Massachusetts Institute of Technology

Models in Engineering
Key Takeaways

WEEK 4: MODELS IN VERIFICATION AND VALIDATION

Qualities of Great Models: Weeks 1-4

For the duration of this course, we will be building up a list of the "qualities of great models" with the purpose of distilling guidelines for building and using models effectively. Every week the list will grow with new items presented in the course.

From what you have learned in the last four weeks, there are a total of 17 qualities that should be taken into consideration when developing a model:

1. **Model Fidelity**: The model should have the appropriate level of fidelity relative to the decision under consideration and the phase of the design. More fidelity than necessary can make it difficult to evaluate the model and can waste resources which could have been utilized elsewhere. Less fidelity than necessary can result in poor decisions or overconfidence. The choice of fidelity depends upon the system requirements and operating conditions.

2. **Model Credibility**: Credibility refers to whether the results of the model are believed by decision makers. If models are not credible, decision makers will not make decisions based on the model's output, which might waste precious time and resources, or worse still, they may make incorrect decisions that could put the project at risk. There are many ways in which to build model credibility -- one of which is having a set of standards and processes that guide the evaluation and validation of the model.

3. **Linked to Decision Support**: The real value of models lies in using them in the decision-making process, particularly where we have to trade-off between a lot of parameters. The best models make evident how their outputs are to be used in decision-making.

4. **Understandable and Well–Organized**: More than just documented, is it evident where and how you would add to the model? A Model Development Process can lead you to a modularization and organization of the model that is more understandable.

5. **Well Formed for Optimization**: Has the model been constructed to facilitate optimization if necessary? Does it expose relevant optimization information, like gradients or convexity?

6. **Complete Relative to Scope and Intended Purpose**: The model does not leave out any important physics or dynamics. For example, a model of the economy that includes stock prices but excludes bond prices would be incomplete.

7. **Clear Scope**: Particularly for complex systems, modeling the entire system may not be needed for the project. The breadth must be agreed upon at the beginning of the effort: Which system or part thereof will be modeled. For example, in the automobile industry, the initial design iteration may model all of the components of an engine (broad modeling), while other efforts may work with stable interfaces and model only one component (narrow modeling).

8. **Internally Consistent**: The model does not contain any direct contradictions. For example, assumptions on the gravity constant in one section are the same in all sections of the model.

9. **Elegant**: Is the model built using an economy of description -- as simple as possible but no simpler? For example, a model that pulled data from a table and calculated the same parameters from the same data repeatedly might be considered inelegant -- could the result of the computation be stored then reused?

10. **Analyzable and Traceable**: Great models are easily queried. Further, they make it easy to identify what variables or sections of the model contributed to the answer. For example, if the computed thickness of a beam is 6mm, which load cases made the greatest demands on the thickness?

11. **Avoid Optimizing on a Black Box**: If two models are combined, one of which attempts to optimize the other, note that optimization performs more poorly on 'black box' models, where features of the 'black box' model are not evident or cannot be taken advantage of by the optimization routine. Where possible, optimization should be written to take advantage of model structure and features.

12. **Data Extrapolation**: Models are only intended to work over a limited range of data, conditions, physics, and assumptions. Great models describe clearly where they are valid, and where they are not valid.

13. **Availability of Interfaces**: Great models should have accessible interfaces to the underlying data and outputs.

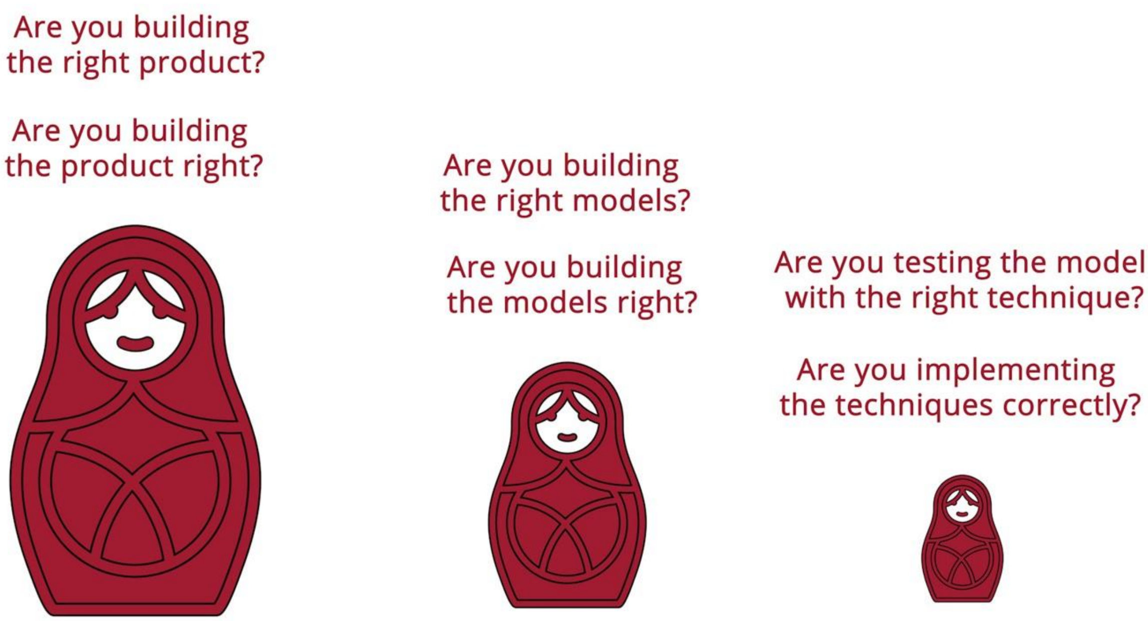
14. **Reusable**: Models should be created in a way that makes them reusable beyond the initial system or situation for which they were created. One way to accomplish this is to choose a modular model structure and to avoid hardcoding parameters into the model. By reusing models across different projects, an organization can create new products faster and with less cost. However, model reuse can also introduce risks if the reuse happens outside of the intended or validated range of applicability.

