**A Systems View of the Smoking Problem: Perspective
and Limitations of the Role of Science in Decision-
Making**

by

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Abstract

The complex issues and relationships surrounding the smoking problem indicate the desirability of a system dynamics computer simulation model for policy development and analysis. This paper describes an initial model-building effort, including reports of initial policy and sensitivity testing of the model. The lack of scientific research on most of the relationships and parameters required in such a model forced heavy reliance upon intuition in the model development. The sensitivity of simulated model outcomes to many of these assumptions demonstrates the need for a more concentrated multi-disciplinary research effort if forecasting and policy determination are to be carried out with confidence.

Introduction

In 1965, the U.S. Surgeon General released the now-famous report linking smoking with lung cancer and other diseases. Ever since, there has been a continuous conflict in this "smoking problem". Researchers continue to find more hazards to smoking while the cigarette industry continues to deny these reports; health officials lobby for more stringent cigarette standards and more restrictions on smoking while the industry tries to counter this; education has attempted to help smokers quit and prevent the initiation of smoking while advertising has continued to exploit the "attractiveness" of smoking.

These factors which affect the portion of the population that smokes interact in a dynamic way. But certain proposals to solve or reduce the smoking problem may have results that are counterintuitive. More stringent cigarette

standards may reduce tar and nicotine content in cigarettes which in turn should reduce smoking related morbidity and mortality. However, this reduced smoking-related morbidity and mortality in turn is likely to increase societal approval of smoking which may in turn increase the smoking population. The complicated set of interactions in the smoking problem should be analyzed carefully in trying to set public policy in an effective manner, even if we begin by assuming an overall objective of reducing the prevalence and impact of smoking.

This paper presents a simplified and preliminary system dynamics model of the smoking problem and reports tests of certain policy alternatives as to the efficacy in reducing the smoking population and smoking-related morbidity and mortality. By its method of approach to analysis, the paper is as much a statement of the inadequacy of focused social and policy-impacting scientific research, as it is a presentation of a scientific methodology for policy-seeking. For lack of relevant evidence, most of the relationships and parameters in the model had to be generated by intuition, rather than from empirical analysis.

Two examples may help to illustrate the difficulty. Significant research has been done to determine differentiating characteristics between smokers and nonsmokers. Saslow and Matarazzo list thirty-four such characteristics which have been statistically verified to differentiate smokers from nonsmokers. These characteristics include such factors as age, sex, income, residence, psychological tension level, emotional status and smoking habit of parents. But incorporating these variables into a dynamic causal model is very difficult. What are the key factors that influence the initiation of smoking and to what degree do they influence it? Sparse scientific evidence exists to answer these questions. As a second example, despite the theoretical work of Harris, we know that it is impossible to find empirical evidences for

for relationships such as the effect of price on the initiation of smoking in the United States.

We therefore developed the model with as many interactions as we thought reasonable and incorporated relationships to the best of our ability, guessing frequently but hopefully not arrogantly as to possible effects. The conclusions derivable from the model at its present stage of development are therefore more presentations of hypotheses worth further refinement and testing than guidance to current policy-makers.

The Model

The model* focuses on the complex interactions which affect the initiation and quitting of smoking. This divides the population into three levels: potential smokers, smokers, and ex-smokers. Among the key variables that the model measures are the proportion of the population in these three levels, and the mortality levels derived from the three population levels. (Fig. 1)

Figure 1. The Population Macro-System

* A more detailed discussion of the computer equations of the model is available, as are complete listings of the DYNAMO-documentor output.

The initial model was developed in the following eleven interrelated sectors:

1. Population -- the population is divided into three levels: potential smokers, smokers, and ex-smokers;
2. Contaminants and their effects -- representing the contaminants absorbed by smokers and their effects on morbidity and mortality;
3. Factors affecting Initiation -- the factors affecting the initiation of smoking, converting potential smokers into smokers;
4. Factors affecting Quits -- the factors affecting the quitting of smoking, converting smokers into ex-smokers;
5. Factors affecting Intensity -- factors affecting the intensity of smoking, or the number of cigarettes smoked per smoking person per year;
6. Factors affecting Price -- examining the effect of various variables on the price of cigarettes;
7. Restrictions on Smoking -- examining the factors that determine the general societal level of smoking restrictions;
8. Perceived Hazards -- examining the identified maladies and other factors which affect the perceived level of hazards due to smoking;
9. Societal Approval of Smoking -- describing the effects of various factors on society's attitudes of approval/disapproval towards smoking;
10. Tobacco Industry Spending -- examining the industry income and its effects on the industry's tools to maintain and/or increase smoking;
11. Anti-Smoking Campaign -- examining the attempts of the anti-smokers to reduce smoking.

