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Abstract

One of the most difficult tasks system dynamicists have is presenting the key concepts of system dynamics to senior decision makers quickly. The paper presents three, very small, stock and flow models that were developed quickly and used in presentations to senior managers of New York State government agencies to show them the potential power of developing formal models to address key issues. The first model shows senior managers how their view of a program's performance could be inaccurate, and offers an alternative explanation that was not obvious prior to model development. The second model shows how a successful policy would appear to fail when measured using system stocks. The third model provides an example of how a small stock and flow model was used to obtain the confidence of an expert advisory group unfamiliar with the system dynamics methodology. These small models represent the beginning of what the authors hope is a growing number of small formal models that can be used to identify insights that highlight the power of system dynamics for those working in the public sector.

Lessons from Simple Stock and Flow Models

Introduction

One of the most powerful tools system dynamicists have is the ability to quickly identify and map important stocks and the behavior of those stocks over time. Andersen and Richardson (1997) begin their group modeling interventions with simple stock and flow models, they refer to them as concept models, in order to quickly get a group up to speed on the use of system dynamics icons, structure generating behavior, and formal simulation. Homer (1993) developed a formal system dynamics model to examine the issue of the prevalence of cocaine use in the United States, yet a simple stock and flow structure of people who have ever used cocaine shows how self-report surveys can be inaccurate. Forrester begins World Dynamics by identifying the key stocks. Warren (2001) argues that identifying the key stocks is important from a strategic perspective while Randers (1980) advocates that simple models capable of simulation should be built as quickly as possible during a formal system dynamics modeling project. Sweeney and Sterman (2000) have found that graduate students from an elite business school have difficulty understanding stock and flow concepts. Ossimitiz (2002) has also conducted empirical research that indicates that the subjects tested had difficulty in stock and flow thinking. Building on these perspectives, this paper examines three small formal stock and flow models that were developed within hours of being given the problem statement and that quickly provided insights to different clients.

Model 1: Waiver Slots Model

The New York State Office of Mental Health developed a pilot program for children with psychiatric problems that would provide children and their immediate families with intensive case management services. This program targeted children requiring a psychiatric intervention that was less than hospitalization, but more than what was currently available in existing programs. The program was designed to save money by reducing the number of psychiatric hospitalizations (these are high cost services), while at the same time providing opportunities to meet the treatment needs of these children.

The pilot program was designed to accommodate a maximum of 125 children. It was structured so that children presenting themselves at hospitals in need of psychiatric services would be evaluated based on a set of standard evaluation practices. Through the evaluation process, these children would be divided into one of three groups: 1) children requiring immediate psychiatric hospitalization; 2) children not needing immediate psychiatric hospitalization, but deemed in need of intensive case management services; or 3) children not requiring any mental health services.

The program provided services to those children in Group 2, with Group 2 being further broken down into two categories. Although the standard evaluation practices used were considered state of the art, they were not deemed to be fool proof. It was possible that some children deemed eligible for the intensive case management program would not respond to this treatment and would end up requiring a psychiatric hospitalization to meet their needs. The rest of the children entering the program would be suitable and would respond well to this form of treatment.

Furthermore, experts setting up the program assumed that the program would work for only two-thirds of the children. In addition, the program experts thought that it would take four months to determine that the program was not working for a child. Children for whom the program worked would remain in the intensive case management treatment program for an average of nine months before being discharged.

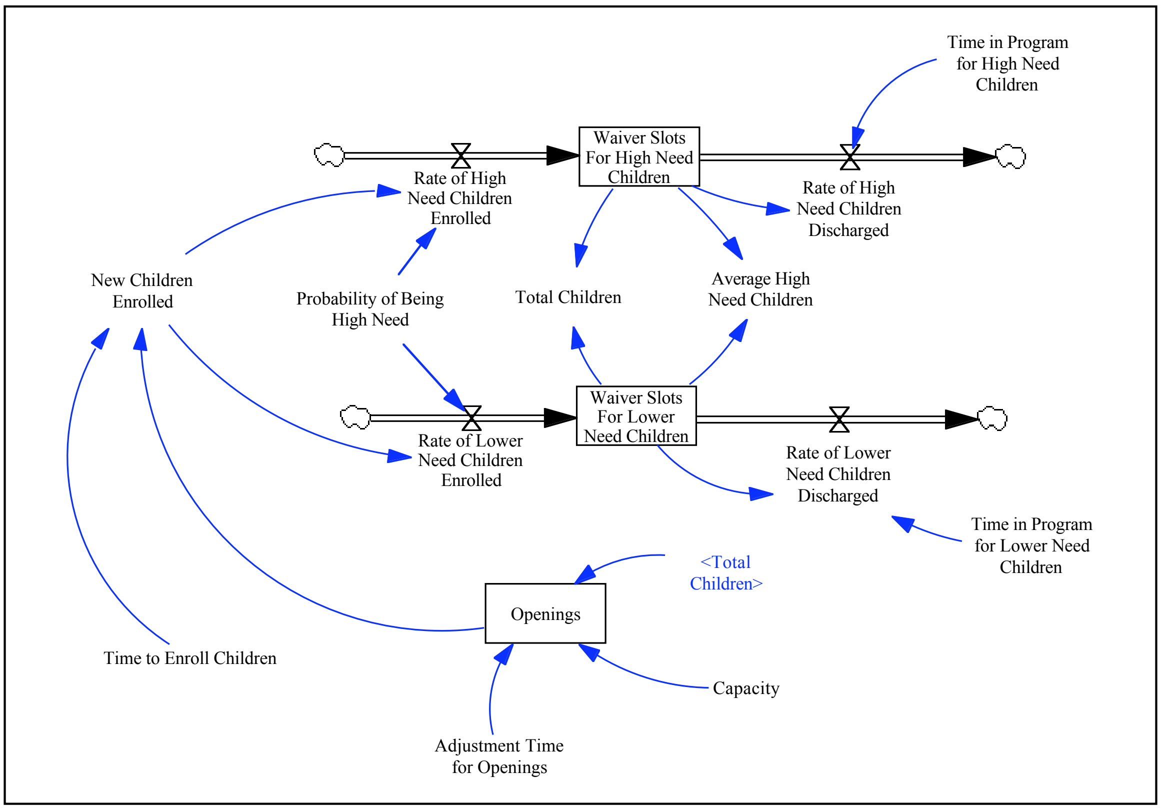
Since it was designed as a pilot program, an evaluation of the program was scheduled to be conducted after the program had been in operation 18 months. The purpose of the evaluation was to determine whether the program was functioning as anticipated and whether it should be replicated in other parts of the state. The author was asked to spend a few hours with the evaluation team, comment on the data that were collected, and provide a feedback perspective on the program's operation.

