Sensitivity Analysis in OptiSlang
An Important Step for Ensuring Quality Optimization

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OptiSlang – Sensitivity Done Right

Parametric Analysis: What Is It And What Do We Do With It?

Parametric analysis is a wonderful thing. Once a parametric simulation is setup many different variations can be run with little to no extra effort, something that would be prohibitively expensive and time consuming in terms of real world tests. The low incremental cost of running parametric variations of a completed model is one of the greatest values of simulation but there comes a point where the number of variables and combinations becomes unwieldy. Not everything will fit comfortably on an Excel spreadsheet and the questions that are asked will become more demanding. A few what-if studies can easily expand into a full characterization of a design-space and multi-objective optimization. There may be variables that are important for certain outputs but not others, or that cause essentially random/unpredictable variation in the outputs. The total combination of inputs may be too large to explore in a reasonable amount of time and in any case the model that was perfectly suitable for one or a few number of cases may not be suitable for large amount of runs in a parametric analysis.

Moving Beyond A Few What-If Cases & Guess and Check

![Image](image.png)

In light of all of these complexities a standardized procedure is needed to embark on any serious parametric analysis. The goals of a parametric analysis should be to characterize the design space using a minimum amount of actual simulation runs. The benefits of a well characterized design space are hard to overstate, as it can be incredibly informative as well as predictive. It is very common to run an optimization with the characterization of a design space rather than the full parametric simulation itself, normally a great efficiency savings. This characterization is typically known as a metamodel or response surface. There are several pitfalls to generating such a metamodel, however, that may not be readily apparent and it is easy to put in significant time and effort into generating something that the engineer may not even realize is useless. Some of the issues that can be encountered are as follows.
Parameter Elimination – Useless parameters

Some parameters will have no effect on the results of interest and can be removed, an incredibly valuable process. The number of input parameters is equivalent to the dimensionality of the parameter space and there will be a drastic reduction in the efficiency of future optimization and sensitivity studies if this can be reduced. A sensitivity analysis first thing is key for identifying parameters that do not contribute anything to the analysis.

Predictive Quality – Worse Than Useless Parameters

The only thing worse than a parameter that contributes nothing is a parameter that works against your ability to perform an optimization at all. In order to have a quality metamodel, its predictions must be able to explain the large majority of the variation in the model. A large fraction unexplained variation relative to the parameter space is an indicator of a poor fit. For instance, the global stress maximums on a model may be dependent on several causes. It may
be better to take stress readings from local areas of the model, otherwise the inputs may not be able to clearly explain the variation coming from multiple sources. Parameters that are sensitive to noise in the model or that are not good choices for clear inputs and outputs have this quality. Parameters like these are often indicators of a poorly posed problem and can be an early warning sign that your problem may not be optimizable. Identifying and improving these types of parameters are a good way to increase the power of any generated metamodel.

**Overfitting – Accuracy Is Not Predictive**

When it comes to a useful metamodel, accuracy is not enough. The metamodel has to not only predict the points that you have but also the points that you don’t have yet. Take a look at the model graph to the right and ask yourself if the most accurate line is the best representation of the trend? There is a tradeoff between accuracy and future predictive power. This problem is known as overfitting and the only way to deal with it is validation. A simple version of validation would be to split the data in two and only fit the model to some of the data. Then the quality of the model is judged on how it predicts the other part of the dataset. More modern variations on this technique involve cross-validation, ie doing several such splits, to overcome possible statistical issues with just one dataset split.

![Figure 4 - A complex model (green) shows high accuracy for the training data (red) but how does it predict new values (orange)? A simpler, less accurate model (blue) is the best tradeoff between accuracy and predictive power](image)

**The Best Metamodel – You Don’t Have To Be A Machine Learning Specialist**

From simple polynomials to nonlinear Kriging, there are several different ways to create a metamodel. It also takes expertise in each different metamodel type to avoid the above pitfalls. Each algorithm may be variously strong or weak to the pitfalls mentioned. In addition, the process of eliminating parameters and validation/cross-validation are important to the success of each algorithm and can be time consuming as well. It is almost another optimization problem to find the optimal metamodel, with the inputs being the algorithm choice, parameters to keep and the validation strategy. This creates the possibility of a great deal of manual work, work that may require expertise outside of an engineer’s area of training.

