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Confidence in Models and Simulations: A Multi-Stakeholder Analysis

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Abstract. System stakeholders from multiple disciplines increasingly interact with computer models and simulations to make critical decisions. Advanced digital models have transformed how engineers interact, analyze requirements, develop and verify system elements, and test them to validate that they meet stakeholder needs. However, these models are often developed by a specific discipline for its own purposes. Convincing other stakeholders to accept the results of these tools can be a challenge, and indeed, the adoption of models and simulations at the level of system development still lags the pace of the underlying computational and application advances. The acceptance of models and simulations remains largely a function of the subjective preferences of engineers and other stakeholders. In this paper, we investigate the social and technical factors that contribute to the acceptance and effectiveness of models and simulations, what we refer to as model confidence. We combine a literature review with practitioner interviews to identify constructs and attributes influencing model confidence. Model confidence results from the interplay of model-related, modeler-related and stakeholder-related constructs. The constructs identified in this study populate a model confidence framework currently being developed. They highlight important considerations for future research and practice to enable improved and increased use of models and simulations in multidisciplinary settings.

Keywords. Model confidence; Simulation; Credibility; Trust; Digital Transformation

Introduction

Product development, like many enterprise functions, is increasingly employing the capabilities of digital models and simulations to increase the scope of engineering analysis during design, accelerate the pace of product development, or optimize performance across a product’s lifecycle. Engineering models may be used to represent, learn, and transform knowledge across different problem-solving contexts involving various stakeholders [1]. They can depict a product’s form, function, behavior, or performance and may be used across disciplines through the product lifecycle. These shared models help identify differences, critical priorities, and consequences of design choices for respective stakeholders and collectively. Models used in this way can be powerful tools to enable decision-making. Before basing their decisions on a model, however, engineers, stakeholders and managers must assess whether a model is suitable for the task. Such assessment involves considering whether a model is valid, accurate,

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conceptually coherent, and representative of different disciplinary perspectives. We refer to the outcome of this assessment as the degree to which the stakeholders have confidence in the model, or model confidence. That is to say, based on their review of a number of different dimensions, do they have enough confidence in the results the model produces to use them in making significant or critical decisions? The model confidence phenomenon applies equally to all model uses, both in the early phases (requirements modeling, feasibility analysis) and late phases (system optimization, quality assurance) of product development.

We argue that model confidence enables efficient transdisciplinary engineering (TDE) because developing confidence in a model, particularly one created by a technical discipline other than the evaluators, requires integrating knowledge across discipline boundaries. Effective TDE and the model development lifecycle share the stages of problem framing, analyzing problems, and exploring the impact [2]. During the early problem framing, modelers and stakeholders communicate to define a model's scope and intended use. Modelers represent their domain knowledge and solve engineering subproblems by designing and testing models. Finally, the predicted technical and organizational consequences of using the model drive design decisions.

Given the critical role model confidence may play in TDE, we believe there is a need to develop an integrative framework that characterizes model confidence, including the social and technical influencing factors and their relationships. Existing literature on models and simulations constrains the definition of model credibility to the numerical and functional evaluations of model properties such as verification and validation [3]. However, model confidence is a social concept as much as a technical concept because trust and new learning are built over time through multiple social interactions [4], [5]. We assume that model confidence represents a decision-maker's judgment that the model's usage results in expected outcomes under given contextual circumstances. This judgment formation depends on subjective beliefs (e.g., trust in model capability or model developers) and preferences (e.g., risk-taking).

In this work, we use an inductive approach to characterize model confidence. Specifically, we synthesize insights from a literature review and practitioner semi-structured interviews. The analysis reveals three types of constructs: model-related, modeler-related, and stakeholder-related. This analysis leads to initial hypotheses about how relationships between these constructs manifest into model confidence. Section 1 begins with an overview of traditional and emerging perspectives on model confidence in literature. Section 2 defines the model confidence constructs and examples of measurable attributes of those constructs. Section 3 presents hypotheses about construct relationships as a causal graph. Section 4 summarizes the concluding remarks, limitations, and future directions.

