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HUMAN-INTELLIGENCE AND MACHINE-INTELLIGENCE DECISION GOVERNANCE FORMAL ONTOLOGY

by

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المنـــارة للاستشارات

ABSTRACT

HUMAN-INTELLIGENCE AND MACHINE-INTELLIGENCE DECISION GOVERNANCE FORMAL ONTOLOGY

Faisal Mahmud
Old Dominion University 2018
Director: Dr. T. Steven Cotter

Since the beginning of the human race, decision making and rational thinking played a pivotal role for mankind to either exist and succeed or fail and become extinct. Self-awareness, cognitive thinking, creativity, and emotional magnitude allowed us to advance civilization and to take further steps toward achieving previously unreachable goals. From the invention of wheels to rockets and telegraph to satellite, all technological ventures went through many upgrades and updates. Recently, increasing computer CPU power and memory capacity contributed to smarter and faster computing appliances that, in turn, have accelerated the integration into and use of artificial intelligence (AI) in organizational processes and everyday life. Artificial intelligence can now be found in a wide range of organizational systems including healthcare and medical diagnosis, automated stock trading, robotic production, telecommunications, space explorations, and homeland security. Self-driving cars and drones are just the latest extensions of AI. This thrust of AI into organizations and daily life rests on the AI community's unstated assumption of its ability to completely replicate human learning and intelligence in AI. Unfortunately, even today the AI community is not close to completely coding and emulating human intelligence into machines. Despite the revolution of digital and technology in the applications level, there has been little to no research in addressing the question of decision making governance in human-intelligent and machine-intelligent (HI-MI) systems. There also exists no foundational, core reference, or domain ontologies for HI-MI decision governance systems. Further, in absence of

an expert reference base or body of knowledge (BoK) integrated with an ontological framework, decision makers must rely on best practices or standards that differ from organization to organization and government to government, contributing to systems failure in complex mission critical situations. It is still debatable whether and when human or machine decision capacity should govern or when a joint human-intelligence and machine-intelligence (HI-MI) decision capacity is required in any given decision situation.

To address this deficiency, this research establishes a formal, top level foundational ontology of HI-MI decision governance in parallel with a grounded theory based body of knowledge which forms the theoretical foundation of a systemic HI-MI decision governance framework.

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"What you seek is seeking you" – Rumi

This thesis is dedicated to the untiring efforts of those striving for the goodness of humankind.

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I would like to recognize some individuals for steering and supporting this endeavor.

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My family and extended family members– Thank you for everything. Whether you believed in me or not, it is achieved!

A little boy, back in early 1990s. Despite benighted about PhD, he admired those having such a degree. Why? An uncle of his used to be called Dr. X….and that enamored him. The little boy vowed himself that one day, he would be the same. Finally it happened…

Lastly, if I flubbed to acknowledge anyone…thank you for judging me, spurring me, rebuking and criticizing me…you know what? Because of all these, I am completing this bouncy ride with a smile…Thank You!

NOMENCLATURE

HI	Human Intelligence, (No Units)
MI	Machine Intelligence, (No Units)
AI	Artificial Intelligence, (No Units)
DL	Descriptive Logic, (No Units)
A	Abductive Meaning, (No Units)
D	Deductive Structure, (No Units)
HCI	Human-Computer Interaction, (No Units)
HMI	Human-Machine Interaction, (No Units)
$\rightarrow$	Implies, (No Units)
$\neg$	Not or Negation, (No Units)
$\subseteq$	Subset, (No Units)
$\cap$	Intersection, (No Units)
$\in$	Element of, (No Units)
< >	Triple, (No Units)
{ }	Set, (No Units)
$\forall$	For All, (No Units)
◊	Possibly True, (No Units)
□	Necessarily True, (No Units)

