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System Dynamics Methodology

Research Project Descriptions

Index

Taylor, TRB, Ford, DN and Ford, A. "**Improving model understanding using statistical screening**". System Dynamics Review. Vol. 26, No. 1. Pp. 73-87. Jan.-March, 2010.

Taylor, T. R. B., Ford, D. N. and Ford. A, "**Model Analysis using Statistical Screening, Clarifications and Extensions**", Proceedings of 2007 International System Dynamics Conference, Boston, Ma. July 22-26, 2007

Doyle, J. K., Ford, D. N., Radzicki, M. J., and Trees, W. S. (2002). "**Mental models of dynamic systems, in System Dynamics and Integrated Modeling**", edited by Y. Barlas, from Encyclopedia of Life Support Systems (EOLSS).

Ford, D. and McCormack, D., "**Effects of Time Scale Focus on System Understanding in Decision Support Systems**," Simulation and Gaming, An Interdisciplinary Journal of Theory, Practice, and Research. Vol. 31, No. 3, pp. 309-330, Sept., 2000.

Ford, D. N. "**A Behavioral Approach to Feedback Loop Dominance Analysis**" System Dynamics Review. Vol. 15 No. 1 pp. 3-36, Spring 1999.

Doyle, J. and Ford, D., "**Mental Models Concepts Revisited: Some Clarifications and a Reply to Lane**," System Dynamics Review, Vol. 15, No. 4, pp. 411-416. Winter, 1999.

Ford, D.N. "**The Application of System Dynamics to Concurrent Engineering**," *INSIGHT. International Council on Systems Engineering*. Vol. 2, No. 3, pp. 20 – 23, Fall, 1999.

Ford, D. and Sterman, J., "**Expert Knowledge Elicitation for Improving Formal and Mental Models**," System Dynamics Review, Vol. 14, No. 4, pp. 309–340, Winter, 1998.

Doyle, J. and Ford, D., "**Mental Model Concepts for System Dynamics Research**," System Dynamics Review, Vol. 14, No. 1, pp. 3-29, Spring, 1998.

Ford, D.N. and Paynting, R. "**Linking Academic Theory and Industry Practice with Student Interactive Projects**". *The Center for Quality Management Journal.* 4(2): 19-32. 1995.

Improving model understanding using statistical screening

Timothy R. B. Taylor, David N. Ford, Andrew Ford

System dynamics models are often constructed to improve system performance by identifying and modifying feedback mechanisms that drive system behavior. Once identified, these feedback mechanisms can be used to design and test policies for system performance improvement. A preliminary step in developing policies is the identification of high-leverage parameters and structures, the influential model sections that drive system behavior. The current work clarifies and extends the use of statistical screening as a tool to improve model understanding, explanation, and development with a six-step process. Statistical screening adds rigor to model analysis by objectively identifying high-leverage model parameters and structures for further analysis. Statistical screening offers system dynamicists a user-friendly tool that can be used to help explain how model structure drives behavior.

Taylor, TRB, Ford, DN and Ford, A. “Improving model understanding using statistical screening”. System Dynamics Review. Vol. 26, No. 1. Pp. 73-87. Jan.-March, 2010.

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Model Analysis using Statistical Screening, Clarifications and Extensions

Timothy R. B. Taylor, David N. Ford, Andrew Ford

System dynamics models are often constructed to improve system performance by identifying and modifying feedback mechanisms that drive system behavior. Once identified, these feedback mechanisms can be used to design and test policies for system performance improvement. A preliminary step in developing policies is the identification of high leverage parameters and structures, the influential model sections that drive system behavior. The current work clarifies and extends the use of statistical screening (Ford and Flynn, 2005) as a model analysis tool with a six step process that identifies specific model sections for further analysis and development. The work also presents a method that clarifies the results of model analysis with statistical screening to practicing managers. Example application to three models, including the tipping point model (Taylor and Ford 2006, 2007) Bass diffusion (Sterman 2000), and World3 model (Meadows et al. 1974), illustrate the use of the tool and method. Statistical screening offers system dynamicists a user-friendly tool that can be used to help explain how model structure drives system behavior.

