Case Study: Comparison of Spreadsheet and System Dynamic Techniques for a Government Funding Process

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Purpose and Overview

This paper describes the results of a study to create a preliminary system dynamics model of a typical government funding process in which normal commercial labor and market pressures do not apply. The funding process, called the net operating results (NOR) process, controls how the direct hourly labor rate charged by a government agency for its work is adjusted yearly to ensure break-even operation over the long term.

The purpose of the study was to determine if the system dynamics methodology was an appropriate tool for modeling the NOR process which has traditionally been modeled with spreadsheets, and to facilitate a deeper understanding of the process and its complexities. Since the NOR process was mandated for government agencies only a few years ago, this model offers insight into how the NOR process might respond in the future based on different "what-if?" assumptions. Results for the first few years of a ten-year simulation appear to track historic data well, which helps validate the model. However, the results indicate that the process is inherently unstable over the long term due to accounting delays. In year ten, results show radically different behavior than current projections based on historic data.

Overview of Current Net Operating Results (NOR) Process

Most government agencies do not operate to make profits in the same way that commercial companies do. The agencies also do not operate to lose money purposely. The NOR process controls how the direct hourly labor rate charged by a government agency for its work is adjusted yearly to ensure break-even operation over the long term. This direct hourly rate is called the Stabilized Rate.

The annual NOR is defined as the difference between total annual revenue and total annual cost for an agency. The accumulated operating results (AOR) are the ongoing accumulation of the annual NOR for an agency. At the end of each year, an agency calculates its NOR and modifies its AOR accordingly. Dividing the AOR by the direct hours documented by the agency for that year gives the indicated amount by which the stabilized rate must be adjusted to ensure breakeven operation in following years. Currently, agencies use spreadsheet technology to facilitate the NOR process.

The NOR process seems fairly straightforward at this point. As shown in Part A of the simplified spreadsheet in Figure 1, the approach described in the previous paragraph works as long as the direct hours and annual cost remain constant and no additional surcharges are necessary. Implicit in this approach is also the assumption that the indicated rate change is applied the very next year. In reality, the indicated rate change calculated at the end of Year 1 does not get applied until the beginning of Year 3, resulting in a 13-month delay. This adds complications to the NOR process.

Year	Direct Hours Available	Current Stabilized Rate	Annual Cost	Annual Revenue	NOR	AOR	Indicated Rate Change	Surcharges	New Rate
A									
1	5000	$ 50.00	$ 200,000	$ 250,000	$ 50,000	$ 50,000	$ (10.00)	$ -	$ 40.00
2	5000	$ 40.00	$ 200,000	$ 200,000	$ -	$ -	$ -	$ -	$ 40.00
3	5000	$ 40.00	$ 200,000	$ 200,000	$ -	$ -	$ -	$ -	$ 40.00
B									
1	5000	$ 50.00	$ 200,000	$ 250,000	$ 50,000	$ 50,000	$ (10.00)	$ -	$ 40.00
2	5000	$ 50.00	$ 200,000	$ 250,000	$ 50,000	$ 100,000	$ (20.00)	$ -	$ 30.00
3	5000	$ 40.00	$ 200,000	$ 200,000	$ -	$ 100,000	$ (20.00)	$ -	$ 20.00
4	5000	$ 30.00	$ 200,000	$ 150,000	$ (50,000)	$ 50,000	$ (10.00)	$ -	$ 20.00
5	5000	$ 20.00	$ 200,000	$ 100,000	$ (100,000)	$ (50,000)	$ 10.00	$ -	$ 30.00
6	5000	$ 20.00	$ 200,000	$ 100,000	$ (100,000)	$ (150,000)	$ 30.00	$ -	$ 50.00
7	5000	$ 30.00	$ 200,000	$ 150,000	$ (50,000)	$ (200,000)	$ 40.00	$ -	$ 70.00
8	5000	$ 50.00	$ 200,000	$ 250,000	$ 50,000	$ (150,000)	$ 30.00	$ -	$ 80.00
9	5000	$ 70.00	$ 200,000	$ 350,000	$ 150,000	$ -	$ -	$ -	$ 70.00
10	5000	$ 80.00	$ 200,000	$ 400,000	$ 200,000	$ 200,000	$ (40.00)	$ -	$ 40.00
11	5000	$ 70.00	$ 200,000	$ 350,000	$ 150,000	$ 350,000	$ (70.00)	$ -	$ -

Figure 1: Simplified Spreadsheet Examples of the NOR Process
Spreadsheets are currently used to calculate changes in the stabilized rate to achieve breakeven operation.

Part B of Figure 1 shows the results of this approach with the 13-month accounting delay and keeping direct hours and annual cost constant. Now, the AOR from Year 1 is carried into Year 2 so that the Year 2 AOR is the sum of the Year 2 NOR and the Year 1 AOR. The resulting rate change for Year 2 is greater due to the larger Year 2 AOR, and the rate change from Year 1 has not yet taken effect.

As can be seen in Part 2 of Figure 1, this 13-month accounting delay causes significant modifications to the stabilized rate which results in greater variation among yearly revenues. The variation in annual revenues then drives larger swings in the stabilized rate to form a feedback loop.

Of course, the large oscillations indicated in Part B actually never occur because agency management devotes a great deal of time and attention each year to keeping the stabilized rate under financial control. Additionally, direct hours and costs do not remain constant. Management just focuses on the current year’s end without worrying about consequences in future years. In fact, it is implicitly assumed that there are no major future impacts; any consequences occur within a couple of years at the most. Furthermore, because future values of many variables, such as direct hours and costs, are unknowable with spreadsheet technology, management sees no utility in carrying out future calculations as seen in Part B in Figure 1. All feedback is lost.

Even when the process appears to be “under control” financially, many of the players involved would admit that this control is only surface-level and that many decisions in the process are made without sufficient information or without a full understanding of their longer term effects. In an effort to better understand the NOR process and its feedback loops, a causal loop diagram was constructed.

Figure 2 presents a high-level diagram of the current NOR process with 13 variables of interest and their associated causal relationships indicated by arrows. As with standard causal loop diagrams, causality is represented by “+” and “-” arrowheads. A “+” represents a direct relationship whereby a change in one variable causes a similar change in the second variable and a “-” represents a direct relationship whereby a change in one variable causes an opposite change in the second variable. Figure 2 also shows the major feedback loops that dominate the behavior of the current NOR process. There are three balancing (negative) loops and one reinforcing (positive) loop.

