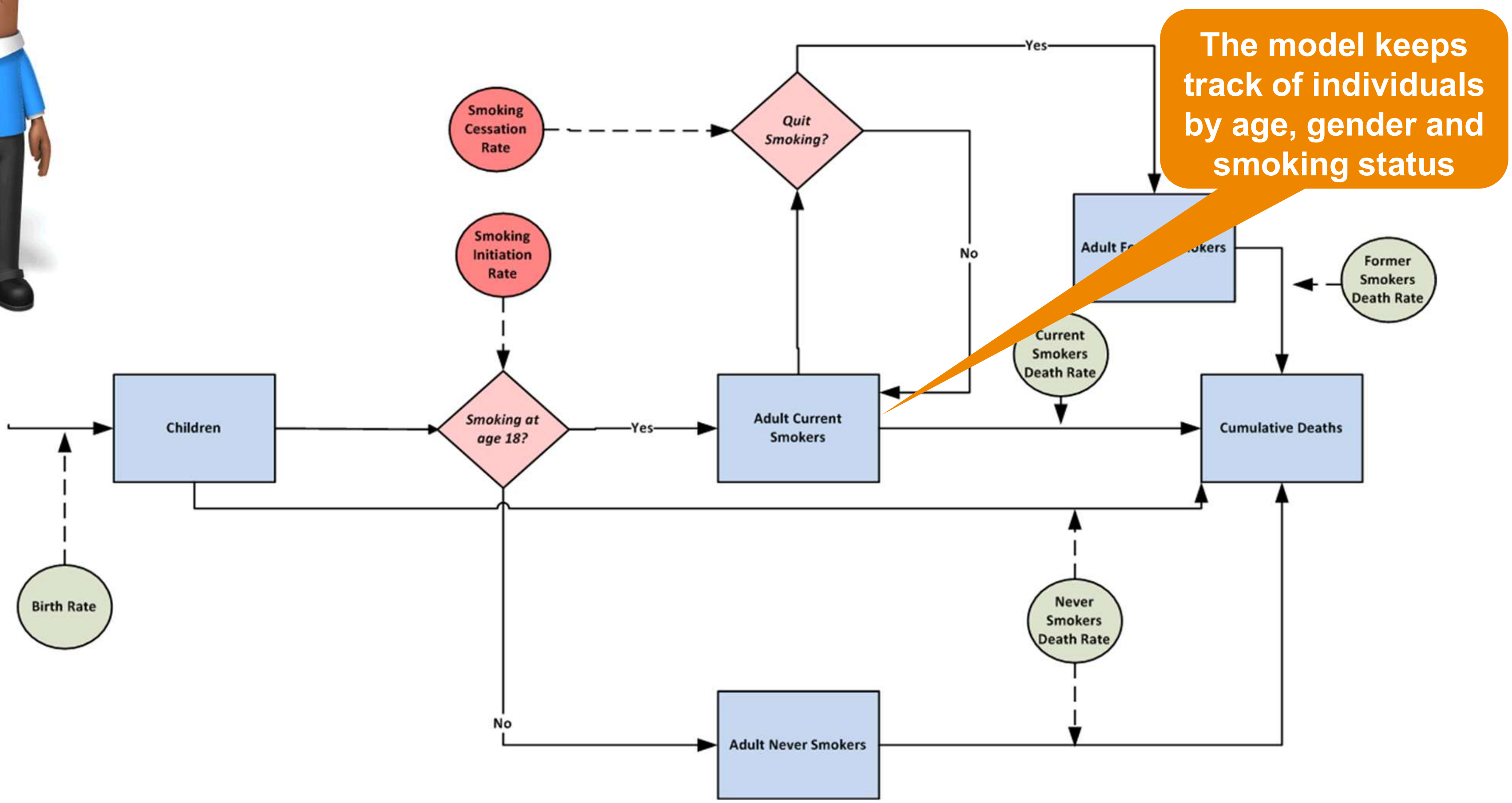
Model Dynamics

Stocks and Flows

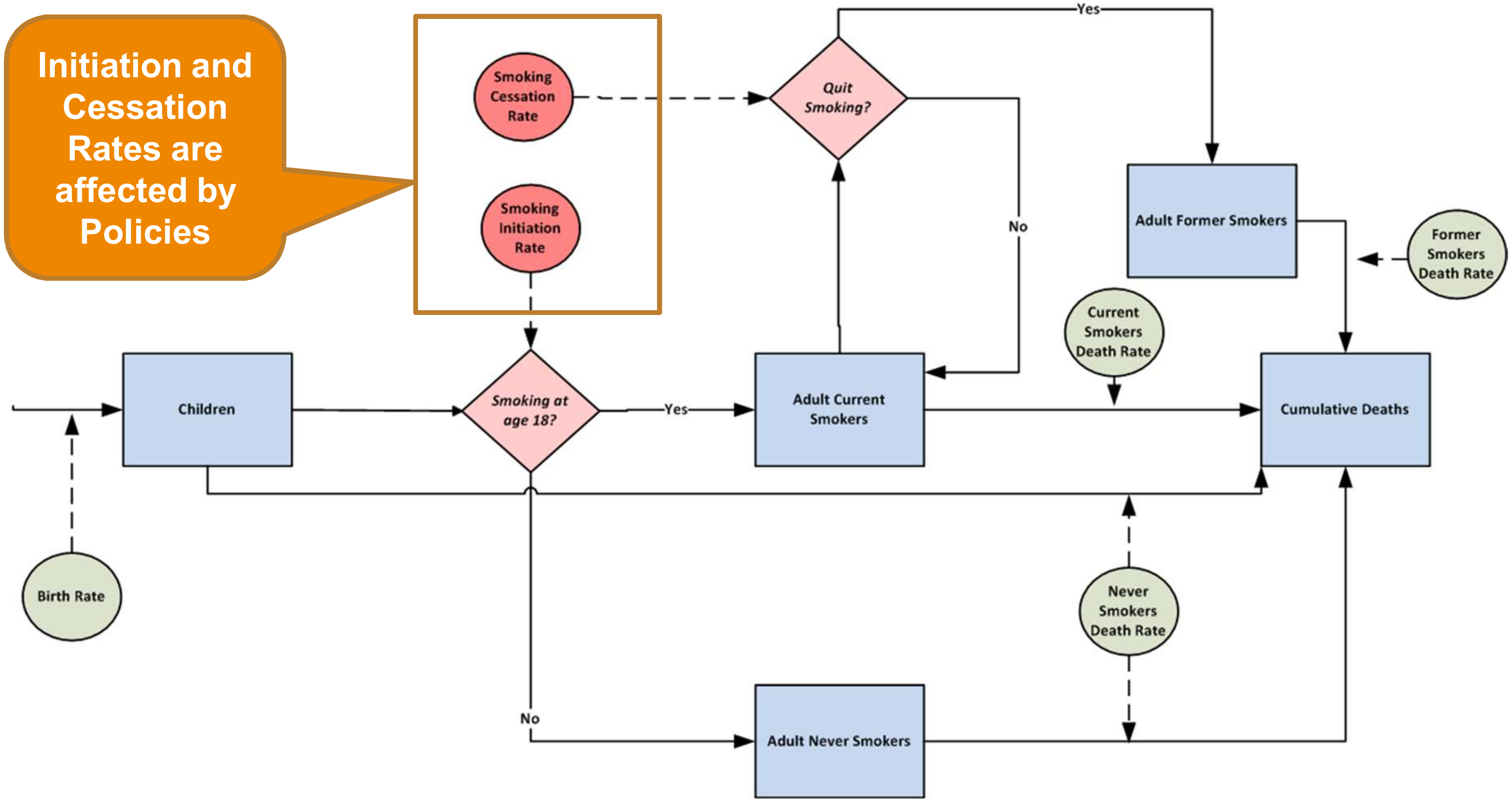
f(λ, Smokers(t)) = Initiation Rate due to Endogenous and Endogenous Causes



