Calibration of Complex System Dynamics Models
A Practitioner's Report

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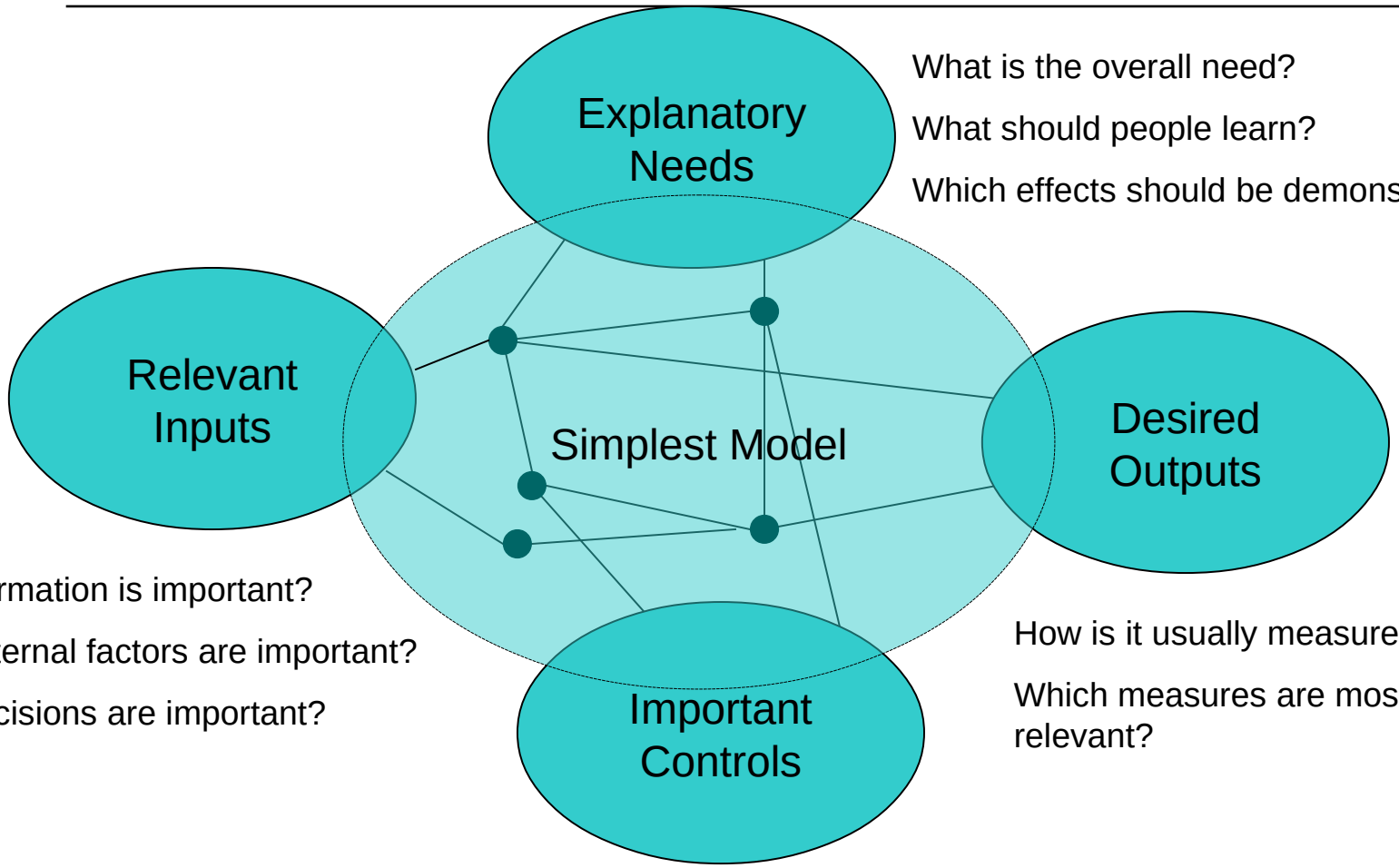
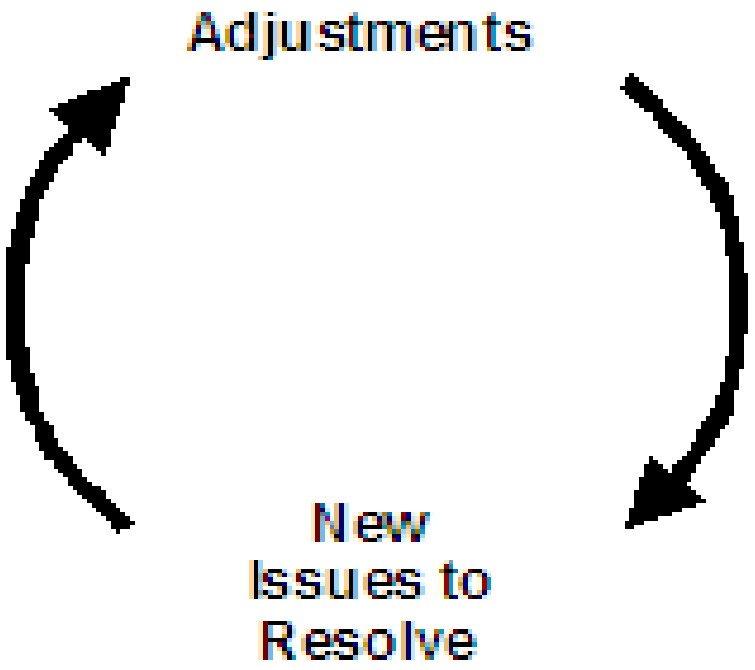
Motivation: the "Simplest Model" may not be Simple