What is needed is a better way. A way that doesn’t just offer an engineer the same tools available to a machine learning specialist but also applies them in such a way that a metamodel can be generated with
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confidence. The fantastic benefits of parametric optimization should be easily accessible to all engineers, allowing them to get the most out of their simulations.

The OptiSlang Sensitivity Analysis

The OptiSlang approach to sensitivity analysis accomplishes this in a way that is accessible to engineers yet powerful in the way it will reliably generate a quality metamodel. The manual work involved in overcoming or detecting problems with the model, selecting suitable parameters, validation and algorithm selection are done by the software.

OptiSlang is integrated with Ansys Workbench through an easy to use plugin. This means that it can work with Ansys HPC and HPC Parametric packs to fully parallelize both the solver and the solver runs. The sensitivity analysis shown here is for generating the metamodel but the plugin also offers optimization, robustness and ETK (for advanced pre and postprocessing) functionality as well. OptiSlang may also be launched as a standalone program for more advanced workflows and capabilities.

The Design of Experiments (DOE) process setup will allow efficient statistical sampling of the design space. The input parameter ranges are set in a dialog and there are a number of advanced options available but the defaults will be suitable for the vast majority of users. Advanced options include selecting a DOE algorithm, defining criteria for constraints and objectives, importing specific parameter start values and integrating the results from other results.

Figure 5 - (left) While a variety of statistical tools are commonly available to the practicing engineer, there still remains a lot of manual work to do. The OptiSlang approach (right) pushes the software automation boundary further with CoP and MOP (explained below)

Figure 6 - OptiSlang can be seamlessly brought into existing Ansys Workbench workflows
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Coefficient of Prognosis (CoP) and Metamodel of Optimal Prognosis (MOP)

OptiSlang’s original Coefficient of Prognosis (CoP) methodology gives you a single, easy to understand percentage that relays to you the quality of the generated metamodel. For each output of your parametric problem, this number will be prominently displayed to let you know the quality of the generated metamodel. This number is not just accuracy, it uses cross-validation and penalizes overly complex models to avoid overfitting. The COP metric gives you confidence that you can successfully apply this metamodel or will let you know that your model may not be suitable for optimization.

How do you know that the final model presented is the best model possible? This is what the Model of Optimum Prognosis (MOP) algorithm accomplishes. For every output parameter it tries a variety of metamodels and parameter combinations and returns the one that gave the highest Coefficient of Prognosis. If eliminating a parameter yields the best model, it will return that model, as shown in the second metamodel response surface above, where one of the two parameters was shown not to be necessary.

Conclusion

Generating a suitable metamodel for a parametric model than can confidently be used for optimization and prediction is a difficult task for the reasons described in this paper. In this process, it becomes necessary to employ statistical training to ensure the quality of the generated model or to use more advanced tools. The OptiSlang sensitivity analysis procedure offers an automated way to generate these metamodels and their corresponding quality metrics. Whether you use the metamodel in a subsequent optimization, as an external Reduced Order Model (ROM) or as a guide to fix issues in your simulation model, you have the information you need to apply it in the most suitable way.
Find out more about OptiSlang:

A sensitivity analysis is just the first step in applying a parametric model to answer new types of questions. Advanced optimization can characterize the Pareto front and clearly define the trade-off curve between conflicting objectives. Parameters are not limited to just scalars, signals can be extracted, post-processed and optimized. Robustness and reliability analysis help characterize the non-deterministic scatter in your design and allow avoidance of fragile, over-optimized designs.

For more information or to schedule a software demo, contact us:
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