Analysis Techniques – Delving Deeper

In order to understand differences between simulations and data, or to understand trends in the response you typically have to explore the system response.

Exploration using **Cause and Effect Diagrams** is a useful analysis technique for clarifying and documenting where to look.

A Cause and Effect diagram starts with a parameter you are interested in examining and is used to map interrelation with other parameters / phenomena.

The cause and effect diagram helps document the things you need to examine more closely to determine the cause of behavior you are seeing.

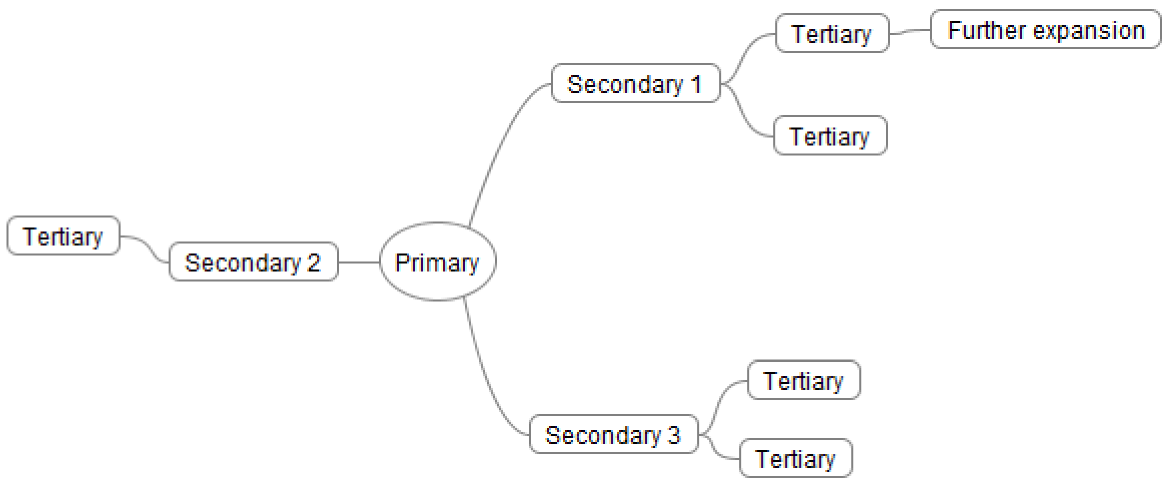
Technique 2 - Cause and Effect Diagram

Steps to develop a cause and effect diagram:

1. Write down the parameter of interest.
2. Around this write down each factor that directly affects the parameter of interest. Draw lines connecting these parameters to the central parameter of interest. These are the primary factors.
3. For each primary factor, write the set of things that directly impact that factor again connecting to the factor with lines. These are secondary factors.
4. You can continue the process, with tertiary factors, but typically you start to look at these in more detail to eliminate branches that are irrelevant for the current analysis before expanding very far.

Cause and Effect Diagram

The form of the cause and effect diagram looks something like the tree below. It may be expanded out further than represented here.



Cause and Effect Diagram

The interaction between parameters is governed by the TRACE equations. Thus the equations solved by TRACE provide a guide to the parameters that directly impact a parameter of interest.

Unfortunately, some of the equations are complex and may obscure simple relationships, so alternate formulations of the equations and physical intuition are often important.

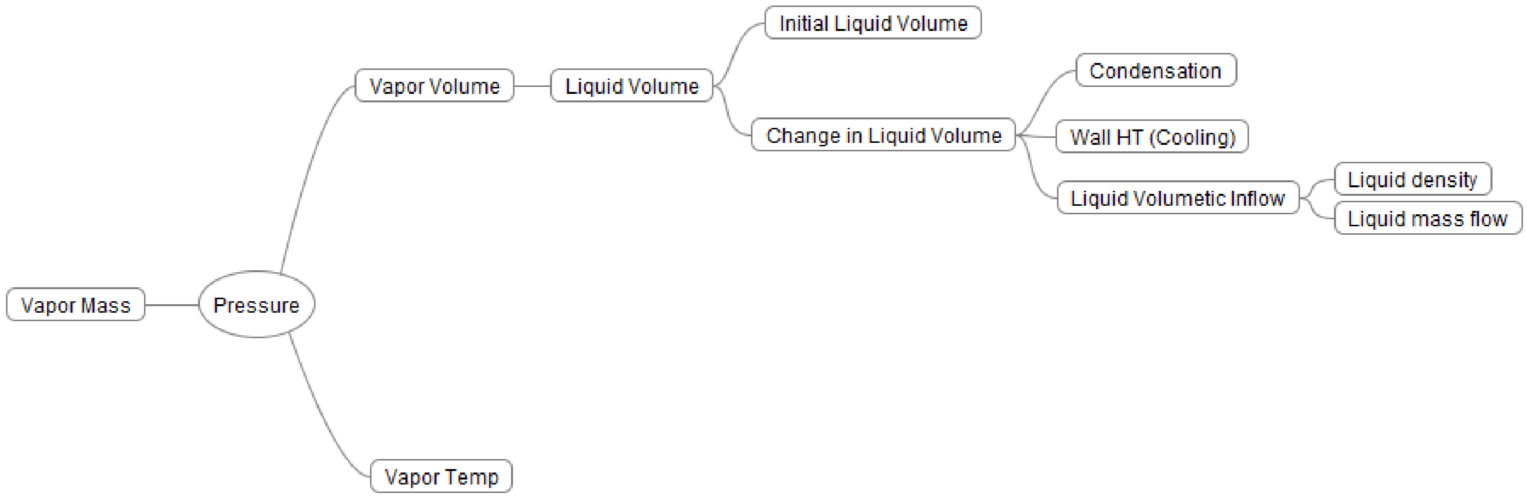
Note that some behaviors that are exhibited in the solution may not come from the physics that is modeled, but may be an artifact of how the physics is implemented numerically (e.g., numerical diffusion, discontinuities at transitions between regimes, etc.) Some awareness of the numerical implementation of the physics and how this affects the system response is sometimes required to identify problems in a model.

