Applying System Dynamics to Business: An Expense Management Example

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Abstract

If you're new to system dynamics, it may be hard to see a pragmatic application to your business needs. This companion article to "Pipeline Inventory: The Missing Factor in Organizational Expense Management" [1] describes a seemingly simple problem and how a common approach may make things worse, not better. System dynamics offers an effective, easy solution. The associated model can be downloaded for experimentation.

Is system dynamics for you?

Perhaps you've read of system dynamics in books such as *The Fifth Discipline* [2] and concluded it doesn't apply to you. You may have seen how system dynamics can solve big problems for companies with deep pockets: forecasting demand for a new car design [3] or estimating the effects of policy decisions on a regional electric power system [4]. Something applied to such big problems probably won't affect you; you certainly can't afford it.

This short article will demonstrate by example that system dynamics can solve problems of the magnitude seen by many middle managers, and such approaches don't need to have prohibitive costs. It provides a short introduction to system dynamics, describes a real management problem, presents a model that can be used to solve the problem, and closes with a summary of the lessons that can be drawn. The model [5] is also available to examine in closer detail.

What is system dynamics?

System dynamics is a method of solving problems by computer simulation. Like many simulation methods, it offers the promise of less expensive learning—it's cheaper and faster to experiment with the effect of new policies on a computer model than on a real system with real people, equipment, and processes.

System dynamics [6] incorporates features that make it especially useful for certain problems:

- System dynamics can model the effect of information feedback on the future direction of the model. For example, if the cycle time in a production process becomes excessive, management would typically intervene to make changes, while many process simulations would simply report that cycle time was continuing to grow. System dynamics handles this easily.

- To facilitate the use of information feedback, system dynamics carefully separates information accumulated about the state of the system and information fed back from that state to control the evolution of future states.

These two key features enable a system dynamics model to address situations that evolve over time. Research indicates that people are often poor at solving such problems mentally [7].

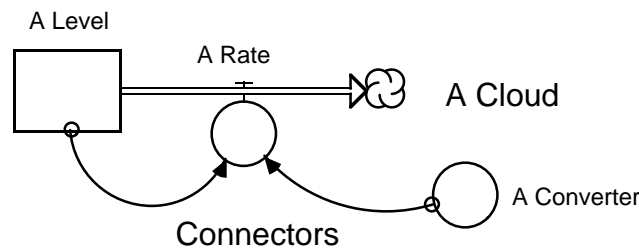The language of system dynamics is simple (figure 1). Levels (also called

Figure 1: The system dynamics "language"

stocks) contain quantities describing the state of the system. If the model (or system) were stopped, each of these would continue to hold its quantity for observation. For example, the amounts of money in various financial accounts are typically levels in a financial system. In a typical system dynamics diagram, these appear as labeled rectangles. If the value of a particular stock is of no concern to the problem at hand, then the stock is shown as a cloud to indicate that it's outside the boundary of the model.

Rates (also called flows) are the inflows to and outflows from the various levels. These appear as labeled valves on pipes connecting levels. If the system were stopped, rates also stop. For example, the paying of interest into an account is a rate. If the system were frozen in time, there would be no flow of interest into accounts.

Connectors and converters (also called auxiliaries) measure the quantities in levels and, through various calculations, control the rates. These appear as as lines with arrows and as circles. Management policies (the rules by which managers make decisions) are modeled by these calculations.

A problem

In business terms

Among their other responsibilities, middle managers must ensure the adequate financial performance of their organizations. That includes ensuring their supervisors don't overspend their budgets.

From time to time, middle managers may see overspending by one or another of their supervisors (or by all at once). That may last a month or two until they bring their spending back under control. Unfortunately, in some cases, overspending recurs a few months later.

Many reasons may be given for this pattern. Vendors may have shipped early (or late), causing expenses to bunch up. Project-related expenses may have been committed at a particular time to meet schedule, not budgetary, commitments. Supervisors may not have been paying attention to their commitments. Some supervisors may need training or counseling.

The middle manager must determine which of these diagnoses is correct and take useful action. Should the manager express frustration, so that the supervisors understand their accountability? Should the company find vendors with shorter and more predictable lead times? Should they all budget more precisely each year? Should the manager simply ignore the problem and hope that over- and underspending will average out over the year?