15. **Verifiable**: The model itself must be verifiable. If the outputs of the model cannot be identified as meeting the modeling needs or matching the calibration data, then the model's credibility for decision-making will suffer.

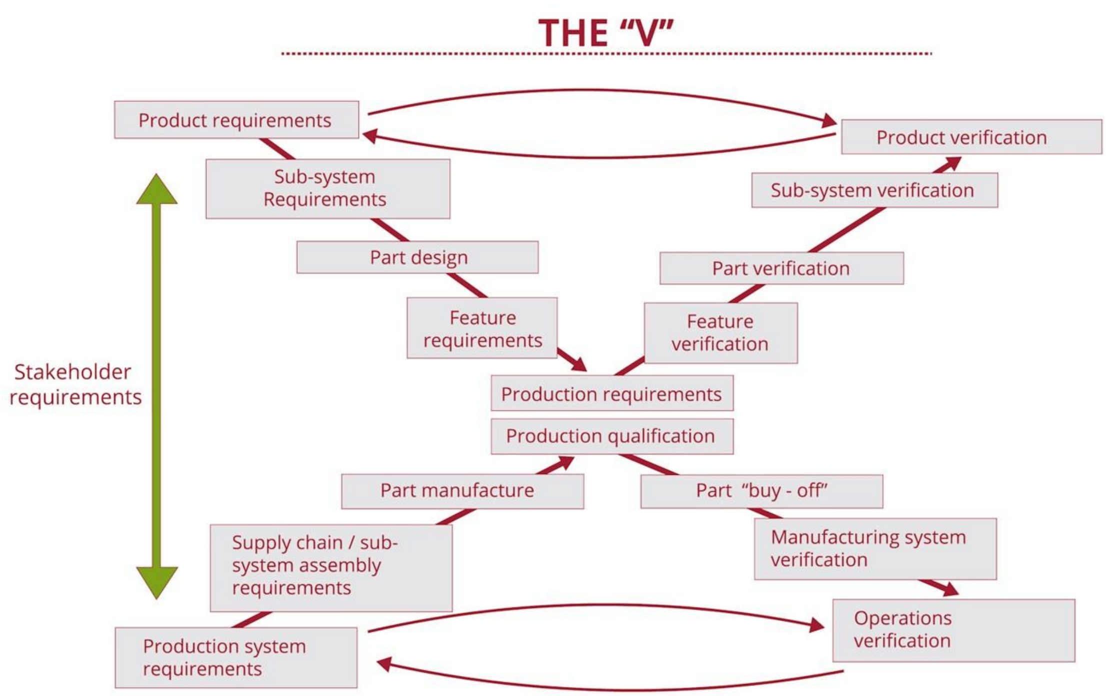
16. **Validation**: The model itself must meet customer needs and expectations. If the model is primarily descriptive, it must be capable of effectively describing the information contained therein, often by layering / delayering information presented. If the model is analytical, it must be shown to improve the decision-making for which it was created.

17. **V&V With Models**: If the model is being used to verify and validate a product / process / business, that model should clearly showcase how modeling is the preferred V&V route for the task. A single model should never be the only V&V tool.

Week 4>Roles of Models in V&V>Models and V&V>



Week 4>Developing a V&V Strategy Framework>



OPTIONS

	Product		Process	
System	Models	*Product simulations*, Videos, FMEA	Models	*Discrete event, simulation*
	Prototype	Functional tests	Prototype	Early pilots
	Production	Reliability testing, user testing	Production	Launch
	Post-prod.	*Warranty analysis,*	Post-prod.	KPI
Sub-system/ Function	Models	*Dimensional analysis* *Life cycle simulation*	Models	*Virtual assembly,Digital mockups*
	Prototype	Bench tests Functional testing Design of experiments	Prototype	DFA analysis, design for ergonomic Pilot factories
	Production	Reliability/cycle testing Functional testing	Production	Piloting
	Post-prod.	OPT	Post-prod.	
Part	Models	*FEA*	Models	*Process simulation*
	Prototype	Bench tests	Prototype	DFM
	Production	FPI	Production	Design of experiments
	Post-prod.	On-going inspection	Post-prod.	KPIs
Feature	Models	Process capability analysis	Models	Process simulation
	Prototype	3-d printing	Prototype	Prototype mfg process
	Production	Metrology/GD&T	Production	SOPs/Pilot
	Post-prod.	SPC	Post-prod.	SPC/Process Auditing