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CHAPTER 1

INTRODUCTION

1.1 Theoretical Background of Ontology

1.1.1 What is an Ontology?

Tracing back to its philosophical origin, “Ontology” is actually derived from two Greek words– “ontos” meaning being and “logos” meaning logical argument or discourse or debate. Thus, ontology means to understand the beingness or existence of anything by providing supportive evidence. Concisely, an ontology provides the foundation necessary to understand the theory of existence of a thing or concept. To answer the question “what” with rooted explanations in any domain of discourse reveals this concept. Many definitions of ontology have been set forth by different researchers, scientists, engineers, and practitioners. In the artificial intelligence (AI) community, the widely received, accepted, and cited definition was given by Gruber (1993). According to Gruber, an ontology is an explicit representation of a conceptualization. Even though this definition was given from a local or application level within ontology classification, it captures the basic idea of an ontology. While building or developing an ontology, it is therefore not just to give the definition of a concept, but also to identify the classes or categories associated with and within that concept, find the relationships within and among those classes or categories, as well as their functions, axioms, and instances, depending on the type or level of the ontology. Ontology allows us to capture as much information as possible about a concept or domain of discourse to bridge the gap of any existing knowledge as well as to generate new knowledge to expend it in the application level.

Noy and McGuinnes (2001) outlined ontology as, *“In reality, there is a fine line where* *the ontology ends and the knowledge base begins."* This definition brings some theoretical requirements for an ontology such as to elaborate the taxonomic terms or classes of a concept, their relationships, functions, and axiomatic relationships to cover the depth and breadth of the knowledge base. Depending on the level, taxonomic terms can range from generic to very specific.

One of the ways to determine the scope of an ontology is to write a list of questions, sometimes known as the competency questions, that a knowledge base relying on the ontology should be able to answer (Noy and McGuinnes, 2001). Furthermore, an ontology should be able to answer some rudimentary questions when it is being developed such as specific concepts that the ontology is to cover, the scope of the ontology, the target domain where the ontology will be used, and how ontology will be validated.

1.1.2 Ontology Levels, Types, and Development Methodologies

Figure 1 (Mahmud and Cotter, 2017) summarizes the primary levels or types of ontologies based on the scope that are found in the existing literature. A foundational ontology is also referred to as a top or upper level ontology. This essentially gives the foundation of subsequent ontology development. The scope of a foundational ontology is to specify the general or universal classifications or categories, relations, and axioms for a body of knowledge such that these concepts are reusable across core reference areas of the body of knowledge. Foundational ontologies are rich in abstractness and consider only the seed or core categories. These seed categories are general in concept and are same across all core reference areas and all domains.

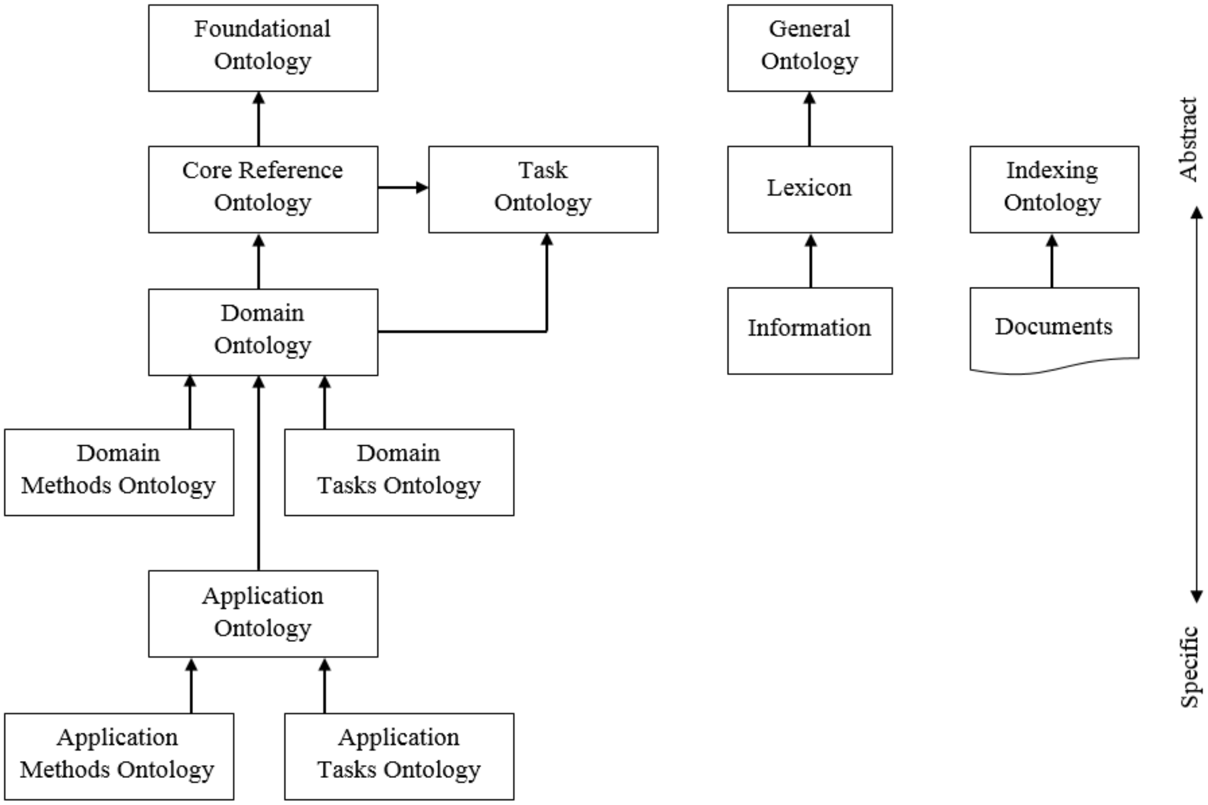
Foundational Ontology
Core Reference Ontology
Task Ontology
Domain Ontology
Domain Methods Ontology
Domain Tasks Ontology
Application Ontology
Application Methods Ontology
Application Tasks Ontology
General Ontology
Lexicon
Information
Indexing Ontology
Documents
Abstract
Specific