As a system dynamics model

Two key structures are sufficient to model this system. One models the flow of orders from the company to vendors, and the other models the flow of bills and information about bills from the vendor back to the company.

Supervisors issue purchase orders to vendors, and those remain in the vendor's backlog until products are shipped (figure 2). Supervisors issue orders to
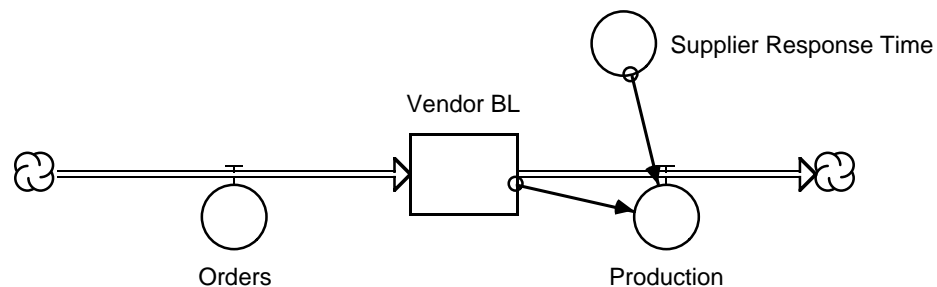

Figure 2: The flow of purchase orders

the vendor, which increases vendor backlog (BL). Backlog is reduced through production. Supplier response time is used in the calculation of production.

A second structure (figure 3) models the flow of reported bills from the vendor back to the supervisor. Shipping by the vendor provides received bills to
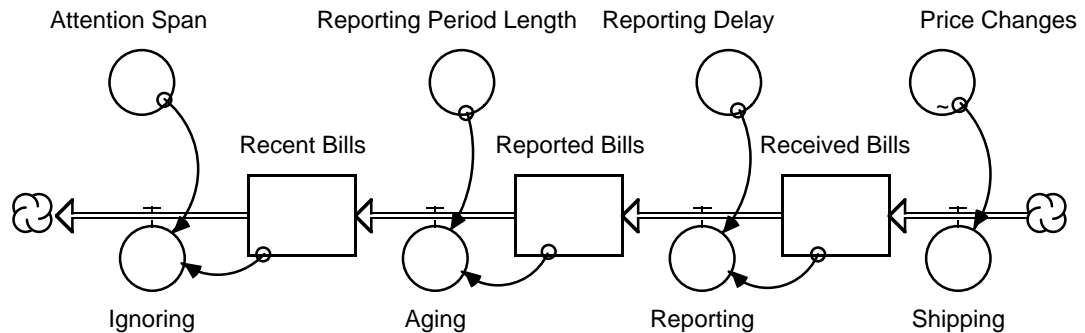
Figure 3: The flow of billing information

the originating company. After a reporting delay (typically to the end of the month), accounting reports the total of all received bills to managers. Numbers in the current report become part of the cumulative history, captured as recent bills, after the end of the current month. After further delay (modeled as management's attention span), they pass into ancient history and are no longer a factor in decision making. In some organizations, expenses incurred in previous fiscal quarters may be ancient history; in others, anything in the current fiscal year may be of importance.

In the model, as in real life, expenses are compared against the budget for the corresponding period. For simplicity, the budget is assumed to be constant, calculated by multiplying the weekly budget amount by the appropriate time periods. While many companies have monthly budgets, people tend to make many real-time spending decisions over shorter time frames. This model aggregates time into weekly chunks.

Managers tend to buy what they had budgeted to buy, modified directly by the variance in the current accounting report. For example, if the manager had planned to buy $25,000 worth of goods and services but was overspent $1,000 in the current report, then orders would be $24,000. If the current report showed $1,000 in underspending, then orders would be $26,000.

That simple rule implies that managers would issue orders far above the planned rate, if reports showed large past underspending. That's unrealistic; management restraint would likely limit spending to some reasonable amount over the current budget, even if money were available.

Reproducing the problem

This model can be initialized in an equilibrium state if all levels have the proper quantities. The real world isn't static, so it's useful to see the reaction of this model to change. The model arbitrarily increases the price the vendor charges for goods by 25% for 4 weeks, starting at week 24.

