Applying Meta-Analysis to Systems Thinking

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Background

Systems Thinking

- Facilitates the understanding of systems, their structure, and important interrelationships with their environment
- Fundamental to Systems Engineering (SE); prior to or during SE
- Epistemology that guides one's habits and practices in understanding the world (Checkland, 1999)
- The process of examining a system as a whole with specific focus on identifying, defining, and understanding a system's interrelationships with it's parts and environment (Senge, 2006; Parnell, Driscoll, and Henderson, 2011; Haskins, 2011)
- Activities include: research, system classification, defining system boundaries, identifying inputs and outputs, and capturing important interactions

The Problem

- Large-scale, complex SE problems are sometimes resistive to systems thinking methods
  - Size and scope make identifying reactions challenging
  - Abstract in nature
  - Complex environments with a morass of interactions and ambiguous boundaries
  - System prominence and influence often spawns many disparate studies and analyses
- Examples include systems of systems (Garrett et al. 2011; Haimes 2012), public policy (Kopach-Konrad et al. 2007; Jackson, Scott 1999; Roberts and Evans, Rhianne 2013), financial systems (Osmundson, Langford, and Huynh 2009), sustainability (Kelly 1998; Levy, Hipel, and Kilgour 1998; Svetinovic 2013) and so-called wicked problems (Rittel and Webber 1973a; Rittel and Webber 1973b)

Why Meta-Analysis?

- Research is a vital component of SE
- It is not uncommon within behavioral and social sciences to find conflicting results between studies
- Prior to meta-analysis (MA), qualitative synthesis was used but came under great scrutiny
  - MA quantitatively synthesizes studies with confounding results by correcting artifacts such as error and bias “to reveal the simpler patterns of relationships that underlie research literatures” (Hunter 2004, 17).

Similar Work

- Most similar work
  - Meta-synthesis prescribes hybrid human-machine-knowledge systems for exploring complex, unstructured problems (Xuesen, Qian, Yu Jingyuan, and Dai Ruwei, 1993)
  - Ford proposed a method of analyzing atomic behaviors to help identify prominent influences in system dynamics models (1999)
  - Later Ford and Flynn proposed a statistical screening technique for the same purpose (2005)
- Other work
  - Gu and Tang (2005) extended the meta-synthesis work and applied it to economic applications
  - Both qualitative and quantitative synthesis models used to create system dynamics models for a large, complex litigation case (Ackermann, Eden, and Williams, 1997)
  - Beasley examined the difficulties inherent in conducting systems thinking and offers a set of heuristics to make it easier (2012)