1. Model Confidence: Theoretical Perspectives

Existing literature explains model credibility, trust, and confidence as associated concepts. They are all context-specific. However, different disciplines define them somewhat differently depending on the varying degrees of interactions between *model, modeler, and stakeholder* (decision maker). Model credibility and trust are considered inherent to a stakeholder and their perception of model attributes. Extending these concepts, we contend that model confidence is a cumulative assessment of model and modeler attributes by the stakeholder, mediated by individual and contextual factors. The following sections briefly review how prior studies have addressed a range of socio-technical aspects related to model confidence.

1.1. Credibility and Modeling & Simulation

The extant literature on modeling and simulation (M&S) defines model credibility as a stakeholder perception of model attributes. Balci [3] proposes that model credibility depends on the quality of the model definition, pedigree, verification, validation, usability, and input data. It is expected that each of these dimensions can be reasonably measured [7], [8]. For instance, the verification process determines whether the model implementation and input data accurately represent the conceptual description and specification. The validation process determines how a model and associated results accurately represent the real world. However, in a multi-stakeholder setting, model credibility is evaluated iteratively through communication; therefore, credibility should involve more than just numerical evaluation of accuracy.

1.2. Trust and Human-Model Interaction

Both technical and social factors have been shown to influence the model trust [9], [10]. Drawing from the literature on the technology acceptance model (TAM) [11], we refer to model trust as a stakeholder's belief that the model performs its functions accurately and efficiently. Unlike model attributes, trust is difficult to measure. The ease of navigation, use of visual design elements, professional image of products, freedom from minor errors, etc., influence the trust [12], [13]. The degree of stakeholder involvement in model development, called facilitated modeling, can enhance the perception of model credibility[14], [5]. While model trust explains the behavioral intention, it does not account for the role of the modeler-stakeholder relationship in the actual model usage. Like model trust, one can also define a stakeholder's trust in the modeler as the perception of the modeler's characteristics, i.e., the belief in modeler expertise, goodwill, and integrity [15]. Modeler trust also requires prior engagement, recognizing and accepting risks associated with trusting the modeler.

1.3. Confidence and Decision-Making

While related to other concepts, model confidence concretely determines a stakeholder's decision to select a model for critical engineering work. In the sense of decision analysis framework, the judgment to use a model emerges from considering (i) the consequences of selecting a model, (ii) stakeholder's beliefs about model and modeler characteristics, (iii) individual preferences, e.g., willingness to take the risk, and (iv) contextual factors, e.g., organizational boundaries or resources. Even though model confidence is bound to a stakeholder's perspective, it manifests through three-way relationships between model, modeler, and stakeholder. For instance, facilitating a stakeholder's involvement in the model specification and development process improves their perception of whether a model can deliver desired outcomes correctly and consistently. Harper et al. provide a comprehensive review of such three-way relationships [5].

As a step toward building the understanding of how three-way relationships between model, modeler, and stakeholder influence model confidence, we begin by identifying model, modeler, and stakeholder-related constructs. Section 2 synthesizes these constructs and related attributes from the literature with insights from semi-structured interviews of subject-matter experts in a large product development organization.

2. Model Confidence Constructs and Attributes

Research in various fields and disciplines, from operations research, systems engineering, to psychology, explore factors that influence the use of models and simulation. To identify sources relating to this research, we implemented a search on Google Scholar with the key "{*subject*} AND {keyword}"; where the subject is either *model* or *simulation*, and keywords including *credibility*, *assessment, verification, validation, acceptance, adoption, confidence, quality, usability, trust, transparency, or development.* We filtered the results from each query by the number of citations and publication year, giving preference to cited and recent articles. This search synthesized 156 sources, and about 30 of those are reported in this paper due to the length limitations.

Interviews with 20 product development engineers and managers at a major automotive company in North America supplement the literature review. The selected participants work on different development stages, from technology development, design release to production. The participants were asked the following open-ended questions: what types of models do you commonly use? How do you build confidence in models and their results? What are the biggest unknowns for you in using models and simulation? The content analysis of the responses is excluded from this paper.