An overview of the initial model, with the main interactions among the various sectors, is included in Figure 2. The plus and minus signs on the arrow-heads indicate the general direction of effect of one sector upon another. For example, an increase in the Perceived Hazards of smoking will tend to produce an increase in the Restrictions on Smoking. This is a reinforcing

or positive (+) relationship. Whereas an increase in Restrictions is shown as inducing a decrease in the Initiation Rate. These forces thus move in opposite directions and the relationship is shown as a negative (-) one.

Figure 2. Interactions Among Sectors of the Smoking Model

Each of the various sectors is composed of a set of complicated interactions, and the sectors also interact with each other. We can begin our more detailed examination with our main interest in the model, which was the percentage of the population in the various categories and the death of smokers. As was shown in Figure 1, the population is divided into three levels: potential smokers, smokers, and ex-smokers.

The potential smokers consist of all individuals over 12 years of age who were never smokers. This population level increases by the population aging rate, i.e., those reaching 12 years of age each year, which is an

exogenous variable. For this model, we have used a population aging rate of 1% which has been the approximate average for the United States in the last decade.

The potential smokers either die never having smoked, in accord with the "potential smoker death rate", or are converted to smokers by the function describing the smoking initiation rate.

The level of smokers is the population that is currently smoking. These smokers either die at the rate of the "smoker death rate", or quit smoking, in accord with the "smoking quit rate" and become ex-smokers.

Ex-smokers are that part of the population that smoked for some time but have quit the smoking habit permanently. Once becoming an ex-smoker, these people leave the level by dying at the rate shown by the "ex-smoker death rate".

We chose this representation of the population for several reasons. First, the three levels can easily be distinguished by the two rates, initiation and quits. Second, it is clear that these three populations have different death rates, which is a key variable in this model. This is also why smokers can become ex-smokers by quitting but ex-smokers (in this model) cannot become smokers again by reinitiating. Ex-smokers are represented here as individuals who have given up smoking permanently and are thus very distinguishable from smokers.

For our initial model equilibrium conditions, we wanted the proportions of the population in these three levels to be equivalent to proportions reported in Statistical Abstracts of the U.S. for the year 1970. From the statistics, we generated figures of 45% for potential smokers, 37% for smokers and 18% for ex-smokers.

The various death rates were determined by estimating the number of

years an individual on the average spends in any one of the levels. The life expectancy of a potential smoker was taken as 74 years, an ex-smoker, 73 years, and a smoker, 69 years. From the data we also estimated that smokers are on the average five years older than potential smokers and ex-smokers are on the average eighteen years older than potential smokers.

The actual numbers used for life expectancy and average age did not affect significantly the simulation results produced by the model. The normal Quit fraction and the normal Initiation fraction were calculated so that the initial proportions of the three levels remained constant. The relative proportions of these three population levels during the simulated time period are determined by the initiation rate and the quit rate.

Figure 3. Factors Affecting Initiation of Smoking

The initiation rate is decreased by increases in restrictions on smoking (such as a restriction in sales), perceived hazards of smoking (individuals are less likely to initiate if the perceived hazards of smoking are higher), anti-smoking campaign activities and the price of cigarettes. It is in turn increased by increases in societal approval of smoking (people are more likely to initiate when society has more positive attitudes towards smoking), and the tobacco industry's lobbying and promotional expenditures.

The quit rate is in turn increased with an increase in perceived hazards of smoking and anti-smoking campaign activities, while it is decreased by an increase in societal approval of smoking and tobacco industry spending.

Figure 4. Factors Affecting Quitting Rate

Societal approval of smoking is the society's acceptability of smoking. The forces of the tobacco industry and the anti-smoking campaign act in opposite directions to each other in trying to sway public opinion about smoking.

Figure 5. Societal Approval of Smoking and its Consequences

As societal approval goes up, the effort to impose more restrictions goes down as does the tendency to or ability to quit. If societal approval rises, the likelihood and acceptability of initiation goes up.

The smokers' death rate is influenced by two factors, the intensity of smoking and the level of contaminants in the cigarettes, in addition to other non-smoking influences upon death rate.