Concerns with Previous Work

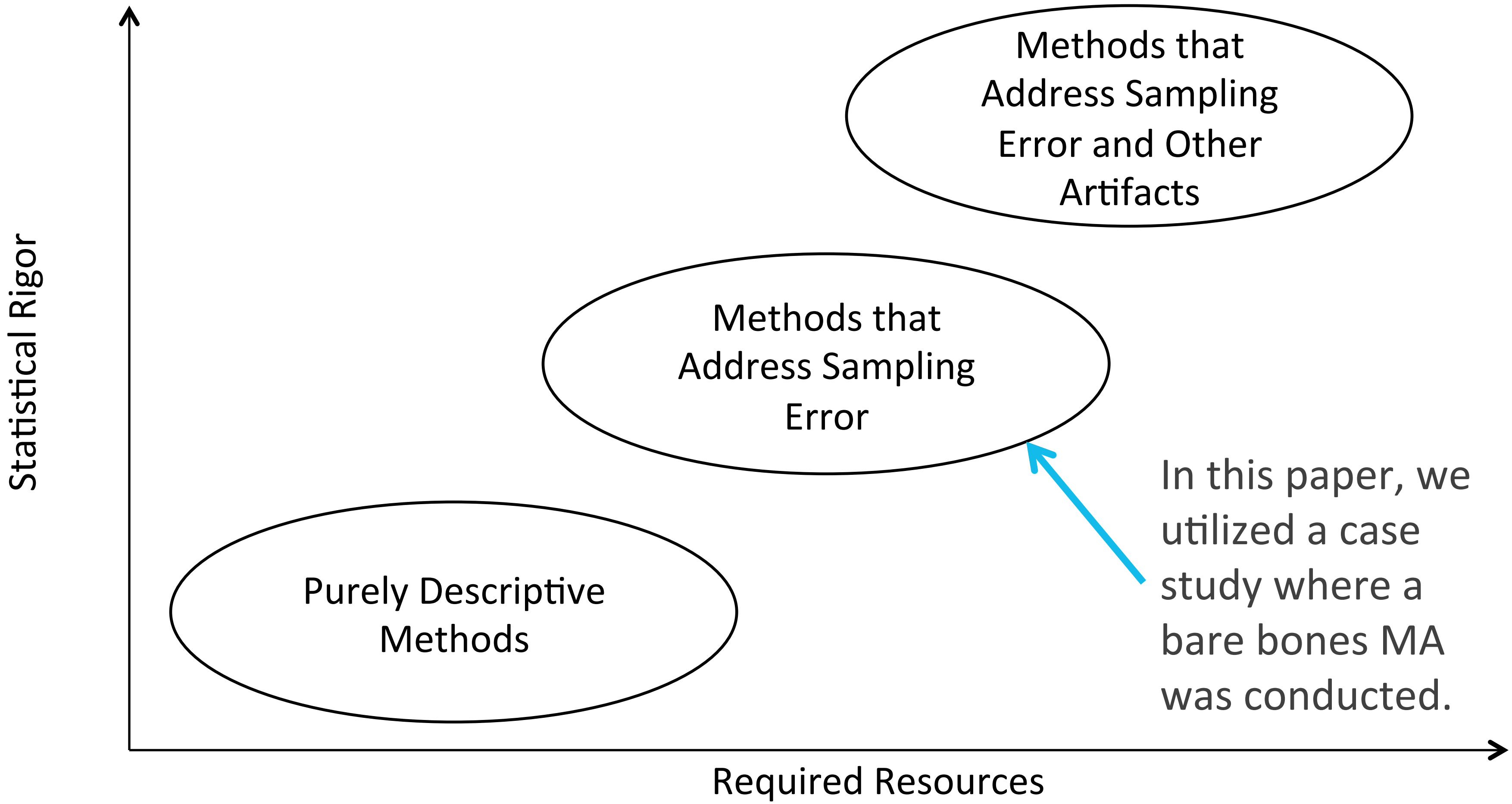
- Xuesen's meta-synthesis also combines studies to form knowledge and draw conclusions
  - Lacks the statistical rigor that MA provides
- Ford and Flynn's work provides a quantitative methodology for screening influences
  - Requires modeling prior to identifying variables, stocks, and flows

Applying Meta-Analysis to Systems Thinking (MAST)

Meta-Analysis

- To find the true relationship between variables, one would have to assess the entire population
- Sample studies assess the relationship between variables within a subset of the population
- As the number of studies increase, rather than getting closer to the true relationship, we often discover confounding results
- MA attempts to provide statistical control across the body of research ascertain the true relationship

MA Method Tradeoff Analysis



In this paper, we utilized a case study where a bare bones MA was conducted.

General MA Process

1. Defining the theoretical relation of interest.
2. Collecting the population of studies that provide data on the relation.
3. Coding the studies and compute effect sizes.
4. Examining the distribution of effect sizes and analyzing the impact of moderating variables.
5. Interpreting and reporting the results.

- DeCoster (2009)

Systems Thinking

- INCOSE defines a system as "an integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements" (Haskins 2011, 5)
- Systems thinking is a holistic framework for viewing and learning about complexity both within a system and within its interaction with its environment
  - More abstract than MA
  - Fundamentally more philosophical than procedural
  - Some cognitive scaffolding is necessary to grow as a systems thinker

