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Model-centric decision-making: exploring decision-maker trust and perception of models

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Abstract

Ongoing research is exploring various dimensions of enabling model-informed decisions, as motivated by the increasing need for individuals and teams to make decisions based on models and model-generated information. Central to this topic is the need to understand what engenders trust in models. This exploratory study uses expert interviews to investigate how various types of decision-makers and actors interact with and use models, including to what degree models are used to inform system decisions and how individuals build trust in models. While anecdotal stories of success and failure exist, empirical studies are needed to truly understand the many facets of human decision-making in model-centric engineering. Such research is expected to generate key insights that can inform current and future practice, as well as determine areas for more extensive study.

Keywords: Interactive Model-Centric Systems Engineering; model-centric; decision-making; sociotechnical; trust; interviews; transparency

1. Introduction

Models are increasingly used to drive major acquisition and design decisions, yet model developers, analysts, architects, program managers and senior decision-makers are faced with many challenges. Blackburn et al. (2015) captured many of these challenges in an investigation of the technical feasibility of radically transforming systems engineering through model-centric engineering [1,2]. Digitized legacy systems and new digital system models will provide the basis for designing and evolving systems in the future [3]. This drives the criticality of models as assets and necessitates change in model-related policy and practices [4]. The Model-Centric Engineering Forum conducted by the US Department of Defense (DoD) Systems Engineering Research Center (SERC) in May 2016 fostered a dialogue between industry, government, and academia on current state of practice and vision for transformation [5].

The Interactive Model-Centric Systems Engineering (IMCSE) research program, initiated in 2014, aims to inform and contribute methods, processes and tools to improve human-model interaction, in support of accelerating the transition of systems engineering to a more model-centric discipline [6]. IMCSE advances knowledge relevant to human interaction with models and model-generated information, drawing from relevant knowledge from other fields (e.g., cognitive science, visual analytics, data science), placing it within the context of systems engineering. Additionally, this research generates knowledge impacting human effectiveness in model-centric environments of the future [7]. As part of this exploration into human-model interaction, German and Rhodes (2016) examined the transition from traditional aircraft cockpits to modern glass cockpits as an analogy case, indicating information abstraction and automation led to new cognitive and perceptual challenges. Non-technical factors will have significant influence in the future of digital system models, including trust, buy-in and belief [8].

1.1. Motivation

The research discussed in this paper explores various dimensions of enabling model-informed decisions, as motivated by the increasing need for individuals and teams to make decisions based on models and model-generated information. Models represent an abstraction of reality in order to make predictions about the future, based on assumptions. Models can come in a variety of forms and formats, but fundamentally are an encapsulation of reality that humans use to augment their ability to make sense of the world, anticipate future outcomes, and make decisions. Among the many challenges are reasoning, comprehension and collaborative decision-making in the face of uncertainty, combining artificial (model-generated) and real data, and effectively utilizing vast amounts of information.

Significant progress continues to be made in the theory and practice of model-based engineering, yet little attention has been given to the complexities of human-model interaction. An open area of inquiry relates to the various facets of humans interacting with models and model-generated information throughout the lifecycle. The 2015 IMCSE Pathfinder Workshop validated the belief that improving human-model interaction would significantly improve model-centric engineering [9]. Additionally, a 2016 workshop report sponsored by the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Air Force Office of Scientific Research (AFOSR), and the National Modeling and Simulation Coalition (NMSC), highlights the need for understanding the individuals involved in the modeling process and how these individuals affect model development and usage [10].Central to this is the need to understand what engenders trust in models. While anecdotal stories of success and failure exist, empirical studies are needed to truly understand the many facets of human decision-making in model-centric engineering.

2. Research Approach

This study aims to generate insight into decision-maker trust and perception of models and model-generated information through expert interviews. Experts in system decision-making accumulate various kinds of knowledge and wisdom, often through years of hard-earned experience. Rather than theorize on how various actors interact with and trust models, this interview-based approach allows us to gather qualitative, empirical data by asking them directly. This study is ongoing and is not meant to offer definitive truth for all types of decision-making with models, but rather to serve as an exploratory study into a little-researched area. This study is primarily scoped to decision-makers and systems experts found within the defense and aerospace communities.

2.1. Sampling

Unlike quantitative research, which advocates random sampling approaches, qualitative research seeks to “select ‘information-rich’ respondents who will provide you with the information you need” [11]. For this study, we have primarily used judgmental and expert sampling to identify “persons with demonstrated or known expertise in an area of interest,” [11] along with individuals who, although perhaps not widely known as “experts,” were judged to have experience relevant for achieving the objectives of the study. In this study, we broadly view an expert as an individual who works or has worked as an actor within model-based decision-making processes, and can provide knowledgeable insight and perspective informed through his or her experiences. The definition of an expert is clearly open to interpretation as an “expert” may very well be in the eye of the beholder, and an improper interpretation on the part of researchers may lead to a biased sample of participants that fails to adequately represent a population. From our perspective, however, all participants were judged to have relevant experience and credentials through either their individually known work with models or that of the organizations for which they have worked, primarily experience found within the domains of defense and aerospace. While the study is ongoing, thirty individuals have been interviewed at the time of writing.

Interviews for this study followed a semi-structured format that allowed interview participants latitude to share a wide range of perspectives and insights while following guiding questions aimed at generating insight for the study objectives. Table 1 presents a list of the general questions asked.

1.	What types of decisions do you make, or help others make, with models?
2.	What is the degree to which the decisions you make are based on models?
3.	Do you view models as a primary or supplementary source in decision-making?
4.	How do you develop trust in models?
5.	How do you judge if a model can be trusted?
6.	How much transparency do you desire?
7.	What factors have led to inappropriate trust in models?
8.	What limits your ability to use models to make decisions?
9.	What challenges or failures have you experienced with the use of models in system decision-making?
10.	What approaches or policies have been applied, or would you like to see applied, to mitigate those challenges?
11.	How desirable would the ability be to directly interact with models real-time while making decisions?

Table 1. List of Interview Questions

3. Decision-Making Flow of Model-Generated Information

High-level decisions incorporating an explicit model in the decision-making process include the following broad components:

1. A model that represents some aspect of the system of interest
2. Human actors
3. A decision to be made

While simplified, a generic conceptualization of the model-influenced decision-making process is helpful for facilitating discussion surrounding this research space. In this general framework, the information generated from a model is the common thread that connects the three generic commonalities listed above. First, a model must be created or already exist before it can be of use in a decision-making context – this creation of the model itself generates information relevant to decision-making before it is even "used." Next, the model in question generates information designed to facilitate a better understanding of an issue for which a decision must be made. Exactly what happens to this model information varies from context to context, but all contexts involve model information flowing *from* an actor (i.e. modelers or analysts directly interacting with the model), *through* another actor or actors, and ultimately *to* a final decision-making actor. Where decision-makers reside in the process seems to be more along a spectrum of the flow of model information. Within different decision-making contexts, actors may even find themselves in different roles. For example, in a mid-level decision-making context, an actor may be the individual *to* whom the information is flowing, yet in a higher-level decision, the same individual may become a *through* actor. In decisions involving more than one actor, however, all model-informed decisions involve information being generated and flowing from those directly interacting with a model, flowing through an actor or actors, and lastly reaching a final decision-maker to whom the information flows.

To elucidate this conceptualization, it may be helpful to examine a specific case example that illustrates this flow of information. Figure 1 illustrates one such scenario where a model is used to inform decision-makers in a war game. The senior level decision-maker (Senior DM) identifies a modeling need, and interfaces with a model architect to create the desired model. The architect works with a team of modelers

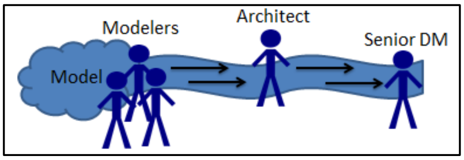

Fig. 1. Example Flow of Model-Generated Information

who develop and test the model and produce model outputs that are communicated through the architect to the decision-maker in response to specific queries. In this case, the model information flows *from* the team of modelers who comprise the initial actors, then flows *through* the primary model architect, and finally *to* the Senior DM involved with the war game.

At the end of the model-generated information flow there is a fairly discrete decision or set of decisions to be made. These high-level decisions, however, are influenced by countless smaller decisions and actions performed by various individuals within the flow of information. This study seeks to better understand the perspectives and thought processes of these various actors with the hope of better understanding the decision-making process as a whole. In the sampling process we sought perspectives from individuals from all three of our conceptualized categories; however, for the purposes of this paper, *through* individuals comprise the majority of participants. While this study is ongoing, we believe the thirty individuals interviewed at the time of writing present enough information to warrant publishing of the current results.

4. Trust

Ricci et al. (2014) describe how trust in models relates to a user's perception of how close to a specified reality a constructed model is perceived to be. Ultimately, a good decision "is one based on a trusted, truthful representation of both reality and values" [12]. The 2015 IMCSE Pathfinder Workshop report notes that numerous challenges exist within model-centric development, including challenges surrounding "perception of truthfulness and trust" in models, as this aspect of trust can ultimately affect "the timeliness, quality, and confidence in model-based decisions" [9]. The Pathfinder report also expresses a desire not just for models to be trusted, but for that trust to be supported with underlying evidence [9]. Blackburn et al. (2015) articulates a vision for developing model-centric environments into a "single source of technical truth" for decision-makers [2]. West and Pyster (2015) communicate the idea of digital system models offering an "authoritative representation" of systems [3]. Gass and Joel (1981) note, however, that all models "reflect modelers' views of how the decision problem can be resolved," and that these views carry inherent assumptions and limitations that decision-makers must consider prior to determining if the subsequent modeling results appropriately align with their decision at hand [13]. With this in mind, the goals of developing single sources of "truth" and "authoritative data" will require decision-makers to evaluate and determine how much trust they should place in this data. This trust can be improperly calibrated, however, potentially resulting in overreliance or underutilization. Engendering an appropriate level of trust within decision-makers is crucial to effective use of models in decision-making.

Literature addressing human trust in automation offers insight that can be useful when applied to this discussion on human trust in models. This relationship seems rather natural when considering that automation may arguably be nothing more than a model of operation algorithmically programed into a machine. In the article "Humans and Automation: Use, Misuse, Disuse, Abuse," Parasuraman and Riley highlight multiple potential pitfalls to consider when placing humans into interaction with automation. Misuse is defined "as overreliance on automation (e.g. using it when it should not be used, failing to monitor it effectively), disuse as underutilization of automation, […] and abuse as inappropriate application of automation by designers or managers" [14]. While examining factors that may contribute towards use and application of automation, Parasuraman and Riley identify that "trust often determines automation usage" [14]. This taxonomy of use, misuse, disuse, and abuse can provide a useful framework for thinking about how humans interact with complex models as well.

But what exactly is meant by "trust?" Lee and See (2004) define trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" [15].

Specifically addressing misuse and disuse, Lee and See express that “[o]vertrust is poor calibration in which trust exceeds system capabilities; with distrust, trust falls short of the automation’s capabilities” [15]. This idea of calibration “refers to the correspondence between a person’s trust in the automation and the automation’s capabilities.” Trust in automation implies belief that the automation will do what it is supposed to do, while trust in models assumes that the models will provide the information you want. Both automation and models represent technologies that require a certain amount of trust as the underlying processes and assumptions may be difficult to fully understand. The goal is not just for models to be used, but to be used appropriately; models, much like automation, have limitations of effectiveness and applicability. Overreliance in models can lead to misuse by inappropriately applying models outside of their inherent limitations. Conversely, improper lack of trust in models can lead to decision-makers discounting relevant model information that could have otherwise aided in the understanding and solution of issues. By examining the human aspect of human-model interaction, this study aims to generate understanding that can lead to appropriate “calibration” of human trust in models. Before seeking to influence the human actors, however, it is necessary to understand how those actors actually work in practice.

