Simulated Innovation for Distributed Team Product Development and Low Spend Strategies

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Introduction

Advancements in simulation technology are supported by rapidly evolving enablers such as low-cost Cloud infrastructure, easy access to high-performance computing platforms, on-demand Machine Learning models, and secure multi-user environments. These advancements present an opportunity to more holistically integrate simulation into new product development and deliver solutions in a completely virtual process. There is no debate that stand-alone technologies, like COMSOL Multiphysics, offer an advanced task-by-task solution to challenging technical problems. Simulated Innovation incorporates these technologies into a product delivery business process. This process relates well to our current environment of distributed workforces and reduced spend strategies. Since we are developing products in a completely virtual environment, there is no carbon footprint during the development cycle. The expectation is delivering a product design achieving 97% of final requirements. The intent of this paper is an introduction to a typical COMSOL Multiphysics product development business process.

New Product Development Process

There are many examples of New Product Development (NPD) processes, but in general most are Stage-Gate processes. The Stage-Gate process segments development into gate reviews, stages, and control points. The gate reviews are attended by the technical team, program management, and leadership representatives. Deliverables include market analysis, business cases, past action reviews, and decisions whether to continuing investing in the NPD program. Stages are defined periods of time where focused execution is carried out by the program team. Deliverables of a stage include results from various planned activities. Between stages are control points where an extended-team reviews deliverable results, mitigates risk, evaluates failure modes, repeats activities where necessary, and agrees to launch into the next stage. All activities focus on the deliverables of the Product Requirement Document (PRD) and have the flexibility to pivot depending on customer feedback.

The example Stage-Gate process for Simulated Innovation includes many of the same gates, stages, and control points found in traditional NPD processes. The Multiphysics based segments begin with Stage 2 - Defining Simulation Requirements and end with Stage 3f - Verification & Validation. The Gate reviews 1 thru 4 are business specific and descriptions are not included in this article. Each business decides the reviewing team and the level of leadership approval needed depending on the complexity and specific business case for the NPD program.

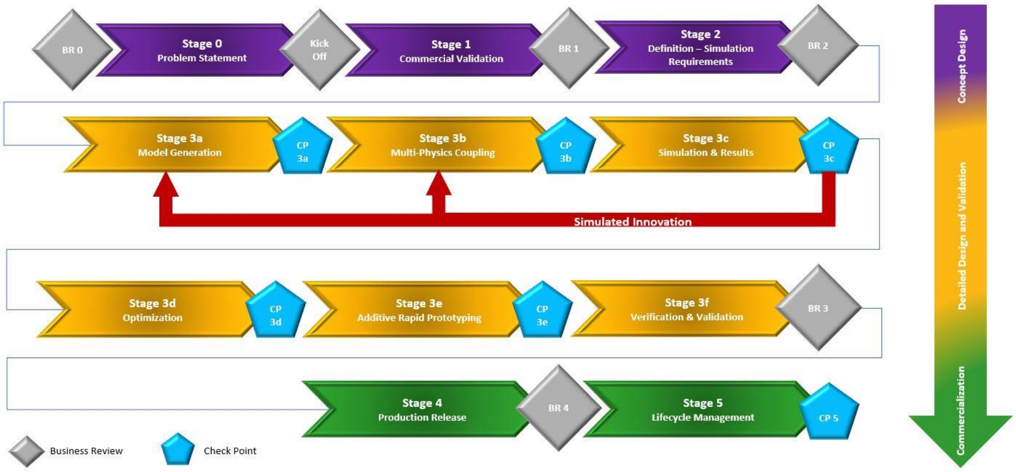

Figure 1: Simulated Innovation Stage-Gate Process

Stage 2: Definition – Simulation Requirements

The Multiphysics based NPD process begins with Stage 2: Definition - Simulation Requirements**.** This Stage, shown in Figure 2, assumes that the previous activities have produced a Business Case and a Product Requirement Document (PRD). The PRD is the 'voice of customer' and contains the program deliverables. It is considered the contract between the business and the program team. Any changes to the PRD should include a discussion about cost and schedule impact to deliver a modified scope.