Models sometimes need to be complex, making them hard to understand and trust. To be useful, such models must be well calibrated and tested

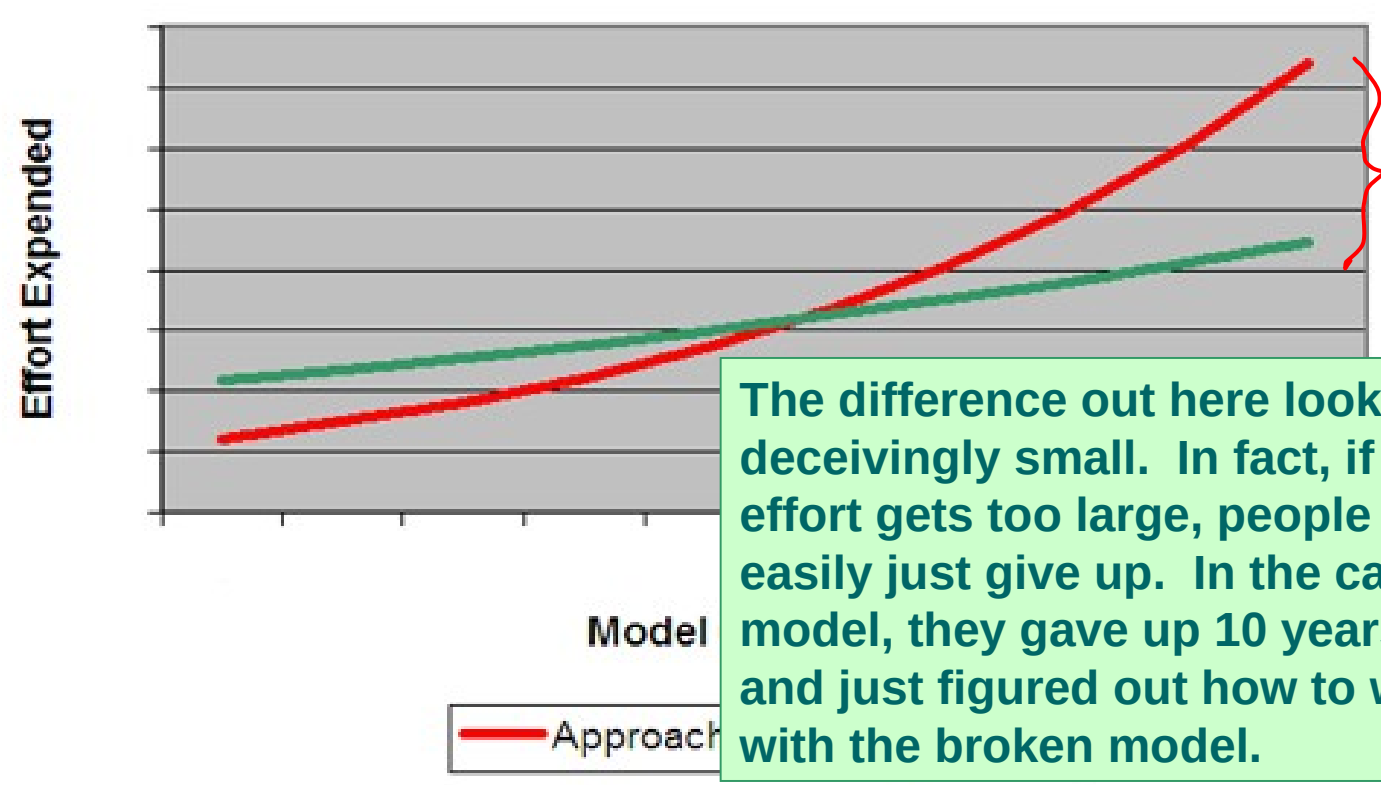


The Problem: Model Calibration/ Re-Calibration Loop



Effects of the model calibration loop are non-linearly related to model size and complexity

Effort Expended vs. Model Complexity for Two Approaches



The difference out here looks deceivingly small. In fact, if the effort gets too large, people can easily just give up. In the case study model, they gave up 10 years ago and just figured out how to work with the broken model.

- Both approaches scale exponentially with complexity
- Approach A (informal calibration) can be effective for less complex models
- Approach B (formal calibration strategy) essential for complex models

A Case in Point

- *Context: large, complex business training simulation model*
- *Conversion from a different SD language into I-Think®*
- *Also, design flaws in the original model had to be corrected*

Case Model Particulars

- *57 inputs, 296 outputs*
- *Strong interaction between calibration, verification, and validation*
- *Required a clear calibration strategy*
