Modeling Risk Classification Scheme for System Dynamics Modeling

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Abstract

System dynamics modelers face a broad spectrum of risks toward achieving project objectives. As they gain experience, their risk identification and management capabilities increase. By applying classification techniques from taxonomy development, the collective knowledge of previous modelers has been captured in a classification scheme for system dynamics modeling risks. The classification scheme allows modelers to more efficiently and effectively consider modeling risks by reducing the variation in their knowledge levels. The classification structure is focused on the steps of the system dynamics modeling methodology and the achievement of system knowledge and improvement objectives. As part of a broader modeling risk management approach, the risk classification scheme assists modelers in identifying and prioritizing the anticipated sources of modeling risks for a project. With that knowledge, they can more effectively identify the appropriate techniques for managing risks and then efficiently apply those techniques in a timely fashion through the entire project cycle.

Key words: system dynamics methodology, modeling risk, taxonomy development

1 Introduction

While system dynamics modeling projects have many similarities, individual projects also present unique challenges, or risks, to modelers and their clients. The system dynamics methodology is designed to assist modelers in addressing many of these risks. However, the complexities of modeling projects can increase the difficulties for modelers to successfully identify the specific risks on a particular project. This can result in the projects not effectively supporting their intended objectives.

Researchers have recognized this challenge through the years. Although not necessarily calling them "risks," discussions of modeling risks and how to manage them can be found in many literature sources, focusing on testing methods (Sterman 2000; Forrester 1961). However, the literature has not revealed focused efforts to capture these risks in a structure that supports modelers in consistently identify the specific challenges to project success.

The internal auditing profession faced similar challenges in their assessment of business process risks. In response to these challenges and others, they developed an approach to business risk management that includes a business risk dictionary, a risk classification structure that strives to improve the consistency with which risks are identified, discussed, and managed.

By adapting the principles of business risk management to the system dynamics modeling process, a system dynamics modeling risk management process was developed. To support that process, a taxonomy development process was applied to develop a system dynamics modeling risk dictionary. This dictionary, a classification system for modeling risks, allows modelers to use a common language, drawing upon the experience of other modelers, to efficiently and effectively identify and source the risks to successfully developing and using system dynamics models.

As a result of using the resulting system dynamics risk dictionary, modelers are guided to more consistently consider a broader range of modeling risks. They also have a framework for discussing modeling risks with clients, process participants, and other modelers. Even if the system dynamics modeling risk management process is not applied, consistency benefits are achieved.

2 Business Risk Management

In 1985, the Committee of Sponsoring Organizations (COSO) of the Treadway Commission was created and chartered with studying the factors that contribute to fraudulent financial reporting. The commission was charged with developing recommendations for improving financial controls.

The commission developed an integrated approach to internal controls that focused on risk management. Risk management was defined as "a systematic approach to identifying, analyzing, and proactively dealing with risks" (Committee of Sponsoring Organizations of the Treadway Commission 1994). This approach challenged auditors to enhance their traditional transactional approach with the more proactive, process-focused approach.

Importantly, the commission suggested that the traditional focus on auditing financial risks be expanded to focus on managing business risks. A business risk is defined as "the threat that an event or action will adversely affect an organization's ability to achieve its business objectives and execute its strategies successfully" (Economist Intelligence Unit 1995).

Three essential elements were identified for successfully managing business risk and became the defining characteristics of the business risk management approach (Economist Intelligence Unit 1995):

1. development of a common business risk language,
2. development of an effective organizational control structure, and
3. creation of a process view leading to business process control.

The common risk language is for all members of the organization to use when discussing business risk. Without a common language, it is difficult to have a common understanding of the business risks and the methods employed to manage them. Communication is hampered, which negatively impacts the efficiency and effectiveness of the control environment.

The suggested framework, often referred to as a "risk dictionary," for classifying the business risk language organized the risks into these top-level classifications (Economist Intelligence Unit 1995):

- Environment risks – arises from external forces that could either put a company out of business or significantly change the fundamental assumptions that drive its overall objectives and strategies.
- Process risks – arises when business processes are not achieving what they were designed to achieve.
- Information for decision making risks – arises when information used to support business decisions is incomplete, out-of-date, inaccurate, late, or simply irrelevant

These top-level headings were offered as guidance, not as the only structure, for organizations as they started down the path of implementing the business risk management approach. The only strict requirement was that the organization develop a common structure for their risk dictionary and utilize that structure throughout the organization. However, there is no evidence that the business risk dictionary process has a foundation in a formal taxonomy development process.

3 Taxonomy Development

To provide a structured approach to the development of the system dynamics modeling risk dictionary, taxonomy development methods were applied.

