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Teddy Steven Cotter
Old Dominion University

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A PROPOSED TAXONOMY FOR THE SYSTEMS STATISTICAL ENGINEERING BODY OF KNOWLEDGE

T. Steven Cotter
Old Dominion University
tcotter@odu.edu

Abstract
In the ASEM-IAC 2012, Cotter (2012) identified the gaps in knowledge that statistical engineering needs to address, explored additional gaps in knowledge not addressed in the prior works, and set forth a working definition of and body of knowledge for statistical engineering. In the ASEM-IAC 2015, Cotter (2015) proposed a systemic causal Bayesian hierarchical model that addressed the knowledge gap needed to integrate deterministic mathematical engineering causal models within a stochastic framework. Missing, however, is the framework for specifying the hierarchical qualitative systems structures necessary and sufficient for specifying systemic causal Bayesian hierarchical models. In the ASEM-IAC 2016, Cotter (2016) specified the modeling methodology through which statistical engineering models could be developed, diagnosed, and applied to predict systemic mission performance. In the last research update, Cotter (2017) proposed revisions to and integration of IDEF0 as the framework for developing hierarchical qualitative systems models. In that work, Cotter noted that a hierarchical causal Bayesian socio-technical modeling body of knowledge was yet to be developed, validated, and peer reviewed. This paper reports research into development of a core taxonomy for the systems statistical engineering causal Bayesian socio-technical modeling body of knowledge.

Keywords
Body of Knowledge, Systems Statistical Engineering, Taxonomy

Introduction
Cotter (2012) documented the evolution of statistical engineering from its conceptual origins over last 40 years and offered its definition as "… the integration of statistical theory with technical, engineering, information systems, managerial, financial, and economic knowledge to solve applied complex organizational and societal problems that involve elements of risk or uncertainty in their outcomes." Cotter (2018) expanded the research term to "systems statistical engineering" (SSE) to recognize that complex organizational and societal problems exist only in systems of interconnected processes. As a research domain, however, the question arises as to what conceptually is systems statistical engineering? What is its ontological foundation? As a first step toward building the systems statistical engineering ontological foundation, this research compiled all prior works on statistical engineering and Cotter's on systems statistical engineering and applied exploratory concept analysis to build an initial concept map taxonomy.

Concept Extraction Methodology
The corpus consisted of five seminal articles discussing the state and future of statistical thinking and first proposing statistical engineering published in Quality Engineering 22(3), six seminal articles debating the concept of statistical engineering published in Quality Engineering 24(2), and five ASEM-IAC papers by Cotter (2012, 2015, 2016, 2017, 2018) laying the foundations for the systems statistical engineering body of knowledge. The 2010 discussion of the state of statistical thinking was the culmination of two decades of research into and publication about statistical thinking by Roger Hoerl and Ron Snee (Hoerl, et. al., 1993). Over the two-year period from 2010 to 2012, statistical thinking evolved into the concept of statistical engineering. With little further development in the statistics community, Cotter evolved the concept into systems statistical engineering with the objective of establishing a causal Bayesian hierarchical modeling approach necessary and sufficient for complex socio-technical systems engineering.

The core SSE concept map was use build using the definition of statistical engineering set forth by Cotter (2012). The concept map was refined from review of the corpus literature using the hierarchy of semantic relations methodology set forth by Madsen (2001, 2002) and Nuopponen (2005, 2006). The general core concept mapping process flow was:

1. Establish the purpose and delimitation of the concept analysis.

2. Identify the knowledge domain of interest.
3. Compile the literature into a corpus
4. Elaborate a primary hierarchical concept system.
5. Systematically analyze the literature elaborating a taxonomic category, clarifying relations within the category, differentiating the category from those of its current level, clarifying synonymy and polysemy and equivalence, modifying the category, and validating concept intention with appropriately defined competency questions.
   - Core concept
     - Generic subordination
       - Generic coordination
       - Generic superordination
     - Indirect generic coordination with other categories
     - Object properties and characteristics
6. Repeat steps 4 and 5 to refine the concept map taxonomy.