Although the experts initially anticipated that the program was going to be appropriate for two-thirds of the children entering the program, the evaluation found that the program was appropriate for 84 percent of the children receiving services. After some discussion, the experts concluded that this higher rate was due to the screening procedures used at intake. Furthermore, they decided that the screening procedures and the personnel using them warranted closer examination to determine if this could be replicated in other programs with similar clientele.

The stock and flow model contained in Figure 1 was quickly (about 2 hours of listening and modeling) developed to examine how patients flowed through the system. As this was a new program starting out with no participants and growing to a maximum of 125, the author was originally interested in capturing the growth of the program and thinking about the transitions that would need to occur in order to move the program from a start-up endeavor to one that functioned in equilibrium.

The model was built based on two primary assumptions: 1) the program would not be suitable for one-third of the participants and they would leave after four months, and 2) the program would work for two-thirds of the clients and they would leave after nine months of treatment. The simulation model generated output that was very close to that collected through the evaluation.

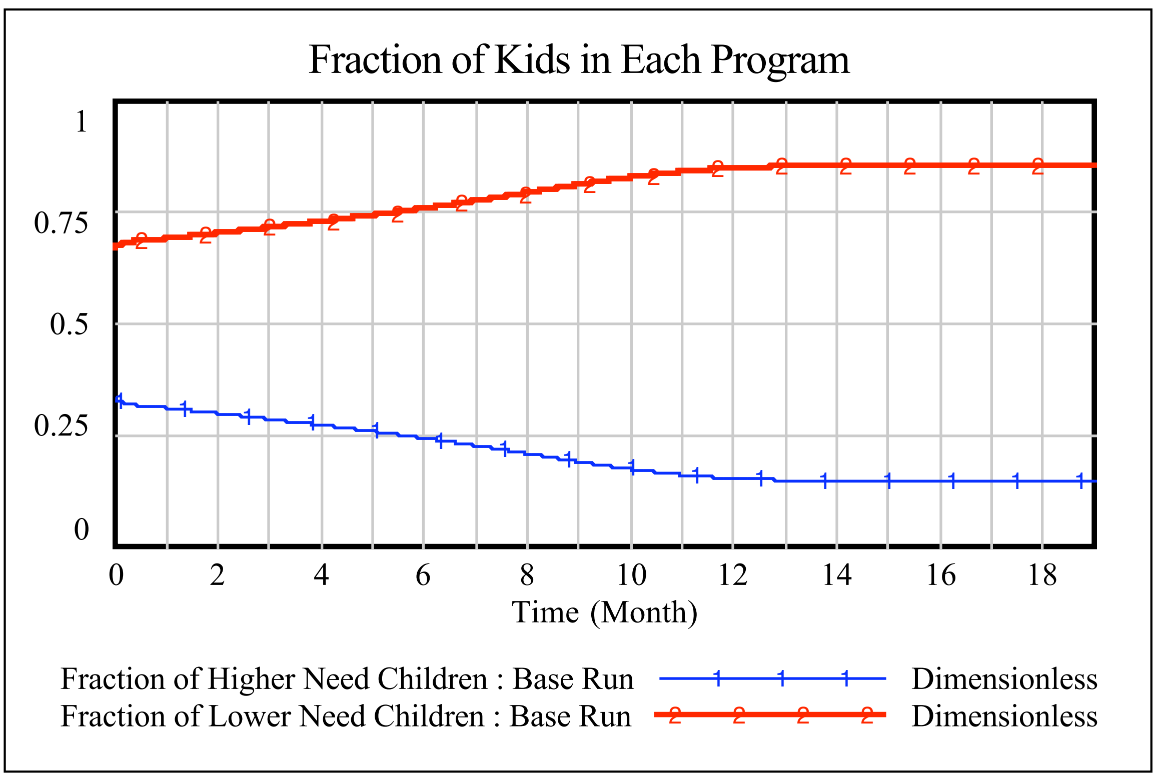
Figure 1
Stock and Flow Model of the Waiver Program



The simulation model showed that by month twelve (see Graph 1) the program had reached an equilibrium whereby 85 percent of the participants were suitable for the program and 15 percent were not suitable. Since the model did not change any intake parameters, an explanation for this behavior had to be found elsewhere.