Figure 1: Ontology Types (Mahmud and Cotter, 2017).

Some examples of foundational ontologies include Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), Basic Formal Ontology (BFO), Frame-Ontology, Socio Culture Ontology, Geography Markup Language (GML), and the Suggested Upper Merged Ontology (SUMO). Foundational ontology development methodologies include BFO, Cyc, DOLCE, GFO, PROTON, and SUMO (Mascardi and Paolo, 2007). A foundational ontology is independent of a particular problem or domain. On the other hand, at the application level, ontological taxonomies and axioms become more specific to the particular problem or knowledge being defined.

Compared to foundational ontologies, core reference ontologies further specify the concepts, relations, axioms, and functions of an area of a body of knowledge with reference to the respective foundational ontology and are reusable across domains. Examples of core reference ontologies include hydroOntology, Towntology, and CityGML. Core reference ontologies can be developed through application of the general SENSUS methodology (Jones et al, 1998).

Domain ontologies provide the particular concepts, relationships, functions, axioms, and instances relevant only to a specific knowledge domain. Domain ontologies examples include those for biomedical, information science, engineering, internet, medical, and software engineering. Task ontologies specify the vocabulary of terms used in problem solving tasks that are common across domains within a core reference area. Conversely, domain task ontologies specify the vocabulary of terms used in problem solving tasks specific to a given domain. Likewise, domain methods ontologies specify specific methods vocabularies (data collection, design, testing, engineering, software development, etc.) necessary to operationalize the domain. Domain ontology development methodologies include TOVE (Toronto Virtual Enterprise) (Gruninger and Fox, 1994), ONIONS (ONtologic Integration of Naïve Sources) (Gangemi et al., 1996), COINS (COntext INterchange System) (Wache et al., 2001), METHONTOLOGY (Fernandez et al., 1997), OTK (On-To-Knowledge) (Sure et al., 2006), and UPON (United Process for ONtologies) (De Nicola et al., 2009).

Application ontologies, application task ontologies, and application methods ontologies are further specializations of domain ontologies to represent particular knowledge models within a given domain. During the last twenty-five or so years, application ontologies have been developed as the vocabulary foundation for expert systems, which emulate human expert decision making. In general, application ontology development methodologies are bottom-up with reference to the relevant domain ontology. Application ontology development methodologies include CommonKADS, DILIGENT, Enterprise Model Approach, KACTUS, METHONTOLOGY, or TOVE (Corcho et al., 2003) (Cristani and Cuel, 2005).

The current research focuses on establishing the formal foundational ontological basis of human-intelligence and machine-intelligence (HI-MI) decision governance, which in turn, will form the theoretical foundation of a systemic HI-MI decision governance body of knowledge.