The exploratory SSE concept map taxonomy was built using the concept map facility in the Docear academic literature suite.

The Exploratory SSE Taxonomy

Cotter (2012) set forth the following definition of statistical engineering as:

> … the integration of statistical theory with technical, engineering, information systems, managerial, financial, and economic knowledge to solve applied complex organizational and societal problems that involve elements of risk or uncertainty in their outcomes.

Cotter further noted that this definition encompasses the major themes found in the CTIS study, the ASQC working group's recommendations, and in the literature.

- Integrates theoretical and applied statistics with engineering, information systems, managerial, financial, and economic decision making.
- Requires interdisciplinary knowledge and cross-disciplinary teamwork in a strategic framework to address complex organizational and societal problems.
- Admits that complex organizational and societal problems exist only in systems of interconnected processes.
- Recognizes that variation exists in organizational and societal processes making future outcomes of decisions made today uncertain and risky.
- Recognizes that understanding the unique nature of both common and special causes though validated statistical models is the key to reducing variation in future outcomes.

In that paper, Cotter first proposed an SSE generalized variance transfer function model as

$$\begin{aligned} &\text{Min } \mathbf{Y}_{\text{Total}} = f(\mathbf{w}'(\mathbf{Y} - \mathbf{T})) + \varepsilon \\ &\text{s.t.} \\ &\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\boldsymbol{\gamma} + \epsilon \\ &\mathbf{L}_X \le \mathbf{X} \le \mathbf{U}_X \\ \text{possibly}\quad &\mathbf{L}_Z \le \mathbf{Z} \le \mathbf{U}_Z \end{aligned} \tag{1}$$

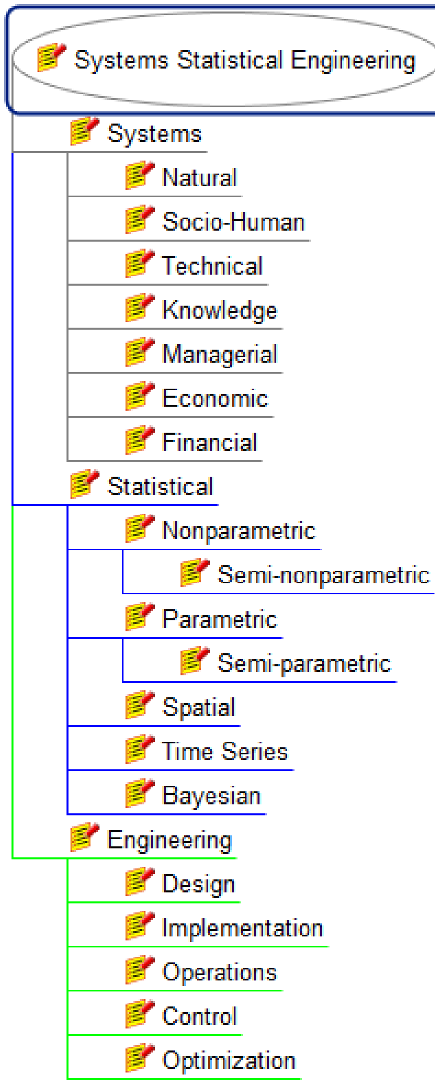
which he subsequently revised to the following causal Bayesian hierarchical model (Cotter, 2016) to integrate hierarchical, state space dynamics.

$$\begin{aligned} &\text{Min } \mathbf{Y}_{\text{Total}} = f(\mathbf{w}'(\mathbf{Y}_{\text{pred}} - \mathbf{T})) \\ &\text{s.t.} \\ &\mathbf{Y} = \mathbf{F}(pa_i, u_{xi})\boldsymbol{\beta} + \mathbf{F}(pa_j, u_{zj})\boldsymbol{\gamma} + \varepsilon \\ &\mathbf{L}_X \le \mathbf{F}(pa_i, u_{xi}) \le \mathbf{U}_X \\ \text{possibly}\quad &\mathbf{L}_Z \le \mathbf{F}(pa_j, u_{zj}) \le \mathbf{U}_Z \end{aligned} \tag{2}$$

The above information formed the basis for establishing the primary SSE concept map illustrated in Exhibit 1.