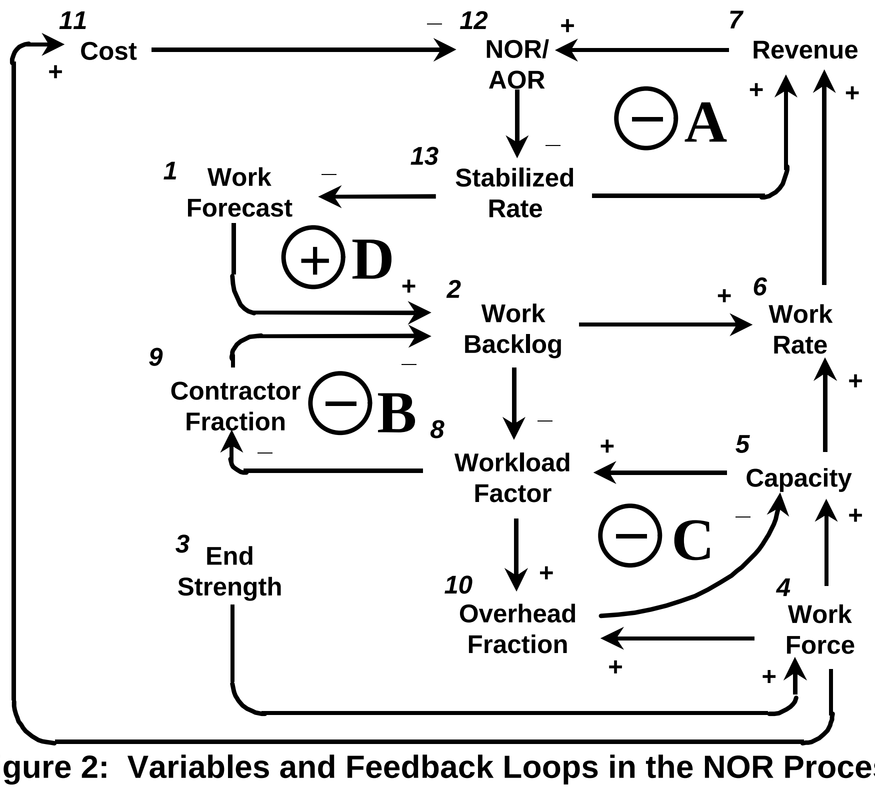

Figure 2: Variables and Feedback Loops in the NOR Process
Thirteen major variables interact through four feedback loops to cause the long-term instability of the NOR process.

Loop A (7-12-13) is the first balancing loop. As Revenue (7) increases, the NOR/AOR (12) increases which results in a decrease in the Stabilized Rate (13) to bring Revenue back down. Consequently, if Revenue decreases, the NOR/AOR decreases which increases the Stabilized Rate to bring Revenue up.

Loop B (8-9-2) is the second balancing loop. This loop attempts to bring capacity and workload into balance by moving some of the work to (or from) outside contractors. The Workload Ratio (8) compares Capacity (5) to the desired level of Work Backlog (2). Capacity is defined as the number of direct labor hours available for contract work. If the Capacity of the system is larger than the Work Backlog, the Workload Ratio is greater than 1.0 which indicates that the system has excess Capacity. A Workload Ratio greater than 1.0 decreases the Contractor Fraction (9) so that less work goes to outside contractors. Conversely, if new work sufficiently increases the Work Backlog relative to Capacity, this can decrease the Workload Ratio below 1.0. A Workload Ratio less than 1.0 increases the Contractor Fraction (9) so that more work is moved to outside contractors. If the Work Forecast (1) declines over time, the Contractor Fraction balancing loop will tend to move less work to outside contractors so that more direct labor hours are used, attempting to bring capacity and workload into balance.

Loop C (8-10-5) is the third balancing loop. As the Workload Ratio (8) increases, the Overhead Fraction (10) increases so that less personnel are made available for direct contract work. This reduces Capacity (5) which then reduces the Workload Ratio. For a decrease in the Workload Ratio (indicating insufficient Capacity), the balancing loop lowers the Overhead Fraction thereby making more personnel available for direct contract work which increases Capacity. Similar to the Contractor Fraction balancing loop, if the Work Forecast (1) declines over time, this loop will tend to move more personnel to overhead so that less direct labor hours are used, attempting to bring capacity and workload into balance.

Loop D (1-2-8-10-5-6-7-12-13) is the reinforcing loop and represents the only opportunity for altering the Work Forecast (1). Within this reinforcing loop are the balancing loops A and C. New work comes in through Work Forecast (1), enters the Work Backlog (2), and is compared to Capacity (5) in the Workload Ratio (8). Modulation of the Workload Ratio up or down has a direct effect on the Overhead Fraction (10) which in turn affects Capacity (5) as managers shift labor between direct labor and overhead in an attempt to balance capacity with workload. This is the balancing loop C. A higher Capacity creates a higher Work Rate (6). The amount of work completed generates Revenue (7) which increases the NOR/AOR (12) (assuming Cost (11) remains constant). An increase in the NOR/AOR results in a decrease in the Stabilized Rate (13) to bring Revenue down so that the NOR/AOR approaches zero. This is the balancing loop A. However, as the Stabilized Rate decreases, the Work Forecast increases because the Work Forecast is equal to the funding available divided by the Stabilized Rate. Thus, for a constant level of funding, a lower Stabilized Rate results in a higher Work Forecast.

As with most system dynamics analyses, each of these loops is easy to understand and predict in isolation, but they are extremely difficult to understand and predict when all four loops interact as they do in the real NOR process. To make the situation even more complex, each loop has a different time frame (delay) over which it operates. As a result, one loop may dominate in the short-term, but a different loop may begin to dominate over the long-term. Only by translating the current NOR process into a system dynamics model can we begin to understand how the process truly reacts to changes over time. APPENDIX A provides an overview of the NOR structural model used in this analysis.

Model Data

Data used to validate the structure of this model was provided by a specific government agency struggling with the NOR process. The data consists of actual numbers for fiscal years 1994-1997 and projections for fiscal years 1998-1999. Graphs in this paper have either been normalized or had the scales removed to protect the actual data values. The following list describes the types of data that were provided for each fiscal year:

- End Strength (Personnel)
- Stabilized Rate
- Total Direct Labor Hours
- Total Overhead Costs
- Total Costs
- Total Revenue
- ODC as Percentage of Revenue

Although the NOR model was created using a specific set of data, the structure of the NOR process as depicted in Figure 2 is the same for any government agency or facility. Because the underlying system structure is the same for any agency or facility, the qualitative results will be the same even though there may be differences in specific data used in each model. For example, for any agency one would see oscillations in the Stabilized Rate. The amplitude and frequency of the oscillations would most likely vary due to differences in specific data, but the system behavior of oscillations will persist because of the balancing loop that exists among Stabilized Rate, Revenue, and NOR/AOR for all agencies.