Figure 4 shows the result to be an oscillatory spending pattern. In weeks 24-28, prices increase 25% over the budgeted amount. Since that's applied as the
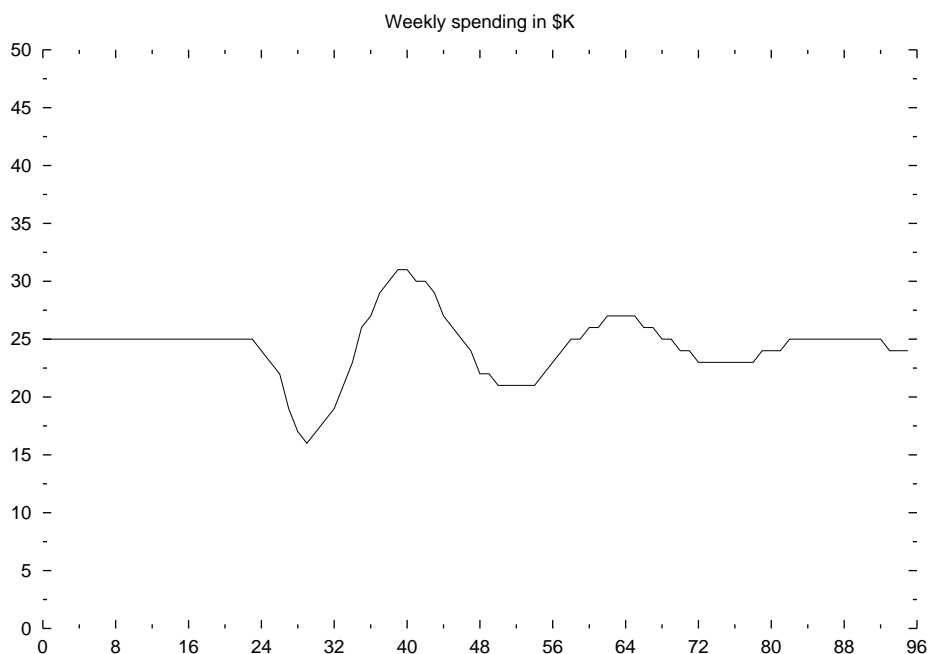
Weekly spending in $K

Figure 4: Orders in the base system

vendor is shipping products, the variance reported starts to rise soon afterwards. As the variance rises, the supervisor reduces ordering to compensate. By week 29, the full effect of the increased charges is felt, and spending is at its lowest.

As the effect of the changed price declines, spending rises again. As the supervisor had underspent for several weeks, extra money is available, and the supervisor spends it, perhaps purchasing those items delayed earlier.

By week 40, spending has peaked and reported underspending is declining, thanks to bills from the vendor from the previous 11 weeks' spending levels. At this point, the cycle repeats. The graph shows a period (time for one complete cycle) of almost 24 weeks or 6 months.

Thus a simple model of a reasonable spending policy can replicate a pattern of periodic overspending as described in the opening section. This model is now ready for use in testing alternatives.

Solving the problem

One must first select the criteria by which solutions are judged. One could choose to minimize the maximum overspending, some measure of the fluctuation in spending level from the budgeted amount, or the time before the system had once again become stable. That selection would be done in a way that addressed

the concerns of company management.

This example uses the variation in weekly orders sent to the vendor as its criterion. Other criteria may lead to different conclusions.

There are many ways to address this problem. One can vary vendor lead time, vary management pressure, or provide different information in accounting reports.

Figure 5 shows only a small variation in system response as vendor response

Figure 5: Sensitivity of orders to vendor response time

time is varied from 2 to 12 weeks while management pressure is held steady at 100%. It's interesting to note that the amplitude of the oscillation is slightly larger at 7 weeks than at shorter or longer periods, but the difference is small.

Figure 6 shows a bit larger variation as management pressure is varied from 50% to 150% of normal and supplier response time is maintained at 8 weeks. While managers may want to add pressure to correct out-of-control spending, this model suggests that to be counterproductive. That's because management pressure exaggerates inherent structural tendencies in the system, so a tendency towards fluctuations would just be made worse.