Purpose: Build an initial SSE taxonomy based on an exploratory concept map.
Delimitation: Complex systemic organizational, product, and service design problems that involve elements of risk or uncertainty in their outcomes. Broader societal problems are excluded due to the extreme nonlinearities and discontinuities that exist in those often-conflicting non-logical conflicting processes.
Elaboration: Elaborate primary SSE taxonomy

Exhibit 1: Exploratory core SSE hierarchical concept system.



The terms glossary is provided in Exhibit 2.

Exhibit 2: Exploratory core SSE terms glossary.

Name	Definition	Type
Systems Statistical Eng.	Integration of statistical, technical, engineering, information, managerial, financial, and economic knowledge within a causal Bayesian hierarchical model to solve applied complex organizational, process, and product problems.	Concept
Systems	A collection of interconnected transformation processes organized within a hierarchical cybernetic control structure that efficiently and effectively transforms energy, information, and material inputs into usable output products and services under the influence of environmental, internal systemic, and input non-controllable noise sources.	Concept
Natural	A community of living organisms whose existence and functioning within collections of non-living components is subject only to environmental forces.	Concept
Socio-Human	Communities of human individuals that self-organize, function, and interact within five environmental systems: (5) Chronosystem, (4) Macrosystem, (3) Exosystem, (2) Exosystem, and (1) Microsystem.	Concept
Technical	Human designed complex network of automation, intelligent machines, and humans that interact to produce output products and services usable by other automation, intelligent machines, and humans.	Concept
Knowledge	The practices, processes, hardware, and software applied to the collection, organization, transformation, storage, and communication of sets of data that convey information and knowledge.	Concept
Managerial	Organizational policies, processes, and structures for planning, organizing and staffing, and controlling toward attainment of organizational goals.	Concept
Economic	Interlinked agencies and institutions that exchange information and money through social relations for the purpose of producing goods and services.	Concept
Financial	A bounded set or sets of lenders, investors, and borrowers that exchange funds for the purpose of creating and maintaining an economic system.	Concept
Statistical	Numerical models that map systemic, process, or product performance to their respective causal, correlational, and random variance components.	Concept
Nonparametric	Infinite dimensional parameter space model that makes no or few distributional assumptions about the error term.	Concept
Semi-nonparametric	Mixed finite dimensional space parameters and infinite dimensional parameters of interest.	Concept
Parametric	Finite dimensional space parameters with a proper identically, independently probability distribution error term.	Concept
Semi-parametric	Finite dimensional space parameters of interest and infinite dimensional nuisance parameters for the error term.	Concept
Spatial	Statistical methods that are constrained by space relationships such as distance, area, length, height, or angle in mathematical computations.	Concept
Time Series	Statistical methods for analyzing time ordered data for the purpose of estimating dynamic statistics and predicting future values.	Concept
Bayesian	Statistical models that represent a set of variables and their conditional dependencies.	
Engineering	The application of natural scientific laws, principles, and attributes to the design, implementation, operation, control, and optimization of chemical, information, physical, and biological systems of transformation processes and the socio-technical products and services that they output.	Concept

Exhibit 2 (continued): Exploratory core SSE terms glossary.

Name	**Definition**	**Type**
Design	The decision-making process in which basic scientific and mathematical knowledge is applied for the purpose of devising a system, component, or process to meet desire performance objectives.	Concept
Implementation	The scale-up from design or prototyping to full production operations.	Concept
Operations	The analysis and optimization of productive processes using scientific and mathematical models.	Concept
Control	The application of automatic control theory to the design of detectors to measure output process performance and provide difference to target information as corrective feedback to adjust input parameters to achieve the desired target performance.	Concept
Optimization	The application of mathematical models to maximize a set of process parameters relative to a set of specifications and subject to a set of constraints, while keeping all other parameters within their respective specifications and constraints.	Concept

Systematical analysis of the 2010 statistical thinking literature elaborated the following additional taxonomic categories and relations.