To determine if a taxonomy could be developed, the fundamental properties of a taxon, a classification within a taxonomy, were considered (Ruscio, Haslam, and Ruscio 2006). If the classes do not display these properties, then the risk dictionary would be more accurately identified as a typology or an empirical classification. A taxonomy structure is a more rigorously defined subset of a typological structure, which is a more defined subset of a general classification system.

Strictly, a taxon has to display properties regarding its latent structure, boundary, and endurance. A latent structure contains the fundamental nature of the construct and exists regardless of how various individuals choose to conceptualize or measure it. The cases within the taxon should share a deep commonality. This can be contrasted with the manifest structure, which utilizes observable features and depends significantly on the theoretical assumptions and measurement decisions that form the structural basis. Typically, the latent structure is inferred from observable relationships between variables in the manifest structure.

Each taxon should identify a category with a distinct boundary. The taxon should have a finite membership that could theoretically be counted. While distinctions with a taxon can be identified on a continuous scale, the boundaries between taxa should be non-arbitrary and objective. This criterion is the one that is most often the determinant of whether the classification system captures taxa or categories. The criteria might be useful, but not identify taxa. In addition, the taxa criteria should be objective at the latent level. The boundary criteria and the taxa should be reasonably enduring, persisting for a timeframe that is significant to the system being classified.

Since the modeling risk dictionary classification structure does not display distinct boundaries, the structure is more properly classified as a typology, rather than a taxonomy. The iterative nature of the system dynamics modeling process contributes to the lack of distinct boundaries.

A generic process for developing a taxonomy within an information technology environment (Table 1) was used as the basis for developing the modeling risk dictionary (Harris, Caldwell, and Knox 2003). The process starts by analyzing the existing information and determining the user needs for the information. Combining the results of these analyses generates the initial information vocabulary. The vocabulary forms the basis of the taxonomy, which is then applied against the information and tested with users. This is an iterative process until the users agree on the value of the taxonomy. Then the taxonomy is implemented for the broader community, utilizing feedback from the community to guide improvements to the taxonomy.

Table 1. Information Technology Taxonomy Development Process

Steps	Actions
Analyze	Inventory information assets (current and planned)
	Audit end-users' information needs as well as their usage and access patterns
	Establish information vocabulary
Define, build, test, and refine	Design and populate taxonomy
	Index, link and cluster a test bed of information assets
	Test with users and content managers
Implement, monitor, and maintain	Implement taxonomy, index all information assets
	Monitor usage and user/content manager feedback

The scope of this research encompasses the analysis step for the modeling risk dictionary. The scope also includes the definition step through initial testing for both the risk dictionary and the risk techniques database. Full testing and implementation of the modeling risk dictionary and the risk techniques database require long-term consideration and is, of necessity, beyond the scope of this research, but is envisioned as part of future work.

4 Developing the System Dynamics Modeling Risk Dictionary

The system dynamics literature does not reveal any attempts to classify the risks that system dynamics modelers could encounter during the planning, development, and utilization of their models. Possibly, this reflects the focus on building confidence and credibility, which has its roots in the early days of system dynamics (Forrester 1961). In addition, the business risk viewpoint was developed in the late 1980's and has been slowly emerging since then (Committee of Sponsoring Organizations of the Treadway Commission 1994). The principles are now available for this research.

Taking the viewpoint that the system dynamics methodology is a process leads to the possibility of applying the business risk dictionary approach and developing a modeling risk framework, or typology, that identifies the modeling risks that can be anticipated during the system dynamics modeling process steps.

4.1 Developing the Modeling Risk Framework

The taxonomy development process (Table 1) was used as the basis for developing the modeling risk framework. The analysis step generated the framework and led to the definition step which populated the modeling risk dictionary. The specific research tasks within each of the steps are described in the following sections.

4.2 Information Analysis and Needs Analysis

The system dynamics modeling process form the starting point for the modeling risk framework. Applying the taxonomy development process, this framework was built from a review of foundational system dynamics methodology literature, including theoretical and applied publications. The methodological literature focused on subject matter expertise and the model development literature provided the user perspective that the taxonomy development process requires.

Although there is some variability in the names applied to the key steps in the system dynamics methodology (Forrester 1961; Randers 1980; Richardson and Pugh 1981), a common iterative process for developing system dynamics models involves these five key steps (Sterman 2000):

- problem articulation,
- formulation of the dynamic hypothesis,
- formulation of a simulation model,
- testing, and
- policy design and evaluation.

These steps capture both of the primary objectives, increased system understanding and system improvement, of system dynamics applications. This framework (Figure 1) is aligned with the steps of the system dynamics modeling process, supporting a tight integration of the modeling risk management with the overall method.