1.2 Research Objectives

This research has the two primary objectives of building:

1. A foundational formal ontology for HI-MI decision governance systems.
2. A grounded theory based foundational body of knowledge (BoK) for human-intelligence (HI) and machine-intelligence (MI) decision governance.

1.3 Problem– The Gap in Knowledge

There has been little to no research addressing the question of decision making governance in HI-MI systems. There also exists no foundational or any levels of ontology for HI-MI decision governance systems. Further, absence of an expert reference base or body of knowledge (BoK) alongside ontological framework forces to rely on existing best practices or standards that differ from organization to organization and government to government, contributing to systems failure in complex mission critical situations. It is still debatable whether and when human or machine decision capacity should govern or when a joint human-intelligence and machine-intelligence decision capacity is required in any given decision situation.

1.3.1 Research Question

The research question addressed by this study is:

What foundational ontological structure and axioms are necessary to succinctly specify the HI-MI decision governance body of knowledge as assessed by the ontological design criteria of clarity, coherency, extendibility, minimal encoding bias, and minimal ontological commitment (Gruber, 1995)?

1.3.2 Research Delimitation

Research in twenty-first century human and machine intelligence can be summarized along two domains: the intelligence domain and the decision source domain (Cotter, 2015) as shown in Figure 2. The current study is demarcated within HI→MI and MI→HI to establish a formal foundational ontological basis of human-intelligence and machine-intelligence (HI-MI) decision governance.

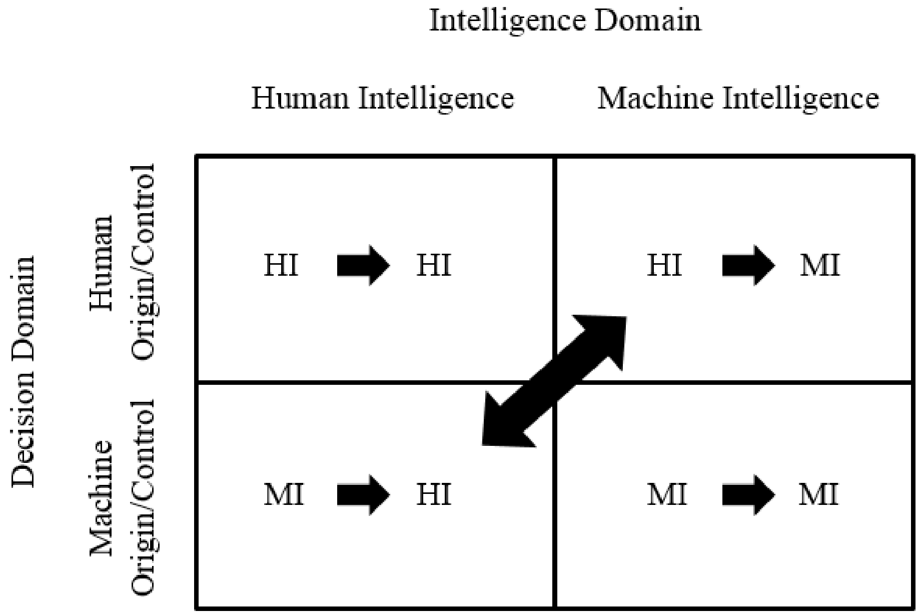
Intelligence Domain
Human Intelligence
Machine Intelligence
Decision Domain
Human Origin/Control
Machine Origin/Control
HI ➡ HI
HI ➡ MI
MI ➡ HI
MI ➡ MI

Figure 2: Intelligence VS Decision Domains (Cotter, 2015).

1.3.3 HI-MI Intelligence Implications for Engineering Systems Management

The artificial intelligence community’s ambitious goal of completely modeling and replicating human cognition in computers is still in its infancy, regardless of progress in the invention of highly sophisticated tools and technologies to roughly represent human cognition abilities in machines. With this singular objective, developed AI applications fundamentally treat humans as discontinuities to be avoided or as objects in human-centered smart service systems. There has been a lack of research into cognitively cooperative human-machine decision making systems. To begin addressing this gap, this research develops a formal foundational ontology and a grounded theory based, high-level foundational body of knowledge for HI-MI decision governance. This research is built on two premises and one proposal.