  - *Such a strategy may or may not scale usefully to smaller models (i.e., may not be necessary)*

First: Employ Fully Traditionally Advocated Best Practices[1]

- Some of our favorites include:
  - *Units checking*
  - *Sensitivity testing*
  - *Transient behavior testing*
    - *Response to perturbations*
  - *Graphical comparisons*
    - E.g., model variables vs. reference behavior data

[1] *c.f., Richmond, B. (2001) An Introduction to Systems Thinking. isee systems, inc., Lebanon, NH & Sterman, J. (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill, New York, NY*

Additional Aspects of the Calibration Strategy used for Case Model

1. *Simplifying the model as much as possible and isolating interactions*
2. *Redesigning along the way*
3. *Carefully documenting throughout process to stay organized and minimize "cycling"*
4. *Knowing when to step away*
5. *Building/acquiring automated tools to help in testing and analysis*

1. Simplifying the Model and Isolating Interactions

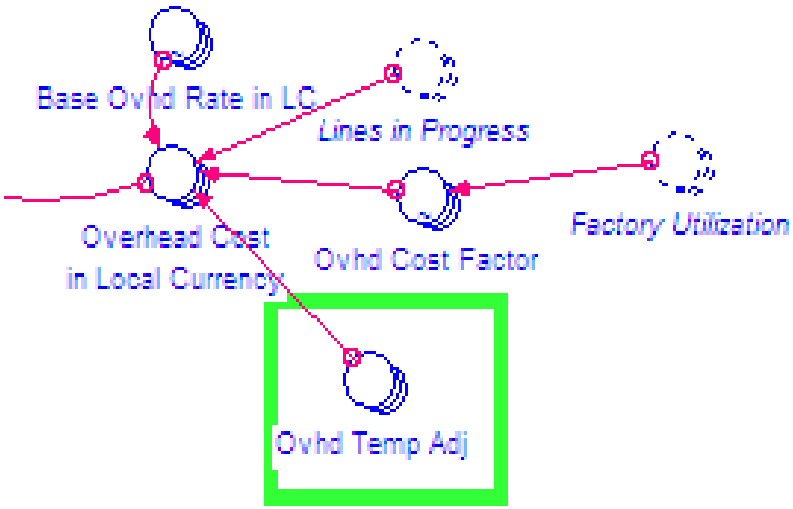
A. *Submodels*
B. *Shims*
C. *Slowing down feedback loops*
D. *Creating cause and effect maps*
E. *Testing/validation at submodel level*
F. *Checking qualitative variables*
   - Validating, calibrating