An analysis of the model indicated that the 85/15 percent breakdown occurred due to the differences in the length of stay each population had in the model. Since the program was determined not to be suitable for a child after four months, the child was discharged to a psychiatric hospital for more intensive services and his or her spot became available. There was a two-thirds probability that this opening would go to a child whose needs could be met by the program. It soon became readily apparent that this was the reason that the program appeared to be meeting the needs of more children than originally anticipated. The model offered a different explanation than that originally identified (i.e., a better intake process). It showed that the leverage in this system is in the time delays in identifying those children for whom the program is inappropriate. Reducing these time delays results in services being provided to more children for whom the program is suitable.

Graph 1



When these results were shared with the senior management team, a light bulb went off. The team realized that it could have been dealing with a program that was underperforming and that the reason for the underperformance might not have been evident from the traditional types of evaluations they were performing. The end result was that they included a system dynamics modeler on additional evaluations to seek out similar insights.

Model 2: Tobacco Model

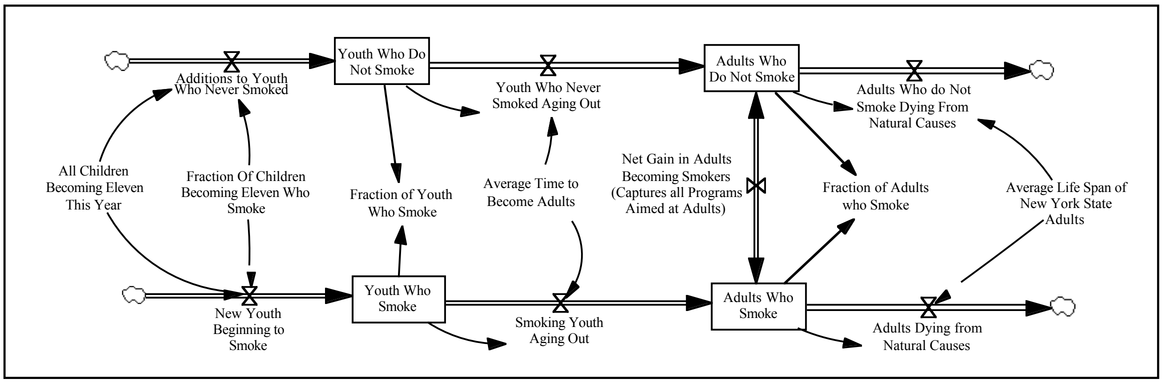
The New York State Health Department runs a number of anti-tobacco programs aimed at stopping children and young adults from picking up the smoking habit as well as getting people who currently smoke to stop. In 2001, the New York State Health Commissioner announced that the agency's goal was to reduce the number of smokers in New York State by 50 percent in five years.

Data[1] are readily available that show 20 percent of youth between ages 11 and 17 smoke, and 22 percent of all adults smoke. Figure 2 contains a stock and flow system dynamics model that disaggregates the population of New York State into four distinct groups, which are determined by age and smoking status. The model is based on the assumption that children enter the system when they turn eleven and age through the process and live, on average, to age 74. Many people do quit smoking each year, but in order for 20 percent of youths and 22 percents of adults to smoke, a net increase of 3,000 more adults must start smoking than quit each year.

[1] These data were obtained from the New York State Department of Health's RFP number 1341466A titled, "Independent Evaluation of the New York State Comprehensive Tobacco Use Prevention and Control Program."

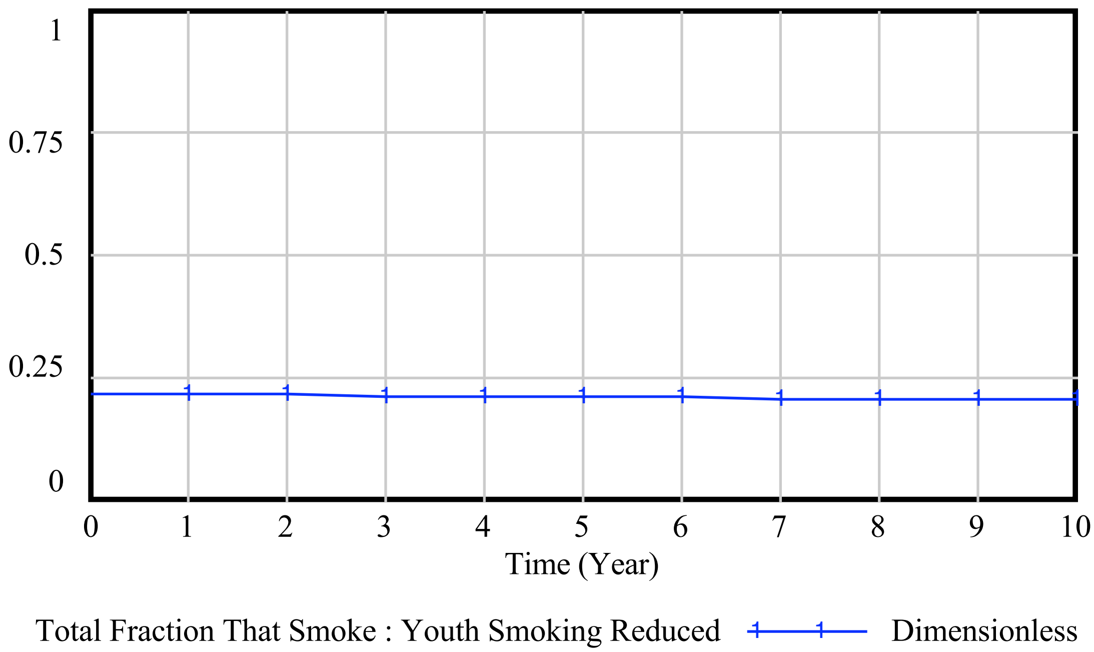
As an extreme simplification of the system and problems to be addressed, this model addresses one key question: how to achieve the stated goal of reducing tobacco dependency by 50 percent in five years. Furthermore, the model focuses on only one policy - reducing the number of youths who start smoking (Fraction of Youth Becoming