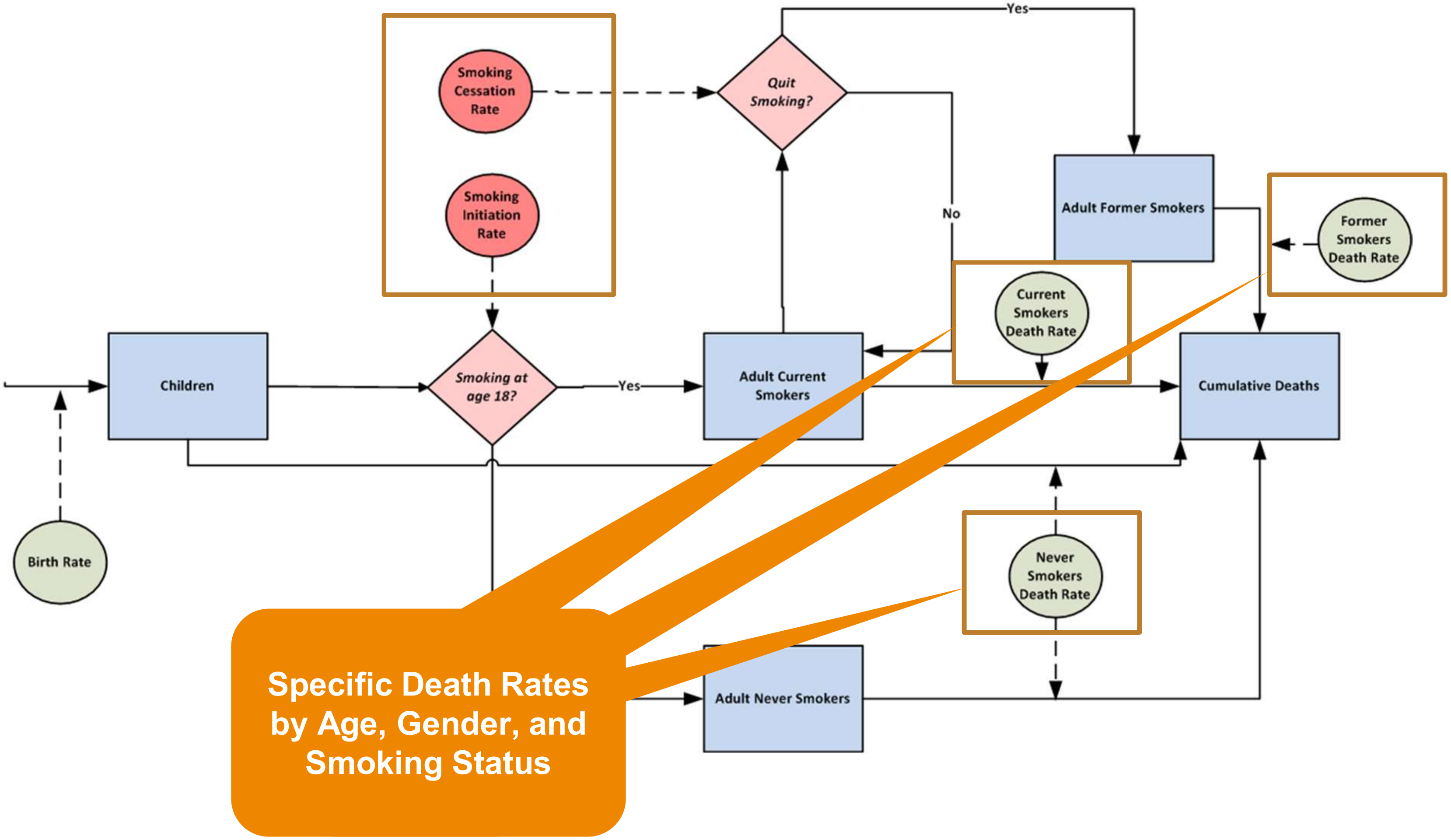
A Basic Compartmental Model



A Basic Compartmental Model



A Basic Compartmental Model



Examples of Compartmental Models Applications

- Status Quo Projections
- Estimation of Policy Effects
- Feasibility Analysis
- What-If scenarios
- Counterfactual Analysis
- Parameter Estimation
- Multiproduct Analysis

Examples of Compartmental Models Applications

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Modeling smoking-attributable mortality among adults with major depression in the United States