1.A. Submodels

- Take troublesome section of model, carefully redesign to be as simple as possible; re-insert into larger model
  - To decide where to use submodel, look for parts of model with clearly known behavior patterns, and “provide” main effects to the rest of the model
- Helps "de-clutter" the larger model and strip away unnecessary parts
- Submodels are also a great place to apply sensitivity testing

1.B. Shims: Temporary Adjustment Factors

- At the beginning of the calibration process When creating models, we often add “shims” to help get numbers into the right range, making it easier to see which parts of the model need more work.



- E.g., if market share is way off, many other numbers in the model will also be way off (production, revenue, costs, etc.)
- To see if these other pieces are correct, we “force” the market share into the right range by adding a temporary adjustment factor
  - Highlighted on the diagram w/bold rectangle to assure later removal or proper documentation

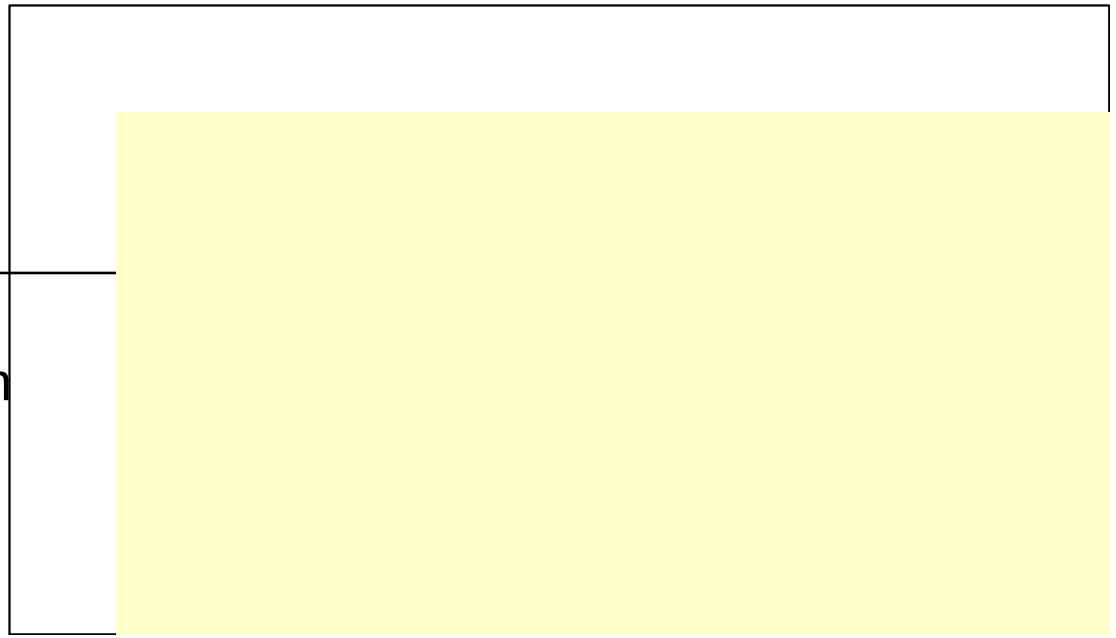
1.C. Slowed Transitions Within Feedback Loops

- In complex models, oscillations can appear in one part of the model due to changes in other parts of the model
- Can be hard to identify cause of oscillations
- One technique is to temporarily slow down the rate of change around selected feedback loops using a SMTH function
- They provide an easy way to temporarily get parts of the model into relatively steady state to enable further calibration and testing