In addition to consideration of the system dynamics modeling method, the verification, validation, and accreditation (VV&A) process often used in the defense modeling community provides a structure for addressing simulation model credibility. This structure focuses on the "four P's" of people, project, process, and product (Balci 2005). Giving consideration to these focus areas generated the system dynamics modeling framework for the modeling risk dictionary (Figure 1). Within each focus area in the framework are a variety of potential risks.

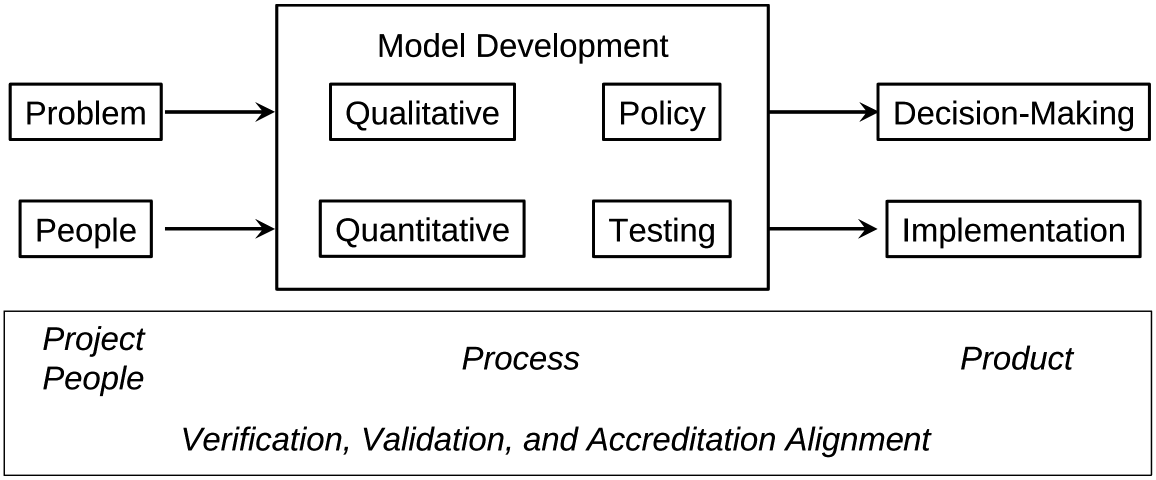

Figure 1. System Dynamics Modeling Risk Framework

In addition to the process-focused format, risk frameworks are often visualized in a tree format where the specific risks are indicated where they are most likely to impact the achievement of process objectives. For the modeling risk framework, the tree format branches are focused on the achievement of the learning and behavior improvement objectives (Figure 2). This structure was finalized during the application of the information analysis steps in the taxonomy development method.

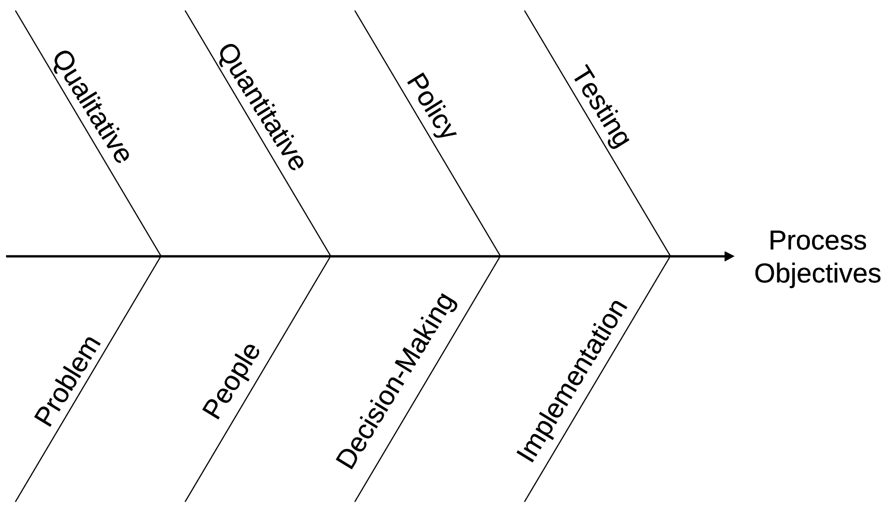

Figure 2. Modeling Risk Tree Diagram

Starting from the COSO definition of business risk, system dynamics modeling risk is generally defined as "the threat that an event or action will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives."

The general definition is used as the basis for more specific definitions within each area of the system dynamics modeling risk framework (Table 2).

