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Exploring the Impact of School Nurses on K-12 System Performance

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Exploring the Impact of School Nurses on K-12 System Performance

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by

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Abstract

The goal of this project was to analyze the contribution of nursing services in K-12 educational systems and to create a system dynamics model for policy testing and exploration. Through analysis of secondary and tertiary data, our discussions with nurses active in the field, and literature on the subject, we created a dynamic hypothesis and a simple model that represents the system we identified. Based on analysis of the model, created by the process presented throughout this work, we found that the incremental contribution of allocating a larger fraction of the budget to nursing services is high at first, but the marginal value declines rapidly and becomes negative after a threshold value has been reached. Further analysis is needed to identify this threshold.

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1 – Introduction

This project, sponsored by the Massachusetts School Nurse Organization (MSNO), was aimed at studying the impact of nurses working in a K-12 school system. The goal of the MSNO was to develop a model that can be used to support lobbying efforts to both attain and retain additional funding for nurses in Massachusetts School Districts. Our goal was to provide an unbiased analysis of the contribution of nursing services and to create a System Dynamics model with regards to the allocation of funds within these school districts. This model was created through analysis of data reported by school districts, discussions with nurses active in the field, and a review of literature relevant to the topic.

First, we created a dynamic hypothesis expressing the relationships identified in the system. This hypothesis was then expanded into a model that would allow experimentation with different funding policies. Based on analysis of the model created by the process presented throughout this work, we identified the most useful performance metrics of our policy tests. Our hypothesis was that nurses would have a large positive effect on several underperforming students, but overall system performance would remain relatively constant. This paper will break down our project goals and conclusions as well as our methodology, problem description and supporting data.

2 – Detailed Problem Description

This work attempts to examine a conflict in school systems between performance goals and budgetary requirements. Specifically we will be looking at the relationship in the system between nurses and teachers and their impact on the population. Schools, in a very simplified view, are goal-seeking organizations attempting to produce optimal results from a fixed budget. In the school systems, the major point of control is the distribution of that budget. In this system this is between teachers who create performance and nurses who create an environment of wellness for the educational process to function. We are looking for policies that optimize the combined effect of those groups.

The underlying process used to create our model was similar to the process outlined by Group Model Building, or GMB, as can be seen in the paper by Anderson/Vennix/Richardson/Rouwette titled Group Model Building: Problem Structuring, Policy Simulation and Decision Support (Anderson, Vennix, Richardson, & Rouwette, 2006). From initial meetings with MSNO staff and early data, we created a feedback loop diagram to relate the relationships between the primary and secondary factors that drive the model. This feedback loop diagram also reflecting our dynamic hypothesis can be seen in the Figure 1.

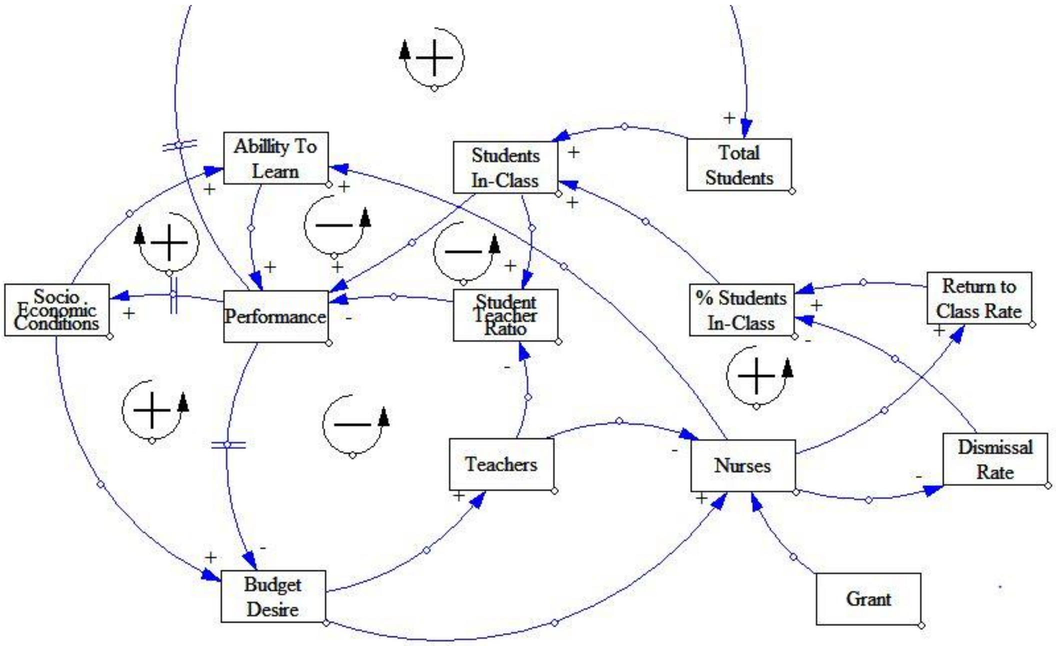


Figure 1 – The Initial Dynamic Hypothesis

The dynamic hypothesis was created partially through relationships contained in the data found in Section 3.1, but mostly through our experiential understanding of the way the components interact. Much of this understanding came from meetings with the MSNO and common knowledge.

The dynamic hypothesis is based on our understanding that changes in funding will most likely affect the two professional employee stocks. The two professional employee stocks are nurses and teachers. This will mean that an increase in teachers will have a negative impact on the number of nurses, and a decrease in teachers will have a positive impact on the number of nurses. From our experiential understanding of this system we determined that nurses would affect three different areas of the model. As supported later in the paper, nurses decrease the dismissal rate in school districts. Our initial findings led us to create two additional relationships that are dependent on the student to nurse ratio. Return to Class Rate is the rate at which the dismissed students return to their classroom. Ability to Learn is a stock that modifies system performance.

Return to class rate and dismissal rate are the components that determine the percentage of the students in class. This, multiplied by total students, gives us the total number of students in class. Based on tertiary information, we decided to base the effect of teachers on performance on the student/teacher ratio. (Finn & Achilles, 1999) Students in class have a positive relationship with the student/teacher ratio, which in turn causes a negative impact on performance. Students in class also have a smaller impact that positively affects performance.

Another variable, acting as a modifier, affecting the ability to learn is the socio-economic conditions. Performance has an inverse relationship with student/teacher ratio, a positive relationship with students in class and a positive relationship to the ability to learn. Performance over a delay affects the total number of students, which increases students in class. It increases socio-economic conditions again over a delay and along with socio-economic conditions it affects budget desire over delay. Budget desire is seen as that community’s desire to perform better. If performance is low, a greater emphasis is placed on increasing performance. As performance increases the community sees less of a need to maintain a higher level of funding. Budget desire determines the funding levels for teachers and nurses with nurses having the additional ability to receive funding through grants.

Based on the data and the dynamic hypothesis, we then proceeded to build an initial model based on the behaviors that we found, seen in Figure 2.

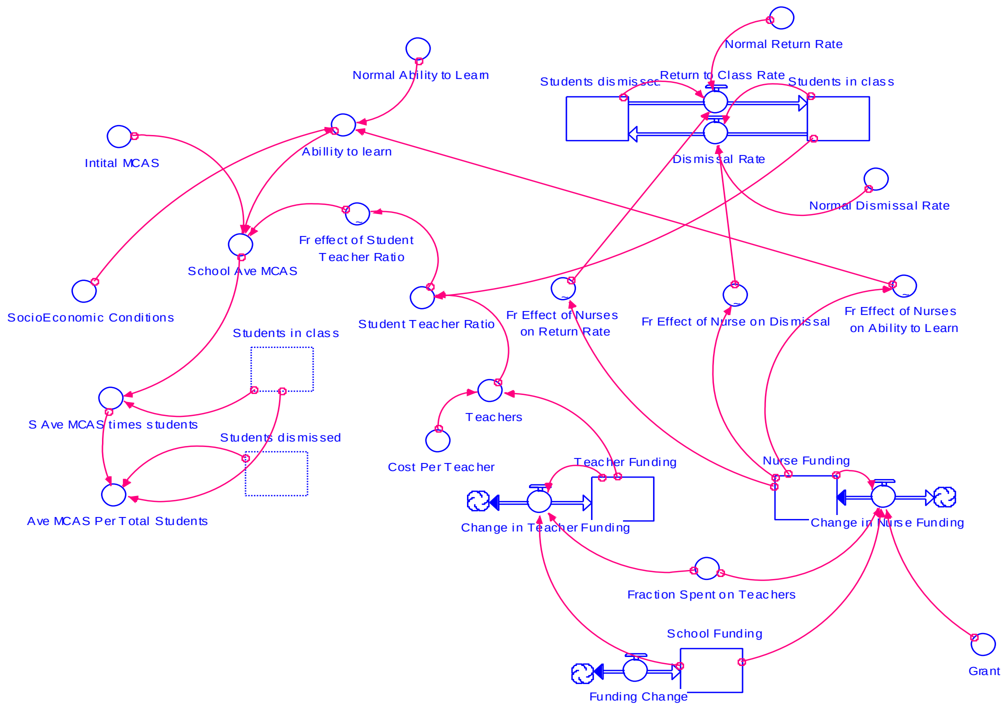


Figure 2 – Initial Modeling Attempt

The model is built using the same relationships as the Dynamic Hypothesis, while removing the internal balancing of the total budget. It was removed so that the budget could be held constant and the Fraction Spent on Teachers could be changed to represent a different budget allocation

After putting this model in an initial equilibrium, we proceeded to adjust the different variables to see their effect on the model as a whole, as well as the Performance Sector. The initial model gave us insights for further refining our model boundary and focusing on the research question.

3 – Methodology and Approach

Before taking the first steps in constructing the final model, we carefully considered the appropriate course of action to take to accomplish our goals. It was important to verify that System Dynamics modeling was indeed the best tool for this problem. One crucial deciding factor was the quality of the data available to us.

3.1 – Data Review

Unfortunately, the data provided by the MSNO only reflected schools with the ESHS grant and thus only showed well-funded nursing programs. We were unable to determine any adequate correlation in the data so the statistic analysis proved to be inconclusive. Regardless, our early work in that area is presented here to show it is more effective to support the relationships in our System Dynamics model with previous studies and experiential data rather than hard statistics.

The MSNO has been collecting data on several different groups of schools for both the 2007 fiscal year and 2009 fiscal year. The data we received contained the total number of students, MCAS scores, graduation rates, number of teachers, number of nurses, and dismissal rates. The rest pertains to the schools' overall budget and the amount spent on medical health services. Each of the schools is grouped by the Department of Education based on property values and school size as a socio-economic indicator. The data we received looked at 27 individual school districts, which were then placed into seven different groups based on the socio-economic characteristics. All the data analysis in this section was based on FY07.