Cause and Effect Diagram

For the MIT pressurizer experiment our key figure of merit is the pressure. Pressure in a system is determined by the vapor space. The behavior can be approximated by the ideal gas law:

$$PV = mRT$$

Cause and Effect Diagram



The cause and effect diagram helps to identify the parameters to examine. Here the ‘vapor volume’ primary parameter is expanded.

Exercise: Expand the cause and effect diagram for the other primary factors. A program called MindMap (used to generate the figure above) is available on the provided computers to help with this if you would like to use it.

Quantitative Analysis Techniques

A cause and effect diagram can help you identify the factors that may cause some behavior you seek to understand. At this point quantitative analysis techniques are useful to identify the cause of a particular trend.

1. Sensitivity analysis – adjust a parameter and rerun simulation to determine impact.
2. Direct comparison – requires a comparison basis (e.g., quantities converted to the same units).
3. Derived data – sometimes data in its current form is not ideal for quantitative comparison. However, data may be combined or manipulated to be in a more useful form for comparison.
4. Big or Small – Sometimes you can estimate whether a particular parameter will have a big or small effect on a parameter of interest. Parameters with small effects can be ignored.
5. Identify Key Analysis Parameters

Sensitivity Analysis

A sensitivity analysis is relatively simple to perform to determine the impact of a model parameter on an output of interest.

Note that sensitivity analysis techniques can be quite sophisticated, involving multiple parameters with statistical techniques for determining the impact of parameters on the output.

Direct Comparison

Direct comparison of quantities is possible when the quantities are compatible. Compatibility depends on the form of the equation that relates the quantities. Common relationships are:

- Summed quantities: $a + b + c = d$

  Direct comparison of terms a, b, c, and d are possible since units must be consistent for summed terms. Changes in a must be balanced by changes in b, c, and d.

- Multiplied quantities: $a * b * c = 1$

  Proportional comparison is possible (i.e., if ‘a’ doubles then b*c must half – you can examine how much each of these change in response to ‘a’).

Direct Comparison

Example - Bernoulli's equation:

$$\Delta \mathrm{P} + \frac{\rho \Delta V^2}{2} + \rho g \Delta h = P_{loss}$$

One can determine how much different terms contribute to the change ΔP as long as compatible terms are selected. Δh does not have the same units as ΔP, but $\rho g \Delta h$ does. Thus some calculation is often required to perform a direct comparison.

Direct Comparison

Example - ideal gas law:

$$PV = mRT$$

The ideal gas law is an approximation, but provides valuable insights. In this case, if only pressure and one other term change, a halving of the vapor mass m will cause the pressure to decrease by half. A halving of the volume V will cause the pressure to double.

If the subscript i is used for initial state and subscript f indicates the final state, then this can be expressed as:

$$\frac{P_f}{P_i} = \frac{V_i}{V_f} \cdot \frac{m_f}{m_i} \cdot \frac{T_f}{T_i}$$

Note that each ratio is unitless so it is not necessary to convert to common units. This is an approximation, but a useful rule of thumb. Thermodynamic tables can be used for more accurate analysis.

Direct Comparison

Energy or **power** are often useful bases for comparison. Many values can be converted to an energy or power value when combined properly with related values. Note that by the conservation of energy equation, if all energy is accounted for, the energy must **SUM** to a constant.