Table 2. Top-Level System Dynamics Modeling Risk Definitions

Area	Risk Definition
Project Planning	
Problem	The threat that events or actions relating to **defining the modeling project and how the system dynamics method can contribute** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
People	The threat that events or actions relating to **the people associated with the project, including modelers, clients, process participants, subject matter experts, and decision-makers** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Model Development	
Qualitative	The threat that events or actions relating to **developing the system dynamics qualitative model, focusing on identification of appropriate structural elements and their relationships,** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Quantitative	The threat that events or actions relating to **developing the system dynamics quantitative model, focusing on the quantitative relationships between structural elements** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Model Analysis	
Testing	The threat that events or actions relating to **how the system dynamics model is assessed** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Policy	The threat that events or actions relating to **policy alternatives and their assessment** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Model Use	
Decision-Making	The threat that events or actions relating to **how decisions are made based on knowledge gained from the modeling process** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.
Implementation	The threat that events or actions relating to **sustainable utilization of knowledge gained from the project or implementation of system modifications** will adversely affect the ability of the system dynamics modeling project to achieve its system understanding and behavior improvement objectives.

4.3 Populating the Modeling Risk Dictionary

The analysis step of taxonomy development established the framework that provides the basis for populating the dictionary. Then the literature review identified the risks that modelers have encountered during modeling projects. These results from the information analysis were then classified according to the modeling framework. A key classification principle was to identify risks as early as possible within the modeling process, especially if the effects of the risk could be felt during multiple steps in the modeling method.

For populating the system dynamics modeling risk dictionary, two primary literature review approaches were pursued. First, foundational publications focused on explaining the system dynamics modeling methodology suggested an initial list of risks for consideration. The next approach was to target research publications focusing on verification and validation techniques. Analysis of the techniques suggested the risks that they were targeting for discovery, management, and mitigation.

Each suggested risk was defined and then classified within the modeling risk framework to provide modelers and clients with consistent definitions of risks so that they are speaking the same language when they are identifying, sourcing, and measuring modeling risks for projects. While the modeling risks typology is always subject to review, the dictionary should not change often, reflecting the durability principle of taxonomy development.

4.3.1 Methodology Focus

An example of a methodology-focused starting point for developing the modeling risk dictionary can be found in “Questions Model Users Should Ask – But Usually Don’t” (Sterman 2000). Captured in these questions are suggested risks that could be included in the modeling risk dictionary (Table 3).

Table 3. Suggested Modeling Risks from Assessment Questions

Question Area	Suggested Risks
Purpose, Suitability, and Boundary	• Purpose • Boundary • Endogenous Behavior • Time Horizon • Aggregation
Physical and Decision-Making Structure	• Physical Laws • Dimensional Consistency • Stock and Flow Consistency • Endogenous Behavior • Delays and Limitations • Rational Behavior • Information for Decision Making
Robustness and Sensitivity to Alternative Assumptions	• Assumptions • Extreme Inputs • Extreme Policies
Pragmatics and Politics of Model Use	• Documentation • Source Data • Testing • Reproducibility • Cost • Revision • Modelers' Bias • Clients' Bias

Another source for suggesting modeling risks is captured in a proposed generalized assessment approach (Randers 1980). This approach focused on consideration of a broad variety of system behavior characteristics that suggest potential modeling risks (Table 4), some of which were suggested in the previous example.

Table 4. Suggested Modeling Risks from Behavior Characteristics

Behavior Characteristics	Suggested Risks
Generate multiple behavior modes	• Behavior Mode Generation
Plausibility of causal structures	• Causal Relationships
Plausibility of parameter values [and dimensions]	• Sensitive Parameters • Dimensional Consistency
Compatibility of individual assumptions with established knowledge	• Assumptions
Internal consistency of the full structure	• Consistency
Completeness with which the model includes the mechanisms thought to generate the problem addressed.	• Boundary • Endogenous Behavior

In addition to these sources, other references focused on methodology were utilized (Forrester 1961; Coyle 1976; Richardson and Pugh 1981). These sources provided similar insights as those mentioned above. Although not all of the preliminary risks were explicitly included the final risk dictionary, their fundamental characteristics were considered. For example, Physical Laws risk was originally identified, as was Spatial Structural risk. Within the final dictionary, they are included in the Physical Properties risk definition.

4.3.2 Testing Method Focus

To create multiple points of contact for assessing models, the system dynamics methodology relies on applying a framework of tests to achieve the confidence-building objective. Commonly, these test frameworks are grouped around structure, behavior, and policy (Forrester and Senge 1980), structure and behavior from suitability, consistency, utility, and effectiveness perspectives (Richardson and Pugh 1981), and informally around structure, behavior, and policy (Sterman 2000). These classifications align well with the modeling risk framework. Analysis of these tests contributed risks for inclusion in the risk dictionary.