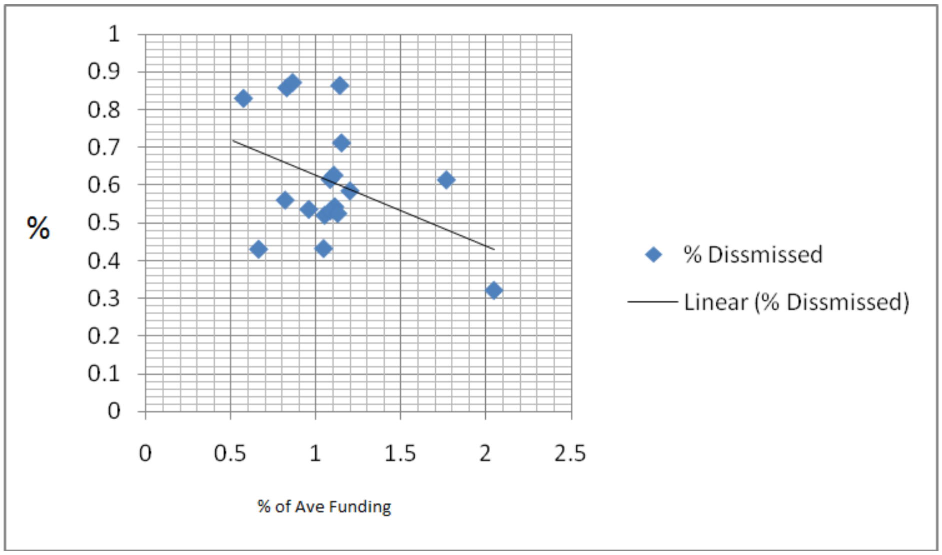


Figure 3 - Graph of Students Dismissed

Figure 3 is a graph of the percentage of students dismissed out of the whole body versus the percentage change in average funding. The best fit line did not prove that the correlation in this data between percentage of average funding and dismissal rates was strong enough to draw conclusions from.

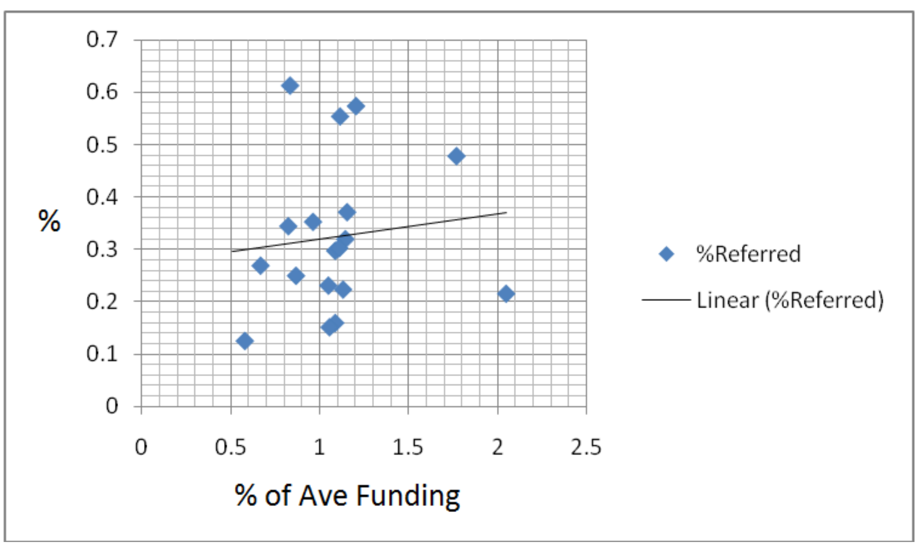


Figure 4 –Graph of Referrals

Figure 4 is a graph of the percentage of the students referred out of the whole body versus the percentage change in average funding. Referral means that a student was sent elsewhere for additional medical care. Once again, the correlation we found was not strong enough to provide effective support for the relationships in our model.

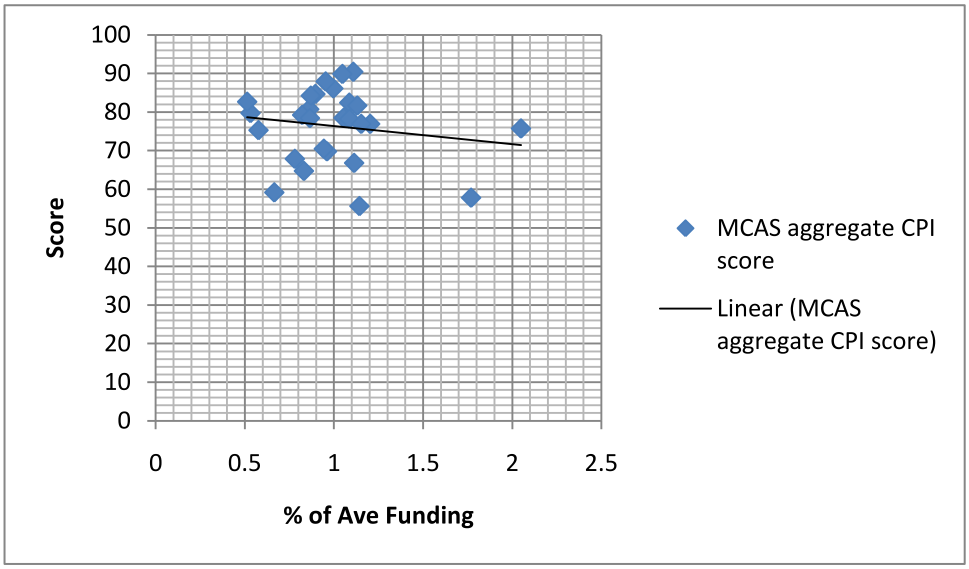


Figure 5 – Graph of MCAS Scores

Figure 5 is graph is of average MCAS scores for the school versus the percentage difference of health funding per pupil when compared to the group average. While this data presented the greatest degree of correlation, it was still far from adequate.

After conducting this analysis, we became aware that the level of aggregation in the data did not allow for an effective correlation between funding and each of these factors. Stratifying data into the groups suggested by MSNO reduces the sample size so any relationship that emerges would bear little statistical support under scrutiny. Each individual school district appears to be distinct enough that numerous confounding variables eliminate the possibility of determining any general conclusions. Thus, we decided that the best way to understand the system was to develop a model using previous research related to the subject and experiential data.

3.2 – Benefits of System Dynamics

While we are unaware of any previous models on the impact of nurses in a school environment, there are several works, which attempt to use statistical methods to examine their effect. Several papers demonstrate that there is a statistically significant reduction in checkouts for medical reasons in schools that employ a full-time nurse when compared to schools that do not. In 2007, a study examined the impact of nurses in several separate target areas including behavior and grades (Bonaiuto, 2007). While many of these papers provide a focused look at one aspect of nurses, conducting a similar experiment would provide little of use to the Massachusetts School Nurse Organization. Instead of focusing on one small part of the problem, the MSNO desired a more holistic tool that could answer a single question: Should lawmakers allocate more funds to school nurse positions?

The question itself has many implications. Allocation of funds is by nature a competitive process; in this case there is a strongly antagonistic relationship between nurse funding and teacher funding. A methodology that demonstrates the impact of nurses would be nearly useless unless it were also able to incorporate the relative impact of teachers in the system. For a model to be of value to the MSNO, it must in some way be able to demonstrate that there is a net positive gain in the system when nurses receive more funding. Modeling the impact of both teachers and nurses provides the solution to this problem allowing us to carefully examine the nature of the antagonistic relationship in the allocation process.

As members of an academic institution, it is important that impartiality is maintained throughout the design process. Instead of working to prove a particular result, creating a model to examine both contributions allows us to remain focused on understanding the complete system. The goal of this project is to deliver a tool to the MSNO that can be used to show the relative strength of several policy options, regardless of the outcome.

According to the MIT System Dynamics Group: “What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops. Stocks and flows help describe how a system is connected by feedback loops which create the nonlinearity found so frequently in modern day problems. Computers software is used to simulate a system dynamics model of the situation being studied. Running "what if" simulations to test certain policies on such a model can greatly aid in understanding how the system changes over time.” (webmaster@clexchange.org, 2000)

System Dynamics allows us to build a model that capitalizes on two of the MSNO’s main resources: the previous papers with regards to different aspects of the impact of school nurses, and the wealth of experiential information available through interviews with school nurses. The experiential information from the nurses can provide a basic structure for a model, while the previous research can be used to corroborate links of the model. In addition to these resources, MSNO was also able to provide several spreadsheets detailing the performance of schools that received grants in Massachusetts public school districts. This data can be used to create reference modes and to corroborate additional relationships within the model, but must be used cautiously. This data is a cross section of all data available from the set of schools that are required to report as part of the ESHS grant and is not representative of the entire Massachusetts school district population. Depending on the selection criteria for the grant, this could bias the information in a number of ways.

System Dynamics has two primary strengths. The first is the ability to test out several policy options, and compare the relative effect of each. The second strength is rooted in the nature of modeling, and is the result of being able to explore the effect of different loops within the model. Complex behavior can be traced to relatively simple structures, and often times it becomes clear where the leverage points in a system are during the modeling process. System Dynamics promotes a more holistic understanding of cause and effect in the model, and allows the user to target areas, which will amplify the performance of the system.

System Dynamics' primary weakness is directly tied to this strength. While System Dynamics can show a chain of cause and effect and be used to experiment with the relative effect of several policy options, it is not able to quantify the effect in the form of a prediction. System Dynamics can predict that policy P will have a positive effect on variable X, or can suggest that Policy P1 will have a greater effect than Policy P2, but generally cannot make a rigorous qualitative prediction such as "Policy P3 will result in 23 more students graduating than Policy P4." It is important that the client understands the limitations of the model, and that the strength of the model lies in qualitative analysis.

As detailed in Section 3.1, the data available is not adequate for quantitative statistical analysis. Therefore, it is apparent that System Dynamics is the best approach to the problem because of the focus on relationships and dynamics rather than the integration of concrete data. In school districts, these relationships are responsible for creating complex aggregate behavior. Only by breaking such a vast system down to basic components can we develop a solid understanding of how it truly functions. By doing so, we were able to construct a model that provides a useful interpretation of reality that data alone could not.

4 – Model Design and Logic

Our model can be broken down into four basic sectors: the Funding Sector, the Staffing Sector, the Attendance Sector, and the Performance Sector. Figure 6 shows the basic relationships between these sectors. The funding sector impacts the Staffing Sector, which in turn affects both the Attendance and Performance Sectors. The Attendance Sector also influences the Performance Sector as well as the staffing Sector, which creates a feedback loop.