Figure 2
Stock and Flow Structure of the Tobacco Use Aging Chain



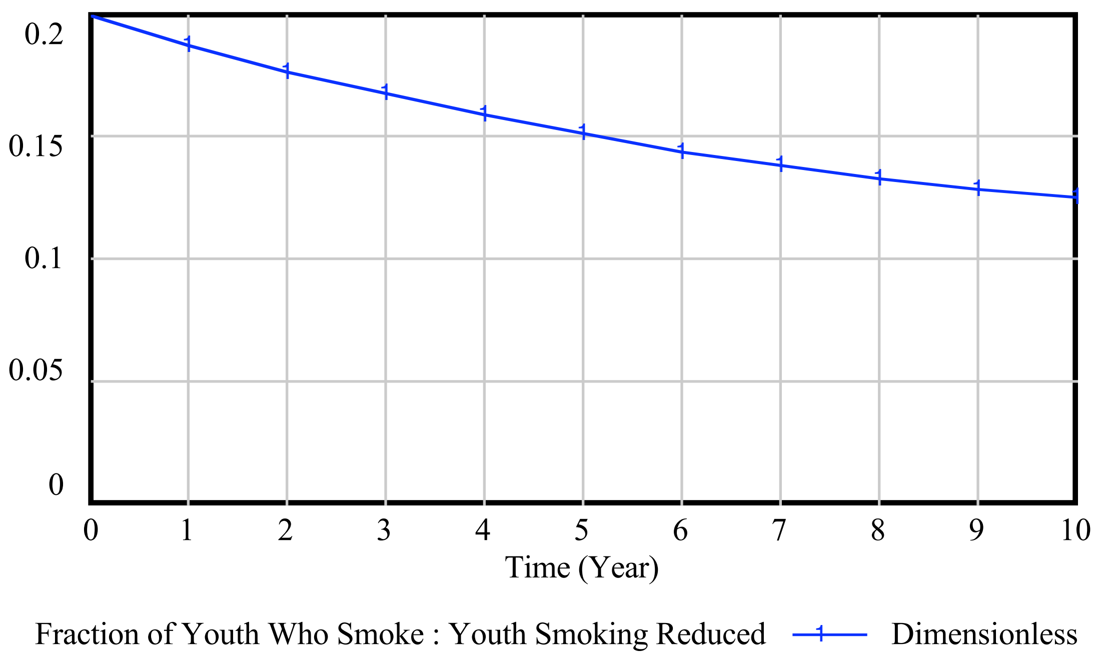
Eleven Who Smoke). Since this policy lever was selected based on the notion that smoking is an addiction, getting youth to not start smoking should be much simpler than getting people who are already smoking, both youth and adults, to stop smoking. The simple stock and flow model allowed us to reduce the Fraction of Youth Becoming Eleven Who Smoke from its initial value of .2 to zero. Stopping youth from becoming smokers would seem to be a very effective policy. The output in Graph 2 shows what happens over a ten-year period when no new youth start to smoke. There is almost no change in the total fraction that smoke. The reason for this is simple. Success is measured in terms of stocks that have a very long residency time. It takes time for youth to become adults and it takes time for those who already smoke to leave the system. Therefore, a policy that would be expected to be extremely effective does not appear to move the system toward achieving the Health Department's goal of reducing the number of smokers in New York State by 50 percent in five years.

Graph 2
Total Fraction That Smoke With The No New Youth Begin Smoking Policy



Graph 3 indicates that the policy does result in substantial changes in the number of youth who smoke, but again, it takes time. An astute observer will also notice that the Fraction of Youth Who Smoke should have gone to zero in seven years, but it does not. This is due to the formulation in the Smoking Youth Aging Out outflow from the Youth Who Smoke level. A queuing process or additional disaggregating would be more appropriate, but would lead to greater detail that was not deemed appropriate for the model's purpose, i.e. showing Health Department officials how focusing policy statements on obvious stocks in the system could be a mistake. Although the model has a number of limitations, it served its purpose. The model showed how a system dynamics model could be useful and how measuring the effectiveness of a policy in terms of rates is more realistic than measuring it in terms of stocks when the average residency in stocks is long.

Graph 3
Fraction of Youth Smoking With The No New Youth Begin Smoking Policy



Model 3: Child Safety Seats

The National Highway Traffic Safety Administration (NHTSA) recently[2] announced that great strides in child passenger safety had been made due in large part to child safety seat programs implemented at the state level. NHTSA reported that 2,658 children under 16 died in traffic crashes nation-wide in 2001, representing a 5.4 percent

[2] National Highway Traffic Safety Administration Press release on February 12, 2003: GHSA News Release re New State CPS Program Assessment Tool.

reduction from the previous record low of 2,811 set in 2000. New York State established a child safety seat program in the late 1990s, and over the last few years it has seen dramatic growth and development. As a result, a number of issues and challenges have arisen with respect to managing and enhancing the program.