Figure 6. Influences on Smokers' Death Rate

As the death rate goes up, it becomes easier for maladies due to smoking to become identified.

In the same way, as contaminants and intensity go up, it becomes easier to identify maladies.

Figure 7. Influences on Identified Maladies due to Smoking

As more maladies become identified or more unequivocally demonstrated, the perceived hazards of smoking increase.

The increase in the level of perceived hazards affects the behavior of smokers. More try to withdraw from smoking or at least to cut down on

Figure 8. Consequences of Perceived Hazards

intensity and begin to smoke cigarettes with lower tar and nicotine content, decreasing the contaminant content. With a higher level of perceived hazards also comes more public pressure to increase the restrictions on smoking.

Among additional elements included in the model are perceived impacts of smoking on non-smokers, subsidies to the tobacco industry, support and impacts of health research, social tension, tobacco industry lobbying, and others.

Reference Mode Data and Computer Simulation

For Vital and Health Statistics the U.S. Public Health Service interviews approximately 50,000 families to determine the characteristics of the population in terms of smoking. The results (discounting for the section "unknown if ever smoked") for several years are included below:

Year	Sex	Present Smokers %	Ex-Smokers %	Potential Smokers %
1965	M	51.1	19.3	29.6
	F	33.3	7.9	58.8
	avg.	42.2	13.6	44.2
1967	M	49.1	18.7	32.2
	F	32.1	7.2	60.7
	avg.	40.5	12.9	46.5
1968	M	47.0	19.7	33.4
	F	31.2	8.1	60.7
	avg.	39.1	13.9	47.1
1970	M	44.4	26.2	31.5
	F	31.7	11.6	58.7
	avg.	38.0	18.9	45.1
1974	M	42.5	27.2	30.2
	F	31.9	12.5	55.7
	avg.	37.2	19.8	42.9

Table 1. Data on U.S. Smoking Populations

The trends can be seen in the following graphs.

Figure 9. Population by Smoking Status

For our reference mode it would have been difficult to duplicate these results. First of all, the statistics themselves are not reliable. Secondly, there have been various "impulses" in the system, such as the 1965 Surgeon General's report.

We were able to have the model duplicate the trends in the smoker and ex-smoker populations; however, we find the trend in the potential smoker population puzzling. The statistics provided were for the population aged 17 years and older, whereas our model is formulated to include all over 12 years. The dip in the potential smoker percent may be due to population age fluctuations or to the difference in bases used. In our model base run, the potential smoker percent continues to rise.

In the base simulation run of our computer model, the following results are obtained.

<u>Year</u>	<u>Present Smokers %</u>	<u>Ex-Smokers %</u>	<u>Potential Smokers %</u>
1970	37.00	18.00	45.00
1975	36.37	18.15	45.48
1980	34.46	18.66	46.88
1985	31.53	19.57	48.90
1990	27.74	20.78	51.48

Table 2. Simulated Data on Smoking Populations (Base Run)

The base run has the smoking population decreasing in proportion while the potential smoker and ex-smoker populations increase in proportion. Because of the continuing increase in population, the actual number of smokers does not decrease immediately.

<u>Year</u>	<u>Smokers</u>	<u>Ex-Smokers</u>	<u>Potential Smokers</u>	(populations in millions)
1970	74.00	36.00	90.00	
1975	76.40	38.12	95.54	
1980	76.01	41.15	103.41	
1985	73.03	45.34	113.26	
1990	67.48	50.54	125.22	

Table 3. Base-Line Model Projection of Smoking Populations

Figure 10. Population by Smoking Status (Model Base Run)

The model was run repeatedly for a 40 years simulated duration, beginning in 1970, but we will not attempt to argue in support of the model's results for more than 20 years because of the many extraneous factors that may influence the real-world situation beyond the 20 year point.

The following five computer-generated graphics show the trends in some of the key variables in the base simulation run of the model.

From Graph number 2 we see that the initiation fraction continuously decreases and the quit fraction increases, which explain the trends in the population variables. In the same graph we see that peer pressure, which is formulated as a function of the smokers/not-smokers ratio, drops also. This results in a system of four interconnected positive feedback loops (indicated in Figure 11) which further increases the quit fraction and decreases the initiation fraction after the first 20 years of the model.