In addition to these testing frameworks, other focused tests have been proposed. While not always adopted for general use, analysis of these tests also indicated modeling risks. The objectives of these tests suggested risks focused on parameters (Peterson 1980; Graham 1980), behavioral characteristics (Barlas 1989), surprise behavior (Mass 1991), sensitivity analysis (Tank-Nielsen 1980), and structural coherence (Coyle 1976).

Tests are not the only indicators of modeling risks to be managed. Best practices and guidelines outlined in the literature also suggest modeling risks. For example, the five formulation fundamentals for decision-making (Sterman 2000) make the case for decision-making structure risk being part of the modeling risk dictionary.

5 System Dynamics Modeling Risk Dictionary

Based on the literature review, the modeling risks were identified and classified in the modeling risk framework (Figure 1). The modeling risks are easily considered with the use of the risk tree diagram (Figure 3). Definitions for each of the modeling risks can be found in Appendix A.

5.1 Model Analysis Risks

Development of the model leads to consideration of risks associated with the analysis of the model, focusing on model testing and policy analysis.

5.1.1 Testing Risks

The testing risks focus on consideration of the challenges that modelers could encounter relative to the selection and application of system dynamics testing methods, including basic and advanced techniques. This continues to consideration of the robustness of the model and range of conditions under which he can be claimed to be valid. Similar to the other development steps, consideration of the risks linked to inferences made from testing must be considered.