Because the initial analysis was limited to a single agency, this preliminary model does not capture the relationship among different agencies when they either use the same resources or compete for the same new business. However, this relationship and its results can be captured by replicating and combining this single agency structure for multiple government agencies.

Management Flight Simulator Interface

In the NOR model, the user has control over several variables via a management flight simulator interface so the user can change variables to compare results for different "what-if?" scenarios in the NOR process. User inputs are both variable and graphical.

In addition to the specific data listed in the Model Data section, the user also has the opportunity to alter the following parameters:

- ***Hire Fraction*** – the average percentage of personnel (relative to the current level of personnel) to hire.
- ***Personnel Loss Fraction*** – the average percentage of personnel (relative to the current level of personnel) that leave.
- ***Average Work Hours per Year*** – average numbers of calendar work hours per year per person.
- ***Productivity*** – average percentage of calendar work hours that are spent productively.
- ***Average Monthly Salary*** – average monthly salary per person.
- ***Overhead Fraction Normal*** – the baseline fraction of available work hours that are spent on overhead.
- ***Capacity Overhead Multiplier*** – a multiplier that increases or decreases the Fraction Overhead based on the current Workload Ratio.
- ***Labor Change Multiplier*** – a multiplier that increases or decreases the Hire Fraction and Personnel Loss Fraction based on the difference between the current level of personnel and the level of personnel indicated in the End Strength data.
- ***Contractor Billing Rate*** – the average outside contractor's billing rate per hour.
- ***Contractor Fraction Minimum*** – the minimum fraction of work that must go to outside contractors.
- ***Contractor Multiplier*** – a multiplier that increases or decreases the Contractor Fraction based on the current Workload Ratio.
- ***Desired Backlog Months*** – the desired number of months over which to spread the current Work Backlog.

NOR Simulation and Results

Using the NOR model, a simulation was run for 120 months (ten years) using a time step of one month. For comparison, nominal data is used for the first four years and data projections are provided for the fifth and sixth years. This data covers roughly half the length of the simulation. Data beyond the sixth year is kept at the same level as the sixth year.

As can be seen by the graphs in Figure 3 through Figure 6, the results of the NOR model are very close to the nominal data up through the fourth year (month 48), which validates the model and increases our confidence in the model's ability to predict future outcomes. For the fifth and sixth years (months 49-72), the model begins to deviate from the nominal data projections, especially with respect to the Stabilized Rate, Cost and Revenue. Beyond the sixth year, nominal data remains at the sixth year level so it is not valid. At this time, the behavior shown by the model dramatically changes.

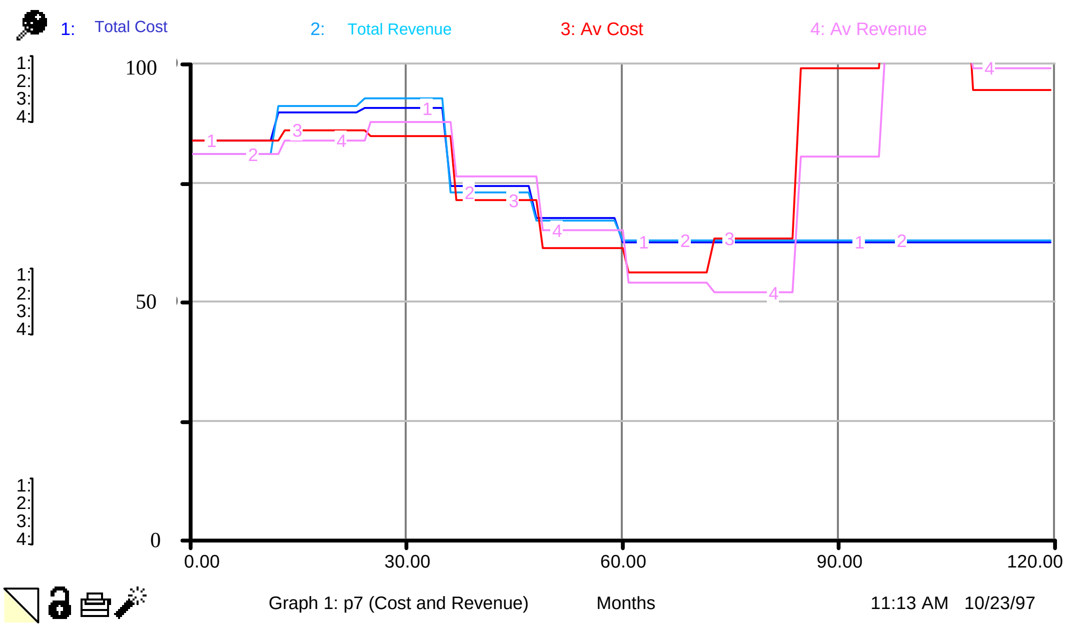

Figure 3: Cost and Revenue Graph

The Cost and Revenue Graph indicates that annual cost and annual revenue will both tend to oscillate individually due to oscillations in the stabilized rate, and the relative difference between cost and revenue will also oscillate (i.e., revenue will be higher for awhile, then cost will be higher for awhile).