4.1. Developing Trust

Consciously or not, decision-makers must have a certain amount of trust present before model-generated information is used in the decision-making process. Few of the actors interviewed have consistent processes to develop trust in new models, yet all have various factors they consider when determining trust. Some factors prove unique to specific individuals or groups of individuals along the flow of information, while other factors appear to be common for individuals throughout the entire flow. In addition to processes or factors influencing decision-maker trust, we want to know more about what specific attributes or types of information about models that decision-makers and actors care about knowing.

5. Key Findings

This section presents preliminary key findings of the study to date. While these findings may not necessarily be novel, they serve to form a compilation of empirical evidence concerning human-model interaction. As this work is ongoing, these findings are expected to grow and evolve. The results are presented in no particular order of importance.

5.1. Technical and social factors influencing trust

As summarized by one participant, “trust is terribly important” within the modeling and decision-making process. While few of the interviewed experts have a specific process used in determining trust, every participant has various factors that they consider while determining the amount of trust to put in a model. This trust is also very contextually dependent, meaning that the trust is not so much in the model as an entity, but in the usefulness of the model for a specific decision at hand. Various factors influence individuals’ trust in models, yet these factors may vary in importance depending on the specific individual involved. A clear theme that has emerged from the interviews, however, is that both technological and social factors come into play when determining the amount of trust that any type of actor is willing to place in a model. In many cases, the importance of technological factors appears to diminish in relation to social factors as actors move further along the flow of model information. Figure 2 illustrates the concept that various technological and social factors influence a decision-maker’s trust in a model. The factors listed are not all-inclusive, but represent some of the factors identified through the interviews. While there may be trends in comparing important factors between the “*from, through, to”* categorizations of actors, such as the generalization that social factors seem more salient for *to* actors than for *from* actors, this is still dependent on the specific individuals involved. A strongly supported generalization, however, is that both technological and social factors play an important role in influencing an individual’s trust, and any attempt to understand trust without considering both types of factors would be lacking.

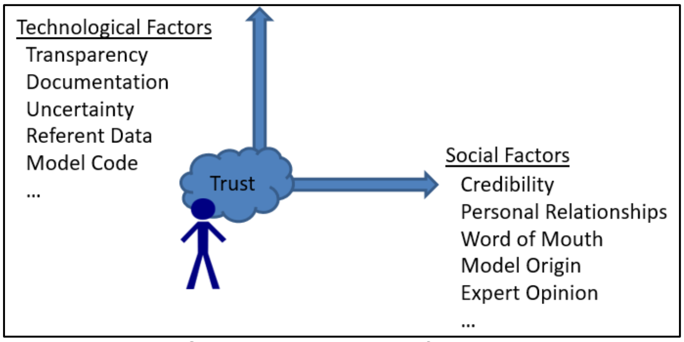

Fig. 2. Sociotechnical Factors Influencing Trust

5.2. Importance of communication

Communication arose as a key attribute of effective model decision-making. Before any effective modeling can be accomplished, senior level decision-makers must construct the problem statement clearly and in a form that unambiguously expresses the information they desire from models. Oftentimes the problem can change, however, therefore consistent communication of the problem at hand is crucial for allowing individuals below them to create or use models to generate relevant and useful information. The onus for this specific communication does not fall solely on senior levels, however, and lower levels must actively update senior decision-makers on progress to gain feedback on whether they are addressing the actual problem. Senior decision-makers must likewise be open and available, to the extent possible, to provide this feedback as necessary. As noted by an interview subject, "models [...] bring their own language with them" that can create communication barriers that stifle decision-makers' understanding of the model output presented to them. Unless a decision-maker is similarly an expert in the model, there needs to be a "translation between output to decision-maker speech," before the information can usefully be incorporated by the final decision-maker. Modeling aims to provide an asset for a decision; however, this asset cannot be effective if it is not useful for a decision-maker, and it cannot be useful if not understood. Instead of relegating discussion between actors to the beginning and end of a decision-making process, employing continuous and iterative communication may further reduce the acceptance barrier by allowing decision-makers to feel as if they walked the up-stream actors to the final model outputs. The flow of information between actors, including both expression and interpretation of information, must be intentional and unambiguous.

5.3. Transparency

Most of the interviewed modelers, analysts, and architects emphasized the importance of having access to precise technical information of models, oftentimes stating a desire to have access to code and the "guts" of the model in question. One such practitioner expressed that he "hopes everyone wants full transparency," seeming to assume that the desire for full transparency is a given for anyone making decisions from models. Transparency serves to enable an understanding of how a model actually works in order to determine if the model should be used for a specific decision. The understanding of a model encompasses, but is not limited to, a model's code, and transparency should include access into practices and decisions involved in creating and validating the model. Moving further along the flow of information decision-making, however, precise information about the models may become less desired, and even unwanted. Comments such as "I trust the people below me" convey the paradigmatic shift that occurs. While details such as model assumptions and uncertainties remain desired, the need for intimate technical knowledge seems to fade. Responses suggest that, even if an actor does not personally require full transparency into a model, transparency should still be available to trusted actors before them in the flow. This suggests a significant point: as actors move further along the flow of information and have less time and ability to personally investigate a model and build their own trust in the model, their trust instead shifts more onto their people to investigate the model for them. In this understanding, the trust for decision-makers is "implicitly on the models, but explicitly on the people."

5.4. Understanding of assumptions and uncertainty

All models are inherently abstractions of reality that contain assumptions and uncertainties. Models are created for a specific reason and context, and while the assumptions within the model aim to help answer those questions, they also fundamentally create bounds of model applicability. Failure to properly understand the inherent limitations found within a model increases the likelihood of the model being used inappropriately. "All models are wrong, but some are useful," [16] and before any can be useful, their limitations must be understood. As models cannot perfectly encapsulate and relate the situation of interest, uncertainty is fundamentally a part of the results, and uncertainty is also fundamentally a part of determining if the results are appropriately relevant to the decision to be made. This uncertainty must be sought after, understood by the sources of model information, and then passed clearly along the flow of information. There is a fundamental need to understand and express model uncertainties throughout the decision-making flow. Organizational and social dynamics can hinder this expression of uncertainty, however. In some instances, uncertainty about an answer may entail negative stigmas and imply failure to do one's job correctly. Decision-making cultures need to strive to drive out fear of uncertainty expression and transparency. The tragedy of the space shuttle Columbia offers a painful reminder of what can happen when important information is not effectively passed along the decision-making flow [17].

5.5. Documentation

Model developers internally carry within themselves the most intimate knowledge of a model's limitations and capabilities. Similar to how modeling is a process of making the internal mental models and expertise found within individuals explicit, documentation is a process of making the assumptions and limitations of a model explicit. Models may very well be validated, even accredited; however, this validation and accreditation are for specific conditions, outside of which the model is no longer valid. Multiple interviews revealed the danger of assuming a model can extend to any context needed when in fact its appropriate contexts of use are much more limited. For a model to have any sort of reuse capability, these assumptions and limitations should be documented in an accessible way so that others can understand how they might appropriately apply the model to their specific situation. Models are built to answer a specific question or set of questions, and the early conceptualizations (e.g. whiteboard drawings) of the model and decisions made in the development process can provide important insight into understanding the model in addition to the documentation of assumptions within the model itself. These conceptualizations, if captured, can provide useful artifacts in the understanding and trust of a model. As models become more complex, documentation of assumptions and capturing of conceptual artifacts and decisions will likely prove crucial in allowing actors to appropriately calibrate their own understandings and mental models of if, and how, a model should be applied to specific decision-making scenarios.

5.6. Primary versus Supplementary

Of the experts interviewed, distinctions emerge concerning the primacy of explicit models in the decision-making process. Some view models as clear primary sources in decision-making, others adamantly express that they should only be supplemental sources, and still others present the oft-favored viewpoint of systems engineers – it depends. Those that favor models as a primary source in decision-making point to the benefits of increased knowledge and insight that models can provide if done correctly. Others that advocate for supplementary use emphasize the danger of abdicating the decision-making process to models, and point to the inability of models to capture every relevant factor in a decision. One participant noted an increasing reliance on modeling and simulation (M&S) in decision-making, unfortunately accompanied with the increasing desire to rely on M&S without having to "understand the fundamental processes behind it." The variations in responses serve to validate the non-definitive (yet still insightful) answer of "it depends." Truly, how models are viewed and used is dependent upon the model users and decision-makers, along with the modeling and decision-making context. Well-established and validated physics-based models, for instance, might prove to be a primary source in a decision-making scenario, while descriptive or predictive models that are less conducive to traditional validation may contribute more of a supplemental input within a wide range of other inputs.

5.7. Independent review

Although models strive to reduce complexity of reality to understandable and workable abstractions, they can still be very complex. Verification ("Did I build the thing right?") and Validation ("Did I build the right thing?") (V&V) are crucial for determining the efficacy and relevancy of a model for decisions [18]. Just as skill is needed in model development and use, checks like V&V are required to hopefully catch the inevitable errors. However, effective V&V likewise requires skill and is liable to its own errors. One longtime system architect we interviewed emphasized the importance of utilizing independent experts who can review and render judgments concerning the credibility of results and believability of the data used. Such a team would be composed of individuals with areas of expertise relevant to the problem. One might view the team as analogous to a forensics team that closely examines the data and code being used and makes judgements that assess the efficacy of decisions made along the flow of model information. Depending on the model and decision-making context, the format and formality of reviews could range from formal, externally-based reviews, to informal, internal peer reviews within a team. Whatever the format, a form of review can serve an important part in the creation of an effective model, and as such, should be a process that is transparent to the decision-makers who are ultimately affected.

5.8. Investment bias and politics

One individual related the story of a program that involved significant investment in modeling and simulation. When the time came for program decision-makers to make a decision, "they had no choice but to accept" the model's answers "given the resources that were spent." Such a story brings to light the potential bias that investment of time and resources into model development will yield correct and reliable results. Further interviews also revealed a potential for decision-makers to use money as a basis for establishing trust in model results. Money may sometimes offer a useful indicator of model capability; however, no matter how much money is spent on a model, the model is still bounded by the problem space it was designed to solve. Just because large amounts of money were spent on a model does not mean that it is appropriate for the decision at hand. If this issue is not a bias in some cases, then perhaps it may be a political pressure to make a decision based off the model results because of the money spent on model development – if not, the money was wasted. Such a logical fallacy should be countered by a fundamental term of economics: sunk cost. Once money and resources have been spent (sunk) they are gone, and no longer should have any bearing on decisions seeking to promote benefit in the future.

5.9. Confirmation bias

In the words of one respondent: "Quite often, what I see is that decision-makers use models as confirmation bias." This statement reflects one potential pathway for models to be used inappropriately, namely, as a means to further one's own preconceptions or agendas that may be incorrect. Just because a decision-maker's intuition for a solution matches up with a subsequent modeling result does not mean the intuition or the modeling was wrong; in fact, it could be a testament to the decision-maker's experience. However, a senior modeler noted the challenge of guarding against bending a model and results to produce answers desired by decision-makers. Another participant expressed the "amusing thing" that in high-level war game simulations, the war games "almost always" are eventually modified so that your side wins. These interviews reflect the importance for all actors to honestly seek truth while participating in the modeling process. Modeling aims to provide solutions to problems; however, if generated and used to advance one's agenda or to inappropriately confirm preconceived notions, the "solutions" provided may in fact be more damaging than if models were not used in the first place.

5.10. Endogeneity of the human

Underpinning this study has been the clear and consistent theme expressing the endogeneity of the human in the model-centric decision-making process. Many senior decision-makers do not have the bandwidth, training, or time to become technical experts in the models that are used to inform their decisions. How do they trust complicated models? As one senior-level decision-maker put it: "The answer is they trust the people." They trust that the people before them in the model information flow handled the data correctly, created, tested, used and analyzed the model correctly, and expressed the results accurately with appropriate information on uncertainties, assumptions, and limitations. Decision-makers trust that those individuals have the appropriate expertise and capability to understand and address the problem at hand. On the other hand, senior decision-makers also need to have the technical judgment to be able to "sniff out" the wrong answers, and have a healthy technical competence appropriate to the decisions being made. As systems and their models become more and more complex, the need for skilled and experienced individuals to work within the flow of information seems to be more necessary than ever. Yet the inevitability of aging and retirement guarantees that the experts of today cannot be the experts of tomorrow. Without the right people capable of handling the complexities we are creating, the system will fail, regardless of the technology and innovation we throw at it.

5.11. Real-time interaction with models

A final question we asked in the interviews concerned the desirability of being able to directly interact with models in real-time while making decisions. Overwhelming, the respondents view interactivity with models as highly desirable. After all, many decisions involve asking "what-if" questions about the model, and direct interaction could serve to gain insight, build intuition, and speed innovation without needing to go through other human actors. This support for model interactivity also comes tempered with caution from some individuals, however. Specifically, caution against allowing actors interactive access to models without a calibrated understanding of the model's capabilities and limitations. As related by one individual, in situations without this appropriate understanding, "I can get lots of results real quick, and I can make lots of bad decisions real fast." These interviews make abundantly clear the importance for properly understanding a model and its associated assumptions before determining one's trust and usage of model results. Such an understanding is crucial for effective and appropriate interaction with models. As stated in another interview, "If you make it so fools can use it, fools will use it." So while direct interaction with models may be rightly desired based off its potential benefits, development and deployment of interactive models must also advance in a smart and conscientious manner to ensure that actors are not being set up for failure due to ignorance of their own limitations.

6. Discussion

The increase we see in system modeling is driven both by a desire to better understand complex systems and issues as well as by increases in technological and computational capability. Similar to technical modeling in many ways, automation involves increasing automation in systems as advancements in technology allows. Often this increase results in gains of efficiency and safety, yet the history of automation has also shown that humans are not just outside users of systems, but rather are endogenously critical components of the system. Experience has also shown that increasing technological capability for the sake of technical achievement, without proper consideration for the human component, can have dire consequences. Bainbridge (1983) writes about the "ironies of automation," where introducing automation can sometimes increase the workload and complexity of tasks it aimed to reduce [19]. With gains in modeling complexity and capability pointing to a model-centric paradigm of engineering, we should be cognizant of potential "ironies of modeling" where failure to appropriately account for human decision-makers and actors results in worsening decision-making processes we aimed to improve.

7. Future Research

This study aims to generate empirical insight into how human actors interact with and trust models, while also providing a starting point for continued exploration into how human actors and decision-makers trust, perceive, and interact with models. Through the interviews conducted, we hope to identify important considerations surrounding human-model interaction and trust that experts deem important for effective model use and decision-making. These considerations include practices that interviewed experts implement to aid in their decision-making, along with identified challenges and potential mitigations to challenges that can degrade effective model-centric decision-making. The insights gained from these interviews are planned to be coupled with empirical case studies examining human interaction with complex, abstracted systems to gather information about how human actors and decision-makers actually perform in practice. The descriptive insights gained through empirical research will be bolstered with normative research on decision-making and biases. Taken together, we envision these various threads of research weaving together towards prescriptive outcomes of heuristics and design principles to inform policy, design, implementation, and use of model-centric engineering.

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