Figure 11. Positive Feedback Loops Involving Peer Pressure

Societal approval of smoking (Graph 2), which is partly a function of perceived hazards of smoking, drops. This is a result of the increase in perceived hazards of smoking (Graph 3), which is a result of the in-

crease in the identified maladies due to the increase in health research (all in Graph 3).

The decrease in societal approval of smoking eventually leads to an increase in restrictions on smoking (Graph 4).

The perceived hazards of smoking affect the behavior of smokers as well by decreasing the intensity of their smoking and the contaminants per cigarette (by shifts toward lower tar and nicotine cigarettes) (Graph 1). This decrease results in the decrease in the number of smoking-related maladies per smoker (Graph 1). This decrease is not enough to overcome the other factors, such as health research (Graph 3), which continue to increase the perceived hazards of smoking.

The model, if carried out to 2010, results in potential smokers % = 64.93, smokers % = 11.97, ex-smokers = 23.1. This is due to the positive feedback loops in the system which drive the smoker % to such a low figure. This is basically due to the assumption that health research will continue to find hazards due to smoking.

PAGE 4 FILE SMOKE1 SMOKE1 5/14/78 17:17 BASE RUN

SRMS=S,SRMXS=X,CABS=C,INT=N,P=P,CONRC=R

Graph 1 (Base Simulation Run)

Graph 2 (Base Simulation Run)

Graph 3 (Base Simulation Run)

PAGE 6 FILE SMOKE1 SMOKE1 5/14/78 17:17 BASE RUN

RS=R,DFDRS=D,DFIRS=I,FSDF=F,PBIRS=B

Graph 4 (Base Simulation Run)

Graph 5 (Base Simulation Run)

Simulated Policy Tests

We have tested the effects of four possible public policies on the output of the computer simulation model. These policy alternatives are:

1. Federal contribution to anti-smoking funds;
2. An increase in the price of cigarettes (an effective tax);
3. A reduction in the contaminants in cigarettes;
4. A ban on all pro and con cigarette advertising.

The simulated outcomes of these policies are discussed below.

1. There has been some pressure for the government to spend additional funds on anti-smoking campaigns. In this model, when public funds are appropriated to an anti-smoking campaign we see a minor impact on the relative proportions of the population levels and subsequently on the total number of deaths.

In this model run, by the year 1990 the relative proportions of the population groups are smokers = 27.44%, potential smokers = 51.77%, ex-smokers = 20.79%, compared to the base run results of smokers = 27.74%, potential smokers = 51.48%, ex-smokers = 20.78%.

The major changes can be seen in Graph 7, in the way the increase in anti-smoking funds in 1980 affects advertising and lobbying. This results in a minor change in the perceived hazards of smoking (Graph 6) which causes the minor changes in the population outcomes.

2. The impact of a tripling of price (an effective tax) of cigarettes was tested on the model. The increase in price was imposed in 1980. The immediate effect on the smoking population was not great (smoker % = 24.31 vs. 27.74 in the base run) but was meaningful. The increase in price affected mostly the initiation fraction (Graph 9) and the intensity of smoking (Graph 8).

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PHS=P,IHS=I,ISRMS=*,SEPNSE=E,HRES=H,TSUB=T
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Graph 6 (Policy-Test #1: Federal Contribution to Anti-Smoking Campaign)

Graph 7 (Policy Test #1: Federal Contribution to Anti-Smoking Campaign)

PAGE 5 FILE SMOKE1 SMOKE1 5/16/78 13:15 SWTP

SRMS=S,SRMXS=X,CABS=C,INT=N,P=P,CONRC=R

Graph 8 (Policy Test #2: Effective Tax)

PAGE 6 FILE SMOKE1 SMOKE1 5/16/78 13:15 SWTP

IF=I,QF=Q,PF=P,SAS=S

Graph 9 (Policy Test #2: Effective Tax)

3. The third policy evaluated in the model was a reduction in the contaminant content of cigarettes by 75% in the year 1980. The "contaminants" in cigarettes are here defined to be the causes (admittedly not yet fully known) of smoking-related maladies and mortality. This policy is intended to decrease the direct health risks of smoking. However, such a policy has interesting consequences. In the model run, the smoker % = 27.00 compared to 27.74 in the base run in the year 1990. But by the year 2010 the population by smoking status has the following characteristics: smoker % = 13.97, potential smokers % = 64.96, ex-smoker % = 21.07 compared to the following results in the base run: smoker % = 12.97, potential smoker % = 64.38, ex-smoker % = 22.65. This policy results in a slight increase in the long-term projected smoking population! The total number of deaths in the 40 year period are 176.80 million in the policy run whereas they are 177.39 for the base run. Thus, although the smoking population is larger, the death rate is slightly lower because of the decrease in the contaminant level.