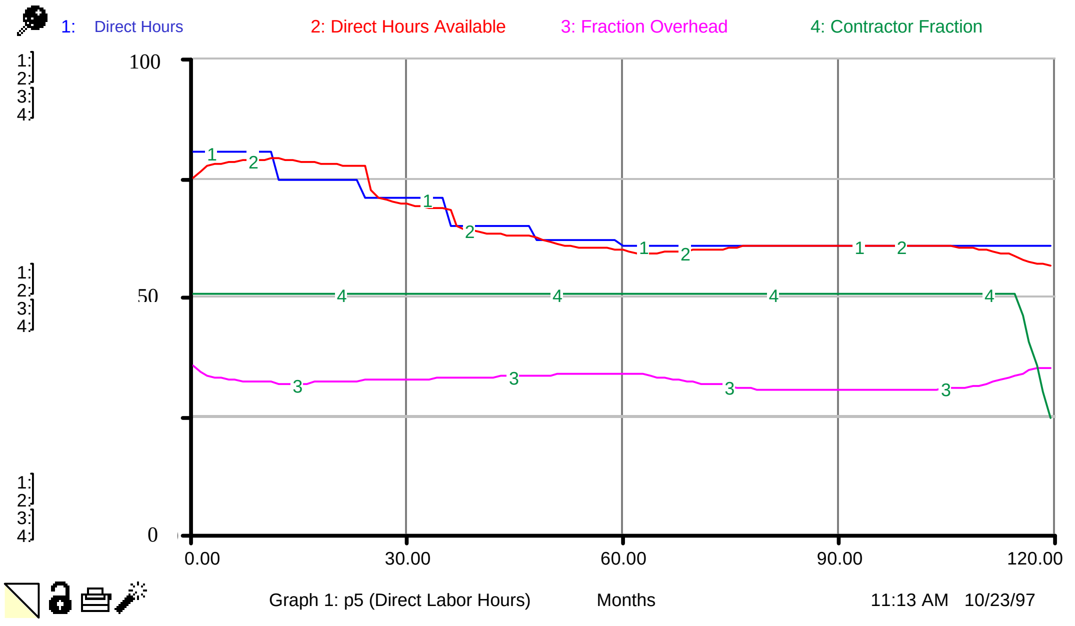

Figure 4: Direct Labor Hours Graph

The Direct Labor Hours Graph shows that the NOR model accurately replicates the level of direct labor hours available over time compared to the actual direct hours data specified by the user. This graphs also indicates that as direct labor hours available decrease in response to less incoming new work, eventually less work will be passed to outside contractors and more work will be moved to overhead functions because the number of direct hours available is too high compared to the incoming new work load.

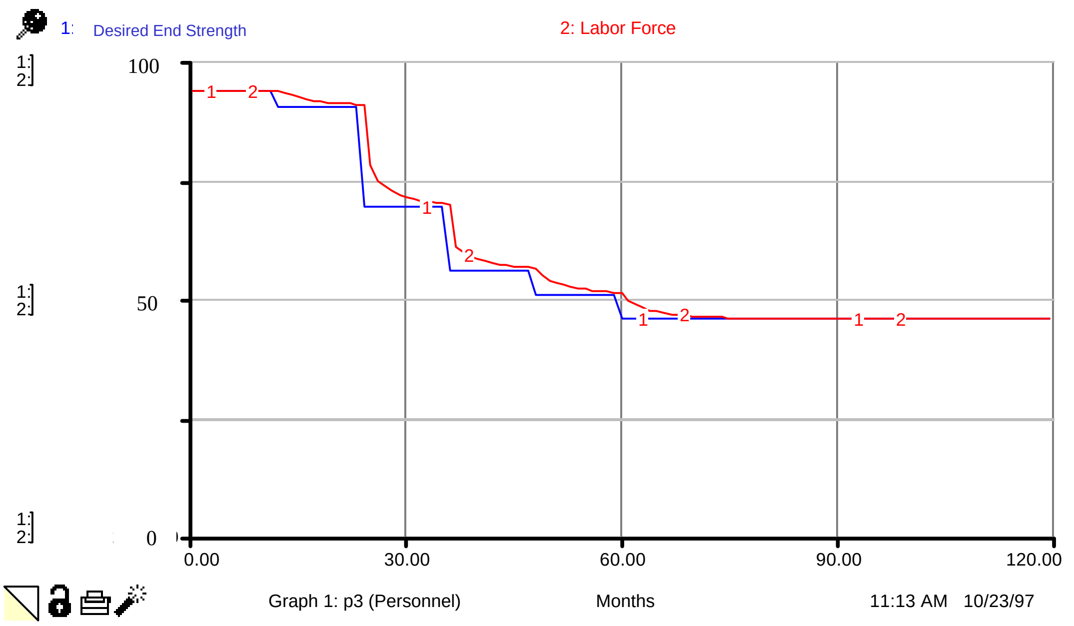

Figure 5: Personnel Graph

The Personnel Graph shows that the NOR model accurately replicates the level of the labor force over time compared to actual end strength data specified by the user.

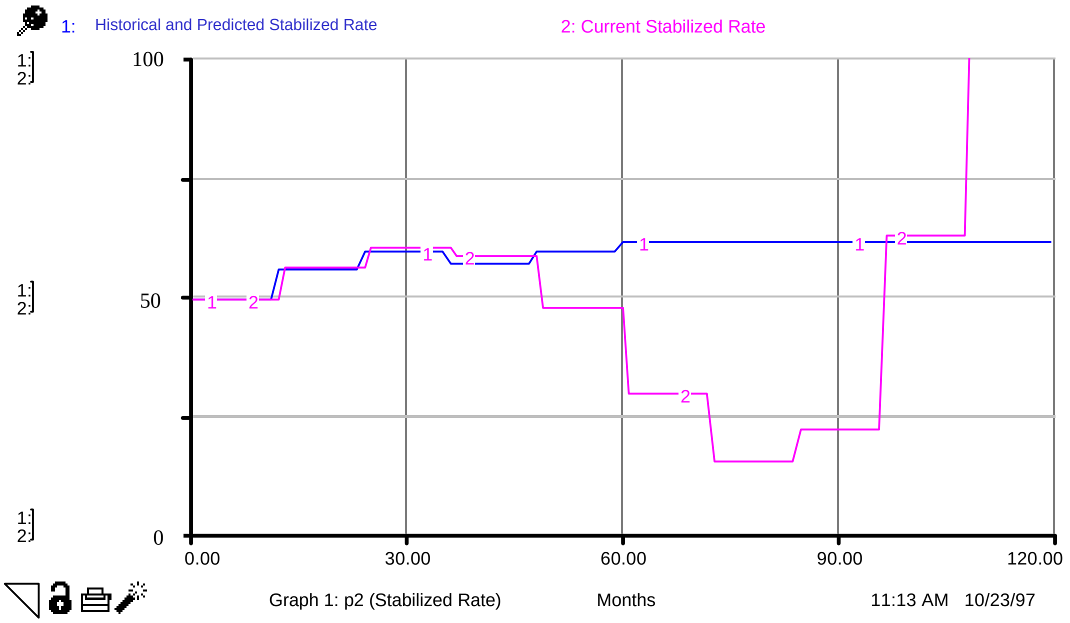

Figure 6: Stabilized Rate Graph
The Stabilized Rate Graph verifies the inherent instability of the NOR process as the oscillations of the stabilized rate grow larger over time due to the delay between the calculation of a new stabilized rate and the application of that new stabilized rate.

The primary behaviors of interest shown by the NOR model are amplifying oscillations in the Stabilized Rate, Cost and Revenue which signifies that the NOR process is inherently unstable, as alluded to in Part B of the spreadsheet in Figure 1. Consequently, a great deal of managerial time and effort must be expended to keep the NOR process under control and in balance.