Keywords: Model analysis; Model development; Statistical screening; Tipping point

Taylor, T. R. B., Ford, D. N. and Ford. A, “Model Analysis using Statistical Screening, Clarifications and Extensions”, Proceedings of 2007 International System Dynamics Conference, Boston, Ma. July 22-26, 2007

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Mental models of dynamic systems, in System Dynamics and Integrated Modeling

James K. Doyle, David N. Ford, Michael J. Radzicki, W. Scott Trees

Mental models play a central role in system dynamics efforts to improve learning and decision making in complex systems. In fact, the system dynamics methodology can be generally described as a feedback process in which mental models are used to develop a computer model, which in turn creates new opportunities for learning that improve the accuracy, coherence, and complexity of mental models, This article describes the history of the mental models concept in the fields of system dynamics and psychology, and offers a comprehensive definition of the term for use in system dynamics research. The characteristic of mental models of dynamic systems identified by the empirical literature are reviewed, with an emphasis on important flaws and limitations, as well as their underlying causes, which typically limit the utility of mental models for dynamic decision making. A mental model-based theory of dynamic decision making is presented that is consistent with this evidence, and the mechanisms by which system dynamics computer modeling can improve mental models within this theoretical framework are described. The implications of the theory for developing appropriate techniques for studying mental models, as well as specific priorities for future research, are discussed.

Keywords: system dynamics, mental models, dynamic decision making, learning, causal reasoning, simulation, information processing, memory, cognitive processes, cognitive limitations, bounded rationality, feedback.

Doyle, J. K., Ford, D. N., Radzicki, M. J., and Trees, W. S. (2002). Mental models of dynamic systems, in System Dynamics and Integrated Modeling, edited by Y. Barlas, from Encyclopedia of Life Support Systems (EOLSS).

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Effects of Time Scale Focus on System Understanding in Decision Support Systems

David N. Ford and Dalton McCormack

Successfully managing dynamic complex systems requires an understanding of how structure influences both short and long term behavior. Therefore, decision support systems designed to improve performance by increasing user understanding require features that address both short and long time scales. The authors report the results of empirical research on the effects of features that facilitate different time scale focuses by users of management flight simulators on system understanding. System understanding was measured in two ways: with questions about the structural relationships and by performance measures pertaining to the management of a complex system. Participants were divided into two time scale groups. Results were disaggregated based on causal distance and the timing of impacts to relate time scale focus and system understanding. A second experiment evaluated and improved the hypothesis to include the interaction of the time scale of system control and the time scale focus on improving system understanding and performance in managing dynamic systems.

Keywords: decision-making, time scales, management flight simulator, system dynamics, system understanding, learning, decision support systems

Ford, D. and McCormack, D., "Effects of Time Scale Focus on System Understanding in Decision Support Systems," *Simulation and Gaming, An Interdisciplinary Journal of Theory, Practice, and Research*. Vol. 31, No. 3, pp. 309-330, Sept., 2000.

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A Behavioral Approach to Feedback Loop Dominance Analysis

David N. Ford

Feedback loop dominance is a critical tool in explaining how structure drivers behavior. Current analytic tools for loop dominance analysis are tacit, not codified, unable to accurately identify dominant loops or inapplicable to most models. Most loop dominance analysis tools focus on model structure to link structure and behavior. We use a behavioral perspective to define dominance, improve descriptions of behavior patterns and identify two important and incompletely developed areas of feedback analysis: simultaneous dominance, by multiple loops and shadow loop structures. An analytic procedure is presented, illustrated and compared to an alternative analysis method. An evaluation of the behavioral approach is the basis for identifying new issues and future research opportunities.

Keywords: system dynamics, loop dominance, model analysis

Ford, D. N. “A Behavioral Approach to Feedback Loop Dominance Analysis” *System Dynamics Review*. Vol. 15 No. 1 pp. 3-36, Spring 1999.

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Mental Models Concepts Revisited: Some Clarifications and a Reply to Lane

James Doyle and David N. Ford

This article revisits a conceptual definition of "mental models of dynamic systems" proposed for use in system dynamics research by Doyle and Ford and commented on by Lane. Lane's proposed amendments to the definition are discussed in turn, with particular attention to the history and appropriate use of the term "cognitive map." A revised definition informed by Lane's commentary is offered.

Keywords: mental models, system dynamics, cognitive map

Doyle, J. and Ford, D., "Mental Models Concepts Revisited: Some Clarifications and a Reply to Lane," *System Dynamics Review*, Vol. 15, No. 4, pp. 411-416. Winter, 1999.

The Application of System Dynamics to Concurrent Engineering

David N. Ford

Concurrent Engineering or simultaneous engineering imposes a lot of challenges on the project manager to successfully finish the project on account of the diversity of actions and agents, and the relationships and interactions between each entity. The diversity and tight coupling of various components makes it impossible to understand and improve concurrent engineering if the sole focus is on individual entities. The system has to be analyzed from a holistic view considering all the causal paths between each activities. Being a complex system, effective modeling and analysis will assist the designers and managers of concurrent engineering to understand how different components influence each other in order to design changes that will improve the performance. The paper addresses use of system dynamics to model these causal relationships, resultant structural feedbacks and effects of policies implemented in the system.