The initial result of the decrease in contaminants per cigarette is an increase in intensity (smokers may increase smoking to compensate for the lower levels of "contaminants" per cigarette). But this diminishes rapidly because of the decrease in contaminant absorption per smoker (Graph 10).

The quit rate goes up rapidly at first but levels off (Graph 11) because of the decrease in identified smoking-related maladies per smoker and the slower rise in perceived hazards (Graph 12), which is all due to the lower contaminant level.

These results have interesting implications. If such a policy were instituted it may reduce maladies and mortality due to smoking but may

Graph 10 (Policy Test #3: Reduced Contaminants)

PAGE 24 FILE SMOKE1 SMOKE1 5/16/78 12:24 SWTC01

IF=I,QF=Q,PP=P,SAS=S

Graph 11 (Policy Test #3: Reduced Contaminants)

increase the number of smokers.

4. The fourth policy tested is to ban all advertising (pro and con) for cigarettes in 1980. The results show a faster decrease in the smoker population than in the base run, smoker % for 1990 = 27.14. This is due to the fact that the model assumes that the cigarette advertising is a more powerful influence on smoking than the anti-smoking advertising is against smoking.

Sensitivity Testing

The model was further tested by performing the following sensitivity analyses:

1. Tension stepped up by factor of three in 1980;
2. Fraction of smoking permitted in public set equal to zero in 1980;
3. Tension stepped up initially;
4. Effect of societal approval of smoking removed from influencing health education;
5. Effect of societal approval of smoking removed from influencing health research;
6. Social learning time increased to fifteen years from ten years;
7. Total identifiable smoking-related maladies decreased to seven from ten;
8. Tail effect of restrictions on initiation changed;
9. Population growth set equal to zero in 1980;
10. Smoking-related maladies prevented set equal to 4 instead of 0;
11. 10% noise level in societal approval of smoking.

The results from these sensitivity tests indicate that the model is as sensitive (or even more so) to these parameter changes as to some of the policy tests shown previously. Since most of the relationships in the model were chosen thoughtfully but in fact arbitrarily, this indicates that the variables in the model must be more accurately determined for the results to be taken seriously.

Limitations of Science in Decision-Making

The smoking model and the experiments conducted with it, as presented in this paper, provide a case illustration of the limits of science's role in public policy-oriented decisions. Beginning with a central concern for the smoking process and its impact upon morbidity and mortality, the model's scope includes the forces perceived as important in the development and implementation of policies intended to control and reduce the smoking problem. Those forces can be acknowledged to include medical, behavioral, economic, sociological, and political relationships.

Despite the controversy surrounding the Surgeon General's and related reports, the medical linkages between cigarette smoking and morbidity and mortality are among the least uncertain of the model formulations. Other aspects of the model representation, such as the impacts upon health research funding of society's attitudes towards smoking, are much more speculative in both structure and parameter values. The biomedical relationships are better understood and more reliably measured than are the socio-economic-political variables.

But to what extent is the methodological approach taken here--of feedback systems representation, quantification and computer simulation analyses--affected by data inadequacies? Surely the causal loop diagrams themselves and the logical and/or intuitive conceptualization based on those diagrams, are not affected by the data limitations described. To the extent public policy insights into smoking issues can be gained from the process of diagramming or the resulting visual representations, constraints on information availability are not material.

However, in regard to the computer simulation results the consequences are different. For many modelled parameters policy implications are unchanged over a fairly wide range of numerical values. Surprisingly, for example, different mortality assumptions made little impact upon model projections. But for far too many socio-economic-political relationships, model outcomes turned out to be very sensitive to assumed changes of relationships that were well within the bounds of data uncertainty.

In the smoking problem the limits of utility of scientific decision-aiding approaches are set by the limited social science knowledge available. The authors suspect that the same constraint may dominate many other areas of public policy formation. The model presented in this paper is only a preliminary representation of the issues and relationships that must critically affect the development and effectiveness of public policy on the smoking problem. A serious commitment to coping with the consequences of cigarette smoking warrants a dedicated multi-disciplinary research effort to elaborate and provide data support for the approach taken here.