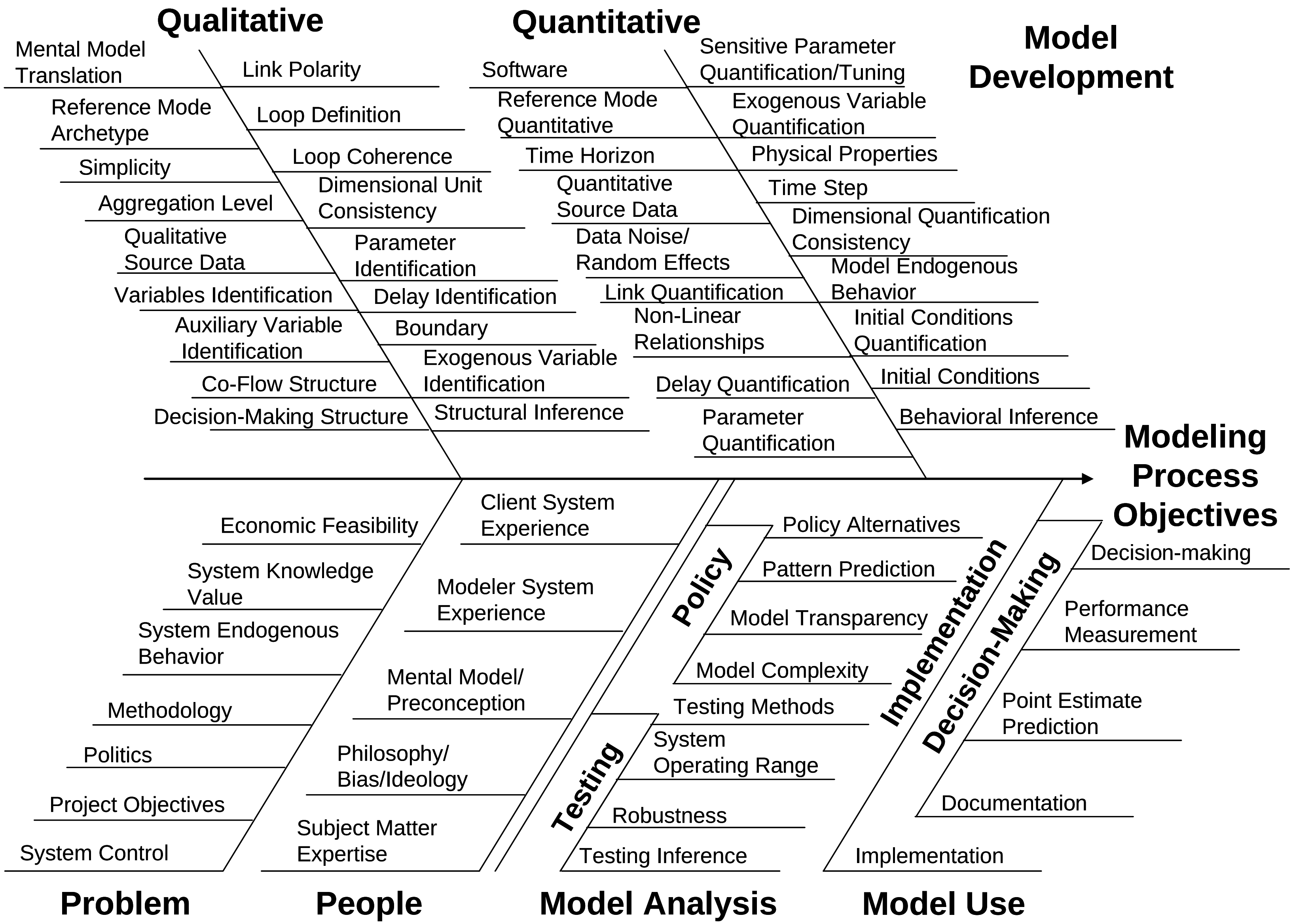

Figure 3. System Dynamics Modeling Risk Tree Diagram

5.2 Project Planning Risks

The project planning risks are those anticipated to be encountered early in the project, even before the project has really been initiated. The risk dictionary identifies risks associated with the problem on which the project is focused and risks associated with the people who will be involved in the modeling process.

5.2.1 Problem Risks

The Problem Risks include consideration of project objectives and the anticipated project value, including both economic value from improved system performance and value from knowledge elicited from the modeling process.

Consideration of the feasibility for applying system dynamics is addressed through the system endogenous behavior and methodology risks. In addition, consideration is given to the political environment in the organization to anticipate how that will affect the project.

The final project risk considers whether the state of control of the system, including components, parameters, and people, supports successful modeling, analysis, and improvement.

5.2.2 People Risks

The People Risks encourage consideration of the experience levels of both the modelers and clients. Their experience with both the targeted system and with system dynamics modeling should be considered. Similar consideration is directed toward other subject matter experts who contribute knowledge to the project.

Consideration is also given to risks associated with the mental models and preconceptions that the project participants have. Successful management of these risks mitigates their effects during the model building and analysis steps.

Giving early consideration to the philosophy or biases of project participants addresses their capabilities to utilize system thinking skills, techniques, and tools to understand and improve the target system.

5.3 Model Development Risks

The risks associated with model building are first classified into those closely linked with model development. Then, the risks focused on model analysis are captured in separate classifications. Within model development, the risks are focused on either qualitative or quantitative model building.

5.3.1 Qualitative Model Development Risks

Qualitative model development focuses on the identification of structural elements and their linkages. System dynamics relies on the elicitation of information in mental models and the application of reference mode archetypes to guide the qualitative model development process. Therefore, risks associated with archetypes and mental models are considered. Additional risks can be encountered with the qualitative data sources that are tapped for model building.

The proper identification of structural elements forms the basis for many of the risks in this class. These elements include the stocks and flows at the foundation of the model and the auxiliary elements that are included to capture the relationship structures in the system. The risks associated with identification of links, delays, and parameters are also addressed here. The structural elements form the basis for loop identification, and consideration of the risks associated with assigning polarity and maintaining dimensional consistency.

Receiving special attention are co-flow and decision-making structures. These structures are not intuitive to many modelers and are not encountered in all models. As a result, consistent development can be more challenging. Therefore, the risk dictionary encourages explicit consideration of these risks.

As the model evolves, the boundary definitions become important for enabling the model to generate behavior in an endogenous manner. The boundary definition leads to consideration of risks associated with the identification of exogenous variables.

Because the development of qualitative models supports the inference of system performance based on the structural elements, consideration is given to the risks associated with the aggregation level of the model. Additional consideration is given to the simplicity of the model, which contributes to whether the relationship between the system and the model is strong enough to support inference.

5.3.2 Quantitative Model Development Risks

As its name implies, quantitative model development focuses on the quantification of structural elements and their linkages. An initial risk to consider focuses on the capabilities of the software being used to simulate the models. Other risks that modelers often associate with software include the time step used and the time horizon modeled.

Most of the risks encountered in quantitative model development have relationships with structural element *identification* risks in qualitative model development, starting with consideration of data sources. In addition, the impact of data noise or random effects is considered. Quantification risks for links, delays, parameters, and exogenous variables are all addressed. Dimensional consistency must be considered for all quantities.

Special consideration is given to the quantification of non-linear relationships. These relationships are often especially crucial to effective modeling, leading to explicit consideration.

After the initial quantification of the models, consideration is given to risks focused on dimensional consistency. In addition, physical properties risks are considered. This consideration includes spatial and temporal risks. Considering these risks sets the stage for considering risks associated with identifying and tuning sensitive parameters.

Consideration of the risks associated with the initial conditions contributes to managing the model endogenous behavior risks. The final risks to be considered during quantitative model development are those associated with the inferences made from the model behavior.