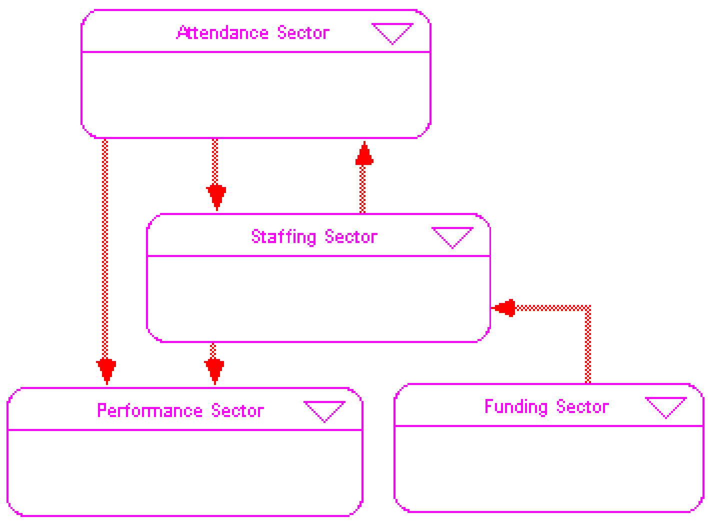


Figure 6 – High Level Map

The only sector that is determined completely exogenously is the funding sector; the remaining sectors rely on complex dynamic loops within the system. Thus, the most effective way to describe the system is to begin with the funding and staffing sectors, and then – rather than considering each of the other sectors individually – follow the relationships that stem out of staffing until the end of each causal loop sequence.

4.1 – Funding Sector

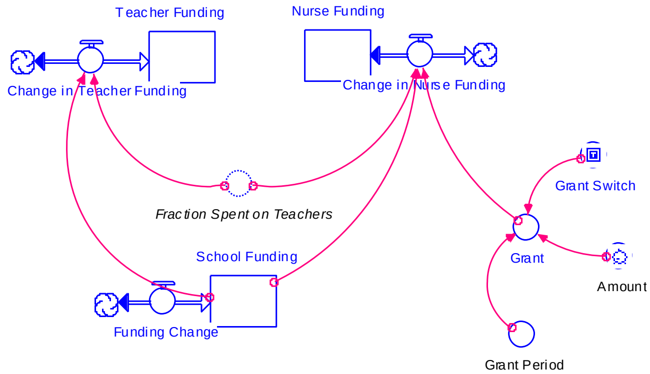


Figure 7 - Funding Sector Map

From discussions with the representatives of the MSNO we determined that, in general, the budgeting process for a school district puts nurses and teachers in an adversarial relationship for funds. The literature also supports that both nurses and teachers have an impact on student learning. It is because of these two factors that our model is built around the relationship of funding between nurses and teachers.

The structure of the funding sector as shown in Figure 7 is primarily designed to accommodate one of the objectives of this project. We want to be able to depict an increase or decrease in school funding and show how money should be allocated between teachers and nurses. Thus, the starting point of the model is the School Funding Stock and the Change in Funding Flow, which are exogenous to the system. The variable Fraction Spent on Teachers functions as a decision to be made by administrators of the school district and is also exogenous.

Two stocks depend on School Funding and Fraction Spent on Teachers: Teacher Funding and Nurse Funding. Each of these stocks has a flow, which regulates the amount of money that teachers and nurses receive respectively. The Change in Teacher Funding Flow is the product of the Fraction Spent on Teachers and the total School Funding, and adjusts the Teacher Funding Stock to reflect that amount. The Nurse Funding Stock and flow function similarly using the inverse of Fraction Spent on Teachers because in this model, we assume that all the funding that teachers do not receive goes to nurses. Additionally, the Nurse Funding Stock takes into consideration a Nurse Grant variable. Since the nurse grant comes directly from the state is not a part of the school district's budget, it must be external to the School Funding Stock and is exogenous to the system. The Change in Funding Flow, Fraction Spent on Teachers and Nurse Grant are effectively the three most important factors that will determine how the system behaves.

$$Change\_In\_Nurse\_Funding = Nurse\_Funding-(School\_Funding*(1-Fraction\_Spent\_on\_Teachers)+Grant)$$

4.2 – Staffing Sector

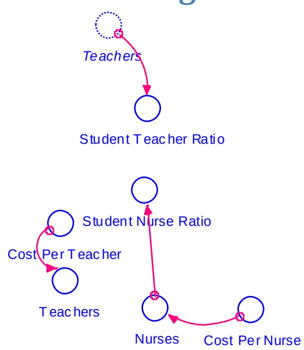


Figure 8 - Staffing Sector Map

The Staffing Sector, which is shown in Figure 8, essentially serves as an intermediary between funding and the other two sectors. Its role is to translate the budget allocated for nurses and teachers into the actual number of staff members employed in the school district. For the sake of simplification, the model assumes that both nurses and teachers can be hired and laid off instantaneously so there is no need to develop any feedback loops in this sector. Nurse Funding divided by the Cost of Nurse yields the number of Nurses, and likewise, Teachers is determined in a similar manner.

$$Nurses = Nurse\_Funding/Cost\_Per\_Nurse$$

Teachers = Teacher_Funding/Cost_Per_Teacher

However, the Attendance and Performance Sectors do not rely on the numbers of nurses and teachers but rather the Student to Nurse and Student to Teacher ratios. Nurses and Teachers are divided by the Students in Class stock in the Attendance Sector to calculate these values.

4.3 – Nurses

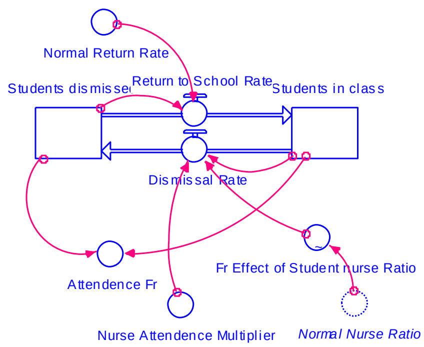


Figure 9 - Attendance Sector Map

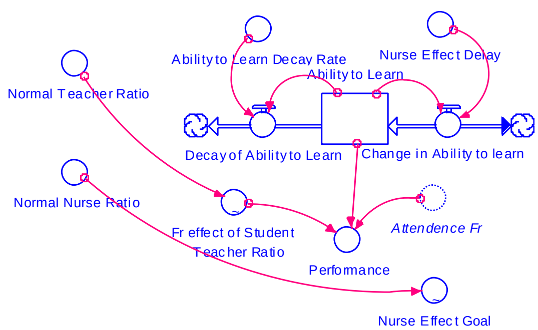


Figure 10 - Performance Sector Map

Nurses impact the Attendance Sector and the Performance Sector as seen in Figures 9 and 10 respectively, because they improve student health and consequently their ability to learn. Nurses also reduce dismissal rates by resolving issues that may otherwise result in the student being sent home sick. Thus we must examine the relationship between nurses and both these sectors to understand the full extent of their role in the system.

The student to nurse ratio is inversely related to the effectiveness of nurses because a lower ratio implies that there are proportionately more nurses to deal with the needs of the students. In the Attendance Sector, the Student to Nurse Ratio influences Dismissal Rate through the Fractional Effect of Student to Nurse Ratio. This fractional effect takes the Normalized Student to Nurse Ratio and yields a factor that determines Dismissal Rate. The graphical function in Figure 11 shows this relationship.

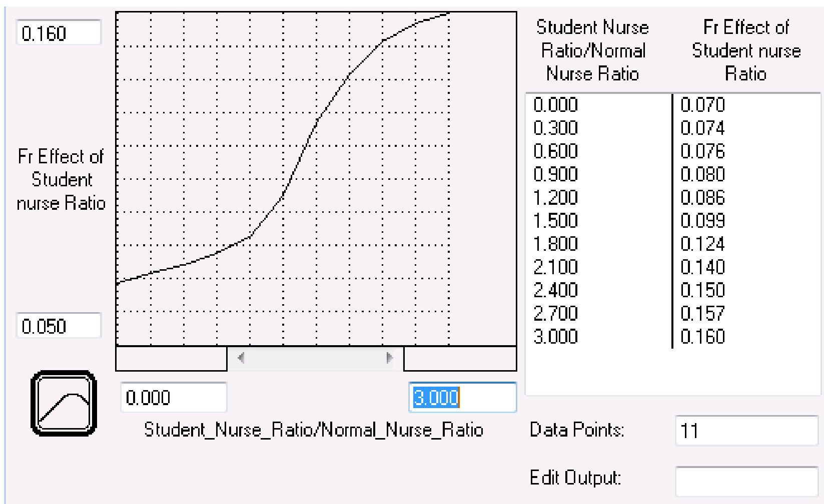


Figure 11 – Fractional Effect of Student to Nurse Ratio

From our research, we found literature that presented different data but similar trends. Dismissal rates for schools without nurses were between 15.7% (Allen, 2003) and 18% (Pennington & Delane, 2008) while rates with nurses ranged from 5% (Pennington & Delane, 2008) to 11% (Allen, 2003). We assume that the limit for the dismissal rate if no nurses are present is 16% of the students in class. The presence of nurses can reduce this to as little as 7%. The curve grows exponentially because if student to nurse ratio is extremely high (very few nurses), the addition of just a few nurses would be enough to significantly improve their ability to attend to the needs of the student body.

Multiplying this fractional effect by the stock of Students in Class determines the Dismissal Rate, which is an outflow from that stock. Dismissal Rate flows into a stock representing the Students Dismissed, which itself has a flow called Return to Class Rate going back into Students in Class. This allows us to see the number of students currently in class, the number of students dismissed and by dividing the students in class by the total number of students, we can know the fraction of students in class or Attendance Fraction, which is the best indicator of the performance of the Attendance Sector.

Attendence_Fr = Students_in_class/(Students_in_class+Students_dismissed)

The two stocks and their respective flows both form balancing loops. The Return to Class Rate is the product of Students Dismissed and a Normal Return to Class Rate so the greater the Students Dismissed Stock, the greater the Return to Class Rate Flow, which consequently lowers the stock. Similarly, Dismissal Rate is found by taking the Students in Class stock and multiplying it by the Fractional Effect of Nurses, which, unlike the Normal Return to Class rate, is determined internally by the system.

Dismissal Rate = Students_in_class*(Fr_Effect_of_Student_nurse_Ratio)
Return_To_School_Rate = Students_dismissed*Normal_Return_Rate

It is also important to highlight the impact of the Students in Class Stock outside of the Attendance Sector. The Staffing Sector is affected because Student to Nurse and Student to Teacher Ratios are directly proportional to the number of Students in Class. Thus, another balancing loop emerges since a low Student to Nurse Ratio will increase the Students in Class Stock and in turn increase this ratio again.