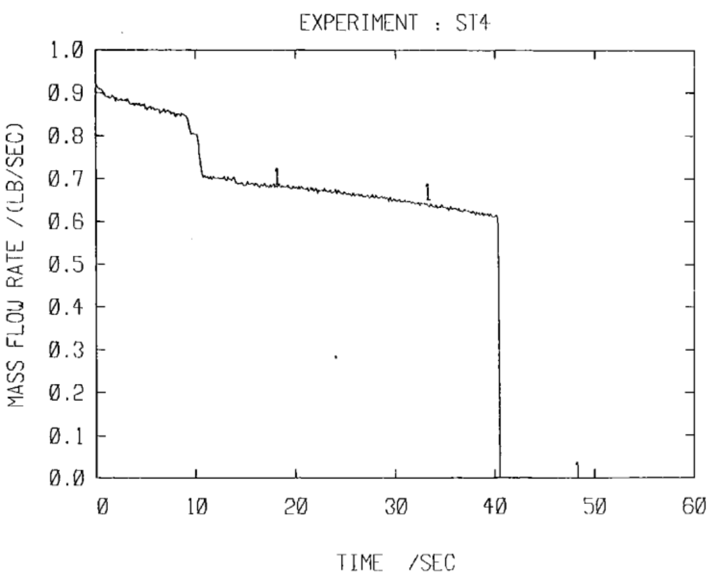
Analysis then reduces to tracking the exchange of energy between different parameters.

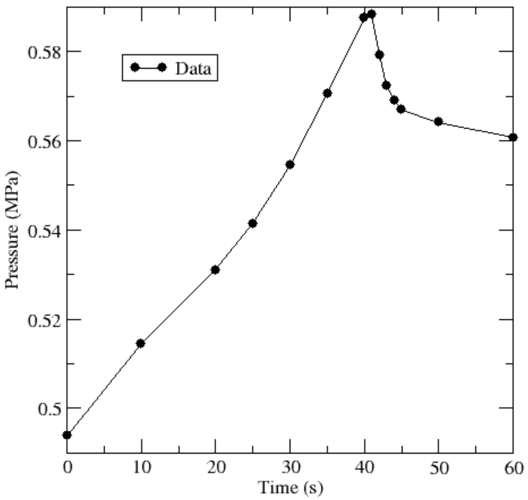
Derived Data

Sometimes the numerical or experimental data that is available is not directly useful for analysis, but is sufficient to derive the data needed for analysis.

MIT Pressurizer Test ST4 Derived Data

For this test we have geometry data, the mass influx, and pressure response. What other useful data can be derived from this?





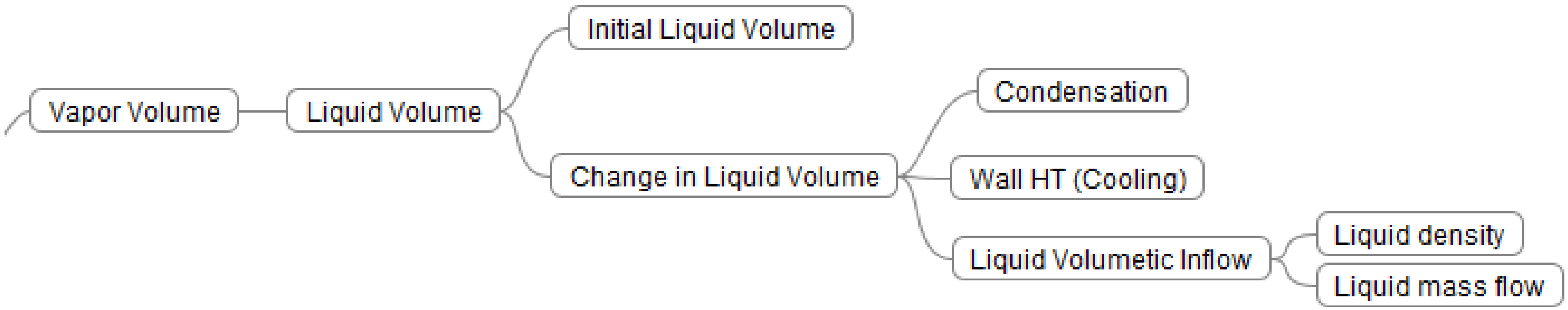
Big or Small

After identifying the factors that directly impact an item in the cause and effect tree, assess which parameters will be big and which will be small.

This is primarily useful if:

- The answer is obvious.
- The relative size of different factors can be estimated fairly easily.

Big or Small



Assess which items on the Vapor Volume tree are big and which are small. How would you quantify your assessments? Is there a simple calculation?

Identify Key Analysis Parameters

Key analysis parameters are parameters that characterize "Big" items in the cause and effect diagram.

For example, liquid volume is expected to play a big role in the MIT pressurizer ST4 experiment. A parameter that is relatively easy to get from TRACE and characterizes the liquid volume for this test is the liquid level.

Key analysis parameters are often available in or derivable from experimental data since they typically were important for analysis of the experiment.

Comparison of the simulation and experimental data for key analysis parameters helps provide an assessment of how well the simulation is performing and can help isolate the source of problems.

Analysis Exercise

For this exercise we will play the cause and effect game. The rules are:

1. Only look at model parameters that are directly represented in our cause and effect diagram (i.e., figure out how a parameter ties into the physics before examining it).
2. Focus on one branch of the cause and effect diagram at a time when reviewing the model.
3. Play “Big or Small”. Estimate the impact of different parameters, and examine the factors that are expected to have the largest impact first. Ignore parameters that are very small in comparison.

Open MIT pressurizer exercise 2 (MITPzrTestST4Exercise2) and follow the instructions.