To examine the effects of selected laws and policies on the child passenger safety education program in New York State, it was decided that a simulation model would be built. The problem to be addressed by the simulation model was: "How do you reduce trained technician turnover and increase coverage in order to maximize the number of correctly installed child safety seats in New York State?"

The modeling project is being guided by an Advisory Board comprised of experts in the field of child passenger safety. Board members have no specific modeling experience and have never worked with system dynamics models. The model shown in Figures 3 and 4 was used to introduce the Board members to the potential uses of a system dynamics model. The model focused on the issue of correctly installed child safety seat coverage in New York State.

In New York State, there are 2,000 certified child safety seat technicians. Each year, through child safety seat events and at permanent fitting stations, approximately 7,000 child safety seats are fitted correctly. Furthermore, 3,000 new child safety seats are given away and fitted into vehicles each year. Therefore, the New York State Child Passenger Safety Education Program is responsible for insuring that 10,000 additional children each year are riding in child safety seats that are properly installed.

In New York State, children under the age of four are required to ride in child safety seats. The number of children under the age of four in New York State, excluding

New York City[3], is 728,000. Interviews with experts about the installation of child safety seats indicates that 90 percent[4] of all child safety seats are installed incorrectly. If it is assumed that the population of New York State will remain relatively constant, it can be concluded that approximately 15,000 children age out each month and that 15,000 babies are born and will require child safety seats each month. These assumptions are obviously wrong as the population of New York State increased from approximately 17 million in 1990 to 18.5 million in 2000 according to census data.

The stock and flow model shown in Figures 3 and 4 was developed to show the Board how increases in the capacity of the child safety seat program would change the fraction of child safety seats installed correctly (Fraction Installed Correctly). Using a slider, project participants were able to increase or decrease the number of child safety seats installed correctly to see how that change would influence the fraction of safety seats installed correctly. In addition, it was observed that when the number of seats installed correctly through the child safety seat program exceeds the number of children being born each month, 100 percent compliance was still not obtained. This occurred because of a nonlinearity in the model that reduced the effectiveness of the child safety seat program as more people participated in the program. It was explained to the project participants that this nonllinearity was included to capture the idea that as more and more people participated in the program, those remaining would be more difficult to reach and/or unwilling to participate.

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[3] New York City was excluded as public transportation is readily available. This is not to say that children in New York City do not ride in cars, but that calculating actual use would take more resources as this point than are available.

[4] Data collected by Stephanie Zaza et al (2001) indicated that 85 percent of child safety seats were installed incorrectly. The 90 percent figure was used as it was obtained from discussions with members of the Advisory Board.

Figure 3
Stock and Flow Structure for the Child Safety Seat Model

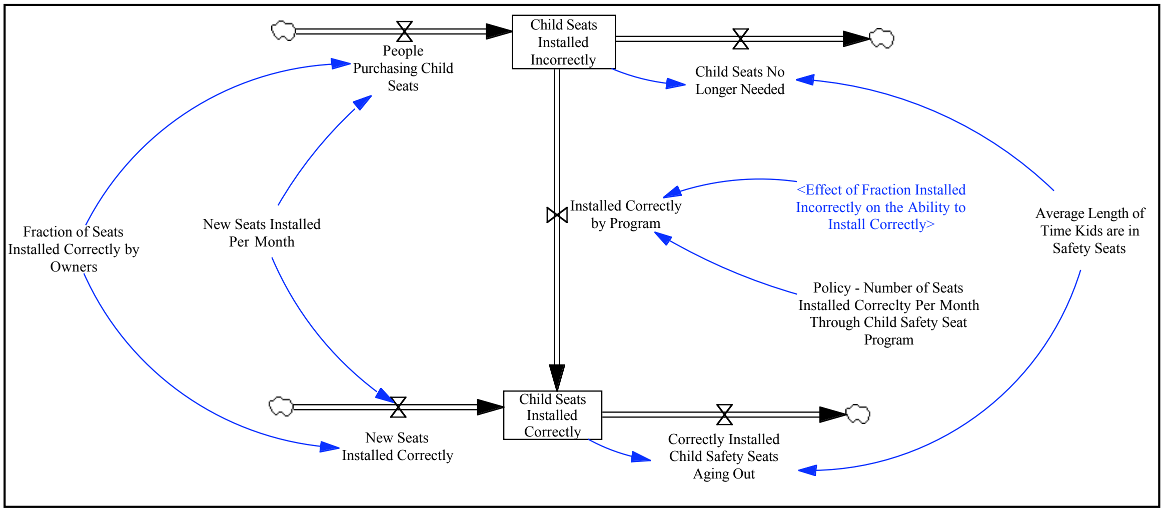
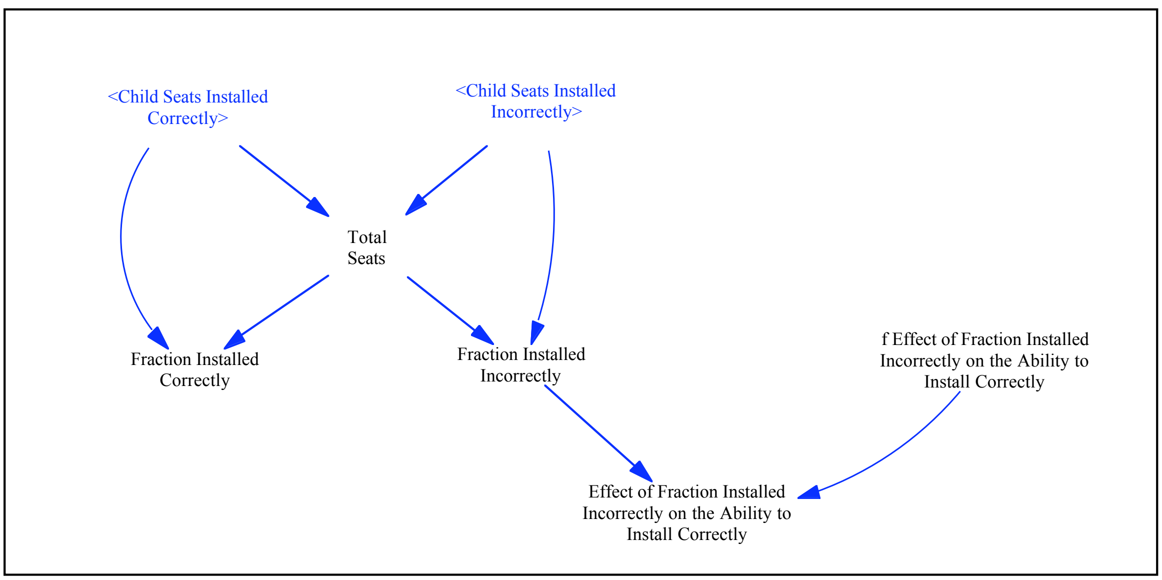