Aside from the Attendance Sector, the Student to Nurse Ratio influences the Performance Sector by improving Ability to Learn. The Ability to Learn Stock is a soft variable that is not quantifiable in the real world. Our research suggests that there are ways in which nurses improve student health that will increase how effectively they learn. These involve a school nurse's role in identifying and addressing auditory, visual, BMI and postural problems in students. Figure 12 summarizes the frequency of these incidences in Massachusetts from a population of 1.1 million students.

	Frequency in Students	Percentage of Total Students
Visual problems	327,825	29.8%
Auditory problems	296,717	27.0%
BMI problems	309,687	28.2%
Postural problems	154,643	14.1%

Figure 12 – Table of Health Issues in Massachusetts Schools

As nurses help resolve these issues, student health improves and they are in a better condition to learn. However, this impact involves complex, dynamic implications. The effect of nurses here is not instantaneous, nor is it permanent. A graphical relationship shown in Figure 13 was developed to represent an impending goal that would be sought when the student nurse ration changes. It shows the Normalized Student to Nurse Ratio serves as an input for the Nurse Effect Goal.

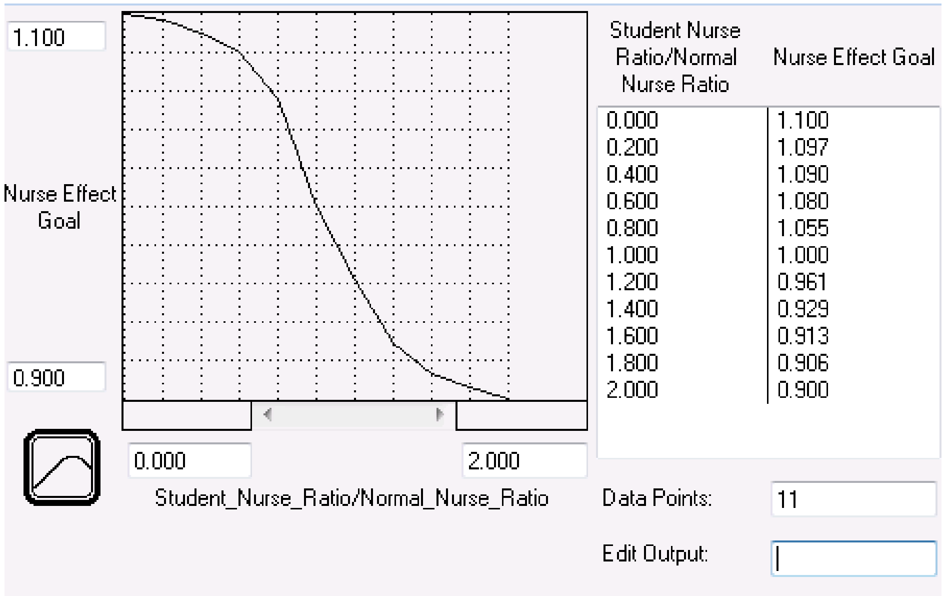


Figure 13 – Modifiers of the Ability to Learn Sector

The intent here is to replicate delayed goal-seeking behavior for the Ability to Learn Stock. The range of the graphical function implies that ability to learn can range from 0.9 to 1.1 due to the Student to Nurse Ratio. However, since nurses cannot instantaneously improve Ability to Learn, we must consider the Nurse Effect Delay.

The Change in Ability to Learn Flow incorporates this delay. This flow takes the difference between Ability to Learn goal based on Student to Nurse Ratio and the current Ability to Learn, and divides it by the delay to determine the increase in Ability to learn at any point in time. Essentially, this will eventually adjust Ability to Learn according to Student to Nurse Ratio.

Meanwhile, there is Decay in the Ability to Learn Flow, which reflects the idea that measures taken by nurses at any point in time will have a diminishing impact over time. The decay is calculated by taking the product of the Ability to Learn Stock and a Normal Decay Rate. This creates another balancing loop which would mean that ability to learn would approach a certain limit without the input of the positive flow from nurses.

Change_In_Abillity_to_Learn= (Nurse_Effect_Goal-Ability_To_Learn)/Nurse_Effect_Delay

Ultimately, Ability to Learn feeds into a variable called Performance, which is the key metric we used to determine the effectiveness of the sector and the entire system as a whole. Performance is intended to parallel student academic performance and test scores but is perhaps better considered as a soft variable because there is no fully comprehensive measure of academic performance in the real world. Performance in the model accounts for the effects of nurses through the Ability to Learn Stock and Attendance Fraction.

The link between Attendance Fraction and Performance is derived from research, which suggests students in class have a greater propensity to learn. In addition to this relationship being intuitively logical, a study in Minnesota found that students who attended at least 95% of classes were twice as likely to pass a language arts test as students who were present less than 85% of the time (Wyman, 2004). To simplify the implications of this, we modeled Performance as the product between each factor that contributes to it. Thus far, we have outlined how nurses impact Performance through Ability to Learn and Attendance Fraction, but there remains one important factor: the effect of teachers.

4.4 – Teachers

In the Staffing Sector we look at the Student to Teacher Ratio as an approximate representation of class size and its impact on student learning. From this graph depicting kindergarten through second grade we can see a large fractional effect of teachers that is dependent on grade level. This is similarly represented in other literature. According to the

Angrist/Lavy paper, the relationship between class size and performance is significant for some grades, and provides estimates for those coefficients (Angrist & Lavy, 1999). The Finn/Achilles paper showed that there is a negative correlation between class size and performance (Finn & Achilles, 1999). To account for the aggregation of grade levels we normalized our fractional effect at a lower level than found in this study shown in Figure 14 (Resnick, 2003).

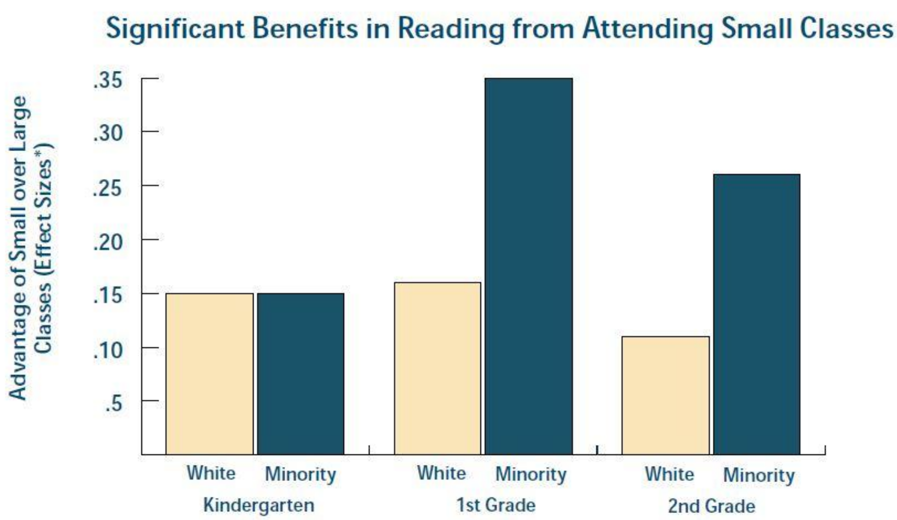


Figure 14 – Graph of Study Findings on Class Size Effect for K-2

The Student to Teacher Ratio is created from the Students in Class Stock divided by Teachers. This relationship then feeds into a graphical function to define the Fractional Effect of Teachers on Performance, which is shown in Figure 15.

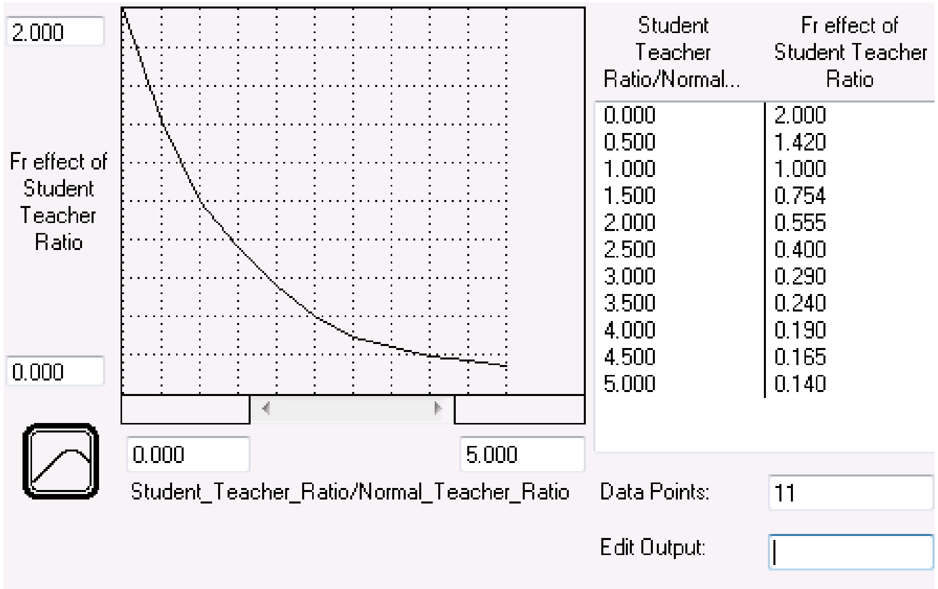


Figure 15 – Graphical Function of Effect of Student Teacher Ratio

Teachers are an external input to the system and do not add feedback loops. Teachers exist in the system from a Performance standpoint to add a counterweight to the effect of increasing nurses and to develop a behavior that results in a maximum saturation level.

Performance = Ability_to_Learn(Fr_effect_of_Student_Teacher_Ratio)*Attendence_Fr*

This completes the system dynamics model we developed for this project. With this finished, we were able to confirm the validity of the model through extreme value testing and experimentation. This would then allow us to test policy changes according to the objectives we set in conjunction with the MSNO, suggest real life responses, and explore the implications of our results to assess the impact of school nurses in Massachusetts.

5 – Model Analysis

5.1 – Extreme Value Testing

To check the robustness of the model, we used extreme value testing to validate its accuracy. An effective model should be able to produce sensible results even under unrealistic conditions to ensure the behavior of any outcome is logical. Usually, it is possible to intuitively predict behavior under extreme conditions. For example, if there are zero teachers in the system, one can infer that student performance will be extremely low. If running the model under these conditions replicates such behavior, we can strengthen our faith in its ability to produce accurate results.

The first set of extreme value tests we ran involved Fraction Spent on Teachers. By setting this fraction to 100% and 0%, we saw how the system behaves without nurses and teachers respectively. The graph in Figure 16 shows the resulting Performance for these two scenarios. The blue line (1) shows Performance when the fraction spent on teachers is 100% (no nurses) and the red line (2) shows it at 0% (no teachers). Performance in the system with no teachers is substantially low which parallels how a real school without teachers would be. Without nurses, Performance is much higher which is logical as well because numerous schools in reality do not have them but do not suffer so drastically in Performance.