The literature review and interview content analysis help identify various social and technical factors relating to model confidence. We categorize these factors into the model, modeler, or stakeholder attributes. The attributes of each category are then aggregated into different constructs. Section 2.1, 2.2, and 2.3 provide working definitions of the model, modeler, and stakeholder constructs, respectively, and their associated attributes. Table 1 provides a brief summary of the same.

2.1. Model-related Constructs

These constructs relate to and describe the model's attributes and how they relate to model confidence.

2.1.1. Capability

The capability construct defines the specific functions and requirements for which a model is designed. This involves making explicit the intended use, including the model's requirements, expectations, assumptions, and limitations [16]. Furthermore, the fidelity of a model defines the level of expected uncertainty in model implementation. Varying levels of fidelity arise from two types of uncertainty: aleatory uncertainty due to noise factors and epistemic uncertainty due to lack of domain knowledge [17].

2.1.2. Accuracy

The accuracy construct evaluates the consistency of a model's input data, code, and known solution examples. The essential part is verification which determines whether the model implementation and input data accurately represent the conceptual description and specification [7], [8]. Additionally, input pedigree is the data source, quality, and

Table 1. Model confidence constructs and examples of attributes

Type	Construct	Attribute	Description
Model-related constructs	Capability	Intended use	Explicit requirements, expectations, assumptions, limitations; Consistency of runtime environment, experiments, and scenario
		Fidelity	Representativeness between model specification and the real world setting
	Accuracy	Verification	Accuracy of model implementation and input data with respect to the conceptual specification
		Pedigree	Input data quality and quantity; the credibility of data source
		Validation	Level of expected uncertainty in model predictions
	Usability	Interactivity	Simulatability, textual explanations and graphic visualization
		Transparency	Precise technical information including inputs, outputs, and internal code.
		Reusability	Availability of reusable solutions to address recurrent problems
Modeler-related constructs	Competance	Domain expertise	Accumulated process knowledge from extended practice
		Task-specific ability	Influencial skills, competancies, and characteristics within context
	Benevolence	Cooperativeness	Behavior demonstrating individual support
		Communication	Exchange of information and knowledge across boundaries
	Integrity	Adherence	Personal commitment to a set of principles
		Ethics	Person’s moral habits, ability to decide right or wrong, and free will
Stakeholder-related constructs	Perceived trustworthiness	Modeler-specific	Perceived reliability of modeler’s actions
		Model-specific	Perceived reliability of model implementation, results and insights
	Perceived risk	Criticality	Consequences to safety and the degree of decision influence
		Vulnerability	Expectation of ill-effects from actions of the modeler
	Individual and contextual factors	Trust propensity	Generalized desposition to trust others irrespective of the situation
		Organizational culture	Responsibility for acting to the results, participation policies, implementation criteria

quantity [18]. A technical review process is generally adopted to audit, inspect, and verify model results/solutions by experts, peers, and independent authorities [19]. Further, model validation compares model results and the real-world setting in accordance with the model's intended use. This defines the dispersion in a model's predictive capabilities due to limited knowledge about the system of interest or noise factors in the prediction process.

2.1.3. Usability

A model is considered usable if it is understandable and plausible to modelers, users, and developers. Interactivity accords with (i) textual explanations for model decisions and results, (ii) rendering visualizations, and (iii) explanation by example, e.g., demonstrating the model interface using an example [20]. At the most detailed level, usability may require transparency, e.g., having access to precise technical information of models. Transparency may be evaluated in relation to the entire model (simulatability), individual inputs, outputs, or subcomponents (decomposability), and internal code (algorithmic transparency) [20]. Model reusability involves using experience and know-how from predecessors to solve complex problems. A pattern (a named, reusable solution to recurrent problems in a particular context of use) facilitates the model usability [21].

2.2. Modeler-related Constructs

These constructs relate to the perceived attributes of the modeler who created the model being assessed, and their relation to model confidence.