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Tobacco

ABSTRACT

Tobacco-related health disparities disproportionately affect smokers with major depression (MD). Although tobacco simulation models have been applied to general populations, to date they have not considered populations with a comorbid mental health condition. We developed and calibrated a simulation model of smoking and MD comorbidity for the US adult population using the 2005–2018 National Surveys on Drug Use and Health. We use this model to evaluate trends in smoking prevalence, smoking-attributable mortality and life-years lost among adults with MD, and changes in smoking prevalence by mental health status from 2018 to 2060. The model integrates known interaction effects between smoking initiation and cessation, and MD onset and recurrence. We show that from 2018 to 2060, smoking prevalence will continue declining among those with current MD. In the absence of intervention, people with MD will be increasingly disproportionately affected by smoking compared to the general population; our model shows that the smoking prevalence ratio between those with current MD and those without a history of MD increases from 1.54 to 2.42 for men and from 1.81 to 2.73 for women during this time period. From 2018 to 2060, approximately 484,000 smoking-attributable deaths will occur among adults with current MD, leading to 11.3 million life-years lost. Ambitious tobacco control efforts could alter this trajectory. With aggressive public health efforts, up to 264,000 of those premature deaths could be avoided, translating into 7.5 million life years gained. This model can compare the relative health gains across different intervention strategies for smokers with MD.

Examples of Compartmental Models Applications

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Modeling the Future Effects of a Menthol Ban on Smoking Prevalence and Smoking-Attributable Deaths in the United States

David T. Levy, PhD, Jennifer L. Pearson, MPH, Andrea C. Villanti, PhD, MPH, Kenneth Blackman, MS, Donna M. Vallone, PhD, MPH, Raymond S. Niaura, PhD, and David B. Abrams, PhD

We used a validated smoking simulation model and data from the 2003 Tobacco Use Supplement to the Current Population Survey to project the impact that a US menthol ban would have on smoking prevalence and smoking-attributable deaths. In a scenario in which 30% of menthol smokers quit and 30% of those who would have initiated as menthol smokers do not initiate, by 2050 the relative reduction in smoking prevalence would be 9.7% overall and 24.8% for Blacks; deaths averted would be 633 252 overall and 237 317 for Blacks. (*Am J Public Health*. 2011;101:1236–1240. doi:10.2105/AJPH.2011.300179)

Examples of Compartmental Models Applications

- Status Quo Projections
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Smoking Prevalence in 2010: Why the Healthy People Goal Is Unattainable

David Mendez, PhD, and Kenneth E. Warner, PhD

ABSTRACT

Objectives. This study examined the changes in smoking initiation and cessation needed to realize the Healthy People 2010 national adult smoking prevalence objective (13%).

Methods. Using data from the National Health Interview Surveys, we calculated smoking prevalence over time with a dynamic population demographics model, examining the effects of changes in smoking initiation and cessation.

Results. The draft objective is unattainable solely through decreases in smoking initiation. It could be achieved through smoking cessation alone only if cessation rates immediately increased by a factor of more than 3.5. Assuming plausible decreases in initiation and increases in cessation, the draft objective is virtually unattainable.

Conclusions. The health objectives should challenge the status quo but be achievable. Formal analysis often can assist in establishing reasonable objectives. (*Am J Public Health.* 2000;90:401–403)

In 1990, the US Public Health Service released Healthy People 2000,[1] its public health objectives for the nation for the year 2000. Included was a very ambitious goal of reducing the prevalence of adult smoking from 25.5% (1990) to 15%. With smoking prevalence at nearly 24% in 1997,[2] the nation will fall far short of this objective. Using formal modeling and examining data through 1994, Pechmann et al.[3] recently projected a prevalence of 21% in 2000 if the steady decline of 0.7 percentage point in effect since the 1970s persists until 2000.

In 1998, the Office of Disease Prevention and Health Promotion circulated draft goals for the year 2010 objectives for the nation.[4] The adult smoking prevalence goal was set at 13%, a modest reduction from the goal for 2000 but a substantial decline from the prevalence likely to exist at that time.[3] The question addressed in this study is what changes in rates of smoking initiation and cessation would be needed to realize the 2010 objective. This in turn permits an assessment of the likelihood that the objective will be realized.