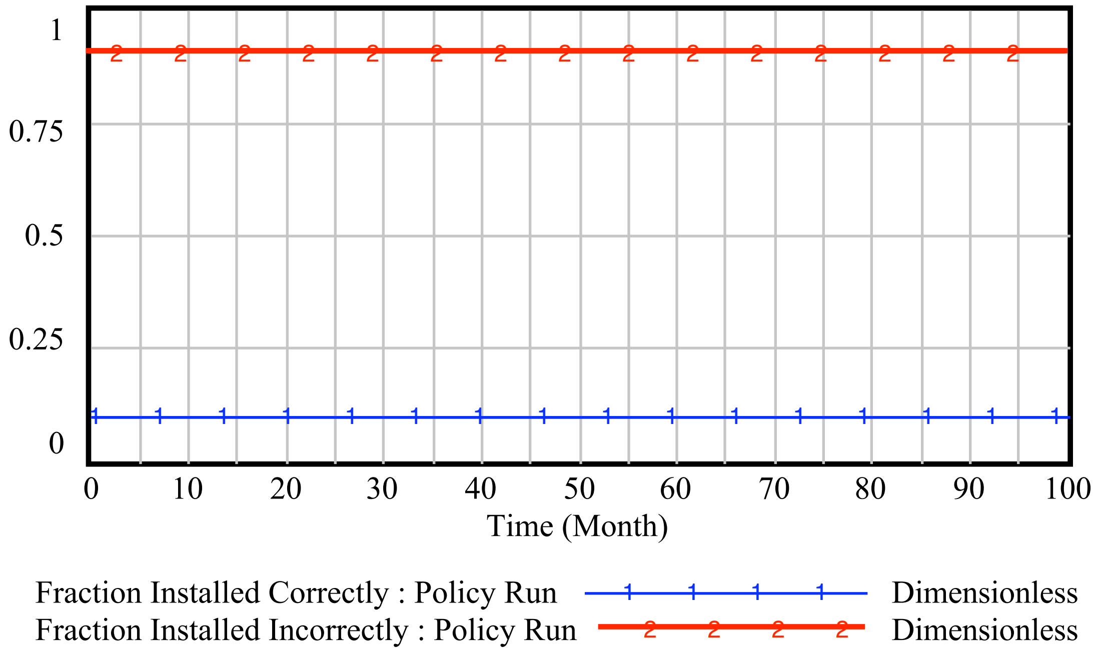
Figure 4
Additional Structure in the Child Safety Seat Model



The participants learned that the number of safety seats installed each year through the program was only a small fraction of all seats installed (Graph 4). Furthermore, the simulation model was used to show project participants that the slider they used represented their system. In the concept model, they could increase the number of seats installed by moving the slider (the results of increasing the number of seats installed to 20,000 per month is shown in Graph 5). In the real world, this would require more events, more training stations, increased utilization of technicians and/or the training of new technicians. These were the issues that the modeling project was going to focus on and it was the area in which the project participants were experts.