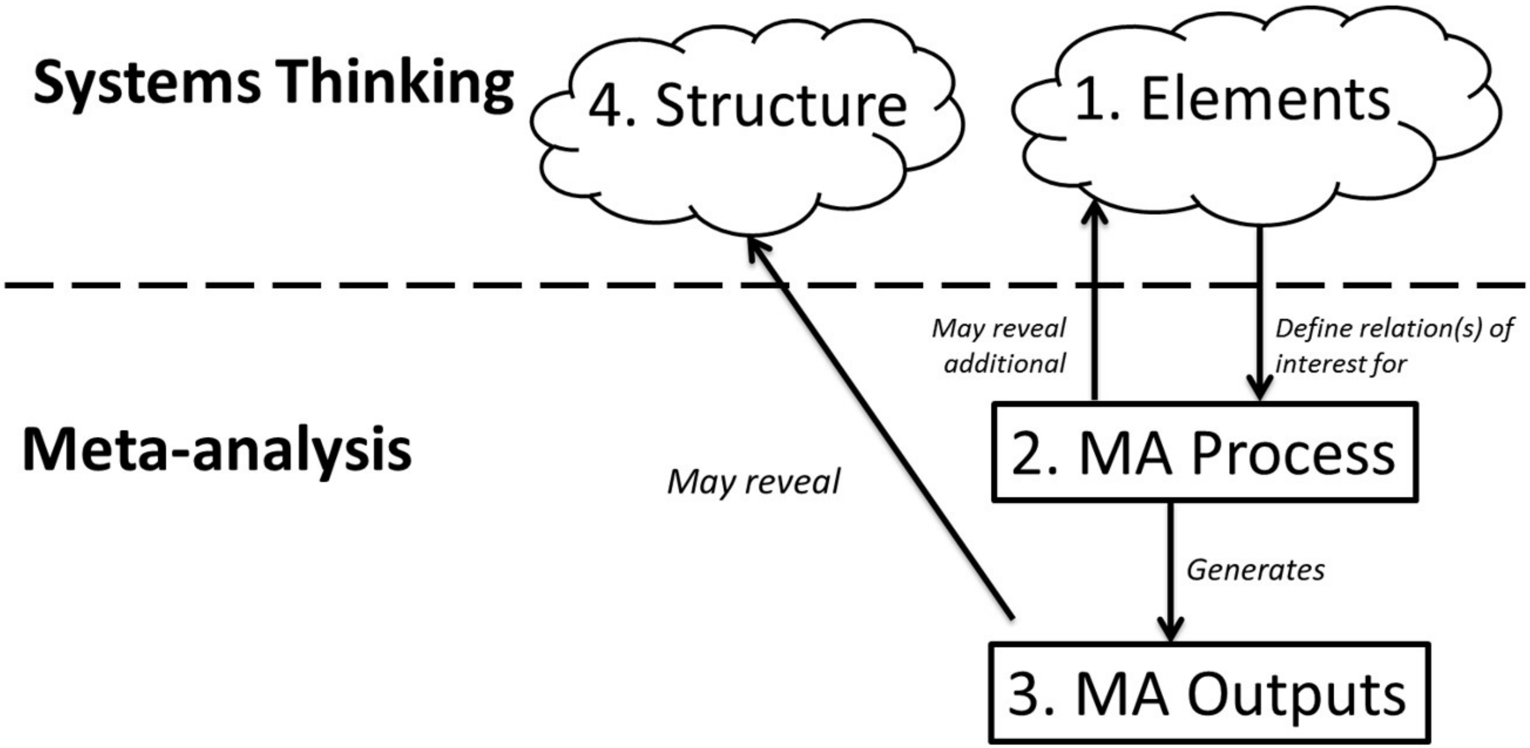
Focus on the Outcomes

- As Driscoll suggests (2011, 28), the outcomes of systems thinking include identifying the system's :
  - Current state
  - Desired output
  - Functions
  - Processes
  - Objectives
  - Structure and elements to achieve the desired output
- MA best aligns with this last outcome of systems thinking
  - The elements of the system interact and create behavior or emergent properties that the individual elements do not display on their own.
  - Structure is a description of the relationships between elements.

Elements and Structure

- Start with defining the system boundary
- Driscoll suggests that the boundary "must be selected to include all of the important interacting elements…and exclude all those that do not impact the system behavior that makes it a system" (2011, 36–37)
- Applying MA may be useful in determining whether to include or exclude elements and their structure

MAST Model



Systems Thinking
4. Structure
1. Elements
May reveal additional
Define relation(s) of interest for
Meta-analysis
May reveal
2. MA Process
Generates
3. MA Outputs

MAST Application

1. Identify an initial set of elements within the system under study
   a. Identify the initial and salient set of systems thinking elements through research and subject-matter expertise
   b. Define the relations of interest between these elements that need further elucidation
2. Conduct meta-analysis or analyze existing meta-analysis of the relations of interest
   a. Collect the population of studies relating to identified system elements
   b. Incorporate any additional variables found in the meta-analysis process as additional system thinking elements
3. Utilize meta-analysis results to understand the system under study
   a. Continue refining the set of systems thinking elements
   b. Identify influences outside the system boundary (i.e. environmental factors)
4. Utilize meta-analysis and other research to reveal structure of the system under study
   a. Consider significant effect sizes and distributions from the meta-analysis as possible relations between systems thinking elements
   b. Employ additional research and subject matter expertise to understand and validate significant relationships