1.C. Example

- Asian products sold in Europe (blue), w/random demand fluctuations Large drop due to factory shutdowns in Europe → wild oscillations in exports → depressed shipments

- Adding a SMTH function on a cost comparison formula removed the wild oscillations in exports, and Shipments returned to normal



1.D. Use Simple Cause and Effect Maps to Isolate Issues

- Obvious, but often overlooked
- Simply sketch out the causal logic associated with a troublesome output

1.E. Checking at the Submodel Level

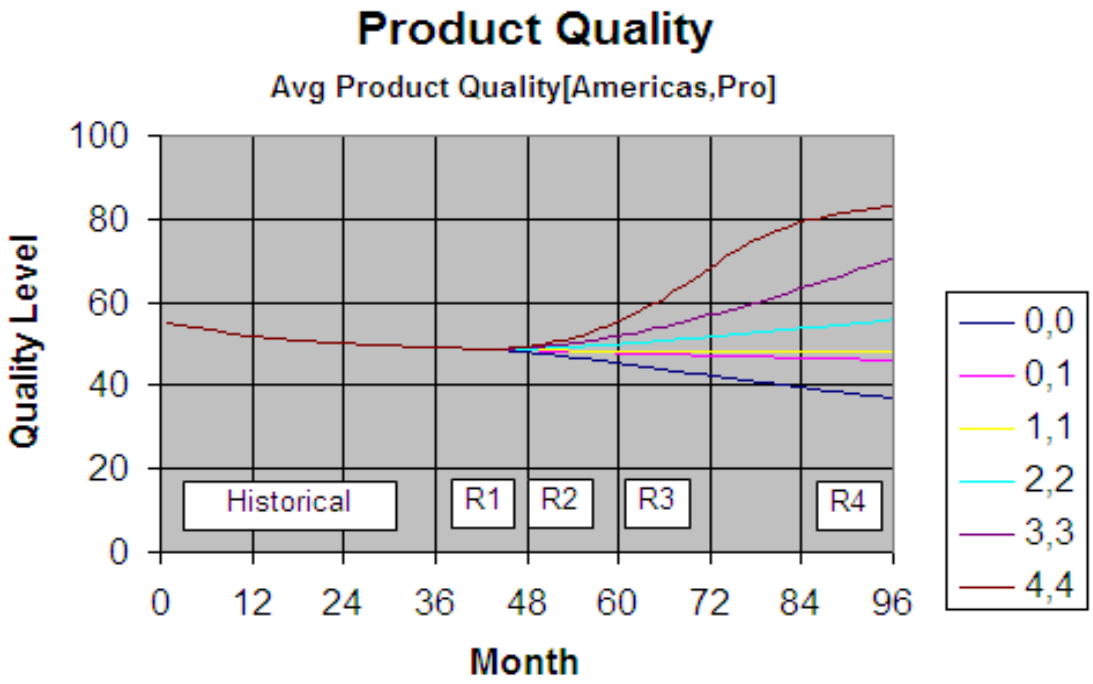
- Thoroughly calibrate segments as individual standalone submodels before trying to calibrate the entire ensemble
- E.g., the components of the logic for quality was thoroughly calibrated and reviewed with the client early on

1.F. Independent Validation And Calibration of Qualitative Parts

- Qualitative parts of a system dynamics model can be tricky
- Case study model had two important qualitative components (submodels)
  - A “Quality” measure which calculates outgoing product quality
  - Factors affecting product market share
    - Qualitative aspects such as market awareness, sales effectiveness, service perception, etc.
- Quite subjective: important to get them “locked down” individually before proceeding to the rest of the model