***Premise 1**: Artificial or machine intelligence can be an associative or key component for joint HI-MI decision making processes given that AI or MI can never completely achieve encoding human cognition but only approach it asymptotically.*

***Premise 2:** Artificial or machine intelligence can be faster and in domain specific decision tasks more accurate than human decision making; however, AI's inability to achieve true general human creative cognitive capacity is still a deficiency in the AI or MI decision making.*

***Proposal**: A foundational ontological framework in parallel with a grounded theory based body of knowledge is a necessary specification for HI-MI decision governance.*

Premise 1 recognizes the potential to improve decision making in systemic mission critical situations through the integration of AI or MI with human cognition. With the current technological progress, AI or MI can asymptotically approach human cognitive intelligence but may never totally replace the cognitive thinking process. The human brain is elastic in nature. As humans understand more about their own cognitive capacity, the human brain will create new tacit knowledge about its own cognition processes i.e. as problems are solved, new unknowns will be identified at a pace ahead of that which humans can achieve to capture and convert the new tacit knowledge into actionable explicit knowledge. AI and MI knowledge and practice must always lag tacit and explicit knowledge of human cognitive processes and capabilities.

Premise 2 is self-evident because it has been demonstrated already by the AI community and researchers that in existing domain specific tasks, machine intelligence outperforms human problem-solving capacity in faster and more effective ways. Conversely, variety in environmental complexity still easily overwhelms the most advanced AI autonomous vehicles and programming robots to perform even simple tasks easily accomplished by human toddlers requires continued refinement of thousands of lines of code. Thus, the resulting proposal establishes the general research framework, that is, developing a general theory and body of knowledge of HI-MI decision governance with a focus on systemic mission accomplishment within widely varying risky and uncertain environments. For this research, the proposal differentiates machine intelligence from general artificial intelligence and delimits the definition of human intelligence and machine intelligence.

Definition 1: *Machine intelligence is the specific artificial intelligence embedded in a machine that attempts to replicate the human decision and task functions required to accomplish a specified systemic mission within a specified systems domain.*

Definition 2: *HI-MI decision governance is the necessary or sufficient or necessary and sufficient domain-specific decisions and actions required for a system of human-machine agents to accomplish a specified systemic mission given an existing state of limited human intelligence and flawed machine intelligence.*

Integrated HI-MI systematic decisions and actions are required to achieve a specified set of mission outcomes under evolving states of human-intelligence and machine-intelligence responses to dynamic environmental constraining forces. The necessary or sufficient or necessary and sufficient set of systemic decisions and actions toward mission objectives is bound only by the current state of HI-MI knowledge within the domain specified mission context. As the state of knowledge increases over the time, the definition of the necessary or sufficient or necessary and sufficient decisions and actions may be refined to achieve reduced risk and uncertainty in systemic mission outcomes.

1.3.4 Research Significance

The theoretical and methodological significance of this study are:

Theoretical: A grounded theory based foundational body of knowledge (BoK) for HI-MI decision governance in parallel with the HI-MI decision governance formal foundational ontology that meets Gruber's (1995) ontology design criteria and is extendible to the World Wide Web Consortium (W3C) by Web Ontology Language (OWL).

Methodological: A unique methodology based on abductive-deductive logical inferences for grounded theory based BoK development with the inductive-deductive interpretations of necessary conditions for ontology design.

CHAPTER 2

BACKGROUND OF THE STUDY

2.1 Literature Review

The historical overview of Human-Intelligence (HI) to Machine-Intelligence (MI) essentially covers four different domains:

- Human to Human Intelligence: HI → HI
- Human to Machine Intelligence: HI → MI
- Machine to Machine Intelligence: MI → MI
- Machine to Human Intelligence: MI → HI

Human to Human Intelligence: HI → HI

Human to human intelligence entails the way intelligence is transferred between humans for cooperation, trade, social, political, or other reasons. Cavemen painted on or engraved cave walls to let others know of their existence and to share knowledge. Even in the modern world, we communicate with each other and transfer knowledge in various forms, sometimes just by talking, e-mailing, blogging, or publication.