5.3.3 Policy Risks

The policy risks focus on the development of policy alternatives for consideration and how understanding is developed from application of the policies. Consideration is given to both the transparency and complexity of the model structure since both could inhibit understanding. The risks associated with predicting results are also considered.

5.4 Model Use Risks

The model use risks focus on how decisions are made based on the modeling process and then how changes will be implemented as a result of the modeling process.

5.4.1 Decision-Making Risks

The decision-making risks focus on how decisions are made based on the modeling process. Consideration is given to the decision-making process and the performance measures that the organization uses for assessing system performance.

While the focus of system dynamics is on behavior patterns, rather than specific point performance, the desire of many modelers and clients to use the modeling process to provide point estimates creates a risk that should be considered.

Finally, the decision-making risks include the risks associated with how the project is documented. The documentation can support long-term use of the model and contribute to greater understanding of how the model operates and can be used.

5.4.2 Implementation Risk

The implementation risk focuses on consideration of sources of risks that will limit the sustainable structural and policy changes that can be anticipated from the modeling process.

6 Future Work

The development of the system dynamics modeling risk dictionary is a component of research leading to a system dynamics risk management framework. The risk dictionary supports the identification and sourcing of modeling risks. Additional research supports the measurement of likelihood and significance of the risks. Linked to a risk management techniques typology, the risk measurement information suggests risk management strategies for the risks. Modelers are then able to develop their modeling risk management plan early in their projects and document results during the entire process. The ultimate objective of the research is to align risk management resource levels, including testing, with the anticipated risk levels.

7 Conclusions

By recognizing the system dynamics modeling method as a process, the business risk management principles can be applied to the development of a framework for managing system dynamics modeling risks.

A key component of this framework is the modeling risk dictionary, which was developed by applying the principles of taxonomy development. Modelers can use the modeling risk dictionary to consistently consider the risks that they might encounter during their modeling projects. Having this resource available to inexperienced modelers supports increasing their rate of climbing the learning curve.

By encouraging risk assessment early in the project, modelers increase the likelihood that they will use appropriate techniques for managing their project risks, either by removing them at the source, avoiding their occurrence, or discovering them and improving the model.

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Appendix A

System Dynamics Risk Dictionary Definitions

1 Project Planning

1.1 Problem

Risk	Definition
Economic Feasibility Risk	the risk that value to be achieved from improved system performance does not justify the project costs.
System Knowledge Value Risk	the risk that the value to be achieved from elicited system knowledge does not justify the project costs
System Endogenous Behavior Risk	the risk that the problem system does not generate behavior endogenously.
Methodology Risk	the risk that the system dynamics methodology is not a strong approach for eliciting system knowledge or driving system performance improvement.
Politics Risk	the risk that political environment in a client organization can affect the decision-making or system improvement implementation.
Project Objectives Risk	the risk that the problem objectives are not clearly defined or are not achievable
System Control Risk	the risk that the level of control in the system, including components and people, does not allow it to be effectively modeled or improved.

1.2 People

Risk	Definition
Client System Experience Risk	the risk that the experience level of system personnel affects their abilities to participate effectively in the modeling process.
Modeler System Experience Risk	the risk that the experience level of the modelers will affect their abilities to effectively model the system, elicit system knowledge, and determine system improvement recommendations.
Mental Model/ Preconception Risk	the risk that the mental models of the modelers or the clients are significantly inaccurate.
Philosophy/Bias/Ideology Risk	the risk that the perspectives of system participants or modelers will affect their capabilities to utilize system thinking skills, techniques, and tools to understand and improve the problem system.
Subject Matter Expertise Risk	the risk that the subject matter expertise used for modeling the problem system limited in level, breadth, or availability.