older. The estimated current annual cessation rates for these groups are 0.21%, 2.15%, and 5.96%, respectively.[5] In this study, we report cessation rates as a "factor" of these values. For example, a cessation factor of 1.5 corresponds to cessation rates 1.5 times each of these annual cessation rates. As in our earlier work,[5] prevalence in this study is consistent with the definition of "current smoker" used in the NHIS before 1992. A change in the definition that year led to the inclusion of some nondaily smokers previously omitted from the category of current smoker. Inclusion of these individuals raises the estimates of prevalence by approximately 1 percentage point.[6]

We used the model to investigate different combinations of cessation and initiation rates that would produce an adult smoking prevalence of 13% by 2010, under 2 different sets of assumptions. First, we assumed that initiation and cessation rates would change instantaneously, in 2000, from their current values to their 2010 values, and then would remain constant throughout the decade. Although this is obviously not realistic, it demonstrates the extreme case of success in controlling tobacco use. Second (the more

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Invited Review

Tobacco control policy in developed countries: Yesterday, today, and tomorrow

Kenneth E. Warner & David Mendez

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Abstract

Introduction: Tobacco control policies have contributed to dramatic declines in smoking in the developed nations. However, the circumstances under which these policies altered the smoking landscape have changed and are likely to change further. As well, decreases in smoking prevalence may have "stalled" at current levels. Because today's smokers differ significantly from yesterday's and the environment in which smokers consume their cigarettes has changed, it is plausible that several of the evidence-based tobacco control policies soon will have run their course in the most advanced tobacco control environments. We ask, therefore, what developed nations can expect of these policies in the future and what novel policy measures may be needed to continue the assault on tobacco.

Discussion: After summarizing tobacco control success in the United States and the findings from tobacco control policy research, we consider the remaining problem focusing on the characteristics of remaining smokers and their circumstances. We then examine constraints on the continuing effectiveness of evidence-based policy interventions. We employ a model to project U.S. smoking prevalence decades into the future, with and without improvements in initiation and cessation rates. We then speculate about novel policy directions that will be needed to further move the needle of tobacco control.

Conclusion: Without substantial innovation in tobacco control policy, further reductions in smoking in developed nations will come frustratingly slowly. Needed policy innovations might be quite radical, such as legislating entirely smoke-free outdoor environments or regulators reducing allowable nicotine in cigarettes to non-addicting levels.

that success owing to policies relating to public education, economic incentives, and law and regulation (Warner, 2006). What remains to be seen is whether evidence-based policy interventions will continue to be the mainstay of tobacco control in those countries in which they have been used extensively and successfully. Multiple characteristics differentiate today's smokers from yesterday's; the environment in which smokers consume their cigarettes has changed radically as well. It is plausible, even likely, that several of the tried-and-true policies soon will have run their course in the most advanced tobacco control environments. The question emerges, therefore, as to what developed nations can expect of these policies in the future and what novel policy measures we may need to continue the assault on the toll of tobacco.

To address that question—not answer it, for the question is inherently speculative—we open with a brief précis of tobacco control success in one country, the United States, and a review of the evidence base regarding policy interventions. We then consider the remaining problem focusing on the nature of remaining smokers and their circumstances. Speculation begins in the next section, in which we examine constraints on the continuing effectiveness of evidence-based policy interventions. The speculation grows in the following section in which we project smoking prevalence in the United States decades into the future. The speculation peaks in the next section, in which we contemplate novel policy directions for the future.

We want to emphasize three contextual aspects of this paper. First, we do not address the vital role that evidence-based tobacco control policies can and must play in low and middle income countries. Second, we focus heavily on the United States, reflecting the value of a case study and the limitations of our expertise. While tobacco control experience varies among the

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Research

Original Investigation

Tobacco Control and the Reduction in Smoking-Related Premature Deaths in the United States, 1964-2012

Theodore R. Holford, PhD; Rafael Meza, PhD; Kenneth E. Warner, PhD; Clare Meernik, MPH; Jihyoun Jeon, PhD; Suresh H. Moolgavkar, MD, PhD; David T. Levy, PhD

IMPORTANCE January 2014 marks the 50th anniversary of the first surgeon general's report on smoking and health. This seminal document inspired efforts by governments, nongovernmental organizations, and the private sector to reduce the toll of cigarette smoking through reduced initiation and increased cessation.

OBJECTIVE To model reductions in smoking-related mortality associated with implementation of tobacco control since 1964.