- Hoerl, Roger W. and Ron Snee. (2010) Statistical Thinking and Methods in Quality Improvement
  - Statistical engineering as a science and discipline.
  - Statistical engineering as an academic research discipline.
- de Mast, Jeroen and Ronald J. M. M. Does. (2010) Discussion of 'Statistical Thinking and Methods in Quality Improvement
  - Statistical engineering as a research paradigm.
- Rotelli, Matthew. (2010) Response to 'Statistical Thinking and Methods in Quality Improvement
  - Statistical engineering research philosophy
- Vining, G. (2010) Statistical Thinking and Methods in Quality Improvement
  - Statistical engineering as a profession
  - Statistical engineering scholarship
- Hoerl, Roger W. and Ron Snee. (2010) Rejoinder: A Consensus that the Statistics Profession Must Change
  - Statistical engineering training

Systematical analysis of the 2012 statistical engineering literature elaborated the following additional taxonomic categories and relations.

- Anderson-Cook, Christine M. and Lu Lu. (2012) Editorial for Statistical Engineering Special Issue
  - Statistical engineering as a profession.
  - Statistical engineering as a systems methodology.
  - Statistical engineering as a means for innovation.
- Anderson-Cook, Christine M. and Lu Lu. (2012) Statistical Engineering – Forming the Foundations
  - Statistical engineering integration with other professions.
  - Statistical engineering as a discipline.
- Anderson-Cook, Christine M. and Lu Lu. (2012) Statistical Engineering – Roles for Statisticians and the Path Forward
  - New roles for statisticians.
  - Academia involvement.
  - Development pitfalls.
  - National professional organizations involvement.
- Hare, L. (2012) Statistical Engineering: Principles and Examples
  - Statistical engineering as a philosophy
  - Statistical engineering as a discipline
- Snee, Ronald D. and Roger W. Hoerl. (2012) Leadership—Essential for Developing the Discipline of Statistical Engineering
  - Contrast of the professional versus the leader in statistical engineering

- Shainin, Richard D. (2012) Statistical Engineering: Six Decades of Improved Process and Systems Performance
  - Statistical engineering as a discipline
  - Statistical engineering as risk management.

Systematical analysis Cotter's (2012 – 2018) development of system statistical engineering elaborated the following additional taxonomic categories and relations.

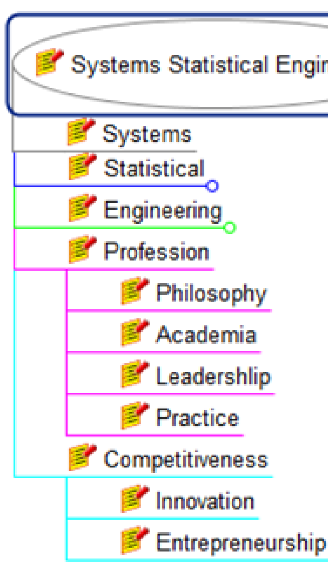
- Cotter, T. (2012) Engineering Management Contributions to Statistical Engineering
  - Statistical engineering within engineering management research.
  - Statistical engineering as a discipline within engineering management.
  - Statistical engineering as an academic discipline.
  - Integration of statistical engineering into other engineering disciplines
  - Integration of statistical engineering into management.
  - Integration of statistical engineering into project management.
  - Integration of statistical engineering into systems engineering.
- Cotter, T. (2015) Statistical Engineering: A Causal-Stochastic Modeling Research Update
  - Statistical engineering as a systems modeling methodology.
- Cotter, T. (2016) A Hierarchical Statistical Engineering Modeling Methodology.
  - Statistical engineering as a systems modeling methodology.
- Cotter, T. (2017) Integrating IDEF0 into a Systems Framework for Statistical Engieering
  - Statistical engineering as a systems modeling methodology.
- Cotter, T. (2018) Systems Statistical Engineering – Systems Hierarchical Constraint Propagation
  - Statistical engineering as a systems modeling methodology.