From the Oxford English Dictionary, a human or human being is defined as "*a man, woman, or child of the species Homo sapiens, distinguished from other animals by superior mental development, power of articulate speech, and upright stance.*" The interaction of human "superior mental development" and "articulate speech" resulted in emergent rational thinking and comparative judgement necessary for decision making and knowledge creation. Decision making or making the best logical choice from available options was initially necessary for human survival. The cumulative outcomes from rational decision making accrued into rudimentary knowledge, which in turn, has evolved into current collective human intelligence. The first question to ask here– *what is human intelligence?*

If the definition of intelligence is learning, reasoning, understanding, planning, problem solving, gathering information from observations, feeling or sensing, then human intelligence should account for all these within the scope of human cognition. Human intelligence allows a human being to think and act rationally and purposefully. Even though there is no exact record of when and how humans were first able to demonstrate the intelligence, it is apparent that million years ago during the cave age, our ancestors were able to record their knowledge by paintings on cave walls or glyphs in stone tablets. From cave wall to stone tablets, animal hide, papyrus, papers, books, and today digital form, human knowledge and intelligence have been recorded and transferred via numerous ways and formats.

In 1938, Wells imagined the World Brain (we know it today as World Wide Web) would allow and apply collective knowledge despite never using the actual term “knowledge management”. It was not until the late 1980s or early 1990s that modern knowledge management and engineering arose within the domain of information and communication technology (ICT). The earliest perspective considered knowledge as being recorded in written form or existing in databases, electronic mails (e-mails), or online libraries. Over recent years, the concept of knowledge stores has shifted toward cloud based knowledge management tools, discussion forums, blogs, wikis, and social media. With technological advancement, it quickly became apparent that the information technology (IT) perspective alone was not sufficient for recording, encoding, and managing organizational knowledge. Therefore, three additional perspectives unfolded alongside with the information technology (IT) perspective.

One perspective addressed the question on how knowledge is created and shared by individuals with a focus on building educational and knowledge sharing capabilities. Everett Rogers (1962) worked on diffusion of innovations, which contributed to understanding how knowledge is created and diffused in social systems. More than a decade later, Thomas Allen's (1977) study on evolved communications systems in science and engineering furthered understanding of the effects of informal and formal organizational structures on knowledge creation and dissemination. Studies on cultural change to create learning organizations by Senge (1990), how organizations work, evolve, and learn by Argyris (1995), the dynamics of knowledge creation in business organizations by Nonaka and Takeuchi (1995) and Von Kroch, Ichijo, and Nonaka (2000) fostered our understanding of organizational learning.

The second perspective has been on improving enterprise effectiveness by collecting and utilizing knowledge. Davenport and Prusak (1998) explained how organizations can advance by generating, codifying, transferring, managing, and using new knowledge. Peter Drucker (2001) introduced two key points– (1) the importance of organizational information and (2) improving competitive advantage by explicit knowledge as a critical resource. Later, Dorothy Leonard (2005, 2014) made significant contributions to understanding creativity, innovation, and knowledge creation as well as management.

The third perspective has been on leveraging information technology (IT) to maximize enterprise economic value. As one of the early researchers, Paul Strassman (1985, 1990, and 2007) emphasized the economic value of information systems. Lesser and Prusak (2003) examined management methods for deriving tangible business value from knowledge management. To date, research continues into the economic value of organizational knowledge in general and within specific private, governmental, and education sectors.

Human to Machine Intelligence: HI → MI

Machine intelligence is a learning, reasoning, understanding, and problem solving intelligent agent embedded within a physical device that attempts to replicate human intelligence, decision making, and tasks directed toward a specific purpose. As the nature of intelligence in machines is based on algorithms or code and thus artificially generated, it is often referred to as artificial intelligence (AI). In ancient Greece, Aristotle dreamed of automation even though he never thought it could be possible. Around the year 1495, Leonardo Da Vinci first sketched a humanoid robot in the form of a medieval knight. It is still unknown whether Leonardo or contemporaries tried to build his design. In 1738, French inventor and engineer Jacques de Vaucanson built and demonstrated a mechanical duck.

The field of artificial intelligence was formally founded as well as the term first coined at the Dartmouth Summer Research Project on Artificial Intelligence in 1956. Since then, AI and its development continued with the advancement of technology as well as automation. The notable work by Nilsson (2010) summarized the timeline of AI development.

