Sensitivity Simulations

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Background

System dynamics modelers normally develop models and implement findings from a deterministic perspective. This approach has great merit. It focuses attention on system structure and behavior as well as ways to change them. Once developed, however, a good system dynamics model is an excellent tool for analyzing system behavior under a wide variety of parametric assumptions. Though such sensitivity analysis can (and should) be done manually through repeated simulation, automated tools allow more complete exploration. Moreover, they can provide information on the distributions of outcomes that strongly effects decision-making.

In this paper we present the basic ideas behind doing multivariate sensitivity simulations (MVSS) and describe how these have been implemented in Vensim®. Then, we present a case study that uses MVSS in the pharmaceutical industry.

Parametric Sensitivity

MultiVariate Sensitivity Simulations, often labeled Monte-Carlo Simulations are most easily described using an example. Consider the introduction of a rodent into an ecosystem with fixed carrying capacity but no predators. We could represent this with a model such as:
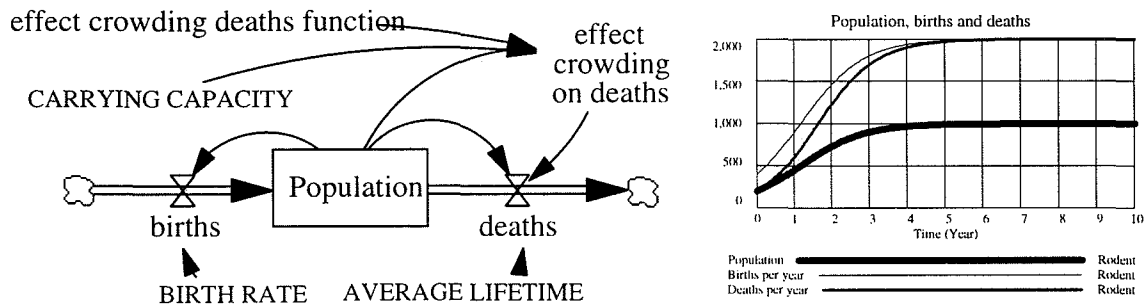

By experimenting, we could discover that a higher birth, longer average lifetime or larger carrying capacity will lead to a population that grows more quickly. In order to do MVSS on this model, we treat these model parameters as statistical distributions instead of constants. In these histograms each bar represents the probability that a parameter falls within the stated range.
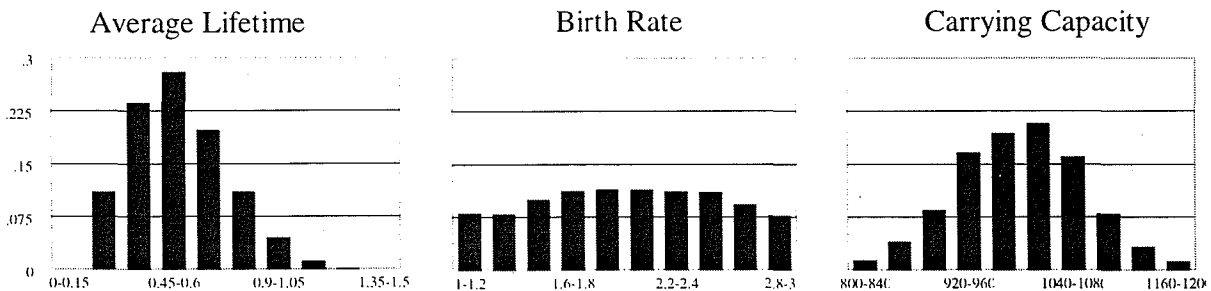
Given these distributions, the simulated population, birth rate and death rate at any time are no longer number. Each is described by a distribution of values. Determining this distribution in closed form is impossible, but it is easy to do by repeatedly drawing from (or sampling) the input distributions and simulating the model. In the following histograms each bar shows the probability that population falls within the stated range.

Population @ 2 - sensitivity

Population @ 10 - sensitivity
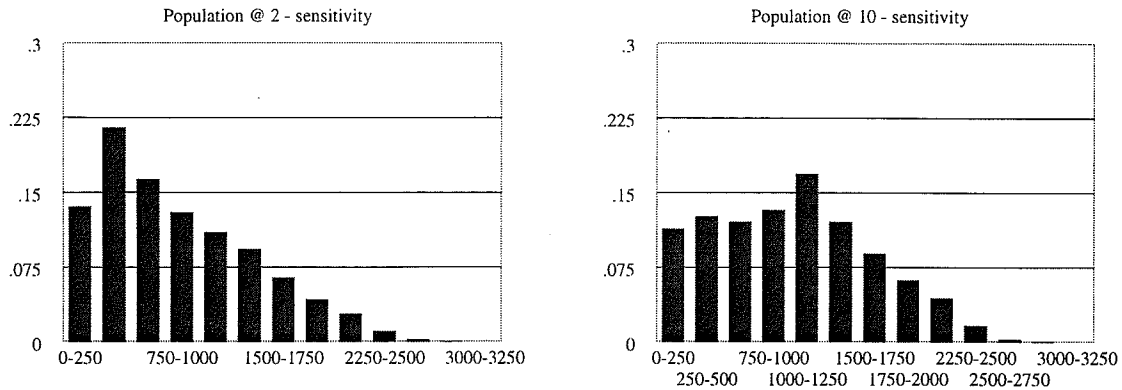
Or, since the standard in system dynamics is to look at time graphs, we can present this as a time plot with confidence bounds:

50% ☐ 75% ▨ 95% ▧ 100% ▦
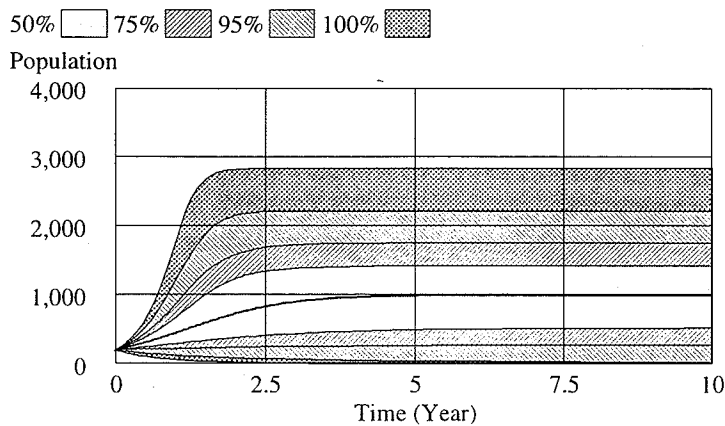
Population

In this graph the entire range of population outcomes is shown. The shadings indicate the percentage of the population outcomes that fall within the different sub-ranges.

MVSS helps you understand the potential range of behavior a model can generate. It also indicates your confidence about predictions of future activity.

Time (Year)

Software Implementation

The implementation of MVSS in Vensim follows from the above explanation. When starting a simulation, you specify which model parameters will have distributed inputs. Vensim provides several distributions for this purpose. It also allows you to specify shape parameters, truncation points, and the number of samples drawn (typically 100 to 5000).

Because of the large volume of calculated output, it is impractical to store all of the MVSS results. Therefore, unlike typical simulations, you need to identify the model variables for which you want the full distribution of output. Having done this, you can launch Vensim and let it do its work. For a simple model like the example above, this will take seconds. For large models, this can take several days.

For reviewing MVSS results, Vensim has two special tools. These are the Sensitivity Graph and the Bar Graph configured to show a sensitivity Histogram - the results of which are shown above.

MVSS combined with a higher quality model became a valuable tool for: (a) evaluating alternative market introduction scenarios, and (b) assessing the HIV drug's role in the company's overall portfolio of R&D projects. Traditionally, the company considered only pessimistic, optimistic and most likely scenarios. The problem with the high and low estimates was their arbitrariness -- some people treated them as 100% confidence bounds, while others thought they were more representative of 50% confidence bounds.

Traditionally, analysts faced three major problems when developing scenarios. First, they lacked integrated formal models that allowed them to see the interactions among a very large number of variables and parameters. Second, they could not represent uncertainties for the input parameters in a realistic way. And third, they lacked a convenient method to transform realistic input uncertainties for lots of parameters into an overall outcome. Taken together, these problems meant that their output ranges had huge ranges of uncertainty. (Imagine how bad the combination of one hundred 'worst case' parameters would look.) In response, analysts cut back on the number of uncertainties they recognized and artificially limited the ranges of those they did recognize. The result was a potpourri of assumptions that analysts could marginally defend, but which yielded outputs that managers and executives could not interpret.

The system dynamics model and MVSS addressed both of these problems and provided meaningful output. While MVSS did not limit the range of uncertainty (more than order of magnitude), it showed that with the right management plan the upside potential was enormous. Moreover, there was only a 30% chance of losing money (with less than a 5% chance of losing more than $100 million). The company found these risks worrisome but acceptable.

The analysis also contributes to an understanding of the company's entire portfolio of R&D projects. Clearly, the 30% chance of losing money is disconcerting, but high financial risk is a fact of life for R&D pharmaceutical companies. They diversify the risk by undertaking many independent R&D projects. Of course, it is possible to start so many projects that none is adequately funded or thoughtfully managed. For the best profitability, a balance must be struck. MVSS for both individual programs and for the portfolio as a whole can help executives strike the proper balance by realistically characterizing the risks and rewards.

Conclusion

MVSS can be a valuable supplement to system dynamics modeling practice. The usefulness of the results, however, depends on the development of high quality models that include all important feedback relationships. Consequently, MVSS must serve as an addition to, not replacement for, thoughtful modeling.