Summarizing the elaboration of the corpus, the following additional statistical engineering concepts were noted.

- Profession
  - Philosophy
  - Academia
  - Leadership
  - Practice
- Competitiveness
  - Innovation
  - Entrepreneurship

These categories were given definitions and incorporated into the core SSE concept system as shown in Exhibit 3.

Exhibit 3: Elaborated core SSE hierarchical concept system.



The terms glossary was updated as set forth in Exhibit 4.

Exhibit 4: Elaborated core SSE terms glossary.

Name	Definition	Type
Profession	Occupation that requires prolonged training, formal qualification, and experience.	Concept
Philosophy	The study of the fundamental nature of properties of systems.	Concept
Academia	The community concerned with the pursuit of systems research, education, training, and scholarship.	Concept
Leadership	Setting a systems discipline vision and direction and providing the motivation to achieve the vision.	Concept
Practice	The application of systems knowledge to the solution of applied complex problems.	Concept
Competitiveness	The quality of being equal to or superior in systemic performance.	Concept
Innovation	Evolving or revolutionizing new systemic knowledge, processes, or products that change society in some manner.	Concept
Entrepreneurship	Taking on risk to bring innovative systemic knowledge, processes, or products to market.	Concept

Conclusions

This paper reported initial research into the development of a core taxonomy for the systems statistical engineering body of knowledge. The taxonomy was developed from the existing corpus of peer reviewed seminal articles on statistical thinking, statistical engineering, and causal Bayesian hierarchical systems modeling using the hierarchy of semantic relations methodology set forth by Madsen and Nuopponen. The resultant taxonomy is comprised of five categories: systems, statistical, engineering, professional, and competitiveness. These categories appear to meet taxonomic criteria of mutual exclusivity and exhaustiveness while integrating broader professional discipline concepts and maintaining a focus on statistical engineering as a systems modeling methodology

Continuing Research

To confirm mutual exclusivity and exhaustiveness, the taxonomy will be encoded into an ontology editor and validated against Gruber's (1995) ontological design criteria and for extensibility compliance to OWL 2 ontologies.

- Clarity – effectively communicate the intended meaning of defined terms.
- Coherency – sanction inferences that are consistent with the definitions.
- Extensibility – semantic vocabulary consistent with related ontologies.
- Minimal encoding bias – conceptualization is specified at each knowledge level without dependence on a particular symbol-level encoding.
- Minimum ontological commitment – make as few definitional claims as possible about the concept being modeled.

References

Anderson-Cook, Christine M. and Lu Lu. (2012) Editorial for Statistical Engineering Special Issue. *Quality Engineering* 24(2), 107-109.

Anderson-Cook, Christine M. and Lu Lu. (2012) Statistical Engineering – Forming the Foundations. *Quality Engineering* 24(2), 110-132.

Anderson-Cook, Christine M. and Lu Lu. (2012) Statistical Engineering – Roles for Statisticians and the Path Forward. *Quality Engineering* 24(2), 133-152.

Cotter, T. (2012) Engineering Management Contributions to Statistical Engineering. *Proceedings from the 2012 ASEM National Conference*, (pp. 108-115). Virginia Beach.

Cotter, T. (2015) Statistical Engineering: A Causal-Stochastic Modeling Research Update. *Proceedings of the ASEM 2015 International Conference*. Indianapolis, Indiana.