2 Model Development

2.1 Qualitative

Risk	Definition
Mental Model Translation Risk	the risk that the mental models of the participants will not be captured effectively and translated into modeling elements well.
Reference Mode Archetype Risk	the risk that the use of a system modeling archetype from the reference mode will guide improper development of the model.
Simplicity Risk	the risk that the model structure is simplified so much relative to the system complexity that the linkage between model and system is tenuous.
Aggregation Level Risk	the risk that the aggregation level does not effectively model the problem system or that it creates a level of complexity that obscures system behavior.
Qualitative Source Data Risk	the risk that valid information necessary to qualitatively model the system is not readily available.
Variables Identification Risk	The risk that the primary variables included in the model, focusing on stocks and flows, do not represent the system structure well so that the behavior reflects the structure.
Auxiliary Variable Identification Risk	the risk that the auxiliary variables and links in a qualitative model are identified incorrectly
Co-flow Structure Risk	the risk that a co-flow situation in the system is not properly recognized and modeled.
Decision-making Structure Risk	the risk that a decision-making structure is not properly modeled.
Parameter Identification Risk	the risk that the sensitive parameters will not be properly identified in a qualitative model.
Link Polarity Risk	the risk that the polarity of links in a qualitative model are assigned incorrectly.
Loop Definition Risk	the risk that the polarity of loops in a qualitative model are determined incorrectly, impacting structural inference.
Loop Coherence Risk	the risk that loops in a qualitative model are not structurally coherent.
Dimensional Unit Consistency Risk	the risk that the units applied to structural elements in a qualitative model are not consistent.
Delay Identification Risk	the risk that the material and information delays in the system will not be properly identified in a qualitative model.
Boundary Risk	the risk that the defined model boundary will affect inclusion of structural or policy elements to generate the endogenous system behavior
Exogenous Variable Identification Risk	the risk that key exogenous variables are not correctly identified for a problem system.
Structural Inference Risk	the risk that the inferences made from the model structure are not valid based on the available information

2.2 Quantitative

Risk	Definition
Software Risk	the risk that the modeling software capabilities, including the integration method, impact the quality of the model.
Reference Mode Quantitative Risk	the risk that the theoretical reference mode does not accurately reflect true system behavior.
Time Horizon Risk	the risk that the time horizon modeled is either too short or too long to effectively represent the system behavior.
Quantitative Source Data Risk	the risk that valid information necessary to quantitatively model the system is not readily available.
Data Noise/Random Effects Risk	the risk that random effects in the data will lead to improper quantification.
Link Quantification Risk	the risk that auxiliary and flow rate links in a quantitative model are quantified incorrectly.
Non-linear Relationships Risk	the risk that non-linear relationships will be quantified incorrectly.
Delay Quantification Risk	the risk that the material and information delays in the system will not be properly quantified in a quantitative model.
Parameter Quantification Risk	the risk that the parameters will not be properly quantified in a quantitative model.
Sensitive Parameter Quantification/Tuning Risk	the risk that the sensitive parameters will not be properly quantified and tuned in a quantitative model.
Exogenous Variable Quantification Risk	the risk that key exogenous variables are not correctly quantified for a quantitative model.
Physical Properties Risk	the risk that physical properties or flows will not be modeler correctly, including violations of physical laws.
Time Step Risk	the risk that the time step selected for the quantitative model will improperly reflect the system dynamics.
Dimensional Quantification Consistency Risk	the risk that the values applied to structural elements in a quantitative model are not consistent with the units assigned to the elements.
Model Endogenous Behavior Risk	the risk that the model behavior will not effectively demonstrate the endogenous behavior of the system.
Initial Conditions Quantification Risk	the risk that initial conditions are not properly quantified for the model
Initial Conditions Risk	the risk that the sensitivity of the system dynamics to the initial conditions is not properly identified
Behavioral Inference Risk	the risk that the inferences made from the model behavior are not valid based on the available information

3 Model Analysis

3.1 Testing

Risk	Definition
Testing Methods Risk	the risk that testing methods are not well understood, poorly applied, and/or inefficiently used.
System Operating Range Risk	the risk that the model does not demonstrate acceptable behavior across the full range of realistic operating conditions.
Robustness Risk	the risk that the model does not function well for a breadth of realistic starting conditions and/or parameters.
Testing Inference Risk	the risk that the inferences made from testing methods do not elicit correct system or model knowledge

3.2 Policy

Risk	Definition
Policy Alternatives Risk	the risk that the policy alternatives considered will be too narrow, too broad, or unrealistic.
Pattern Prediction Risk	the risk that the model does not effectively predict the system behavior pattern in the presence of structural, or policy, changes.
Model Transparency Risk	the risk that the model behavior can not be easily linked to the model structure.
Model Complexity Risk	the risk that the model structure is so complex that understanding is limited about the resulting model behavior

4 Model Use

4.1 Decision-Making

Risk	Definition
Decision-making Risk	the risk that the decision-making approach will be limited or faulty in execution or timeliness.
Performance Measurement Risk	the risk that the actual reference mode does not provide an effective indicator of system behavior.
Point Estimate Prediction Risk	the risk that the model does not effectively and accurately predict specific system behavior at a specific time.
Documentation Risk	the risk that the modeling project documentation will affect the level of understanding or the value achieved from the modeling project. This risk must be considered for both the short-term and over a longer time period.

4.2 Implementation

Risk	Definition
Implementation Risk	the risk that the level of implementation of recommendations from the modeling project will affect the value achieved.

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