2.2.1. Competence

Competence implies technical expertise in referent systems and other abilities (e.g., interpersonal skills and coordination) relevant to the problem domain. A modeler's expertise is the accumulated process knowledge acquired over time through deliberate extended practice [22]. A generic model of expertise categorizes individuals into six types: novice, advanced beginner, competent, expert, master, and visionary. Ability is that group of skills, competencies, and characteristics that enable a modeler to influence some specific domain. Ability highlights the construct's task- and situation-specific nature [15]. For instance, a trustee might be highly competent in a technical area but might have little aptitude, training, or experience in interpersonal communication.

2.2.2. Benevolence

Benevolence is the extent to which a modeler is believed to want to do good for the stakeholder, aside from an egocentric profit motive [15]. Cooperativeness pertains to the modeler's behavior demonstrating individualized support [23]. That is, one-to-one relationships, as opposed to one-to-many relationships, show higher benevolence. Cross-functional communication also helps represent, learn about, and transform knowledge across boundaries [24].

2.2.3. Integrity

Adherence to acceptable principles, beliefs, and values reflects personal integrity [15]. However, if a stakeholder does not accept the set of principles, then the modeler's personal integrity is void for the purpose of the given task. Ethics is another attribute of integrity that reflects the modeler's moral habits (virtues), their ability to decide what is wrong or right, and the free will to do what is required of them without being controlled [23], [25].

2.3. Stakeholder-related Constructs

These constructs relate to the attributes associated with the stakeholder who will assess and potentially use the model, as they relate to model confidence.

2.3.1. Perceived risk

Perceived risk is the stakeholder's recognition and assumptions about the consequences of trusting a model and its modeler. Related to this, criticality is a function of (i) the consequences to human safety and mission criteria success, and (ii) the degree to which model selection influences the results [7], [26]. A stakeholder's willingness to be vulnerable depends on the acceptable margins of error and the actions of a modeler expecting that the modeler will pursue actions important to the stakeholder [15].

2.3.2. Individual and contextual factors

This construct encompasses the characteristics of a stakeholder and the context of a decision. Within individual factors, trust propensity refers to the generalized disposition to trust others irrespective of the situation or context [15], [27]. Trust risk-taking depends on the context, domain specificity, and organizational and social norms [23]. Further, examples of organization factors include the responsibility for acting to the results, fostering participation in the development process [28], and implementation criteria such as the timing of the study to support critical decisions and cost/benefit ratios [29].

2.3.3. Perceived trustworthiness

This construct identifies a stakeholder's cumulative trust relating to the specific model and modeler being assessed. Trustworthiness refers to the expectations that may lead to disappointment [15]. Both model-related and modeler-related trustworthiness are context-specific and trust requires a previous engagement on the stakeholder's part.

3. Model Confidence Framework and Future Directions

As a precursor to developing this model confidence framework, we have formulated initial hypotheses about relationships between the constructs. Figure 1 presents the constructs identified in the previous sections and hypothesized relationships.

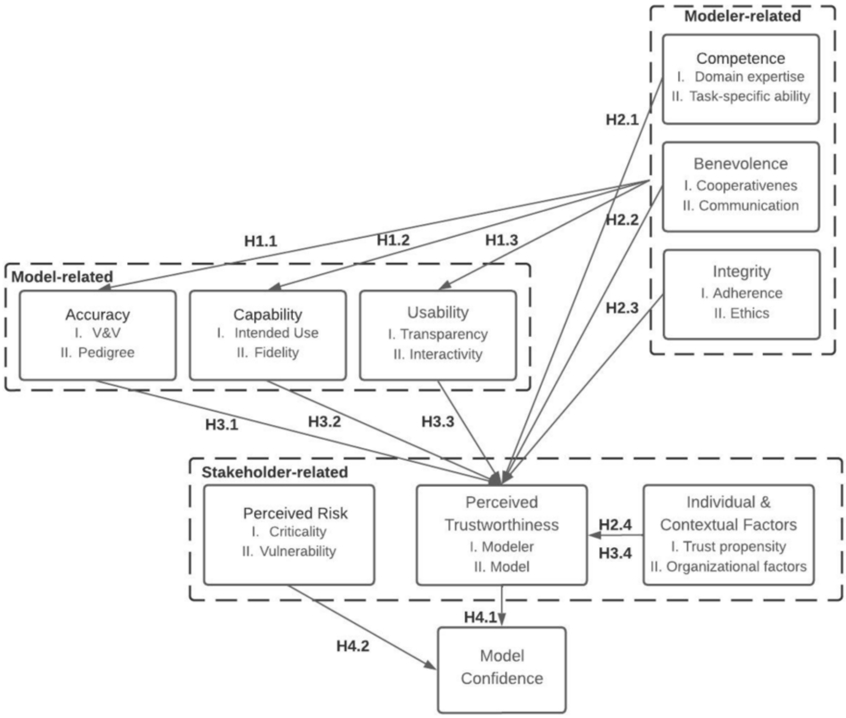

Figure 1. Hypothesized construct relationships and their connection to model confidence

The overall credibility depends on development, verification, and validation procedures, which result from a modeler's relevant competence, willingness to perform well, and principles they follow. Accordingly, hypotheses H1.1, H1.2 and H1.3 theorize the individual connections from the modeler-related constructs to model-related constructs.

H1. Modeler-related competence, benevolence, and integrity influence a model's accuracy, capability, and usability.

Preconditions for trustworthiness involve numerous factors ranging from past interactions to the predictability of future actions. These conditions are primarily explained in literature by competence (H2.1), benevolence (H2.2), and integrity (H2.3) [15]. However, the influence of modeler-related constructs on perceived trustworthiness is mediated by the individual factors and organizational context (H2.4).

H2. A stakeholder's perception of a modeler's trustworthiness depends on the modeler's competence, benevolence, and integrity and is mediated by individual and contextual factors.

The technology acceptance model (TAM) explains a user's *behavioral intention* to use a model in terms of perceived usefulness, perceived ease of use, subjective factors, and contextual factors [11]. This literature has also identified the moderating role of prior usage, experience, risk and trust preferences, and cultural differences. Some of these factors are empirically validated [13]. In the context of the stakeholder-model relationship, perceived usefulness depends on the model's accuracy (H3.1) and capability (H3.2), whereas ease of use is a function of model usability (H3.3). The model's credibility is a dynamic construct assessed throughout the iterative development of models and governed by empirical and observed behaviors reinforcing/adjusting stakeholder beliefs [4], [5]. If the model predictions fail, the credibility reduces. Therefore, subjective experiences and cultural norms influence the resultant trustworthiness assessment (H3.4).

> *H3. A stakeholder's perception of a model's trustworthiness is a function of the model's accuracy, capability, and usability and is mediated by individual and contextual factors.*

The perceived risk (H4.2) counters the combined perceived trustworthiness (H4.1) when deciding whether to use model results [7]. Whenever a stakeholder perceives decision risk to be lower than the aggregate trustworthiness of the model and modeler, they are expected to be confident to base their decision on the model results. In situations where decisions could result in risky outcomes, a stakeholder would require high levels of trustworthiness in the model and modeler [4].

> *H4. A stakeholder's confidence in model usage depends on the model and modeler's perceived risk and trustworthiness.*

Empirical validation of individual relationships is necessary for establishing a model confidence framework. Several tools such as observational studies, surveys, and experiments can provide granular data to perform causal analysis using regression studies. Such statistical analysis might consolidate or falsify the relationships depending on context. Further, the practical implementation of the framework will require qualitative and quantitative measurements of model characteristics, decision risk, stakeholder preferences and the modeler's expertise. These measurements will enable the ranking of dominant factors for a specific context and provide an objective assessment of model confidence.

4. Conclusion

Model confidence represents a stakeholder's perception of model and modeler attributes and is influenced by stakeholder-specific individual and contextual factors. Models enable transdisciplinary engineering through multidisciplinary knowledge exchange. Accuracy, capability, and usability are technical factors behind users' trust in models. Competence, benevolence, and integrity influence a stakeholder's perception of the modeler. In a practical setting, a stakeholder needs to balance the perceived trust in the model and modeler against the potential risk of unexpected outcomes. Overall, the relationships between these social and technical factors can provide a structured way of measuring model confidence to improve the organization's ability to use models and simulations to make critical decisions.

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