Due to the accounting delay (13 months) between the time that the NOR/AOR is calculated and the time that the resulting Stabilized Rate is applied, the oscillating behavior of the Stabilized Rate will grow worse over time. This happens because the NOR/AOR continues to increase (or decrease) for 12 months before the compensating Stabilized Rate can take effect. Because the NOR/AOR increased (or decreased) even more during that time, the next calculation for the Stabilized Rate will be even larger, even though a compensating change was already “in the pipeline”. In essence, the Stabilized Rate is changed again (in the same direction as the previous change) before the previous change has a chance to take effect. Over time, this amplifies the changes in value of the Stabilized Rate as seen in Figure 6.

Bigger changes in the Stabilized Rate then drive bigger changes in Cost and Revenue (Figure 3). As shown in Figure 2, the Stabilized Rate directly affects Revenue and indirectly affects Cost as the Stabilized Rate is used to determine new work coming in. A low Stabilized Rate (as in the middle part of the simulation in Figure 6) increases the amount of new work coming in which increases Work Backlog. As Work Backlog increases, the Workload Ratio decreases (i.e., insufficient Capacity) and more work is moved to outside contractors. Cost increases as more work moves to outside contractors.

From the balancing feedback loops discussed earlier, we know that as the Stabilized Rate increases, the amount of work coming in decreases (because Work Forecast is divided by the Stabilized Rate) which decreases the Work Backlog and increases the Workload Ratio. As the Workload Ratio increases (i.e., excess Capacity), the Contractor Fraction decreases so that less work is given to outside contractors and the Overhead Fraction increases so that manpower is shifted from direct labor to overhead functions. As the Stabilized Rate (Figure 6) increases significantly in the last part of the simulation, we see a sharp drop in the Contractor Fraction and an increase in the Overhead Fraction as well (Figure 4).

The validity of the NOR model simulation does not depend on the exact fit of model results to actual results, but instead depends on the behavior of the NOR process over time. Over the long term, most specific points are irrelevant. The NOR model proves useful by capturing the overall nature of the out-of-phase oscillating behavior of Cost and Revenue, as well as the NOR system structure that drives this behavior (APPENDIX A).

Proposed Improvements to the NOR Process

Several government participants of the NOR process argued that the problems of the NOR process stem from the fact that the government dictates the personnel levels, depending on the agency. These participants hypothesized that the overall process would operate more smoothly if an agency managed its own current personnel levels similar to commercial organizations.

To model these management functions, Figure 7 shows two additional feedback loops made available to the user. Loop E allows the user to make personnel changes depending on NOR/AOR by defining a table function which specifies a multiplier (y-axis) on the fraction of personnel to add or remove based on the current level of AOR (x-axis). Loop F allows the user to make personnel changes depending on the Workload Factor by defining a table function which specifies a multiplier (y-axis) on the fraction of personnel to add or remove based on the current Workload Factor (x-axis).

With the objective of stabilizing the process, these additional feedback loops showed only slight improvement over the initial simulation with regards to the magnitude of the values of the Stabilized Rate, Cost, and Revenue. However, Stabilized Rate, Cost, and Revenue still showed amplifying oscillations which indicates that the system is still unstable with the presence of the two additional feedback loops. As a result, managers can discard the hypothesis that only having better control over current personnel levels would decrease the instability of the NOR process. Of course, these feedback loops were added in an existing government system structure which may minimize their impact. Additional processes, such as labor forecasts based on workload forecasts, would be necessary to represent the full control that most commercial organizations have over personnel levels.

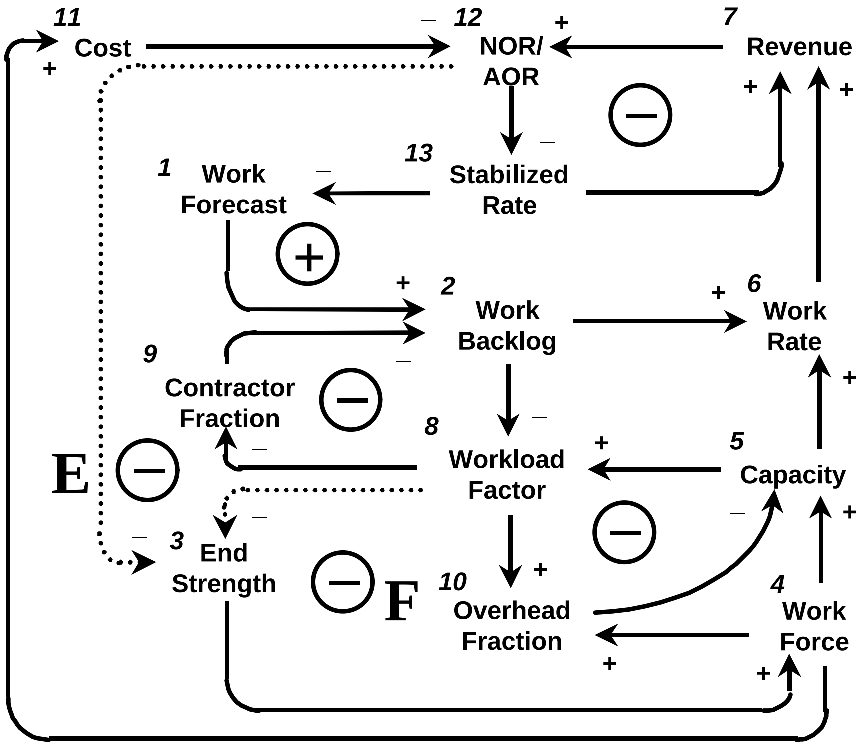

Figure 7: Additional Management Functions to the NOR Process
Some managers hypothesized that increased control over personnel levels would minimize the oscillations in the NOR process.

Other government participants in the NOR process believed that the 13-month accounting delay cause the instability in the NOR process. Because the accounting delays are built into the NOR process, the amplifying and oscillating behavior of the results cannot be eliminated unless the delays themselves are eliminated by applying the new Stabilized Rate in the very next year.

This proved to be the reason why the two feedback loops in Figure 7 failed to improve the stability of the process. Personnel changes were made based on current conditions, but the changes to the Stabilized Rate which affects Work Backlog, Cost, and Revenue were made based on conditions 13 months earlier.