Case Study

MILITARY PERSONNEL MANAGEMENT

The Problem

- Personnel management in the US active duty military is a large, complex system made messy with human behavior
- Personnel requirements increase and decrease given national requirements, i.e. wartime and peacetime needs
- Some personnel policies are similar to civilian policies (evaluations, etc.) while others are different (Post 911 GI Bill, etc.)
- Personnel turnover carries both tangible costs (enlistment bonuses, etc.)and intangible costs (experience, etc.)
- Military leaders develop policies in an attempt to affect turnover in a way that is beneficial to the services
- They are faced with the task of creating policy that will keep the services adequately manned with the right personnel

The Analysis

- Licklider sought to use MA to determine influential factors in active duty military personnel turnover decisions, identify weaknesses in the research and provide a theoretically grounded understanding of active duty military personnel turnover (2011, 3–4)
- There is a plethora of active duty military turnover studies, but they have confounding results
- Bare-bones MA was used to assess the relationships between independent variables and turnover and turnover intent
  - Operations tempo and turnover were the primary focus

The Process

- Predetermined set of inclusion criteria was utilized to determine whether to include a study
- Manual and automated searches for studies
- Coded pertinent information
- Conducted bare-bones MA to correct for sampling error, does not address any other artifacts
  - Weights studies according to their sample sizes
  - Provides a sufficient level of statistical rigor
  - Does not explore the interaction between the independent variables
  - Does not require an overwhelming amount of resources