- In 1950s, initial development took place in the areas of pattern recognition, human learning, cognition, and memory, statistical methods, heuristic programs, semantic representation, and natural language processing.
- During 1960’s, focus shifted toward technical and societal developments for building necessary infrastructure needed for the development of AI. This resulted in faster and more powerful computers as well as the first specialized computer languages for symbolic manipulation. In parallel to civilian research, military support assisted through the development of AI laboratories. One outcome of these initiatives was

“hand-eye” research, which integrated cameras with rudimentary electromechanical prosthetic robotic hands and arms to manipulate simple objects.

- In 1970s, effort focused on the development of computer vision to understand the three-dimensional properties of human vision by translating and filtering differences in two-dimensional arrays to find edges and vertices objects from two stereoscopically mounted cameras. Additional research also took place in processing line drawings, robotics, and in knowledge representation for the development of situation calculus, logic programming, semantic networks, and scripts and frames that are the basis of today’s expert systems and world wide web knowledge retrieval.
- The 1980s is considered as the application era of AI. Speech recognition and processing, consulting systems, expert systems, advancement of computer vision from finding edges and vertices to identification of basic geometric shapes to extracting properties of scenes and modeling solids were some key areas in which major progress was realized. In the program and project level, Japan’s Fifth Generation Computer Systems, the British Alvey Program, Europe’s ESPRIT Initiative, and America’s Microelectronics and Computer Technology Corporation worked toward the goal of creating computers capable of AI inferences from large data and knowledge bases and to communicate using natural language. Similar but slightly different research was also initiated by DARPA’s Strategic Computing Program. Three major applications initiated by DARPA were– (1) Pilot’s Associate to assist an air combat commander, (2) Battle Management System to assist the commander-in-chief of the U.S. Pacific fleet in planning and monitoring the operation of approximately three hundred ships, and (3)

Autonomous Land Vehicle (ALV) to use autonomous vehicles in combat, logistics and supply, and search and rescue.

- Since the 1990s, research and focus have been given to improved representation and reasoning, qualitative reasoning, semantic networks, constraint satisfaction problems, propositional logic problems, representing text as variables, latent semantic analysis, and causal Bayesian networks. Some outstanding work during this time was performed in machine learning, natural language processing, computer vision, and cognitive system architectures.

Machine to Machine Intelligence: MI → MI

Machine to Machine intelligence is the interrelated or interconnected set of machines that are “self-supportive” or “smart” with unique sensors or identifiers to communicate with one another, take measurements, exchange data and information, and based on that make decisions without human intervention. Today, this connectivity of things or machines is widely known as the Internet of Things (IoT). Machine learning, the term first coined by Arthur Samuel in 1959, is the integral part of machine intelligence that learns and predicts without being explicitly programmed by humans.

Machine to machine communication has existed in different forms since the beginning of computer networking. In the 1950s, SAGE research commenced the path of computer to computer network communications to process data for the radar system. In 1968, Theodore Paraskevakos combined computers and telephone systems to create the first caller identification system. By 1970, ARPANET added packet switching networks to implement the protocol suite

Transmission Control Protocol (TCP)/Internet Protocol (IP) and thus is regarded as the formal foundation of today’s Internet.

Theodore’s (1972) research on sensor monitoring system and meter reading capabilities for utilities and the formation of Metretek, Inc. in 1977 to develop and produce commercial remote meter reading and load management system eventually led to the smart meter and today’s concept of the smart grid.

Even though the term IoT was first introduced by Kevin Ashton in 1999, similar concepts such as network of devices have been used and articulated as early as 1982. During the same time, Bill Joy (1999) coined the Device to Device (D2D) communication concept and envisioned machine to machine intelligence as part of his “Six Webs” framework.

The applications of machine intelligence ranges from smart monitoring systems to security networks, medical diagnosis to electronic trading, stretching in multi-directional and diverse domains. Smart cars and navigation systems, automatic sensing, robotics engineering, social networking are some domains heavily developed by deep machine learning. Some evolving areas of machine to machine technology are swarm intelligence (SI), ubiquitous computing, pervasive computing, and ambient intelligence. Most of the research and development for these areas are at the application level.