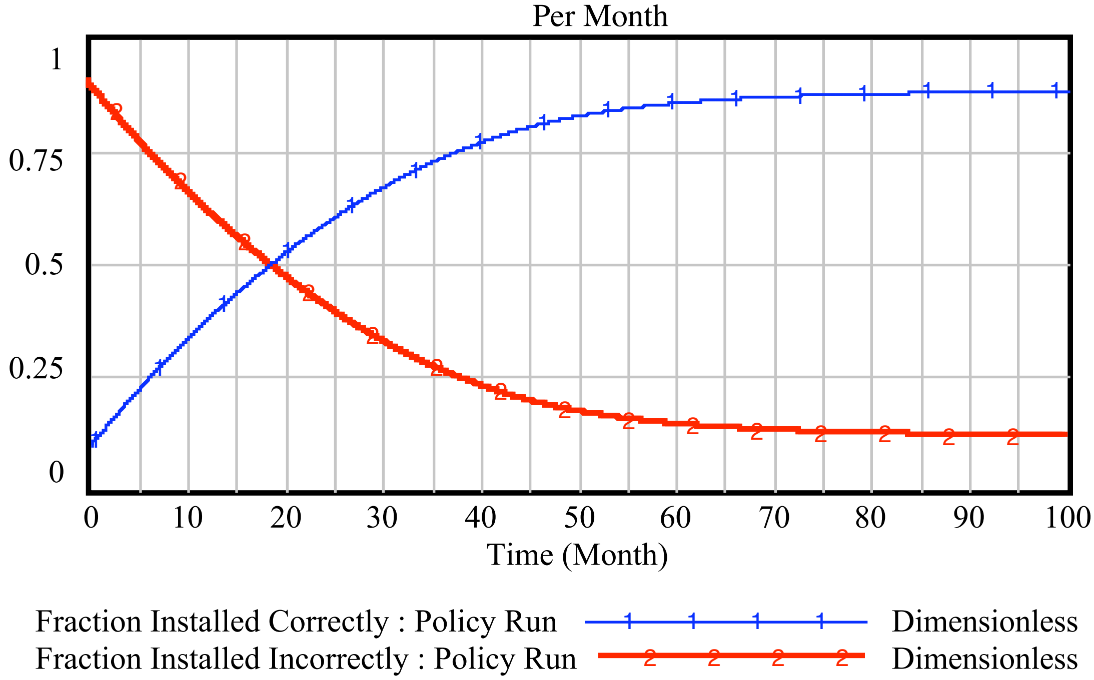
The model was simple enough that project participants could follow and understand what was happening. It included information that they provided, real information from sources they had confidence in, and it told a story that they could accept. The model also introduced them to stocks, flows, information feedback and simulation concepts that would be required for the larger modeling project in which they were going to participate.

Graph 4
Simulation Run With No Changes in the Number of Correctly Installed Child



Safety Seats

Graph 5
Simulation Run With Policy Allowing 20,000 Child Safety Seats to be Installed
Per Month



Conclusion

The three simple stock and flow models provided insights and valuable information to client groups that were not obvious before the development of the model. In the first model, a traditional evaluation indicated that the system performed much better than expected, and attributed this finding to the ability of program managers to develop on the job skills that allowed them, over time, to identify incoming clients more accurately than originally anticipated. The small simulation model, however, showed that the improvement was due to the structure of the system and not to the managers' ability to distinguish between different types of clients. The model convinced decision makers that their initial view was incorrect, that the structure of the system generated the behavior they observed, not their job skills related to identifying clients more accurately.

The second model was developed to examine a publicly stated policy put forth by the New York State Health Commissioner that set the goal of reducing tobacco use in New York State by 50 percent in five years. Aggregating tobacco users and non-tobacco users into four stocks, the mode was used to test a policy that stopped all youth from ever beginning to smoke. In testing this policy, the model enabled policy makers to observed how long it would take to achieve the stated goal. This simple model indicated that focusing on an absolute change in stocks as a policy goal, in the short-run, is not wise. Public policy decision makers would be better off focusing on rates of change rather than system stocks.

The third model showed how a simple model was used to introduce the benefits of simulation to an expert advisory group. Although small, the model included observed data and the expert opinions of advisory group members showing how simulation could be used to observe the behavior of the system given a specific policy.

In sum, these three models show how simple stock and flow models can be used to gain insights, develop trust, point clients in a different policy direction, and introduce clients to system dynamics modeling concepts in an environment that leads to changes in their mental models.

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Appendix I
Waiver Model

Adjustment Time for Openings = 2
Units: Month

Fraction of Lower Need Children=
Waiver Slots For Lower Need Children/Total Children
Units: Dimensionless

Rate of High Need Children Enrolled=
(New Children Enrolled*Probability of Being High Need)
Units: People/Month

Capacity = 125
Units: People

Rate of Lower Need Children Enrolled=
(New Children Enrolled*(1-Probability of Being High Need))
Units: People/Month

Fraction of Higher Need Children=
Waiver Slots For High Need Children/Total Children
Units: Dimensionless

New Children Enrolled=
Openings*Initial Difficulty in Program Start Up/Time to Enroll Children
Units: People/Month

Time to Enroll Children = 1
Units: Month

Openings=
Capacity-(SMOOTH(Total Children, Adjustment Time for Openings))
Units: People

f Start Up ([(0,0)-(20,2)],(0,0),(10,1),(19,1))
Units: Dimensionless

Initial Difficulty in Program Start Up = f Start Up (Time)
Units: Dimensionless

Average High Need Children=
Waiver Slots For High Need Children/(Waiver Slots For Lower Need Children+Waiver Slots For High Need Children)
Units: Dimensionless

Average Length of Stay = (Average High Need Children*Time in Program for High Need Children)+((1-Average High Need Children)*Time in Program for Lower Need Children)
Units: Month

Probability of Being High Need = 0.33
Units: Dimensionless

Rate of High Need Children Discharged = Waiver Slots For High Need Children/Time in Program for High Need Children
Units: People/Month

Rate of Lower Need Children Discharged = Waiver Slots For Lower Need Children/Time in Program for Lower Need Children
Units: People/Month

Time in Program for High Need Children = 3
Units: Month

Time in Program for Lower Need Children = 9
Units: Month

Total Children = Waiver Slots For High Need Children+Waiver Slots For Lower Need Children
Units: People

Waiver Slots For High Need Children= INTEG (
Rate of High Need Children Enrolled-Rate of High Need Children Discharged,
0.33)
Units: People

Waiver Slots For Lower Need Children= INTEG (
Rate of Lower Need Children Enrolled-Rate of Lower Need Children Discharged,
0.67)
Units: People