1.F. Example: Quality

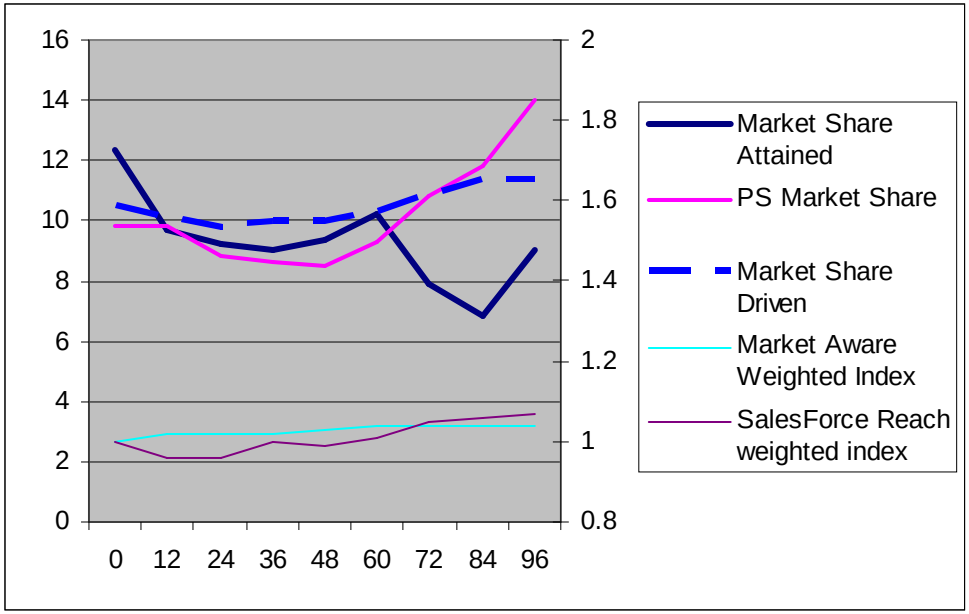
Qualitative Calibration chart showing a family of curves for different model input conditions, used to validate this part of the model with the client



- Each trace in represents the resulting quality for a specific set of input conditions
- Similar graphs were created for different products and regions
  - Client reviewed each for expected behavior
- For rest of project, Quality logic could be ignored (trusted)

1.F. Example: Market Share

- **For this product and region, the “driven” (demand) market share is the blue dashed line**
- **Actual delivered market share is the solid blue line**
- **Difference is caused by inadequate prod’n capacity**



- **PS line (in pink) shows market share produced by old model**
- **The factors at the bottom are two of the six components driving market share in the model**
  - **They were adjusted until the market share performance met the client’s expectations**

2. Redesign Along the Way

- Redesign rather than continuing to tweak the model as calibration becomes difficult and elusive…
- Calibration issues → faulty design
- Apply submodels, simpify logic, etc.

3. Carefully Document Throughout the Process

Changes made late in the calibration process affect other parts of the model that worked properly earlier in the process

- Documentation can be a safety net

A. Revision management
B. Recordkeeping
C. Code reads
D. Maintain a questions list.

3.A. Revision Management

- Naming convention
  - Ver. .A1, .A2, .B1, etc.
- Save frequently, with iterated version number
  - Plus notes re what changed
- Helps with “undo” when needed

3.B. Record-keeping

- Change log (key to model names)
  - What and why
- This discipline is easily overlooked
- Remember! And take the time!
- Include screen shots of model & behavior, data sources, references, quotes/comments/etc.

3.C. Code Reads

- Mindset: everything suspect until shown to be correct/reasonable
- May need help from outsiders
  - Or, at least someone other than author
- The convoluted logic you'll find can be simply amazing
  - And yet, you will vaguely recall that you did in fact create that logic…

Missing "be" or equiv

3.D. Maintain a Questions List

- A special part of the modeling logbook
  - With open check box (and perhaps room for the answer)
    - Not checked until answered
- Serves as an action item list
- May later become part of the model documentation

4. Know When to Step Away

- Enhance your wheel-spinning detector
- Take stock, document current situation in the modeling log
  - Knowns, unknowns, ideas
- Take a break
- After break (or even during the break), new ir
  more easily

I don't know if anyone else experiences this, but I frequently get the real breakthrough insights as soon as I step away – such as 5 minutes into a walk. I've learned to carry notecards and a pen when I take that break.