Figure 2: Definition – Simulation Requirements

Stage 2 is the most critical activity in the Simulated Innovation process. This is where close collaboration between physical (product/application) and virtual (simulation) experts is essential. This Stage begins by conducting a Product Requirement Review (PRR) to understand the program deliverables as clearly as possible. The main task is to transform the physical environment into the virtual environment using tools such as MATLAB/Simulink, control theory, mathematical transforms, physics, and 3D-modeling. Critical actions include establishing material properties, boundary conditions, initial conditions, and process variables. Finish Stage 2 with a Conceptual Design Review (CDR) to examine product design concepts and consider trade-offs in product form, fit, and function.

Stage 3a: Model Generation

Model generation, highlighted in Figure 3, is where the simulation experts create the Multiphysics model. Initial 3D-model geometry can be directly imported into the development platform and should completely define the geometry interfaces. There will be opportunities to modify the geometry throughout the NPD process, but it is important to have the initial geometry represent the physical environment. Multiphysics simulation relies on determining what physics interfaces are required to define the physical system. Interface options include stationary, eigenfrequency, eigenvalue, time dependent (dynamic), and frequency domain. There are many predefined physics interfaces that can be used. If you cannot select a physics interface, consider using the Partial Differential Equations (PDE) interface. The PDE gives the user an opportunity to create custom mathematical models by employing equation-based modeling. Continue Stage 3a by adding the study types to your model. Example study types are like physics interfaces and include eigenfrequency, eigenvalue, frequency domain, frequency domain perturbation, time to frequency FFT, time periodic, and wavelength domain. Finish Stage 3a with the Control Point 3a review, where an extended team of modeling and simulation experts conduct a Preliminary Model Review (PMR)**.**

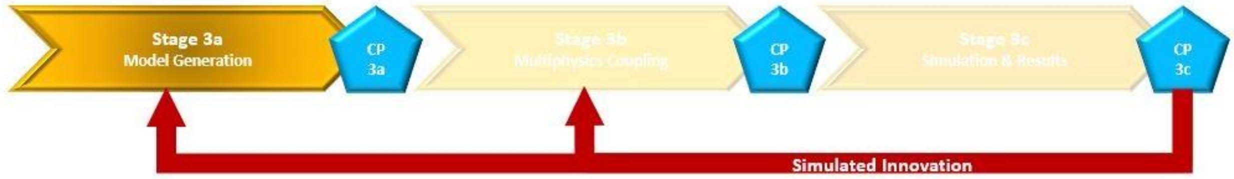

Figure 3: Model Generation

Stage 3b: Multiphysics Coupling

Multiphysics Coupling is shown in Figure 3 and has the deliverable of defining parameters that will solve all equations adopted from multiple areas of physics - as one fully coupled system. Multiphysics software platforms automatically add empty nodes when two or more physics interfaces are set up in a model. These empty nodes provide opportunities to couple the interfaces. Typical nodes include geometry, mesh, material, boundary condition, axisymmetric, and initial value. The technician's task is to add couplings to nodes. Couplings are usually modules that give expanded capability to the software. Typical couplings include electromagnetics, fluid flow, heat transfer, structural mechanics, acoustics, and chemical engineering.

Complex simulations use a large amount of memory. The best practice is to estimate memory use to avoid 'out-of-memory' messages during model rendering. Begin by evaluating the number of node points, the number of dependent and independent variables, the element order, and the sparsity pattern of system matrices. The sparsity pattern depends on the shape of the geometry and mesh density, but also on couplings between variables in the model. Consider using MUMPS and PARDISO which are out-of-core solvers. Memory usage scales as a polynomial, so try to find symmetry planes in the model geometry. If symmetry planes exist, it may be necessary to only solve a portion of the model.