Appendix II
Tobacco Model

Adults Dying from Natural Causes=
Adults Who Smoke/Average Life Span of New York State Adults
Units: People/Year

Additions to Youth Who Never Smoked=
All Children Becoming Eleven This Year*(1-Fraction Of Children Becoming Eleven Who Smoke)
Units: People/Year

Adults Who Do Not Smoke= INTEG (
+Youth Who Never Smoked Aging Out-Adults Who do Not Smoke Dying From Natural Causes-"Net Gain in Adults Becoming Smokers (Captures all Programs Aimed at Adults)", Youth Who Never Smoked Aging Out*Average Life Span of New York State Adults)
Units: People

Adults Who do Not Smoke Dying From Natural Causes=
Adults Who Do Not Smoke/Average Life Span of New York State Adults
Units: People/Year

Adults Who Smoke= INTEG (
+Smoking Youth Aging Out-Adults Dying from Natural Causes+"Net Gain in Adults Becoming Smokers (Captures all Programs Aimed at Adults)"\Smoking Youth Aging Out*Average Life Span of New York State Adults+0.03*Adults Who Do Not Smoke)
Units: People

All Children Becoming Eleven This Year = 171776
Units: People/Year

Average Life Span of New York State Adults = 56
Units: Year

Average Time to Become Adults = 7
Units: Year

Fraction of Adults who Smoke=
Adults Who Smoke/(Adults Who Smoke+Adults Who Do Not Smoke)
Units: Dimensionless

Fraction Of Children Becoming Eleven Who Smoke=
0.1
Units: Dimensionless

Fraction of Youth Who Smoke=
Youth Who Smoke/(Youth Who Smoke+Youth Who Do Not Smoke)
Units: Dimensionless

"Net Gain in Adults Becoming Smokers (Captures all Programs Aimed at Adults)"=
3000
Units: People/Year

New Youth Beginning to Smoke=
All Children Becoming Eleven This Year*Fraction Of Children Becoming Eleven Who Smoke
Units: People/Year

Smoking Youth Aging Out=
Youth Who Smoke/Average Time to Become Adults
Units: People/Year

Total Fraction That Smoke=
(Youth Who Smoke+Adults Who Smoke)/Total Population
Units: Dimensionless

Total Population=
Adults Who Do Not Smoke+Adults Who Smoke+Youth Who Do Not Smoke+Youth Who Smoke
Units: People

Youth Who Do Not Smoke= INTEG (
Additions to Youth Who Never Smoked-Youth Who Never Smoked Aging Out,
1.16098e+006)
Units: People

Youth Who Never Smoked Aging Out=
Youth Who Do Not Smoke/Average Time to Become Adults
Units: People/Year

Youth Who Smoke= INTEG (
New Youth Beginning to Smoke-Smoking Youth Aging Out, 290243)
Units: People

Appendix III
Child Safety Seat Model

Average Length of Time Kids are in Safety Seats = 48
Units: Month

Child Seats Installed Correctly= INTEG (
+New Seats Installed Correctly+Installed Correctly by Program-Correctly Installed Child Safety Seats Aging Out, New Seats Installed Per Month*Average Length of Time Kids are in Safety Seats*Fraction of Seats Installed Correctly by Owners)
Units: Safety Seats

Child Seats Installed Incorrectly= INTEG (
+People Purchasing Child Seats-Child Seats No Longer Needed-Installed Correctly by Program,New Seats Installed Per Month*Average Length of Time Kids are in Safety Seats*0.9)
Units: Safety Seats

Child Seats No Longer Needed=
Child Seats Installed Incorrectly/Average Length of Time Kids are in Safety Seats
Units: Safety Seats/Month

Correctly Installed Child Safety Seats Aging Out=
Child Seats Installed Correctly/Average Length of Time Kids are in Safety Seats
Units: Safety Seats/Month

Effect of Fraction Installed Incorrectly on the Ability to Install Correctly=
f Effect of Fraction Installed Incorrectly on the Ability to Install Correctly (Fraction Installed Incorrectly)
Units: Dimensionless

f Effect of Fraction Installed Incorrectly on the Ability to Install Correctly(
[(0,0)(1,1)],(0,0),(0.0487805,0.281609),(0.114983,0.62069),(0.212544,0.810345), (0.344948,0.931035),(0.480836,0.971264),(0.634146,0.982759),(0.74216,1),(0.902439,), (1,1))
Units: Dimensionless

Fraction Installed Correctly=
Child Seats Installed Correctly/Total Seats
Units: Dimensionless

Fraction Installed Incorrectly=
Child Seats Installed Incorrectly/Total Seats
Units: Dimensionless

Fraction of Seats Installed Correctly by Owners = 0.1
Units: Dimensionless

Installed Correctly by Program=
"Policy - Number of Seats Installed Correctly Per Month Through Child Safety Seat Program" *Effect of Fraction Installed Incorrectly on the Ability to Install Correctly
Units: Safety Seats/Month

New Seats Installed Correctly=
New Seats Installed Per Month*Fraction of Seats Installed Correctly by Owners
Units: Safety Seats/Month

New Seats Installed Per Month = 15719
Units: Safety Seats/Month

People Purchasing Child Seats=
New Seats Installed Per Month*(1-Fraction of Seats Installed Correctly by Owners)
Units: Safety Seats/Month

"Policy - Number of Seats Installed Correctly Per Month Through Child Safety Seat Program" = 0
Units: Safety Seats/Month

Total Seats=
Child Seats Installed Correctly+Child Seats Installed Incorrectly
Units: Safety Seats