Similar to the simplified calculations in Part A of the spreadsheet in Figure 1, removing the accounting delay in the model involved using the annual NOR for the current year to calculate the new Stabilized Rate instead of using the AOR. With this modification to the model, performance greatly improved. As Figure 8 and Figure 9 show, changing the Stabilized Rate based on the annual NOR tended to steady the Stabilized Rate and, consequently, Cost and Revenue.

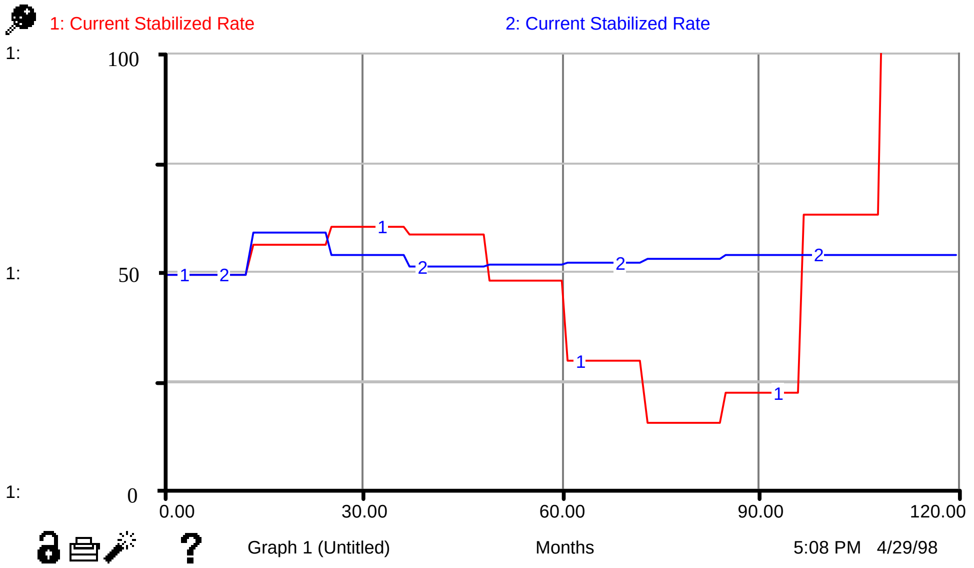

Figure 8: Comparison of Stabilized Rates for Two Simulations
Using the same nominal data, changing the Stabilized Rate based on annual NOR (line 2) indicated less instability than changing the Stabilized Rate based on AOR (line 1).

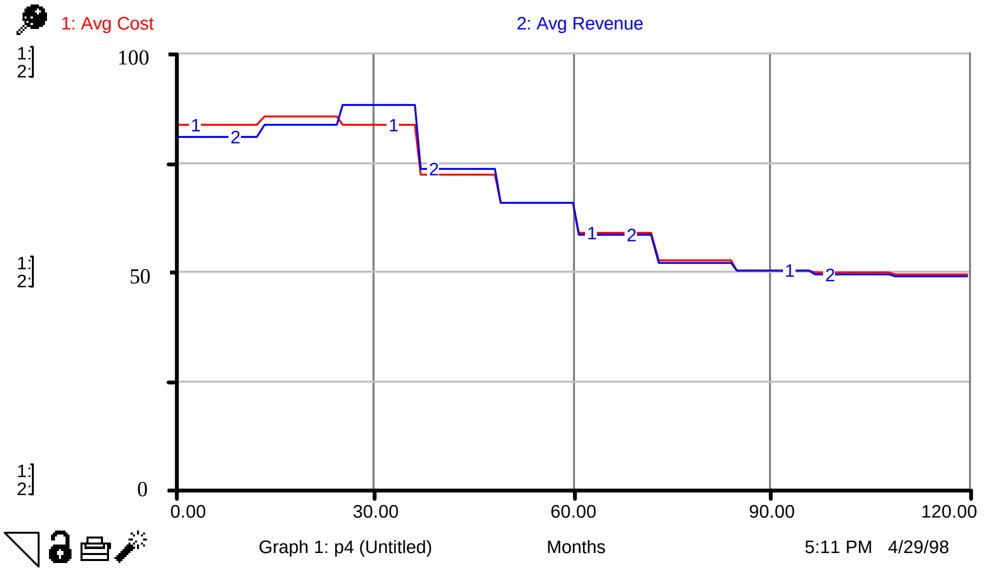

Figure 9: Cost and Revenue Results by Changing Stabilized Rate Based on NOR
Cost and Revenue results tend to stabilize when the Stabilized Rate is based on the annual NOR instead of AOR.

Conclusion and Future Research

While it appears simple in concept and on a spreadsheet, the NOR process is actually quite complex. There are many intricate interactions that play out over time which make it difficult to intuitively understand the process completely. To gain better insight, a system dynamics model of the NOR process was constructed and historical data and future projections from a specific government agency was used. Simulations proved that the model results matched historical results well, which helped validate the model. However, the model showed very different results for future projections. The NOR process appears to be inherently unstable with amplifying oscillations in several key variables.

The government implemented the NOR process only a few years ago. As seen in Figure 3 and Figure 6, the oscillations at this point in time are not great. However, simulations reveal that these oscillations can get out of control rather quickly and may begin to do so soon. The government must realize that it sits on an inherently unstable system that tends toward amplifying oscillations in the Stabilized Rate, Costs, and Revenues. Something must be done before it becomes too difficult to managerially keep the oscillations to a minimum. Simulations indicate that reducing the accounting delay between the time that a change is made to the Stabilized Rate and the time that the new Stabilized Rate is applied has the potential to steady the NOR process.

Additional improvement possibilities to consider in future analysis of the NOR process include altering the rate at which an agency transfers personnel to and from overhead (i.e., indirect) functions, altering the rate at which an agency transfers work backlog to and from outside contractors, and adding commercial-type processes that give an agency full control over personnel level.

APPENDIX A

Overview of the NOR Model

Figure A-1 through Figure A-4 show how the high-level view of the current NOR process in Figure 2 is translated into a system dynamics model using iThink™ software from High Performance Systems.

Four main process sectors have been used: Work Forecast (Figure A-1), Personnel (Figure A-2), Cost and Capacity (Figure A-3), and Accounting (Figure A-4). In each of the figures, variables placed outside the sector box represent variables that are calculated elsewhere in the model (e.g., a direct user input or another sector).