Figure 7 shows the much larger effect of a change in the information reported, with management pressure and supplier response time at normal levels. The four types of reports are:

Current results only The variance is calculated based solely on the budget
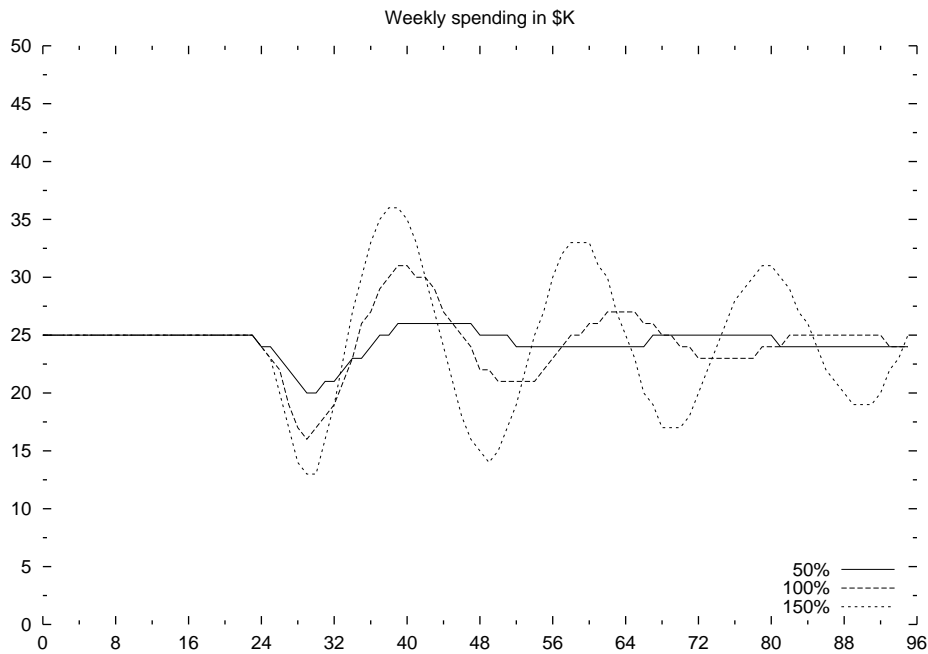
Figure 6: Sensitivity of orders to management pressure

and reported expenses for the current period (a common approach).

Cumulative results The variance also includes the effect of recent bills and the corresponding recent budget (another common approach).

All in-house data The variance also includes the effect of received bills and the corresponding budget (an easy enhancement).

Include vendor backlog The variance also includes the effect of vendor backlog and the corresponding budget (the recommendation in [1]).

While the best results are obtained using all data including vendor backlog, the second best results are obtained when only considering the current period's reported results.

Conclusions

This simple model is able to shed insight into a common management problem: expense control. The type of information given to managers for decision making has far greater impact on expense control than does management pressure or vendor lead time.

While increased management pressure has an unfavorable effect for each of these cases, other testing indicates that changes in management pressure have
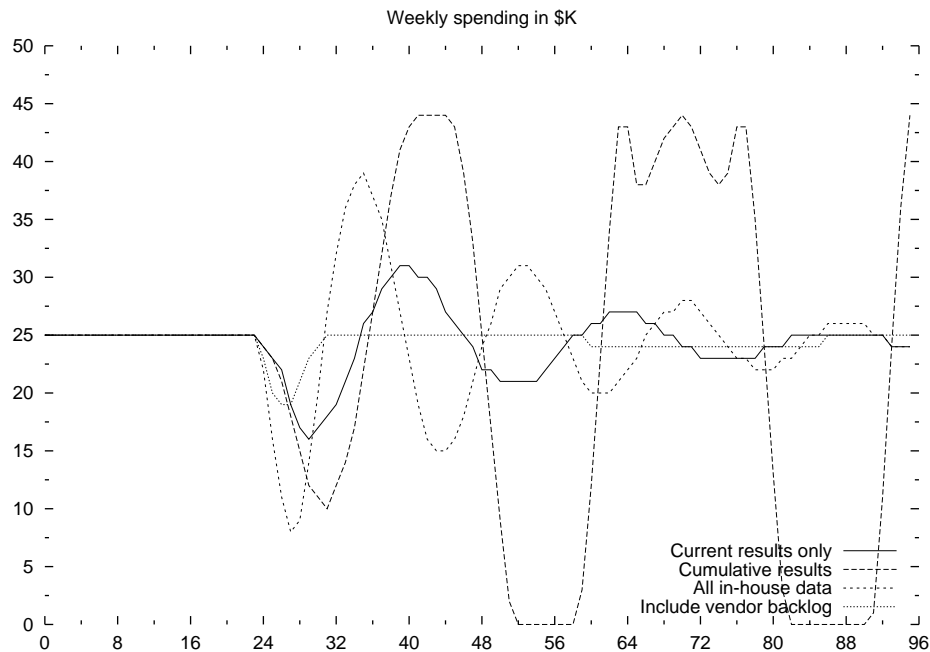
Weekly spending in $K

Figure 7: Sensitivity of orders to accounting reports

the least effect when incorporating vendor backlog data in accounting reports. That's a good sign; with a good organizational system, performance is less sensitive to management style.