Machine to Human Intelligence: MI → HI

Machine to human intelligence is the transfer or gain of knowledge or intelligence that is generated or predicted by machines to humans with the objective of improving human decision making. Despite the progress in the domain of HI-to-MI, MI-to-HI knowledge transfer is still limited within human-machine interactions (HMI) either in the form of human-computer or human-robot interaction. Card et al. (1983) first coined the term HCI in 1980 and then discussed psychological science for analyzing HCI in their seminal work *The Psychology of Human-Computer Interaction*. The Association for Computing Machinery (ACM) defines human-computer interaction (HCI) as a field involving the design, evaluation, and implementation of interactive computing systems for human use. This discipline further includes the studies of the major phenomena surrounding humans and machines. Baecker et al. (1994) defined this interaction as a set of processes, dialogues, and actions employed by a user to interact with a computer to perform a specific task. HCI is now considered a multidisciplinary and diverse domain. From design methodologies of HCI, the primary aim is to create the user interfaces "usable," precisely to say "cognitive usable." Usability is the central focus in design for HCI.

The original academic area for HCI started with computer science, and its original focus was on personal productivity applications, mainly text editing and spreadsheets. The field has constantly diversified and outgrown all boundaries (Carroll, 1997). Research interests in HCI centers in methods for designing novel computer interfaces, implementing interfaces, evaluating and comparing interfaces with respect to their usability and other desirable properties, studying human computer use and its sociocultural implications, modeling and developing theories of human computer use as well as conceptual frameworks for the design of computer interfaces.

In the early 1980s, HCI was a small and focused specialty area. Today, HCI is a vast and multifaceted community, bound by the evolving concept of usability, and the integrating commitment to value human activity and experience as the primary driver in technology (Carroll, 2002). It expanded from early graphical user interfaces to include myriad interaction techniques and devices, multi-modal interactions, tool support for model-based user interface specification, and a host of emerging ubiquitous, handheld, and context-aware interactions. The major domains that have unfolded in HCI can be identified as:

Ubiquitous Computing: The main idea of ubiquitous computing is to allow computing interaction irrespective of time and place. Thus, it can allow humans to access computing power from any device, at any location, and by any format. This paradigm is also described as pervasive computing (Nieuwdorp, 2007), ambient intelligence (Hansmann, 2003), and everyware (Greenfield, 2006). A recent trend is to call this concept the “Internet of Things” (Brown, 2016) where things or devices are inter-networked. The concept of the “Internet of Things” became popular in 1999, through the Auto-ID Center at MIT and related market-analysis publications. The term itself was first coined by Kevin Ashton (Ashton, 2009). Under ubiquitous computing, several sub-domains or research wings evolved:

- **Mobile Computing:** In the form of mobile phones, smart cards, portable computers with the principles of portability, connectivity, interactivity, as well as individuality (Zimmerman, 1999). The downside or potential limitations of mobile computing is just not from the security standpoint, rather, the primary downside is the human interface with the device. Screens and keyboards tend to be small, which may make them hard to use. Conversely, alternate input methods such as speech or handwriting recognition require training.
- **Voice Recognition:** Is often called “speech recognition.” Applications include voice dialing/text, voice command, and speech-to-text processing. Several pioneering daily applications and uses are Amazon’s Echo and Google’s Google Home. Attention-based Automatic Speech Recognition (ASR) models were introduced simultaneously by Chan

et al. (2016) of Carnegie Mellon University and Bahdanaua et al. (2016) of the University of Montreal.

- **Wearable Device:** Comes from the development of wearable computers and also has been called wearable technology or just wearables. From fashion to navigation, fitness tracking to treatment, or even for media and communication, this is becoming popular day by day. Wearable devices are rapidly advancing in terms of technology, functionality, and size, with more real-time applications (Crawford, 2016).
- **Gesture Recognition:** The goal of gesture recognition is the interpretation and implementation of human gestures via mathematical algorithms. Application areas include automotive sector, smartphones, consumer electronics sector, transit sector, and gaming sector. Recent work includes Jaques et al. (2016) on how intelligent virtual agent (IVA) can be designed to both predict whether it is bonding with its user and convey appropriate facial expression and body language responses.

Social Computing: Social computing is fundamentally about computing systems and techniques in which users interact, directly or indirectly, with what they believe to be other users or other users' contributions (ACM). In the application level, social software can be any computational system that supports social interactions among groups of people. Facebook or any similar type of platform are examples of social computing as are Wikis, blogs, online dating, or online gaming. