RT-177
Interactive Model-Centric Systems Engineering (IMCSE)

Sponsor: DASD (SE)

By
Dr. Donna H. Rhodes

9th Annual SERC Sponsor Research Review
November 8, 2017
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www.sercuarc.org

Why is Human-Model Interactivity Important to the Future of Engineering?

Addressing complex systems problems requires both human intelligence and use of models

- Models are useful for generating data and analytics that can be used in human decision making
- Human cognitive limits drive necessity of using models and computational resources
- Models can "automatically" perform certain human functions but humans provide context: under which conditions is the model appropriate and useful?

While progress has been made on model-based engineering

… there has been relatively little investigation of the complexities of **human-model interaction**

IMCSE Pathfinder Workshop (2015)

imagine an ideal world…

An intuitive experience that generates deep insights across the area of relevant decisions that balances time, resources and the desired confidence in the decision outcome

Key Emergent Themes

- ease of interaction
- enabling informed decisions
- guiding human interaction
- human-human interaction
- model re-usability
- trust in models
- curation of models

IMCSE Pathfinder Workshop Report (Feb 2015) has informed our research initiatives

Project Overview


SYSTEMS ENGINEERING RESEARCH CENTER

Interactive Model-Centric Systems Engineering (IMCSE)
Phase 4
Technical Report SERC-2017-TR-103
March 1, 2017

Principal Investigator:
Dr. Donna H. Rhodes, Massachusetts Institute of Technology

Research Team:
Dr. Donna H. Rhodes, Dr. Adam M. Ross, Massachusetts Institute of Technology
MIT Graduate Student Researchers: Students: Michael Curry, Matthew Fitzgerald, Erling Shane German, Jack Reid, Lucie Reymondet,

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IMCSE research program seeks to inform and contribute methods, processes and tools to improve interactivity of humans and models in support of systems decision-making

RT-122 Phase 1/2 May 2014 - Feb 2015
RT-143 Phase 3 Mar 2015 - Feb 2016
RT-162 Phase 4 Mar 2016 - Feb 2017
RT-177 Phase 5 Mar 2017 – Feb 2018

YEAR 4 Activities (Phase 5)

1. Interactive Epoch-Era Analysis
2. Human-Model Interaction
3. Curation of Model-Centric Environments

Rhodes, D.H., and Ross, A.M., IMCSE SERC Reports: Phase 1, Phase 2, Phase 3, Phase 4, www.sercuarc.org

Interactive Epoch-Era Analysis

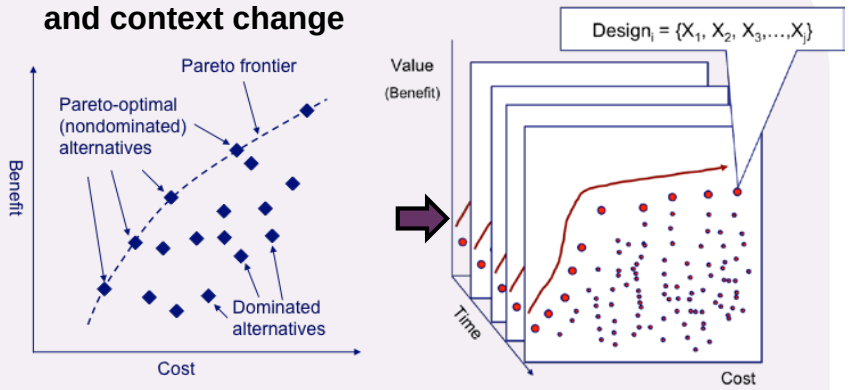
- Curry, M.D., Design as Search Problem: Interactive Visualization for System Design under Uncertainty, Doctor of Philosophy Dissertation, Aeronautics and Astronautics, MIT, June 2017
- Curry, M, Rehn, C.F., Ross, A.M., and Rhodes, D.H., "Designing for System Value Sustainment using Interactive Epoch-Era Analysis: A Case Study from Commercial Offshore Ships," 15th Conference on Systems Engineering Research, Los Angeles, CA, March 2017
- Curry, M, and Ross, A.M., "Designing System Value Sustainment using Interactive Epoch Era Analysis: A Case Study for On-orbit Servicing Vehicles," 14th Conference on Systems Engineering Research, Huntsville, AL, March 2016
- Curry, M, and Ross, A.M., "Considerations for an Extended Framework for Interactive Epoch-Era Analysis," 13th Conference on Systems Engineering Research, Hoboken, NJ, March 2015

Excerpts of recently completed MIT doctoral thesis work of Michael Curry

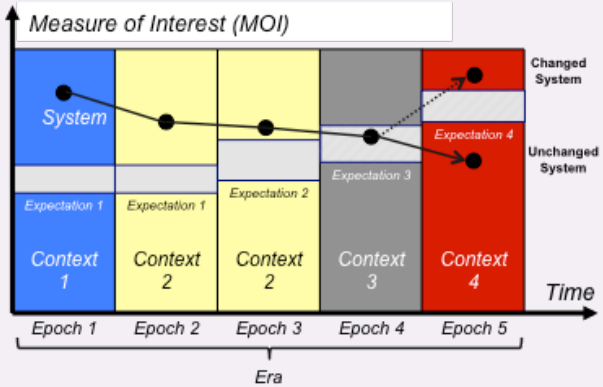
Background

- Tradespace exploration traditionally focuses on analysis of alternatives within a static context and needs
- Epoch-Era Analysis conceptualizes the effects of time and changing context on a system
  - **Epochs**: periods of fixed context and needs (short run)
  - **Eras**: sequences of epochs simulating a potential future experienced by the system (long run)

Tradespace changes over time as needs and context change



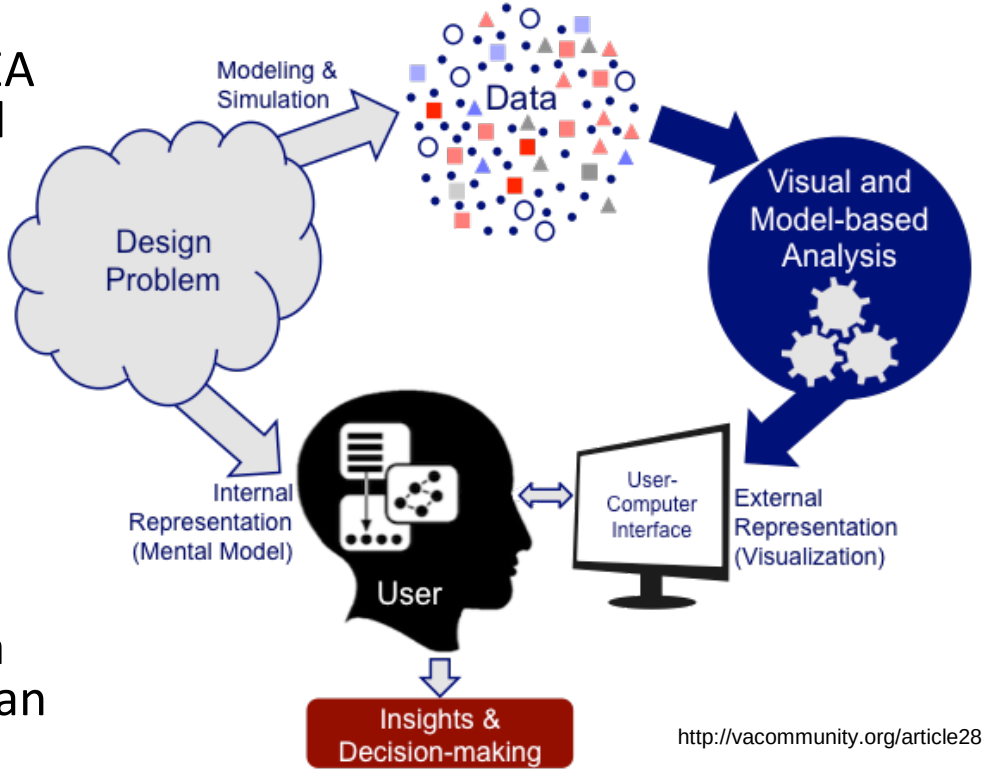
Perceived system value changes over time



How can a method for tradespace exploration under alternative contexts be made more interactive?

Interaction Framework

- Prior frameworks for applying EEA constructs have been introduced (RSC, RMACS)
- Model-generated EEA data sets can be both large and complex
- Motivates a shift from confirmatory to exploratory data analysis which necessitates human interaction

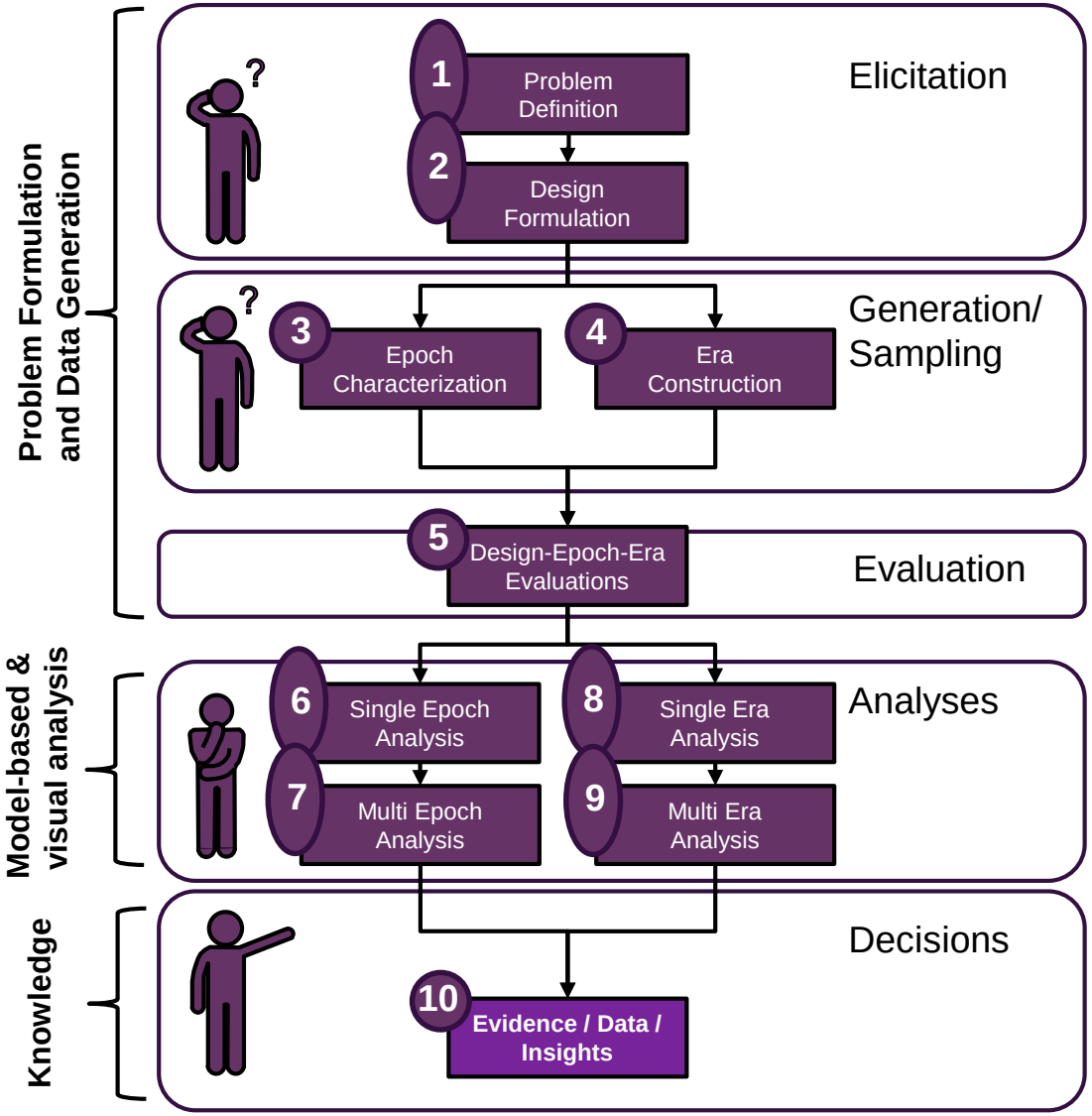


http://vacommunity.org/article28

Curry (2017) MIT Doctoral Thesis

RQ#1: How can the value sustainment of complex systems be enabled through an early-phase design framework that incorporates EEA and explicitly considers human interaction?

IEEA Framework



- Inspired by visual analytics process, extends processes of current method
- Techniques incorporated from visual analytics
  - Heuristic/methodological guidance
  - Visualization
  - Data Management (generation, storage, and transformation)
  - Interactive
- Applied in two cases

Visual Analytics

- Defined as "the science of analytical reasoning facilitated by visual interactive interfaces.“ [40]
- Focuses on the collaboration between human and computer to solve complex problems
- Has shown transformative capabilities in other domains where data volume and complexity is an issue by enabling human-computer collaboration

Visual analytics has been successfully applied in other domains where there is large amounts of data and problem is ill-defined

Financial Fraud

Transportation Infrastructure

Healthcare

Curry (2017) MIT Doctoral Thesis

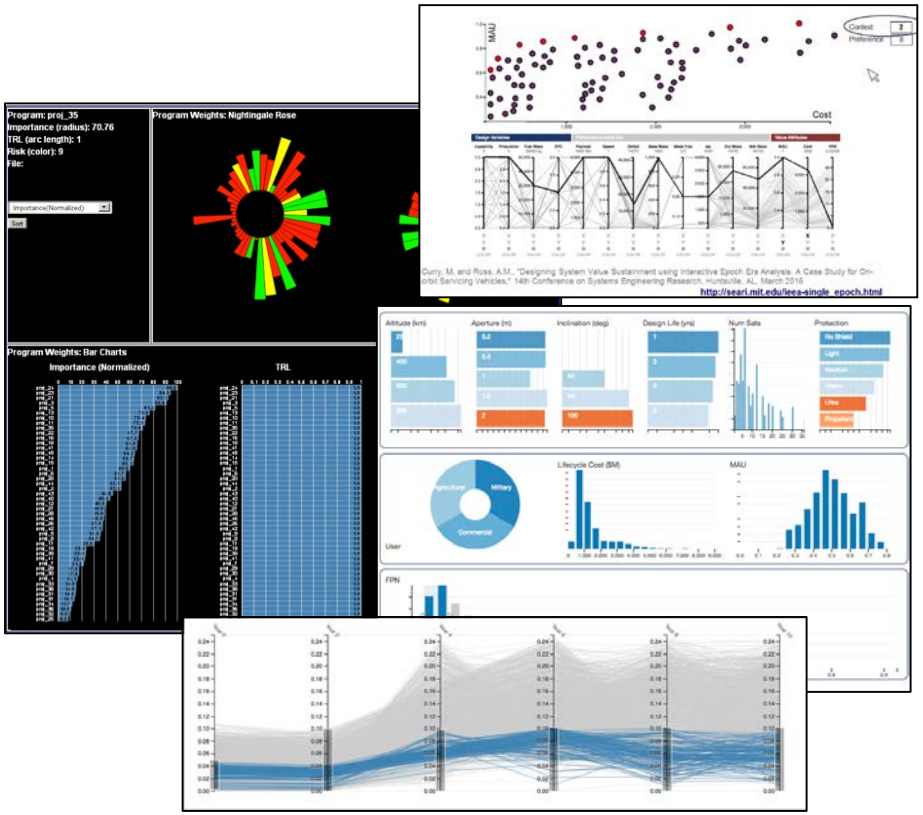
RQ#2: How can existing techniques from the field of visual analytics be incorporated into EEA to enable analysis and comprehension of driving factors of sustainable system value in dynamic operating environments?

Human Performance in Solving Design Problems

- Visual analytics applications have two main components:
  - Visual representation
  - Interaction

- Characterization of benefits of these applications to system design problem requires human-in-the-loop evaluation

Example Interactive Systems Engineering Applications



Curry (2017) MIT Doctoral Thesis

RQ#3: Does interactive visualization improve design problem decision-making and, if so, what are the relative contributions of representation, interaction or other factor to user performance?

Controlled Human-Subjects Experiments (Curry 2017)

- Objective of experiment: determine how well subjects complete tasks for a simplified car design problem
  - Must compromise on optimality to satisfy 4 customer segments
  - Emulates a typical multi-epoch analysis problem

		Visualization	
		No	Yes
Interaction	No	A	B
	Yes	C	D

4 Experimental treatment groups

- 104 subjects recruited via Amazon's Mechanical Turk (Mturk) online crowd sourcing marketplace
  - 26 participants per treatment group

Controlled Human-Subjects Experiment (Curry, 2017)

Curry (2017) MIT Doctoral Thesis

Q#3: Does interactive visualization improve design problem decision-making and, if so, what are the relative contributions of representation, interaction or other factors to user performance?

Selected results:

- **Accuracy**
  - Graphs improve accuracy on trend observation tasks
  - Interaction improves accuracy on sorting tasks
  - Becomes more important with increasing data volume
- **Speed**
  - Adding a graph decreases completion time for trend tasks
  - Adding interaction decreases completion time

Subjects answer several questions about the surrogate engineering design tasks using one of four web-based interfaces (randomly assigned)

- Plain text table of data
- MS Excel-like interactive table of data
- Static graph or visualization of data
- Interactive visualization of the data

For full results of the experiment, see MIT Doctoral Thesis of Michael Curry, 2017 (seari.mit.edu)

HUMAN-MODEL INTERACTION
Model-Centric Decision Making Study

- German, E.S., An Investigation of Human-Model Interaction for Model-Centric Decision-Making, Master of Science Thesis, Technology and Policy Program, MIT, June 2017
- German, E.S., and Rhodes, D.H., "Model-Centric Decision-Making: Exploring Decision-Maker Trust and Perception of Models," 15th Conference on Systems Engineering Research, Los Angeles, CA, March 2017
- German, E.S., and Rhodes, D.H., "Human-Model Interactivity: What Can Be Learned from the Experience of Pilots Transitioning to Glass Cockpit?," 14th Conference on Systems Engineering Research, Huntsville, AL, March 2016
- Rhodes, D.H., and Ross, A.M., "A Vision for Human-Model Interaction in Interactive Model-Centric Systems Engineering," INCOSE International Symposium 2016, Edinburgh, Scotland, July 2016

Interview-Based Study

model-centric decision making

Exploratory study to gain insight into how various types of decision-makers interact with and perceive models (2016- 2017)

Motivated by increasing need for individuals and teams to **make decisions using models** and model-generated information

Explores **how decision-makers build trust in models and to what degree models are used to make decisions**

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

- *MIT and DoD IRB Approved*
- *Investigators: German and Rhodes (PI)*

German, E.S., and Rhodes, D.H., "Model-centric decision-making: exploring decision-maker trust and perception of models" 15th Conference on Systems Engineering Research, Torrance, CA 2017

Areas of Study Findings (unordered)

Three actor decision flow

Importance of intercommunication

Understanding of assumptions and uncertainty

Technological and social factors influencing trust

Importance of model-related documentation

Need for model pedigree

Using models as primary versus supplementary

Non-advocate role in reviews

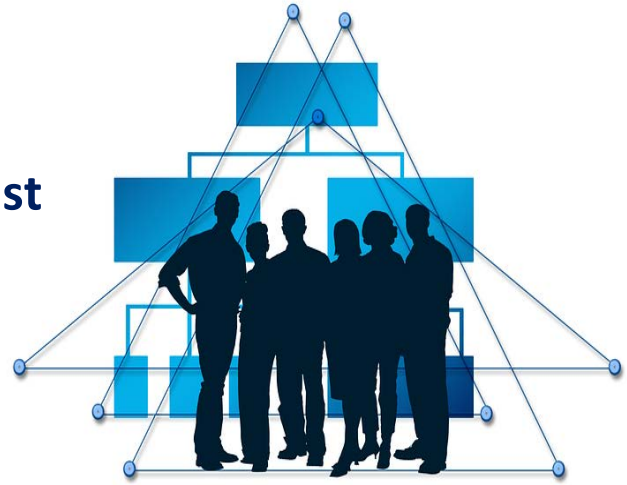
Transparency and trust

Model investment bias and confirmation bias

Factors limiting model-centric decisions

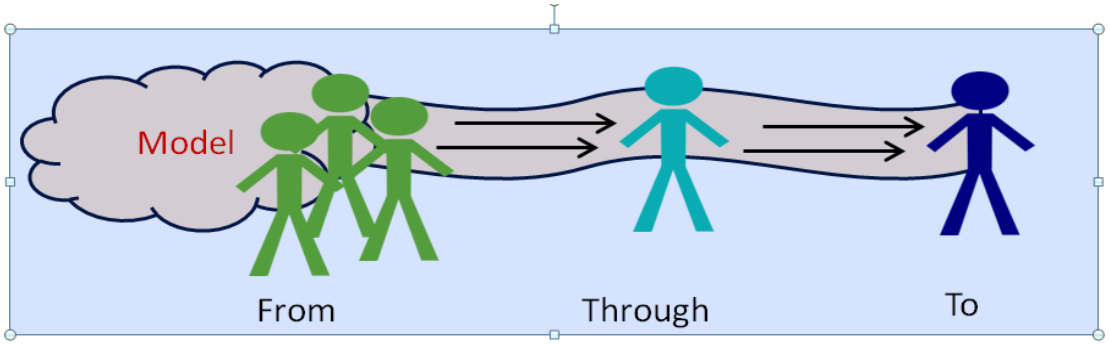
Real-time interaction with models

Viewing humans as endogenous



30 recognized experts

Three Actor Decision Flow

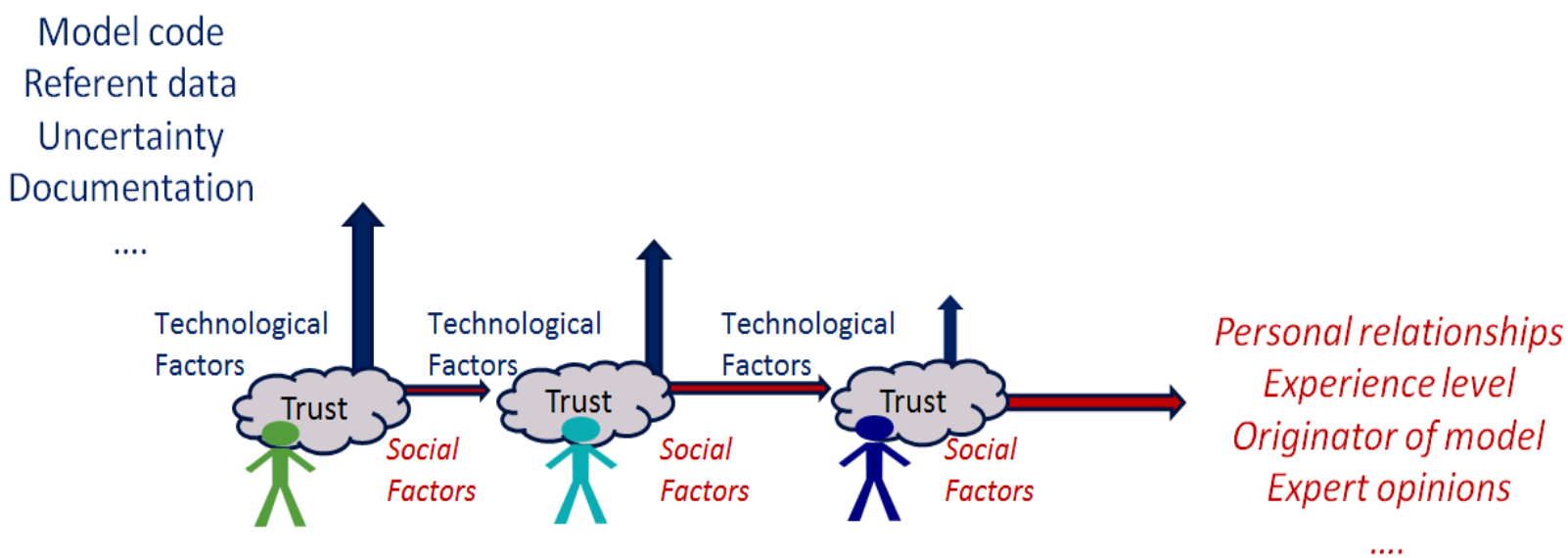


The data suggests that as actors move further along the flow of information and have less time and ability to personally investigate a model and build their own trust in the model, their trust instead shifts more onto their people to investigate the model for them.

… the trust for ultimate decision-maker is “implicitly on the models, but explicitly on the people.”

Factors Influencing Trust

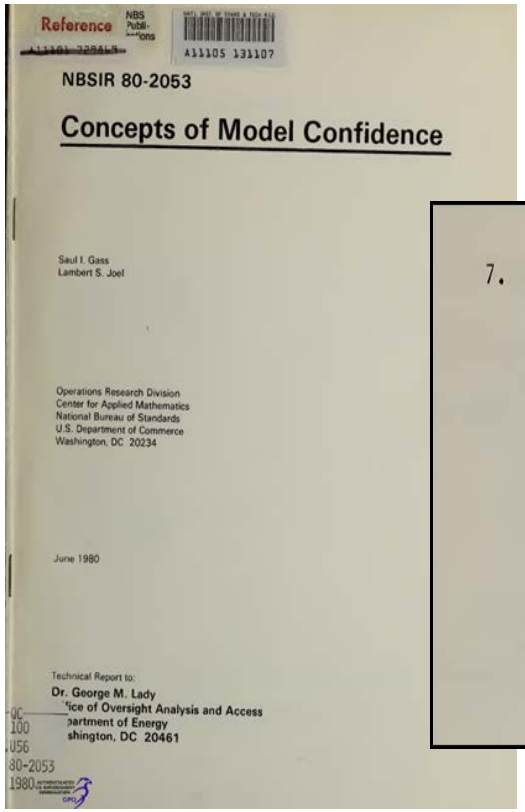
Trust is influenced by both technological factors and social factors, to varying degrees, based on stakeholder role in model-centric decision making process



Study Finding

Model Pedigree

The models generated by various actors and used in various decision-making situations are vast, and this generation and use of models produces information that may influence decision-maker trust in using these models in other situations



Reference

NBS Publications

A11105 131107

NBSIR 80-2053

Concepts of Model Confidence

Saul I. Gass
Lambert S. Joel

Operations Research Division
Center for Applied Mathematics
National Bureau of Standards
U.S. Department of Commerce
Washington, DC 20234

June 1980

Technical Report to:
Dr. George M. Lady
ice of Oversight Analysis and Access
partment of Energy
shington, DC 20461

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1980

7. Model Demographics--an abstract and description of the model antecedents and developmental process, originators and developers, past users, cost, and current developmental activities. This information should enable the decision maker to determine the model's status with respect to past achievements, theoretical and methodological state-of-the-art, and the expert advice that went into its development.

Study Finding

Model Transparency

Varied opinions on how much transparency others need/want

Everyone cares about transparency
…but personally may not need to
"see the code", rely on others to do that

I like to be able to get way down in my code…to see the algorithms doing the calculation.

I never look at the lowest levels…I have associates working on that.

If I have somebody who I trust, as I know their expertise, background … I will trust their model

Study Finding

Factors Limiting Effective Model-centric Decisions

MODEL	HUMAN		
Data availability	Talent of people	Time and money	Educated leadership
Data quality	Inertia to change	Team agreement	Lack of desire to understand
Model complexity	Communication barriers	Skill level	Bad past experiences
Inadequate methods	Changing preferences of decision-makers	Ability to socialize models	Generational differences
Lack of transparency and model documentation	Unwillingness to share models or information	Lack of trust/fear of the unknown	Organizational differences
Interactivity with models		Lack of understanding	

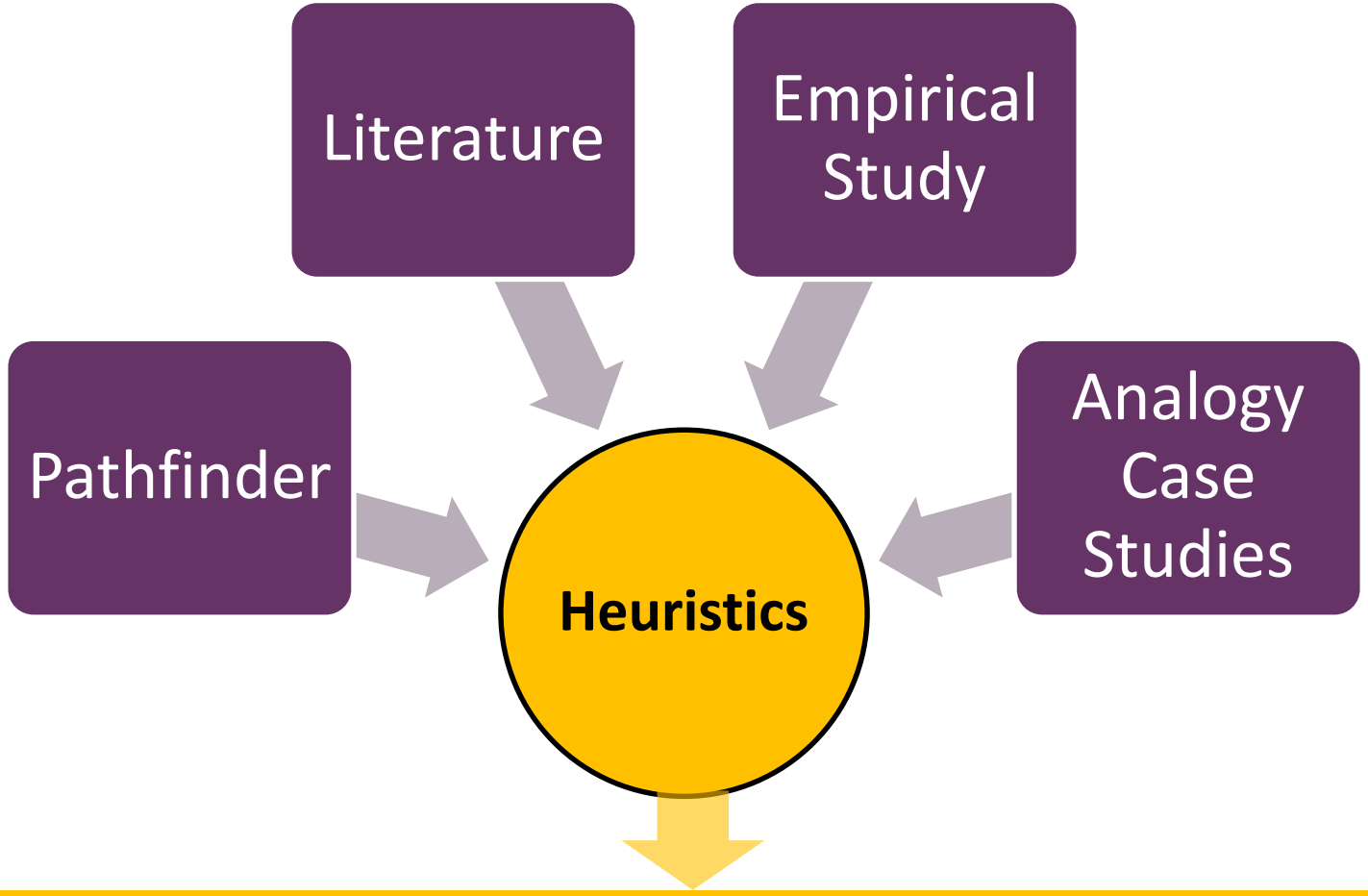
Viewing Humans as Endogenous

Understanding the behavior of a model-centric enterprise requires viewing human actors as endogenous constituents