Cotter, T. (2016) A Hierarchical Statistical Engineering Modeling Methodology. *Proceedings of the ASEM 2016 International Conference*. Charolette, North Caroling

Cotter, T. (2017) Integrating IDEF0 into a Systems Framework for Statistical Engieering. *Proceedings from the 2017 ASEM National Conference*, Huntsville, Alabama

Cotter, T. (2018) Systems Statistical Engineering – Systems Hierarchical Constraint Propagation. *Proceedings from the 2018 ASEM National Conference*. Coeur d'Alene, Idaho.

de Mast, Jeroen and Ronald J. M. M. Does. (2010) Discussion of 'Statistical Thinking and Methods in Quality Improvement: A Look to the Future. *Quality Engineering* 22(3), pp. 130-132.

Docear. http://www.docear.org/

Gruber, T. R. (1995). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal of Human-Computer Studies: 43* (5-6), 907-928.

Hare, L. (2012) Statistical Engineering: Principles and Examples. *Quality Engineering* 24(2), 153-161.

Hoerl, Roger W. Jeffery H. Hooper, Peter J. Jacobs, and James M. Lucas. (1993) Skills for Industrial Statisticians to Survive and Prosper in the Emerging Quality Environment. *The American Statistician* 47(4), 280-292.

Hoerl, Roger W. and Ron Snee. (2010) Statistical Thinking and Methods in Quality Improvement: A Look to the Future. *Quality Engineering* 22(3), 119-129.

Hoerl, Roger W. and Ron Snee. (2010) Rejoinder: A Consensus that the Statistics Profession Must Change, Is Growing. *Quality Engineering* 22(3), 137-139.

Madsen, B. Nistrup; B. Sandford Pedersen; H. Erdman Thomsen; Semantic Relations in Content-based Querying Systems: a Research Presentation from the OntoQuery Project, in K. Simov; A. Kiryakov (eds.): *Ontologies and Lexical Knowledge Bases. Proceedings of the 1st International Workshop, OntoLex 2000*. Sofia: OntoText Lab., 2002.

Madsen, B. Nistrup; B. Sandford Pedersen; H. Erdman Thomsen; Defining semantic relations for OntoQuery, in Jensen, A.; P. Skadhauge (eds.), *Proceedings of the First International OntoQuery Workshop, Ontology-based interpretation of NP's*. Kolding: Department of Business Communication and Information Science, University of Southern Denmark, 2001.

Nuopponen, Anita (2005). Concept Relations v2. An update of a concept relation classification. In Terminology and Content Development, 127−138. B. Nistrup Madsen & H. Erdman Thomsen (Eds.). Copehagen: Litera.

Nuopponen, Anita (2006). A model for structuring concept systems of activity. In Y. Wang, Y. Wang & Y. Tian (Eds.), *Terminology, Standardization and Technology Transfer, Proceedings of the TSTT'2006 Conference*. Beijing: Encyclopedia of China Publishing House.

Rotelli, Matthew. (2010) Response to 'Statistical Thinking and Methods in Quality Improvement: A Look to the Future.' *Quality Engineering* 22(3), pp. 133-134.

Shainin, Richard D. (2012) Statistical Engineering: Six Decades of Improved Process and Systems Performance. *Quality Engineering* 24(2), 171-183.

Snee, Ronald D. and Roger W. Hoerl. (2012) Leadership—Essential for Developing the Discipline of Statistical Engineering. *Quality Engineering* 24(2), 162-170.

Vining, G. (2010) Statistical Thinking and Methods in Quality Improvement: A Look to the Future. Quality Engineering 22(3), 135-136.

T. Steven Cotter is a Lecturer with the Engineering Management and Systems Engineering department at Old Dominion University. He earned a Ph.D. in Engineering Management and Systems Engineering from Old Dominion University, a Master of Science in Engineering Management with a concentration in quality/reliability engineering from the University of Massachusetts at Amherst, a Master of Business Administration with a concentration in finance and a Bachelor of Science both from the University of South Carolina, and a diploma in Electronic Technology from Graff Area Vocational and Technical School (now Ozarks Technical Community College). He is a certified Quality Engineer and Reliability Engineer with the American Society for Quality. His research interests are in engineering design analytics, human-intelligence/machine-intelligence decision governance, human-intelligence/machine-intelligence quality systems design, and statistical engineering.