5. Build/Acquire Automated Tools

A. Automated testing tools
B. Automated analysis tools
C. Code comparison utility

5.A. Automated Testing Tools

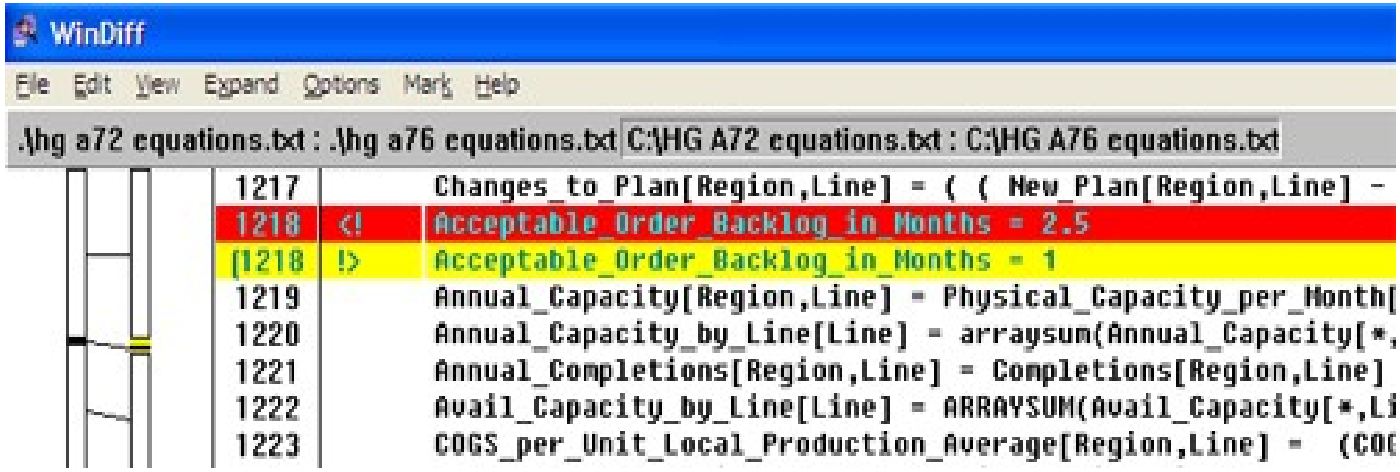
- SD platforms provide sensitivity testing
  - Essential for validating the stability of submodels
  - Help study results of combinations of the many different inputs
- However, preparing the inputs for the sensitivity testing can be time-consuming and error-prone
- Can build special Excel-based tools
  - To generate inputs for these sensitivity tests
  - To assist in analysis of the results
    - Such as the quality profiles shown earlier

5.B. Automated Analysis Tools

- To help analyze results
  - With 296 outputs, it was easy to miss an undesirable change during calibration
- An Excel-based tool was constructed
  - Compared results from multiple model revisions and showed the differences
  - Looked at each time period for all 296 outputs for each model version
- Tool was tedious to construct
  - Thus, it was not built until late in the project
    - Out of necessity at that point
  - Well worth the effort
  - In hindsight, should have been built the tool much earlier…

5.C. Code Comparison Utility

- Borrowed from software dev. world
- Used to find differences between various model revisions (using text file of equations)
- Example: WINDIFF from Microsoft



Text File Comparison Tool (WINDIFF) showing part of a comparison between two model revisions (A72 and A76) – one in red and the other in yellow. All lines that are not colored are identical between the two files. The scrollbars to the left show where in the file differences appear.

Summary

- Techniques described were invaluable in hindsight, but we resisted doing them initially
  - Busy work? Perhaps on small project, but essential for the case study model
  - Should have made the investment even earlier
- Staying organized on a big project is hard
  - Submodels provided points of stability, helped to decide “the problem is elsewhere” and thereby avoid throwing out solid work by accident
- Having a clear strategy was critical, due to complexity and potential for endless cycling
- Continual redesigns improved final quality and actually reduced the total time

Bottom Line: Essential to Have a Calibration Strategy for Large Models

- *Time needed to apply the recommended methods can be significant*
- *Benefits, however, far outweigh the costs*
- *Still…even experienced modelers often wait too long before initiating these necessary disciplines*