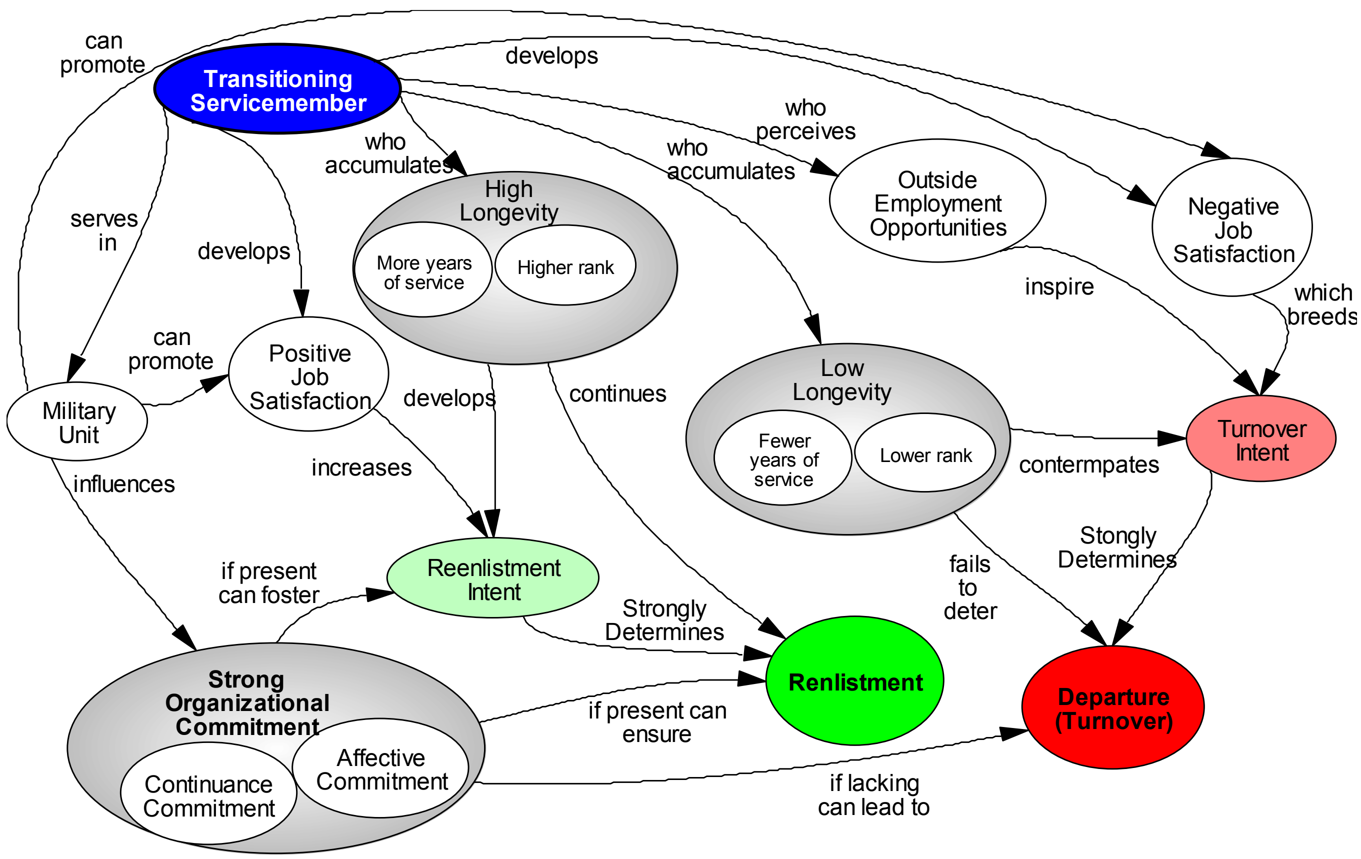
The Results

- The meta-analysis revealed lack of consensus on how to define and measure operations tempo
- Despite the issues with definition and measurement, there were enough studies to analyze that the relationship between operations tempo and turnover intent, a determinant for turnover
- There were not enough studies to analyze the relationship between operations tempo and turnover

Applying MAST to the Results

MAST - Meta-Analysis in support of Systems Thinking					
Systems Thinking	**Elements**		**Structure**		
Meta-analysis	**Dependent Variables**	**Indepenedent Variables**	**Effect Size r**	**Lower**	**Upper**
Data	Turnover	Turnover Intentions	0.508	-0.492	-0.342
		Organizational Commitment	-0.417	0.433	0.582
		Job Satisfaction	-0.309	-0.384	-0.234
		Rank	-0.166	-0.241	-0.091
		Age	-0.100	-0.175	-0.025
		Gender	-0.076	-0.151	-0.001
		Education	0.021	-0.054	0.096
	Turnover Intent	Organizational Commitment	-0.579	-0.654	-0.504
		Job Search	0.481	0.406	0.555
		Education	-0.376	-0.451	-0.301
		Job Satisfaction	-0.337	-0.412	-0.262
		Affective Commitment.	-0.334	-0.409	-0.259
		Continuance Commitment	-0.296	-0.371	-0.221
		Years of Active Duty Service	-0.257	-0.332	-0.182
		Perceived Employment Opportunities	0.230	0.155	0.304
		Rank	-0.129	-0.204	-0.054
		Age	-0.099	-0.173	-0.024
		Number of Dependents	-0.094	-0.169	-0.019
		Gender	-0.082	-0.157	-0.007
		Marital Status	-0.020	-0.095	0.055
		Operations Tempo	-0.001	-0.076	0.073

Systemigram



Discussion

Caution

- MA alone should not frame one's system thinking
- Stakeholder analysis is an integral component of system analysis
- Completing a MA can be extremely time and resource intensive
- This highly deliberate approach is antithetical to the spirit of systems thinking
- More expedient systems thinking techniques and methods should be applied first
- MAST is not appropriate when building general system models

Other Applications

- The MA results could serve as input into the system dynamic modeling screen technique advocated by Ford and Flynn (2005)
- Information about the system structure revealed during the MAST methodology could help during functional analysis and requirements elicitation

Future Work

- Apply MAST to additional problems and case-studies
- Further refine how meta-analysis outputs can be generalized to reveal system thinking elements and structure
- Examine how MAST outputs can help formally derive downstream artifacts in the engineering process such as system dynamic models and functional analysis
- Explore how automated natural language techniques can play a role in streamlining the meta-analysis process

Final Thoughts

- MAST is well-suited to augment initial-stage systems thinking activities surrounding complex, large-scale systems problems that are resistive to traditional, less-formal systems thinking approaches
- MAST is an additional tool to complement current systems thinking methods and approaches

Thank You

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- To the reviewers who volunteered their time and expertise to provide feedback on our work