DESIGN, SETTING, AND PARTICIPANTS Smoking histories for individual birth cohorts that actually occurred and under likely scenarios had tobacco control never emerged were estimated. National mortality rates and mortality rate ratio estimates from analytical studies of the effect of smoking on mortality yielded death rates by smoking status. Actual smoking-related mortality from 1964 through 2012 was compared with estimated mortality under no tobacco control that included a likely scenario (primary counterfactual) and upper and lower bounds that would capture plausible alternatives.

EXPOSURES National Health Interview Surveys yielded cigarette smoking histories for the US adult population in 1964-2012.

MAIN OUTCOMES AND MEASURES Number of premature deaths avoided and years of life saved were primary outcomes. Change in life expectancy at age 40 years associated with change in cigarette smoking exposure constituted another measure of overall health outcomes.

RESULTS In 1964-2012, an estimated 17.7 million deaths were related to smoking, an estimated 8.0 million (credible range [CR], 7.4-8.3 million, for the lower and upper tobacco control counterfactuals, respectively) fewer premature smoking-related deaths than what would have occurred under the alternatives and thus associated with tobacco control (5.3 million [CR, 4.8-5.5 million] men and 2.7 million [CR, 2.5-2.7 million] women). This resulted in an estimated 157 million years (CR, 139-165 million) of life saved, a mean of 19.6 years for each beneficiary (111 million [CR, 97-117 million] for men, 46 million [CR, 42-48 million] for women). During this time, estimated life expectancy at age 40 years increased 7.8 years for men and 5.4 years for women, of which tobacco control is associated with 2.3 years (CR, 1.8-2.5) (30% [CR, 23%-32%]) of the increase for men and 1.6 years (CR, 1.4-1.7) (29% [CR, 25%-32%]) for women.

CONCLUSIONS AND RELEVANCE Tobacco control was estimated to be associated with avoidance of 8 million premature deaths and an estimated extended mean life span of 19 to 20 years. Although tobacco control represents an important public health achievement, efforts must continue to reduce the effect of smoking on the nation's death toll.

JAMA. 2014;311(2):164-171. doi:10.1001/jama.2013.285112

Author Video Interview at jama.com

Supplemental content at jama.com

Author Affiliations: Department of Biostatistics, Yale University School of Public Health, New Haven, Connecticut (Holford); Department of Epidemiology, University of Michigan School of Public Health, Ann Arbor (Meza, Meernik); Department of Health Management and Policy, University of Michigan School of Public Health, Ann Arbor (Warner); Program in Biostatistics and Biomathematics, Fred Hutchinson Cancer Research Center, Seattle, Washington (Jeon, Moolgavkar); Lombardi Comprehensive Cancer Center, Georgetown University, Washington, DC (Levy).

Corresponding Author: Theodore R. Holford, PhD, Department of Biostatistics, Yale School of Public Health, 60 College St, New Haven, CT 06511 (theodore.holford@yale.edu).

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Original article

Arch Argent Pediatr 2015;113(2):106-113 / **106**

Tobacco use during adolescence may predict smoking during adulthood: simulation-based research

Raúl A. Borracci, M.D.[a] and Andrés H. Mulassi, M.D.[b]

a. Biostatistics, School of Biomedical Sciences, Universidad Austral.
b. Council of Cardiovascular

ABSTRACT

Introduction. There is little information about the age of onset of smoking among adolescents and its continuation into adulthood. The objective of this study was to assess the influence of tobacco use during adolescence to predict the prevalence of adult smoking using simulation models.

Material and Methods. Five models were examined based on initiation and tobacco use rates among 421 adolescents. After simulating different scenarios, expected adult tobacco use rates were obtained and compared to those observed in a validation sample made up of 1218 adults.

Results. Models adequately predicted adult smoking rates by comparing them to data obtained using the validation sample (Markov: 37.6% versus 34.5%, $p = 0.109$; dynamic simulation: 32.0% versus 34.5%, $p = 0.197$). The simulation demonstrated that smoking, at least, one cigarette per month during adolescence sufficed to predict adult tobacco use rates. Eliminating tobacco use during adolescence may reduce the rate of tobacco use among adults by 12.2-16.2%.