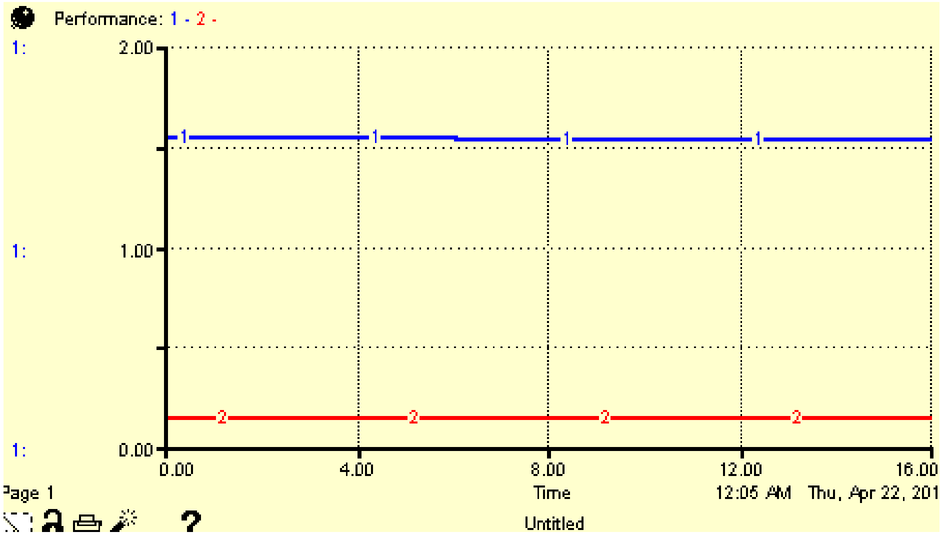


Figure 16 – Extreme Value Base Run

For the next scenario, we tested the system without students in class. In order to do this, we set the initial Students in Class Stock to zero. Additionally, we needed to set the Return to Class Rate as zero as well so students in the Students Dismissed stock do not flow into the Students in Class Stock. Students Dismissed itself can never be zero because it is the denominator for calculating Attendance Fraction. Performance in this system is shown in Figure 17. As expected, Performance is zero throughout because there are no students.

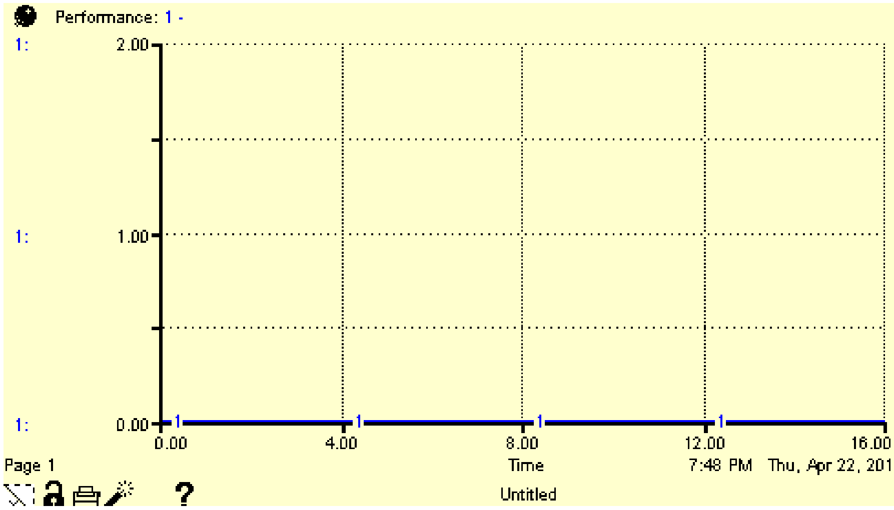


Figure 17 – No Students in Class

In the third extreme value test, we restored the Students in Class Stock but kept Normal Return to Class Rate at zero. This may be compared to a situation where an epidemic is preventing students from returning to class while the school remains open. Figure 18 shows the results and demonstrates how Performance gradually declines. If the simulation were to be run over a longer period, it would eventually reach zero. This is because students are being dismissed without ever returning class, emptying the Students in Class stock. Without students in the system, it is logical that Performance will continuously decline.

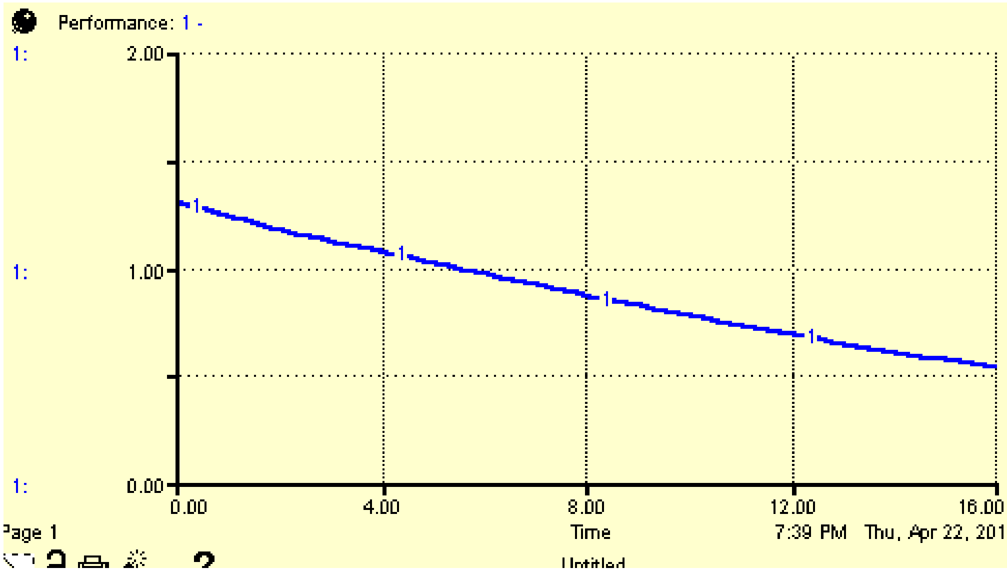


Figure 18 – No Return to Class

By reinforcing our mental understanding of the system, these extreme value tests provide evidence to support the adequacy and versatility of the model. Although this does not conclusively validate the model, it suggests the relational logic we implemented in creating the model does not fall apart. At this point we can begin to run the experiments designed by the MSNO to assess the impact of school nurses on Performance.

5.2 – Policy Experiments

To begin experimenting, we first established the initial conditions for the baseline case that other iterations of the model can be compared to. We assumed a school district with a total of 5000 students out of which 4,250 are in class and 750 are dismissed at time. We selected a negative time as the starting point so that the system will have reached equilibrium by time 0. Additionally, total school funding is 585. The teacher fund receives 98% of this budget while the nurse fund receives 2%, which yields about 573 teachers and 12 nurses. The results of a base run with these conditions are shown in Figure 19. Note that the scale on the *y*-axis has been adjusted from the previous examples so the outcomes of our tests are easier to visually discern.

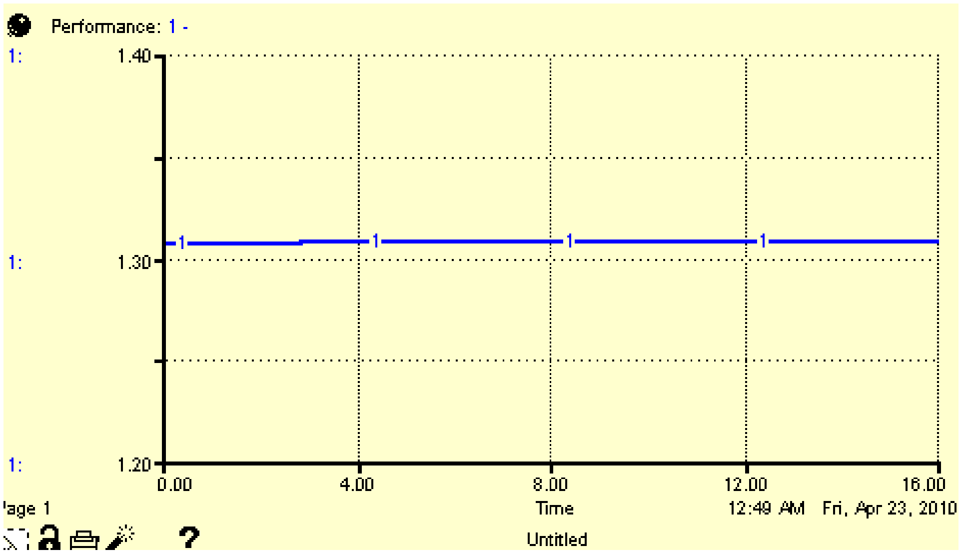


Figure 19 – Experiment Base Run

These initial conditions can have a substantial impact on behavior. It is important to be aware that the results described in this section apply only to the specifications described above. Later on in this paper, we explore in greater detail how modifying these parameters influences behavior and why exactly it does this.

5.2.1 – School Funding Decrease

The first scenario the MSNO asked us to consider was a decrease in school funding. In this example, the school district has lost a portion of its total budget and must remove teacher positions, nurse positions, or a combination of both. Let us then assume that School Funding decreases by 3 and to limit the variety of choices, the administration chooses to cut 3 directly from either the Teacher Fund or Nurse Fund.

Figure 20 shows the outcome of these decisions if the cut occurs at time 8. The barely discernable blue line (1) represents the base case before the budget cut while the red (2) and pink (3) lines show cutting nurses and teachers respectively. Since the total funding in the system is reduced, the repercussions undoubtedly will be negative but the model allows us to see which decision causes Performance to drop the least. Clearly, there is a substantial decline in Performance when cutting nurses but an almost insignificant decline when cutting teachers. This suggests that under the initial conditions, it is preferable that the school district removes three teacher positions rather than three nurse positions since the marginal impact of the nurse positions is higher at the specified initial conditions.

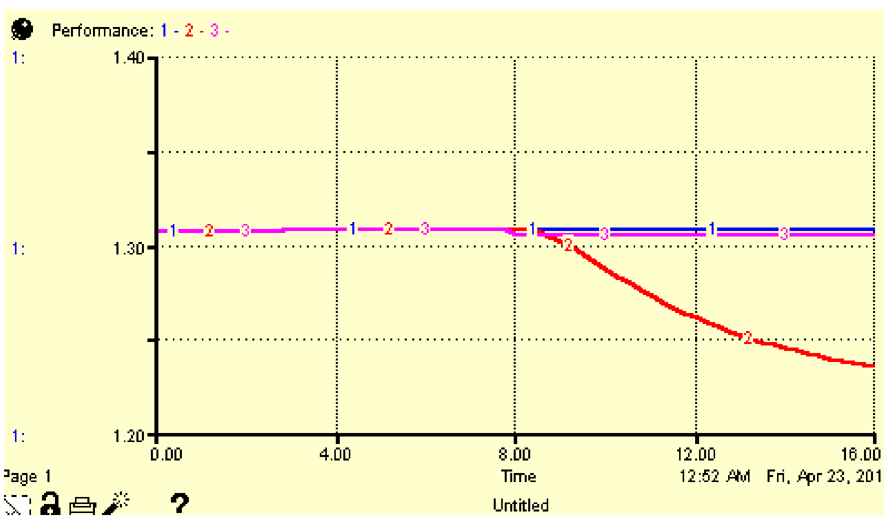


Figure 20 – Funding Decrease

5.2.2 – Budget Increase

In the second scenario, we explored the implications of an increase in School Funding. If funding increases, the administration should allocate the new resources available in the most effective way possible. To contrast the previous experiment, we assume this time funding increases by 3, which can be added to either the Teacher Fund or the Nurse Fund.