- Models influence decision maker behavior in various ways
- Human interaction with models influences how models are conceived and used in decisions

Endogenous point of view (J. Forrester)
Formulating a model of a system should start with the question "Where is the boundary, that encompasses the smallest number of components, within which the dynamic behavior under study is generated?" (G.P. Richardson , 2011)

Encapsulating Findings as Guiding Heuristics



Publications - Guidance Document – Teaching Modules – "Preflight checklist"

Six categories
Human-model interaction heuristics

1. **designing models for human use**
2. **using models in decision-making**
3. sociotechnical considerations
4. **context and assumptions**
5. transparency and trust
6. **mitigating biases**

- *Heuristics encapsulate insights and strategies discovered by experts though experience*
- *Experts apply these intuitively*
- *Heuristics can be used to educate and guide practice of novices, as they learn through their own experiences*
- *Heuristics can be used in projects as "preflight checklist"*
- *Validated heuristics inform the development of policy/practice*

Selected Heuristic

Designing models for human use

Humans should not be forced to adapt to models, rather, models should be designed for humans

- Evolving technology enables more complex and capable models but may not result in increased effectiveness if humans are not appropriately considered
- Humans have cognitive and perceptual limitations that limit amount and types of information they can effectively comprehend and use to make decisions
- Designing for humans requires understanding their capabilities and limitations so that the model intelligence can extend the overall system intelligence

Using models in decision making

Models do not have agency -- the ultimate responsibility for decisions must be upon humans

- Ultimate decision-making authorities are people, and blame cannot be placed upon models for poor decisions
- Model developers, users, and decision-makers have the responsibility to ensure that models are properly understood and appropriately used
- Individuals should be aware of the potential for improperly diffusing responsibilities for decisions upon models
- Policies should clearly establish the responsibilities for which individuals are held accountable in model-centric enterprises

Context and assumptions

Models are created for specific reasons and contexts, and those assumptions fundamentally bound a model's applicability

- A model may be insightful and valuable within one problem context, but the assumptions built into the model may not be valid within some other context
- Evaluating a model's applicability should not just consider whether it has been validated, but in what contexts it has been validated
- Using a model outside of its inherent bounds may lead to model results that are inappropriate for the problem under consideration

Selected Heuristic

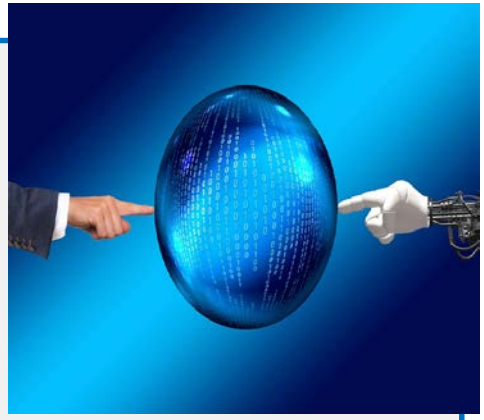
Mitigating biases

Increasing speed of decision-making implies a decrease in time spent analyzing a problem that in turn increases chance of biased judgment

- Model-centric environments enable interaction to build intuition and speed decision-making, but may increase bias
- Complex problems may require focused time and attention to fully understand and develop an accurate mental model of the situation
- While faster decisions are desired if effective, speed itself may set people up for failure by encouraging them to rely upon fast and intuitive, yet bias-susceptible, judgment… rather than more cognitively demanding rational and analytical thought processes

Implications for practice and research

- Empirical data (vs anecdotal evidence) on human-model interaction "state of practice" (based on 30 expert interviews)
- Heuristics encapsulate human-model interaction strategies for use in education, training and practice guidelines



Confirms need for further investigation ….

- Capture patterns of why, when and how various stakeholders interact with models
- Understand most effective means for interaction
- Determine where human interaction is preferred over augmented intelligence
- Inform model-centric enterprise transformation and new leadership roles

Model Curation

- Reymondet, L., Rhodes, D.H., and Ross, A.M., "Considerations for Model Curation in Model-Centric Systems Engineering," 10th Annual IEEE Systems Conference, Orlando, FL, April 2016
- Rhodes, D.H., and Ross, A.M., "A Vision for Human-Model Interaction in Interactive Model-Centric Systems Engineering," INCOSE International Symposium 2016, Edinburgh, Scotland, July 2016

Digital Curation
National Research Council (2015)

- *The phrase "**active management and enhancement**" was chosen to distinguish curation from simply collecting and storing data and information.*