The problem-solving process

While this has been a simple model, most managers would have someone else do the system dynamics work in collaboration with them. If you're working with a system dynamics modeler, you might expect to see the following steps:

Defining the problem The modeler would listen to your problem to under-
stand it and the important factors with a goal of defining a graph of
the problem behavior over time. This graph, called the reference mode,
serves as a benchmark for the system dynamics effort. The model that's
constructed must be complete enough to recreate that reference mode
adequately; only then do you know it's useful for experimenting with so-
lutions. The model should also be simple enough to be understandable.

Creating the model The modeler takes the problem definition and creates a
model capable of reproducing the reference mode. This, as all steps, may
require work with the manager or others to get more information. The

modeler should test the model thoroughly to be sure it works adequately over a range of situations.

Proposing and testing alternatives Once the model can reproduce the problem, the manager and the modeler can propose alternative solutions and test them using the model.

Communicating the result The problem isn't solved until the real world system has been changed, and that requires communication. Depending upon the situation, the modeler may need to create a short report documenting the proposed solution, a presentation to be given to others, or a "learning environment" to be used by others to understand the problem and its solution. Learning environments are somewhat like management video games. They allow others to set policy interactively and see the effects on the system.

Lessons

There are three levels of lessons from this model:

- Expense management

    - If you have recurring expense management problems, you may be giving managers the wrong information.

- Management approach

    - Increased management pressure (increased accountability), may worsen the performance of a poorly structured organization.
    - It's important to have the right information to make good decisions.
    - It's important to know how to respond to information effectively.
    - The responsibility of management is to design and implement a system that achieves the purpose of the organization.

- Approach to problem solving

    - Common, simple, intuitive solutions may be wrong.
    - System dynamics is applicable to common management issues.
    - It's possible to create a simple system dynamics model that is useful for assessing alternative problem solutions. Such an approach doesn't have to be complicated, take a long time, or be expensive.

Rights

References

[1] Bill Harris. Pipeline inventory: The missing factor in organizational expense management. *National Productivity Review*, 18(3):33–38, Summer 1999.

[2] Peter Senge. *The Fifth Discipline*. Addison-Wesley, 1993.

[3] Glen L. Urban, John R. Hauser, and John H. Roberts. Prelaunch forecasting of new automobiles. *Management Science*, 36(4):401–421, April 1990.

[4] Andrew Ford. Estimating the impact of efficiency standards on the uncertainty of the northwest electric system. *Operations Research*, 38(4):580–597, July-August 1990.

[5] Bill Harris. iThink model of expense management. http://facilitatedsystems.com/expmgmnt.itm, May 2000.

[6] Jay W. Forrester. *Industrial Dynamics*. The M.I.T. Press, 1961.

[7] Dietrich Dörner. *The Logic of Failure: Recognizing and Avoiding Errors in Complex Situations*. Perseus Press, 1997.

Appendix:
Getting and using the model

The expense management model [5] is available for downloading in iThink format. High Performance Systems provides a free demo version of iThink at http://www.hps-inc.com/bus_solu/ithink/demo_gate.htm.

The model has three layers: the high-level mapping layer, the model layer, and the equations. Most experimentation can be done on the high-level mapping layer. Press the "Run" button to see the model execute. Click on the small white triangle at the bottom left of the graph to page through the various graph alternatives.

Press one of the radio buttons to select one of the four predefined accounting reports provided to managers and supervisors. Press "Run" to see the results. Vary the vendor's supplier response time and the level of management pressure to see the effect. You can even change the length of time managers and supervisors pay attention to past data, although that will only have effect in "Cumulative results" mode.

If you've modified any of the parameters, you may reset them by pressing the "U" in their control.

You can click on the "To Model" button to see the underlying model structure. You can click on the downward pointing triangle along the left window border to view the equations.