The outcomes of these experiments are shown in Figure 21. The red line (2) is the result of increasing nurse funding and the pink line (3) teacher funding. The blue line (1) again represents the baseline. From the graph, it appears implies that increasing the teacher fund causes an almost negligible increase in Performance. On the other hand, the nurse fund increase has a slight positive effect. Thus, when given an increase in budget, the system receives greater benefits if that increase is directed towards nurses instead of teachers.

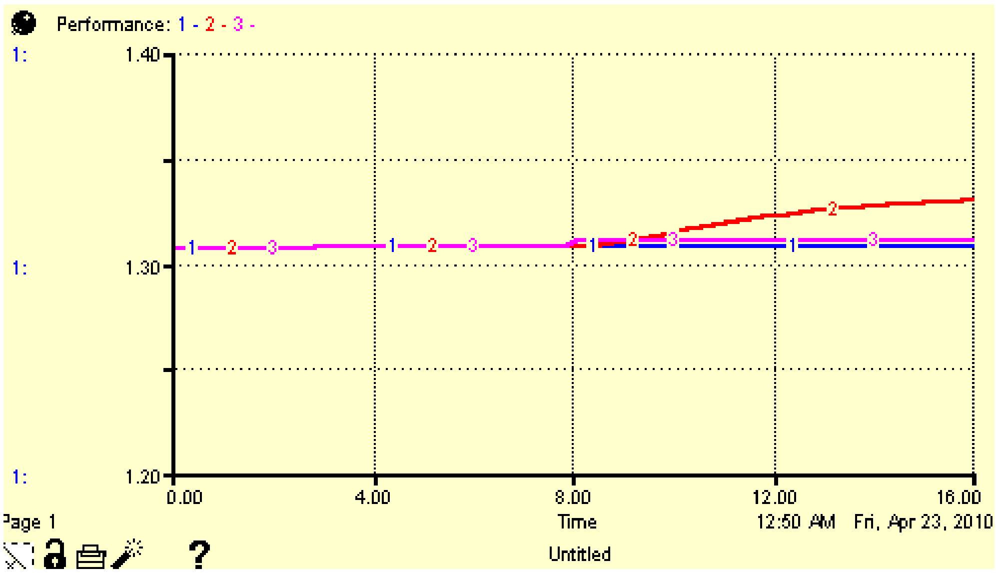


Figure 21 – Budget Increase

5.2.3 – Nurse Grant Reduction

For the final scenario we examined the impact if the Nurse Grant is reduced. As described earlier, the Nurse Grant exists externally from School Funding but feeds into Nurse Funding. We tested an example where a school district receives a grant of 4 but later that grant is halved. This experiment has no bearing on decision-making because it is a single scenario with no relevant point of comparison. Without System Dynamics, it is apparent that an increase in the grant will boost performance and a decrease will cause it to drop but running this trial still produces intriguing behavior that leads to a better understanding of the system.

In the graph in Figure 22, the red line (2) shows a school district that receives a grant of 4 at time 8 where Performance rises considerably. The grant is then cut from 4 to 2 at time 32 at which point there is a drop. Although the grant reduction does seem to be detrimental to the system, the final equilibrium value is closer to Performance with the higher grant than without the grant. After conducting this test, it seems that the grant's impact is path dependent and the benefits of nurses vary at different levels of funding.

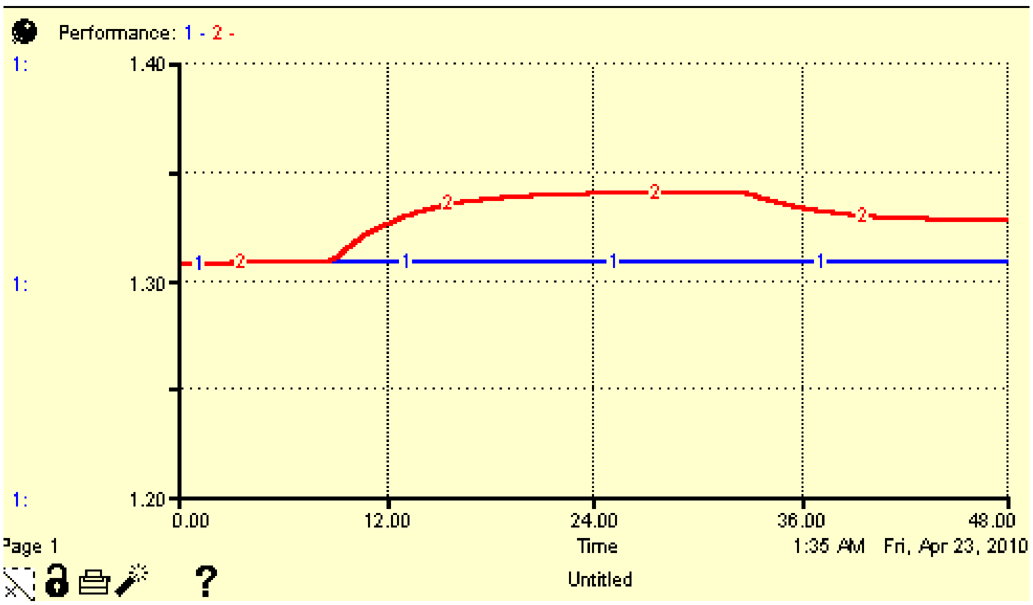


Figure 22 – Nurse Grant

Therefore, it is necessary to further analyze the dynamics of the system to gain a better understanding of its behavior. While the experiments covered in this section may be valid for the initial conditions described, it appears that any deviation from these conditions will yield different results. A powerful tool that can help gain tremendous insight into a system is sensitivity analysis.

5.3 – Sensitivity Analysis

"Sensitivity analysis helps to build confidence in the model by studying the uncertainties that are often associated with parameters in models. Many parameters in system dynamics models represent quantities that are very difficult, or even impossible to measure to a great deal of accuracy in the real world. Therefore, when building a system dynamics model, the modeler is usually at least somewhat uncertain about the parameter values he chooses and must use estimates. Sensitivity analysis allows him to determine what level of accuracy is necessary for a parameter to make the model sufficiently useful and valid." (Breierova & Choudhari, 1996)

When studying a system where hard data is unavailable or incomplete, sensitivity analysis can provide a more comprehensive understanding of behavior under a range of conditions. Since we were unable to find enough statistical evidence to completely support all the parameters we used in the model, the use of sensitivity analysis is an opportunity to gain more confidence in our results. Additionally, we were able to incrementally test changes in input variables and assess the impact on the system's behavior.

5.3.1 – Parameter Sensitivity

We focused our sensitivity analysis on three parameters in the model: Fractional Effect of Student to Teacher Ratio, Fractional Effect of Student to Nurse Ratio, and Nurse Effect Goal. Each variable was individually modified to reflect a change in impact ranging from 80% to 120% of the baseline value. Under these conditions, we ran the test described earlier where nurse funding is increased by 3 at time 8. This allows us to compare how the increase in Performance varies when parameters are changed and suggests whether our original results are broadly applicable for the system.

The graph in Figure 23 shows the sensitivity of the Fractional Effect of the Student to Teacher ratio. Line 1 represents Performance when the fractional effect is 80% of the original run. Each consecutive line of the graph represents a 10% incremental change in the Fractional Effect of Teachers parameter. From these results, it appears that the impact of nurses remains the same regardless of how effective teachers are. However, the relative impact is much greater at a lower baseline value for Performance, as it is a greater proportional increase. As mentioned earlier, Performance is a soft variable so it does not represent a raw value but rather a metric for comparison. Thus the Fractional Effect of Teachers parameter is significant when comparing the impact of nurses with the impact of teachers.

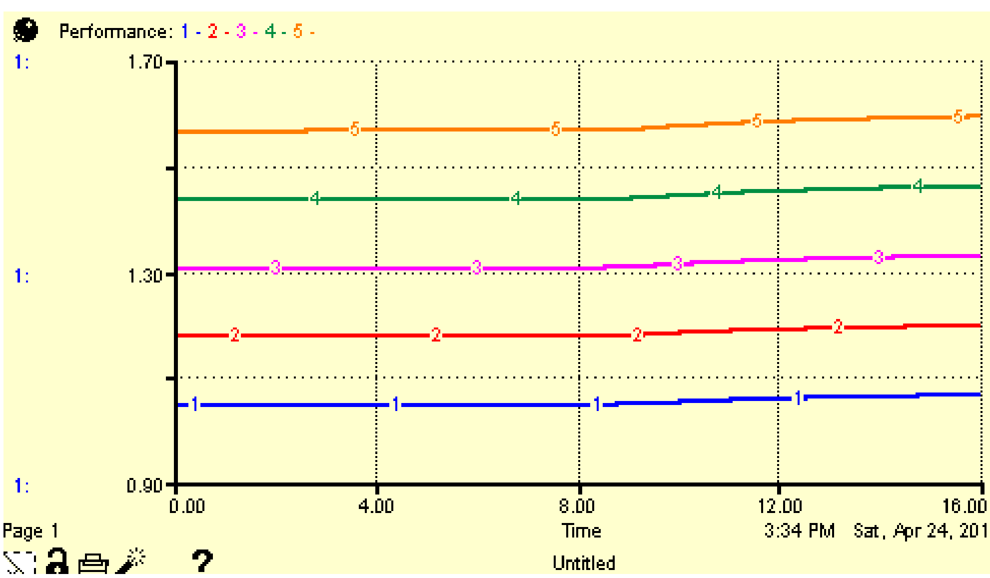


Figure 23 – Fractional Effect of Teachers Sensitivity

Figure 24 shows the sensitivity of the Fractional Effect of Nurses. This refers to the impact of nurses on Dismissal Rate rather than the Ability to Learn Stock. Like the previous graph, lines 1 through 5 represent a range from 80% to 120% of the fractional effect in the baseline run. Again, modifying this parameter affects the proportional increase in Performance rather than a numerical increase. When the fractional effect of nurses is 120% more than the baseline, the benefits of adding nurses are the greatest in this run, implying that the higher the Fractional Effect of Nurses, the more valuable nurses are.