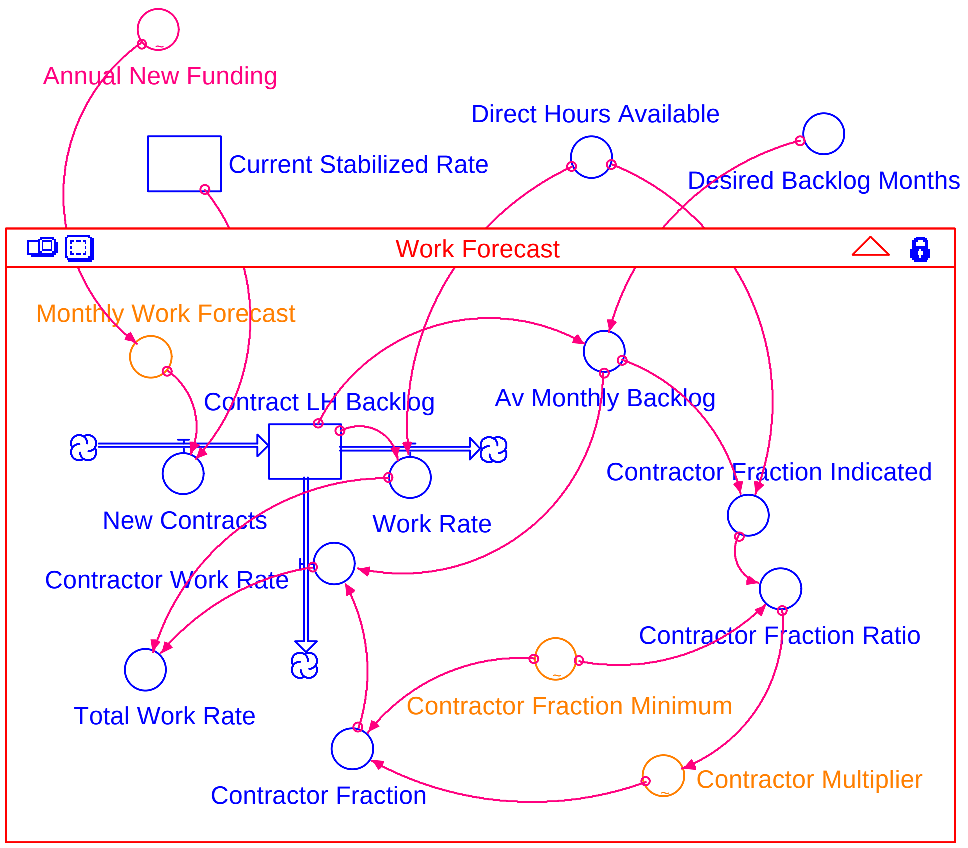

Figure A-1: Work Forecast Sector

The Work Forecast Sector provides the NOR system structure for acquiring new work and completing work in backlog, which also includes the calculation for how much work to pass to outside contractors.

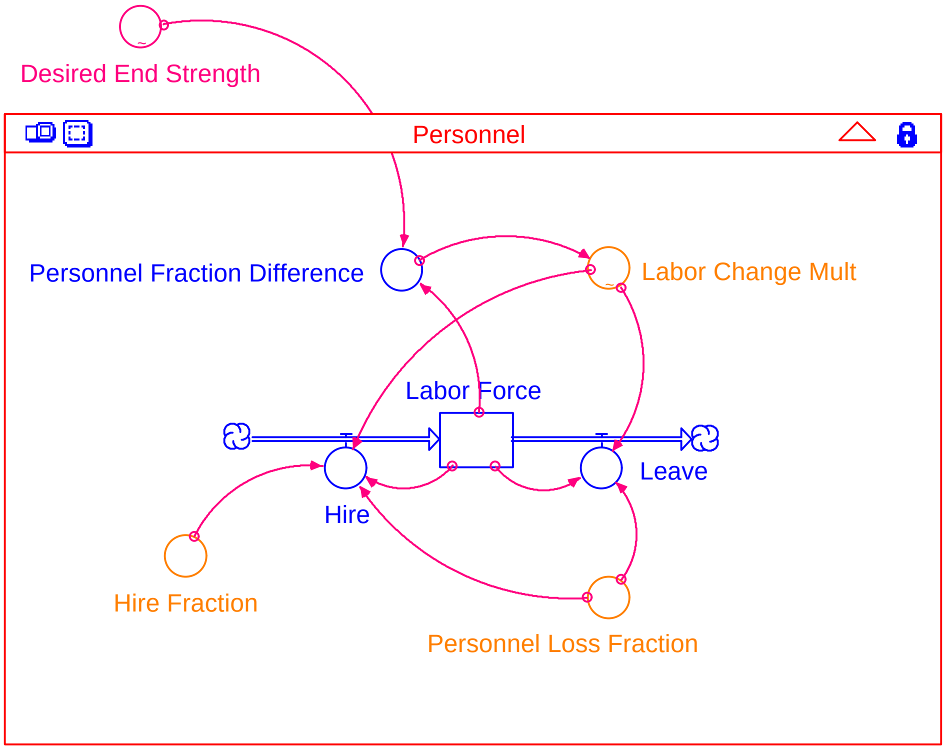

Figure A-2: Personnel Sector

The Personnel Sector provides the NOR system structure for increasing and decreasing the labor force based on end strength data specified by the user.