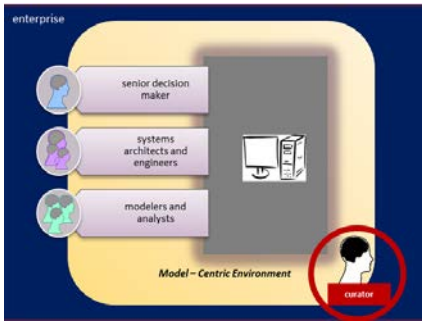
- *Active management denotes planned, systematic, purposeful, and directed actions that make digital information fit for a purpose. It includes coordinated activities that allow users to understand and exploit digital information assets and to ensure their integrity over time.*

- *Active management also refers to activities that ensure that digital information will remain discoverable, accessible, and useable for as long as potential users have a need or a right to use it. It may further involve securing digital information from unauthorized access.*

- *Information management, data management, data stewardship, data governance, and digital archiving are related terms used to describe processes and activities that overlap with curation….**What distinguishes curation from these other fields is its emphasis on enhancing the value of information assets for current and future use and its attention to the repurposing and reuse of information, both within and beyond the context in which it was first created or collected.***

Preparing the Workforce for Digital Curation, National Academies Press, 2015

Driving Factors for "Model Curation"



- Models becoming increasingly valuable, leading to equal/greater value than physical asset
- Modeling competency distributed across individuals/organizations; not developed at an enterprise level
- Models exist at all levels of an enterprise (individual, program, business unit, enterprise) but not managed as enterprise collection
  - Need to distinguish which models are elevated to the enterprise collection (deemed of value and quality to be used across the enterprise, and worthy of distribution outside the enterprise (by exchange, loan, sale…)
- Need for composability of models for specific purposes beyond original use, requires knowledge depth and breadth

Evolving Leadership

Paradigm Shift	Leadership Approach	Enterprise Characteristics Include…
Model Use Throughout Program	"Local" model management	• Models are primary artifacts replacing documentation • Limited reuse of models • Organization embraces importance of models
Model Reuse Across Programs	Model leadership responsibilities	• Models-based engineering as standard practice • Models are reused across programs in business unit • Model-centric enterprise culture
"Digital Twin" Throughout System Lifecycle	"Chief Model Curation Officer" as enterprise leadership role	• System "digital twin" maintained through lifecycle • Enterprise practices for model architecture (modularity, ease of composability) • Model-centric culture embedded across enterprise
IP Inversion	CMCO as top tier executive	• Models (Digital Twins) are key deliverables • Model IP is more valuable than product Models are sold, exchanged, loaned • Innovations emerge from composability of models

Enterprise Level Curation Role
Potential Organizational Forms

Organizational Form	Implementation
Centralized – Top Tier	CMCO is top executive reporting directly to CEO
Centralized – Dotted Line	CMCO has enterprise level authority, "dotted line" reporting to CEO
Franchised	Enterprise segments have CMCOs, conforming to enterprise defined policy and role.
Collaborative	Virtual CMCO role through collaborative committee
Dual Hat	CMCO is one of two roles played by an executive
Delegated	CMCO responsibilities are delegated to a committee, to one or more individuals
Outsourced	CMCO role is performed by an external hire

CMCO – "Chief Model Curation Officer"

Investigating Organizational Forms

Model curation leadership could take alternative forms depending on nature and characteristics of the enterprise

Form	Implementation	Under what conditions
Centralized – Top Tier	CMCO is a top tier executive reporting directly to CEO	High performing model-centric engineering enterprise or has a very aggressive goal to become one. Culture has fully embraced model-centric engineering across the entire enterprise, and believes model leadership is key to competitive advantage and to innovation.
Centralized – Dotted Line	CMCO has enterprise level authority, "dotted line" reporting to CEO	The enterprise is rapidly becoming a high performing model-centric engineering enterprise. The CMCO needs enterprise level authority to make and implement strategic decisions, but is not ready to make the CMCO a full member of the executive management team.

CMCO – "Chief Model Curation Officer"

Example Responsibility
Model Accession

- Accessioning is the process of officially accepting models (and sets of models) into the enterprise level model collection.
  - An accession is the acquisition of a single model or set of models, from one source, under one type of transaction (elevated to global, exchange, purpose…), as of a single date
- Accessioning establishes legal ownership, IP, validity of pedigree, etc.
  - Developed or acquired? Or existing local asset elevated to global asset? Adapted from open source? Purchase or exchange?
- Condition at accession recorded, establishing initial pedigree
  - Model and pedigree info recorded with unique identifier
  - Placed under CM

De-accessioning is also a key responsibility

Role & Responsibilities Definition

Research in progress to develop and validate R&R, including:

- Determine model accessions, de-accessions, acquisitions, loans
- Responsible for policies/practices and model pedigree standard
- Set guidance for use (e.g., model composition strategies)
- Set strategic goals for model-centric practice and environments
- Lead role for composing model demonstrators

Model Curation - Interim Findings

- Semi-structured interviews indicate **enterprise leaders recognize need** for enterprise-level leadership for strategically managing model assets and model-centric environments
- **Seven alternative forms** for model curation leadership have been identified, along with possible conditions under which these the form would be most appropriate
- Curation **knowledge and practices from other areas** (museum, digital, ….) have potential to inform model curation in an engineered systems context
- Numerous areas for **further investigation** and opportunities for **engaging larger community**

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Systems Engineering Research Center (SERC) under Contract HQ0034-13-D-0004. SERC is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the United States Department of Defense.

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