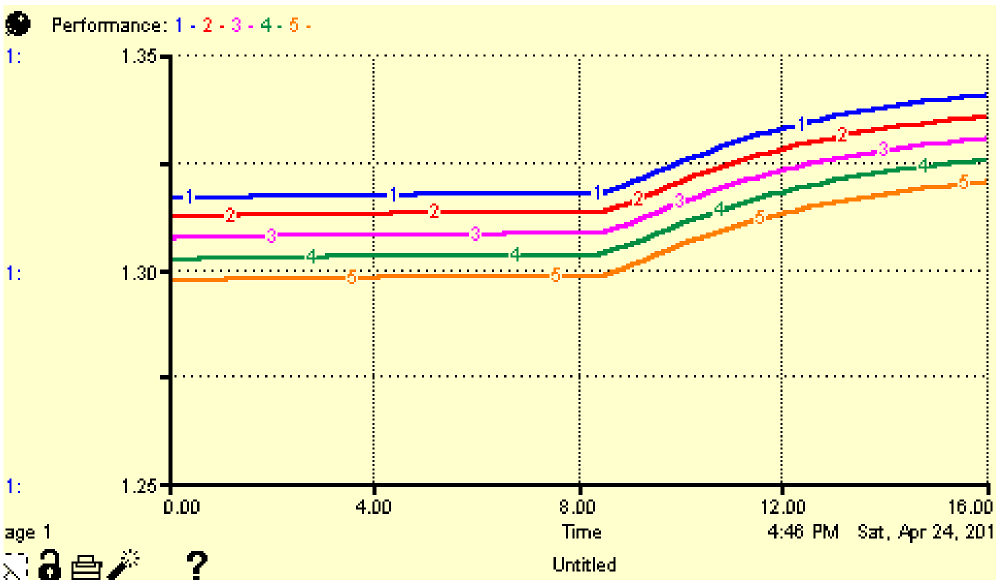


Figure 24 – Fractional Effect of Nurses Sensitivity

The final parameter we examined was Nurse Effect Goal which reflects the degree to which nurses influence the Change in Ability to Learn Flow. The results are shown in the graph in Figure 25 below. Interestingly, this seems to suggest that the greater the impact of nurses on Ability to Learn, the less effective adding nurses is in improving performance. This is because when the Nurse Effect Goal is high, the nurses already in the system have a strong impact on

Performance so increasing the number of nurses yields fewer benefits. Thus a seemingly paradoxical situation arises: the more effective that nurses are in improving student health and Ability to Learn, fewer need to be added to improve Performance.

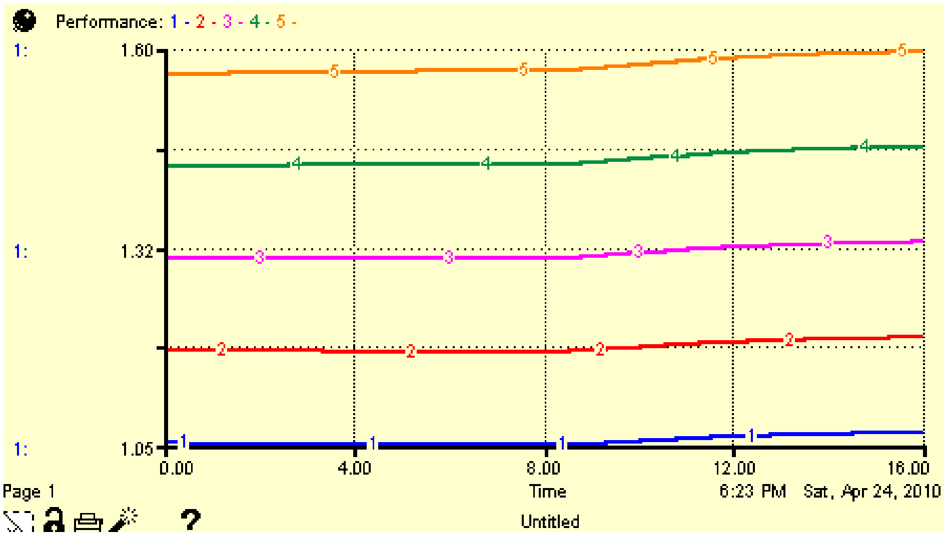


Figure 25 – Nurse Effect Goal Sensitivity

This analysis has considerably broadened our understanding of the dynamics of the system. It is clear that the feedback loops are creating behavior that cannot be discerned easily without modeling. We can continue to learn more about this behavior by performing a sensitivity analysis on input variables.

5.3.2 – Input Sensitivity

From the perspective of the administrators of a school district, the only variable that can be changed in practice is the fraction of the school budget spent on nurses. Using the baseline parameters, we tested the impact on Performance if this fraction varies from 2% to 6%. The results of this are shown in Figure 26. Line 1 shows Performance when 2% of the school budget is spent on nurses and 98% spent on teachers. Each line after that shows the results for an additional percentage of the budget spent on nurses until 6% is spent on nurses and 94% on teachers. This graph highlights a fundamental aspect of the system that is crucial to understand before making real life decisions.

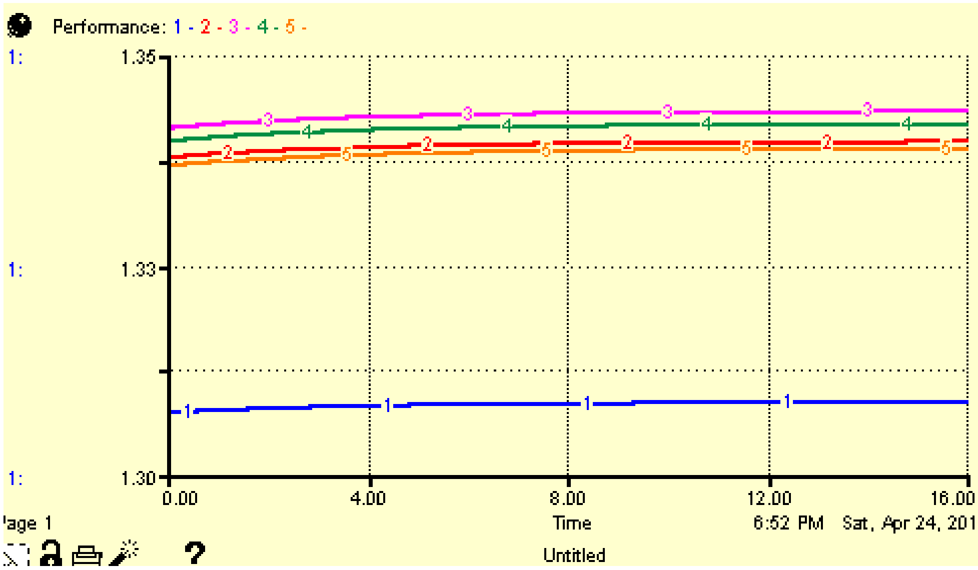


Figure 26 – Input Sensitivity

As the fraction spent on nurses increases, Performance does not change consistently. The change from 2% to 3% (line 1 to line 2) results in a relatively high increase in Performance. Going from 3% to 4% (line 2 to line 3) also increases Performance but to a much lesser degree. However, when the fraction is increased to 5% (line 4), Performance actually declines. When going to 6% (line 5) there is an even greater drop.

This suggests that the fractional spending on nurses exhibits diminishing marginal benefits as nurse spending increases. Thus, the impact on Performance if nurses are added and removed to the system is dependant on how many nurses are in place already. The fewer nurses there are, the greater the benefit of adding another is nurse as opposed to adding teachers. At one point, the system will be saturated with nurses and it will be preferable to increase the number of teachers instead. This saturation point represents the optimal balance of school funding allocation between teachers and nurses.

6 – Limitations and Future Work

6.1 – Data

One of the problems encountered when attempting to model the effect of nurses in a system was a general lack of comparative information. For many of the school districts, the District Comparisons spreadsheets, provided by the MSNO, provided valuable information such as Total Students, Total School Nurses, Total Teachers, ESHS Grant Amount, number of dismissals, and the 4-year Graduation rate. The problem with these data, however, was that they suffered heavily from selection bias. Aside from the fact that the data was provided by our sponsor, and could not be considered truly impartial, the data was only provided for schools which had received an ESHS grant. These data were only available due to one of the stipulations of the ESHS grant that required schools to reports these numbers. Schools that did not receive the grant were not required to report, and summarily, did not.

Another problem encountered with the data was the definition of a dismissal. The ESHS report tracked the student return to class rate, as well as the total number of encounters, but what determined an encounter? Beyond that, were there occasions when a student was dismissed without a visit to the nurse? Were those dismissals tracked using the same system? It would be important for any future study to not just have a larger data set, but to ensure that the data was measured using comparable means.

For future study it would be important to use a much more complete data set. While this project was able to identify that a nurse saturation point exists, it is unable to suggest where that value might be. Several things would be required for the model to make the estimation. First, the effect of nurses would need to be quantified in a much more robust manner, using more data. With data showing the difference in dismissal rate between a school with an adequate number of nurses, and a school without, it would be possible to estimate the effect those nurses were having on the school. Similarly, study could be done comparing the achievement of students with the class size in order to produce a more robust function to model the effect of teachers. Last, and most difficult, would be the quantification of Ability to Learn. With a large enough data set, this could be created by looking at the achievement of students with, and without, an acceptable amount of nurses in the system. According to our model, however, nurses have two effects. Nurses change the attendance rate, which affects achievement, and nurses change the Ability to Learn, which affects achievement. Any such study would have to distill one effect from the other. There is a tool in development currently to provide the sort of information that an extension to this project would require, this tool is developed by the Mass. Department of Elementary and Secondary Education, and is called the District Analysis and Review Tool (DART). The tool aggregates information reported by several sources, including school nurses and administrators, and provides the ability to compare reported statistics amongst different school districts. The goal of the tool is to allow administrators to identify weaknesses in their district by comparing themselves to similarly situated districts, under the assumption that they could investigate, and hopefully solve, any significant negative differences. If populated with enough data, this tool could serve to provide the information needed for a continuing analysis of the effect of nurses on k-12 schools, and could allow for an estimate to be built of the true saturation point for nurses in a given school district.

6.2 – Further Exploration of Model

There is additional work that could be done with the model, this falls in to two categories: the correcting limitations of our data and the expansion of the structures in our model. The current scope of our model is that the links of the model are drawn from the relationships between components and are not quantifying real world data. The analysis can show predicted behavior but does not represent predictions on specific funding or performance levels. Additional research is needed to determine the optimal values in a given situation for our representational variables.