Conclusions. Adolescent tobacco use models adequately predicted the proportion of smokers among adults. Scenarios of restriction regarding the age of onset of tobacco use showed the expected reductions in the rates of tobacco use among adults. Although it was not evaluated in this study, restricting tobacco use among adolescents may help to protect their health and would probably have an impact on the reduction of tobacco-associated mortality among adults.

Key words: *adolescents, smoking, simulation.*

http://dx.doi.org/10.5546/aap.2015.eng.106

Approximately 52% of adults refer to have started smoking between 12 and 17 years old, while 30% started between 18 and 20 years old.[3] In addition, recent studies have analyzed the influence of friendship social networks on smoking take-up among adolescents.[4-6]

Some of the measures proposed to reduce smoking prevalence among adults include reducing the initial contact with cigarettes during adolescence. However, simulation-based studies suggest that, for example, raising the legal age to buy cigarettes does not appear to have a significant impact on the reduction of smoking rates.[7] In addition, reducing contact with cigarettes during adolescence might only have a late effect on the population's health and, in the worst-case scenario, it might just delay the take-up of smoking.[8] Ferrante, D., et al.[9] analyzed the influence of different tobacco control policies implemented in Argentina using simulation models in SimSmoke®. Besides its usefulness to establish health measures aimed at reducing tobacco use, the authors recognize that

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Levy *et al. Population Health Metrics* (2021) 19:19
https://doi.org/10.1186/s12963-021-00250-7
Population Health Metrics

RESEARCH Open Access

Public health implications of vaping in the USA: the smoking and vaping simulation model

Check for updates

David T. Levy[1*], Jamie Tam[2], Luz María Sanchez-Romero[1], Yameng Li[1], Zhe Yuan[1], Jihyoun Jeon[3] and Rafael Meza[3]

Abstract

Background: Nicotine vaping products (NVPs) are increasingly popular worldwide. They may provide public health benefits if used as a substitute for smoking, but may create public health harms if used as a gateway to smoking or to discourage smoking cessation. This paper presents the Smoking and Vaping Model (SAVM), a user-friendly model which estimates the public health implications of NVPs in the USA.

Methods: SAVM adopts a cohort approach. We derive public health implications by comparing smoking- and NVP-attributable deaths and life-years lost under a No-NVP and an NVP Scenario. The No-NVP Scenario projects current, former, and never smoking rates via smoking initiation and cessation rates, with their respective mortality rates. The NVP Scenario allows for smoking- and NVP-specific mortality rates, switching from cigarette to NVP use, separate NVP and smoking initiation rates, and separate NVP and smoking cessation rates. After validating the model against recent US survey data, we present the base model with extensive sensitivity analyses.

Results: The SAVM projects that under current patterns of US NVP use and substitution, NVP use will translate into 1.8 million premature smoking- and vaping-attributable deaths avoided and 38.9 million life-years gained between 2013 and 2060. When the NVP relative risk is set to 5%, the results are sensitive to the level of switching and smoking cessation rates and to a lesser extent smoking initiation rates. When the NVP relative risk is raised to 40%, the public health gains in terms of averted deaths and LYL are reduced by 42% in the base case, and the results become much more sensitive to variations in the base case parameters.

Discussion: Policymakers, researchers, and other public health stakeholders can apply the SAVM to estimate the potential public health impact of NVPs in their country or region using their own data sources. In developing new simulation models involving NVPs, it will be important to conduct extensive sensitivity analysis and continually update and validate with new data.

Conclusion: The SAVM indicates the potential benefits of NVP use. However, given the uncertainty surrounding model parameters, extensive sensitivity analysis becomes particularly important.

Keywords: NVPs, Vaping, Smoking, Simulation model, Public health

Limitations of Compartmental Models

- Cannot fully represent the heterogeneity present on the population.

Limitations of Compartmental Models

Limitations of Compartmental Models

- Cannot fully represent the heterogeneity of individuals in the population.
- **Cannot represent non-random connections and interactions among individuals.**

Limitations of Compartmental Models

Final Thoughts

- **Modelers should recognize when heterogeneity and network effects are important enough to merit abandoning the aggregate approach in favor of an individual-based model**

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- **Models, in general, can and should be designed to answer specific questions, given a specific situation.**

Thank you!

The End