Multiphysics platforms add meshing sequences by default so consider additional meshing sequences where more resolution is required. Solutions are calculated through the mesh boundaries which can add significant computation time. Finally, consider a convergence test to determine if the mesh density is adequate. Finish Stage 3b with the Control Point 3b review, where simulation experts conduct a Detailed Model Review (DMR)**.**

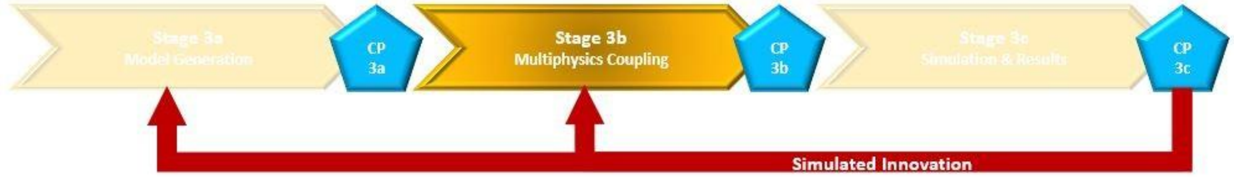

Figure 4: Multiphysics Coupling

Stage 3c: Simulation & Results

Simulation & Results begin by selecting the appropriate solvers as shown in Figure 5. A solver corresponds to the selected study type such as stationary solvers, time dependent solvers, and time discrete solvers. Now it's time to run the first simulation and focus on any error messages or warnings. Convergence errors usually require repeating Stage 3b to review mesh density and meshing sequences. Results are available after you clear all errors. Generated simulation data is available in the form of datasets, derived values, evaluation groups, tables, plot groups, and reports. Solution datasets can be used for post-processing to train machine learning models or other predictive analytic purposes. Multiphysics platforms will also create reports of your simulation results. These include a record of the entire model with information about settings made during the modeling process as well as simulation results in the form of tables and images. Reports, screenshots, and other relevant information can be used in Control Point 3c following a successful simulation. CP 3c begins by conducting a Preliminary Design Review (PDR) to compare simulation results against product requirements. It is also important to create a Design FMEA (DFMEA) that provides failure modes and effects analysis. The DFMEA is an evolving document that is updated during subsequent Stage and Control Point reviews. Throughout Stage 3 customer touchpoints should happen where feedback from internal and external customers is solicited. The red Simulated Innovation process shown in the graphic provides an opportunity to return to Stage 3a or Stage 3b. The NPD goal is to deliver the requirements of the PRD, so compare them against simulation results, the PDR, and the DFMEA.

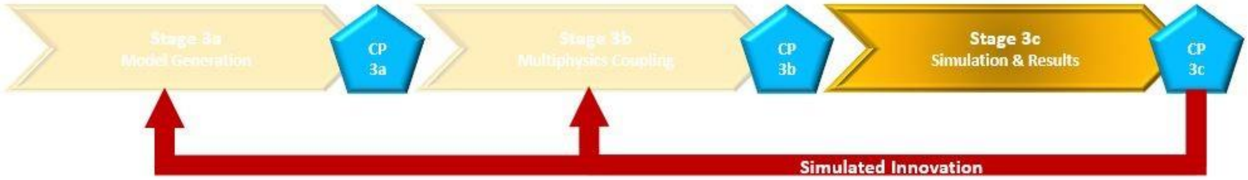

Figure 5: Simulation & Results

Stage 3d: Optimization

Optimization is one of the clear differentiators between traditional and COMSOL Multiphysics NPD. The Multiphysics model is completely digital which provides the opportunity to apply dimension, shape, and topology optimization. Optimization is a type of solver that typically requires an Optimization Module offering both derivative-free and gradient-based optimization tools. Dimensional optimization involves defining variables that can be directly translated to manufacturing. Design variables may be hole sizes or various dimensions of structural members. Derivative-free methods such as bound optimization by quadratic approximation (BOBYQA), constraint optimization by linear approximation (COBYLA), Nelder-Mead, coordinate search, and Monte Carlo are typical. Shape optimization involves free-form alteration of objects by modifying selected design variables. The objective is to improve the shape without over-constraining the design. Gradient based methods are preferred if a critical component function can be identified. Topology optimization treats the distribution of material as a design variable by inserting or removing structures to improve object function. Gradient based optimization is common due to the high number of design variables in most development projects. Typical optimization steps include:

1. Identify the objective function that defines the system.
2. Define a set of design variables that are the inputs to the model.
3. Define a set of constraints, bounds on your design variables, or operating conditions that need to be satisfied.
4. Use the Optimization Solver to improve your design by changing design variables while continuing to satisfy your constraints.

Finish Stage 3d, shown in Figure 6, with Control Point 3d by conducting a Detailed Design Review (DDR) focusing on product design and related simulations to ensure compliance to product requirements. Update the Design FMEA (DFMEA) using the latest post-optimization results and identify any required mitigation plans.

Figure 6: Optimization

Stage 3e: Additive Rapid Prototyping

Additive Rapid Prototyping is a great transition from a complete digital model to additive manufacturing (AM) modalities. Additive manufacturing offers the Multiphysics technician an expanded design space that is no longer constrained by traditional, subtractive manufacturing methods. The preceding Stages, concluding with optimization, will produce a design that maximizes the performance attributes of the product. Begin the AM process by exporting the optimized simulation model using CAD software. The best practice is to first build the model from plastic using a common process such as stereolithography (SLA) to confirm fit of components. Continue AM rapid prototyping by building sub-scale or at-scale components using a qualified AM modality. Finally, develop a plan to move from rapid prototyping to direct digital manufacturing after the design passes the Verification & Validation (V&V) stage. Consider enhancing the model using a Model Based Definition (MBD) method that will provide suppliers with a fully defined, manufacturing-ready model.

Finish this stage with Control Point 3e by conducting an Additive Manufacturing Design Review (AMDR). The AMDR reviews dimensional tolerances, critical to quality (CTQ) measurements, and material integrity. Focus on material properties such as hardness, microstructure, yield/tensile strength, erosion, and surface finish.

Figure 7: Additive Rapid Prototyping

Stage 3f: Verification & Validation

Verification & Validation (V&V) is shown in Figure 8 and is the last Multiphysics stage in the Simulated Innovation NPD process. The V&V stage is where the physical product is tested to validate your design meets the PRD requirements. Begin V&V by creating a test plan that captures critical requirements such as life cycle, performance, hydrostatic, user experience, and ease of assembly. After testing, conduct a Design Verification Review (DVR) to validate prototype unit integrity, verify that the design complies with product requirements, and release the product for test installation or limited production. Identify customer test installations or targeted test groups where product performance is monitored, and user experience feedback is provided. Finally, conduct a Product Validation Review (PVR) to confirm the product accomplishes the intended purpose in the customer installation. If successful, release for full production and maintain the final model in a design-controlled PLM system.

Figure 8: Verification & Validation

Conclusion

A valuable benefit of the simulated development process is that the completed simulation model is also a Digital Twin. All the production assemblies produced from the model create data. Consider developing an Internet of Things (IoT) data acquisition strategy where performance data can begin training the Digital Twin. The analytics opportunity from the Digital Twin relationship can be used to improve product performance and offer preventative maintenance services.

The example Simulated Innovation process is intended to create discussion around Multiphysics simulation within product development programs. The process from idea to final product can be based entirely on digital strategies that adapt well to your current working environment. There is still a need to build prototypes that can be tested under physical conditions. However, the simulations should meet 97% of design requirements before a prototype part is built. This will result in less build-test-rework prototyping cycles, reduce overall spend, and increase speed to market.