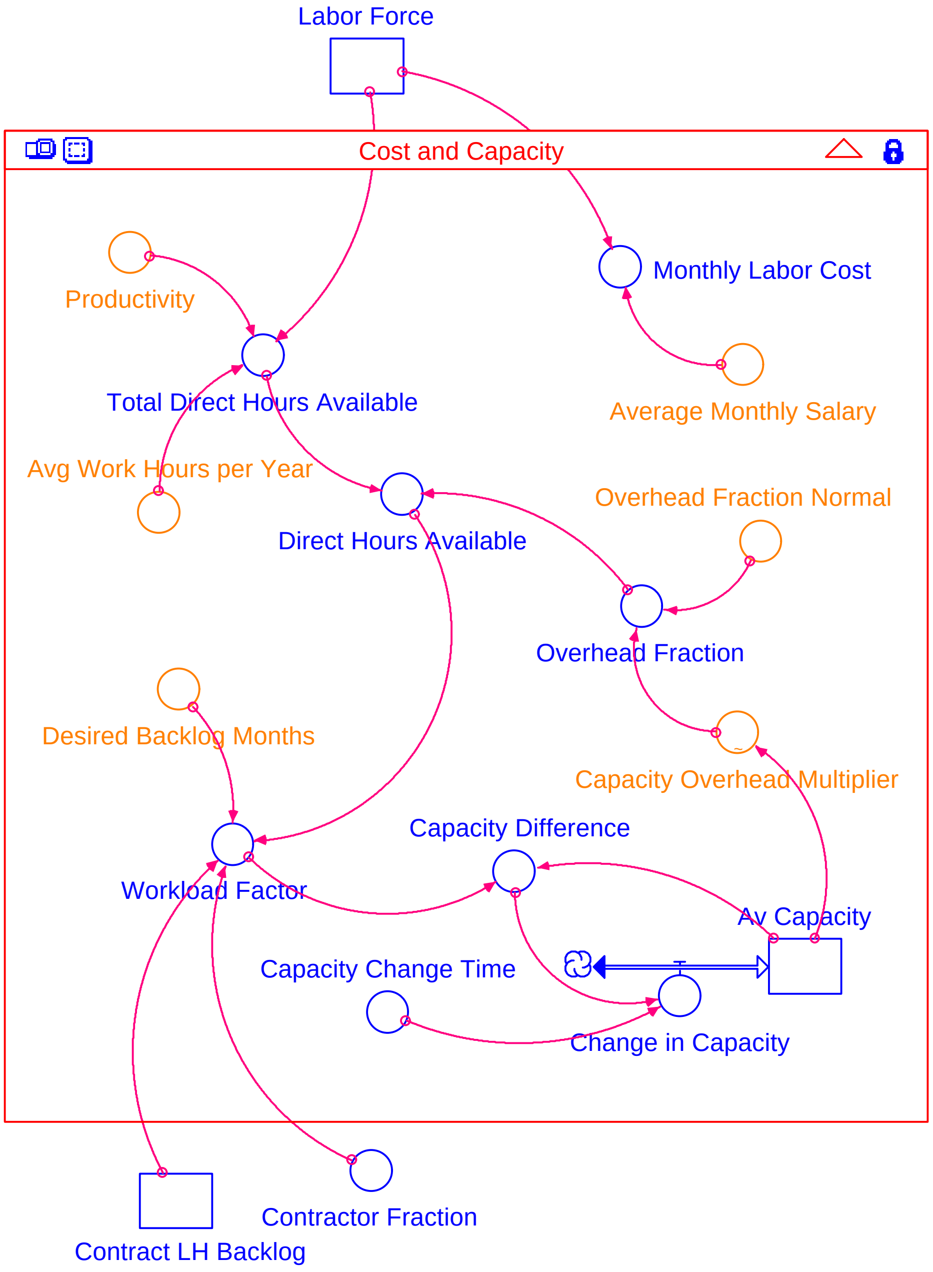

Figure A-3: Cost and Capacity Sector

The Cost and Capacity Sector provides the NOR system structure for determining the overall cost of labor and the number of direct hours available for work, which also includes the calculation for how many work hours to move to overhead functions.

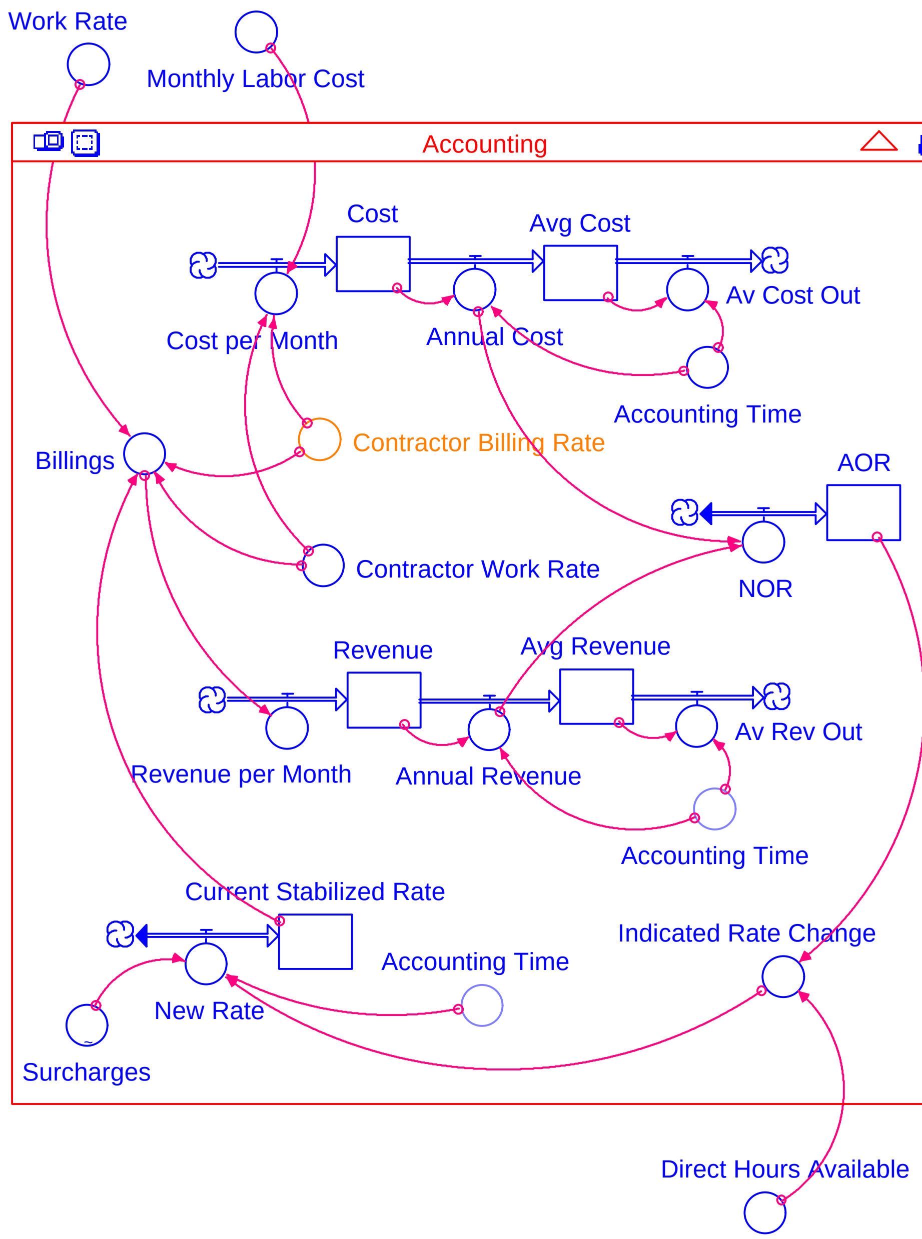

Figure A-4: Accounting Sector

The Accounting Sector provides the NOR financial system structure for calculating annual costs and revenue, net operating results (NOR), accumulated operating results (AOR), and stabilized rate.