Keywords: Concurrent engineering**,** System dynamics, structural feedbacks, causal relationships.

Ford, D.N. "The Application of System Dynamics to Concurrent Engineering," *INSIGHT. International Council on Systems Engineering*. Vol. 2, No. 3, pp. 20 – 23, Fall, 1999.

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Expert Knowledge Elicitation for Improving Formal and Mental Models

David N. Ford and John D. Sterman

Knowledge intensive processes are often driven and constrained by the mental models of experts acting as direct participants or managers. For example, product development is guided by expert knowledge including critical process relationships which are dynamic, biased by individual perspectives and goals, conditioned by experience, aggregate many system components and relationships and are often nonlinear. Descriptions of these relationships are not generally available from traditional data sources such as company records but are stored in the mental models of the process experts. Often the knowledge is not explicit but tacit, so it is difficult to describe, examine and use. Consequently, improvement of complex processes is plagued by false starts, failures, institutional and interpersonal conflict, and policy resistance. Formal modeling approaches such as system dynamics are often used to help improve system performance. However, modelers face great difficulties in eliciting and representing the knowledge of the experts in these systems so useful models can be developed. Increased clarity and specificity are required concerning the methods used to elicit expert knowledge for modeling. We propose, describe and illustrate an elicitation method which uses formal modeling and three description format transformations to help experts explicate their tacit knowledge. To illustrate the approach we describe the use of the method to elicit detailed process knowledge describing the development of a new semiconductor chip. The method improved model accuracy and credibility in the eyes of the participants and provided tools for development team mental model improvement. We evaluate our method to identify future research opportunities.

Keywords: expert knowledge, knowledge elicitation, product development, mental models, system dynamics

Ford, D. and Sterman, J., “Expert Knowledge Elicitation for Improving Formal and Mental Models,” *System Dynamics Review*, Vol. 14, No. 4, pp. 309–340, Winter, 1998.

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Mental Model Concepts for System Dynamics Research

David N. Ford and Doyle, J

Although "mental models" are of central importance to system dynamics research and practice, the field has yet to develop an unambiguous and agreed upon definition of them. To begin to address this problem, existing definitions and descriptions of mental models in system dynamics and several literatures related to cognitive science were reviewed and compared. Available definitions were found to be overly brief, general, and vague, and different authors were found to markedly disagree on the basic characteristics of mental models. Based on this review, we conc luded that in order to reduce the amount of confusion in the literature, the mental models concept should be "unbundled" and the term "mental models" should be used more narrowly. To initiate a dialogue through which the system dynamics community might achieve a shared understanding of mental models, we proposed a new definition of "mental models of dynamic systems" accompanied by an extended annotation that explains the definitional choices made and suggests terms for other cognitive structures left undefined by narrowing the mental model concept. Suggestions for future research that could improve the field's ability to further define mental models are discussed.

Doyle, J. and Ford, D., “Mental Model Concepts for System Dynamics Research,” System Dynamics Review, Vol. 14, No. 1, pp. 3-29, Spring, 1998.

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Linking Academic Theory and Industry Practice with Student Interactive Projects

David N. Ford and Richard Paynting

The Bose Corporation and Massachusetts Institute of Technology (MIT) cooperated in an interactive project to apply system dynamics to product development. Bose and MIT participated at four levels: as individuals, as teams, as sponsors, and as organizations. The participants brought different but complementary objectives, perspectives, and abilities to the project. The MIT team consisted of three graduate students in the Applications of System Dynamics course at MIT's Sloan School of Management. Several product developers and managers of Bose's Systems Products Division participated. The teams used Products Division participated. The teams used a tightly coupled combination of facilitated discussions and model building to explore a current product development issue with the system dynamics methodology. The flexibility of the sponsors, teams, and project design allowed adjustments to both projects; inherent ambiguity and an unexpected change in scope. The integration of complementary projects features and participant capabilities ta several levels helped reach the goals of both the Bose and MOIT teams. This paper reports on the project and participant features that linked theory and practice, and introduces a tool to describe and explain the project. A design for interactive projects could improve projects from both industrial and academic perspectives.

Doyle, J. and Ford, D., "Mental Models Concepts Revisited: Some Clarifications and a Reply to Lane," *System Dynamics Review*, Vol. 15, No. 4, pp. 411-416. Winter, 1999.

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