A possible change in the model was to change nurse effect to chance based. That is that on a given day a student has a certain chance of learning the given material. A student not in class has a very low chance. Performance would be the normal chance of learning times the chance modifier of a health intervention (eye glasses, hearing test), times the student chance in class (dismissal rate), times the teacher/student adequacy ratio. Health invention change would be based on the adequacy of the nursing. These variables would require further research to determine

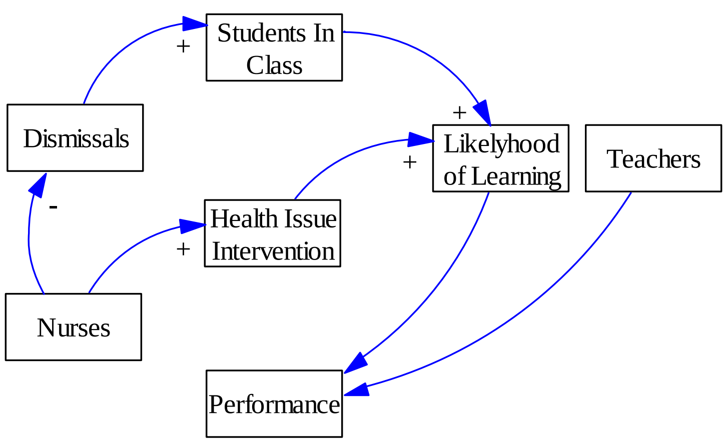


Figure 27 – Future Nurse Effect Dynamic Hypothesis

Sectors that were removed from the original dynamic hypothesis were socio-economic conditions and the budget desire of the community. With the data that we had available these were too difficult to quantify. Socio-economic Conditions was another variable affecting the ability to learn. It modified how effective both teachers and nurses were in the system to performance. Performance has an inverse relationship with student/teacher ratio, a positive relationship with students in class and a positive relationship to the ability to learn. Performance over a delay affects the total number of students, which increases students in class. It increases socio-economic conditions again over a delay and along with socio-economic conditions it affects budget desire over delay. Budget desire is seen as that community's desire to perform better. If performance is low, a greater emphasis is placed on increasing performance. As performance increases community sees less of a need to maintain a higher level of funding. Budget desire determines the funding levels for teachers and nurses with nurses having the additional ability to receive funding through grants.

7 – Conclusion

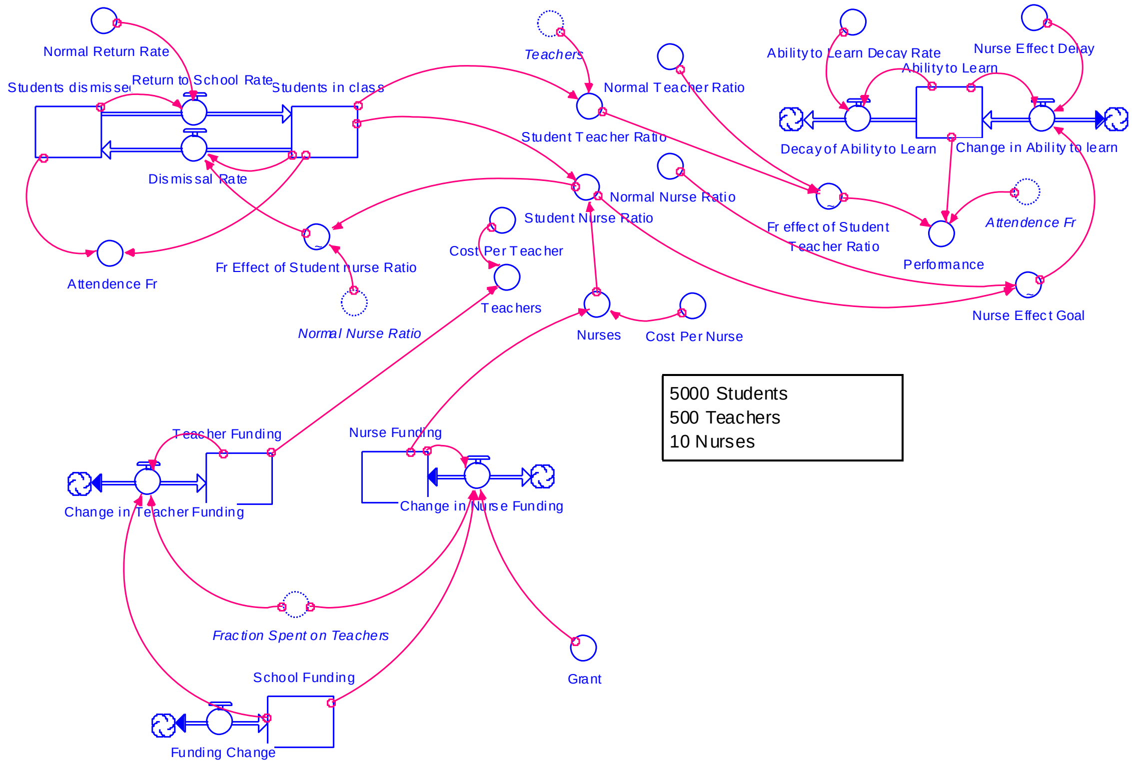
When a nurse is added to a school system, such as the sample system provided by our model, there is a very large corresponding change in the student to nurse ratio. Teachers have a larger impact on the system, yet adding a teacher will have a less significant effect on the student teacher ratio. Because of this, changing the number of nurses will affect the system much more drastically than changing the number of teachers.

The main finding of our project is that there is a saturation point for nurses. At any point below the saturation point for nursing personnel, there is a positive effect of increasing the fraction of the school budget allocated to nurses. Above the saturation point, nurses will begin to begin experience diminishing returns and any fractional budget changes would be better spent on teachers.

For future study, identifying this point of diminishing returns could have important repercussions for administrative decision makers who must decide how to allocate the budget of a school district. The saturation point represents the most effective way to distribute funds in particular school district, yet it must understood that this value would change on a district by district basis. Although this value is transient, further research may be able to reveal a rule by which to determine an acceptable value for a specific district based on some set of parameters.

Appendix

The Model



Equations

Ability_to_Learn(t) = Ability_to_Learn(t - dt) + (Change_in_Ability_to_learn - Decay_of_Ability_to_Learn) * dt

INIT Ability_to_Learn = 1

INFLOWS:

Change_in_Ability_to_learn = (Nurse_Effect_Goal*Nurse_Effect_Multiplier-Ability_to_Learn)/Nurse_Effect_Delay

OUTFLOWS:

Decay_of_Ability_to_Learn = Ability_to_Learn_Decay_Rate*Ability_to_Learn

Nurse_Funding(t) = Nurse_Funding(t - dt) + (- Change_in_Nurse_Funding) * dt

INIT Nurse_Funding = 10

OUTFLOWS:

Change_in_Nurse_Funding = Nurse_Funding-(School_Funding*(1-Fraction_Spent_on_Teachers)+Grant)

School_Funding(t) = School_Funding(t - dt) + (Funding_Change) * dt

INIT School_Funding = 585

INFLOWS:

Funding_Change = 0

Students_dismissed(t) = Students_dismissed(t - dt) + (Dismissal_Rate - Return_to_School_Rate) * dt

INIT Students_dismissed = 750

INFLOWS:

Dismissal_Rate = Students_in_class*(Fr_Effect_of_Student_nurse_Ratio*Nurse_Attendence_Multiplier)

OUTFLOWS:

Return_to_School_Rate = Students_dismissed*Normal_Return_Rate

Students_in_class(t) = Students_in_class(t - dt) + (Return_to_School_Rate - Dismissal_Rate) * dt

INIT Students_in_class = 4250

INFLOWS:

Return_to_School_Rate = Students_dismissed*Normal_Return_Rate

OUTFLOWS:

Dismissal_Rate = Students_in_class*(Fr_Effect_of_Student_nurse_Ratio*Nurse_Attendence_Multiplier)

Teacher_Funding(t) = Teacher_Funding(t - dt) + (Change_in_Teacher_Funding) * dt

INIT Teacher_Funding = 500

INFLOWS:

Change_in_Teacher_Funding = (School_Funding*Fraction_Spent_on_Teachers)-Teacher_Funding

Ability_to_Learn_Decay_Rate = 0

Amount = 5

Attendence_Fr = Students_in_class/(Students_in_class+Students_dismissed)

Cost_Per_Nurse = 1

Cost_Per_Teacher = 1

Fraction_Spent_on_Teachers = .98

Fr_Effect_of_Student_nurse_Ratio = GRAPH(Student_Nurse_Ratio/Normal_Nurse_Ratio)

(0.00, 0.07), (0.3, 0.0737), (0.6, 0.0764), (0.9, 0.0803), (1.20, 0.0891), (1.50, 0.104), (1.80, 0.124), (2.10, 0.144), (2.40, 0.154), (2.70, 0.158), (3.00, 0.16)

Fr_effect_of_Student_Teacher_Ratio = GRAPH(Student_Teacher_Ratio/Normal_Teacher_Ratio)

(0.00, 2.00), (0.5, 1.42), (1.00, 1.00), (1.50, 0.754), (2.00, 0.556), (2.50, 0.4), (3.00, 0.29), (3.50, 0.24), (4.00, 0.19), (4.50, 0.165), (5.00, 0.14)

Grant = Grant_Switch * step(Amount, Grant_Period) +

RANDOM(-5,24) * 0

Grant_Period = 8

Grant_Switch = 1

Normal_Nurse_Ratio = 500

Normal_Return_Rate = 1

Normal_Teacher_Ratio = 13.5

Nurses = Nurse_Funding/Cost_Per_Nurse

Nurse_Attendence_Multiplier = 1

Nurse_Effect_Delay = 4

Nurse_Effect_Goal = GRAPH(Student_Nurse_Ratio/Normal_Nurse_Ratio)

(0.00, 1.10), (0.2, 1.10), (0.4, 1.09), (0.6, 1.08), (0.8, 1.06), (1.00, 1.00), (1.20, 0.961), (1.40, 0.929), (1.60, 0.913), (1.80, 0.906), (2.00, 0.9)

Nurse_Effect_Multiplier = 1

Performance = Ability_to_Learn*(Fr_effect_of_Student_Teacher_Ratio*Student_Teacher_Effect_Mult)*Attendence_Fr

Student_Nurse_Ratio = Students_in_class/(MAX(Nurses, .001))

Student_Teacher_Effect_Mult = 1

Student_Teacher_Ratio = Students_in_class/Teachers

Teachers = Teacher_Funding/Cost_Per_Teacher + step(Teacher_shocks, 8) *Teacher_Shock_Switch

Teacher_shocks = 3

Teacher_Shock_Switch = 0

temp = + STEP(RANDOM(-.01,.01), 24)*0 +

STEP(-.01, 24)*0

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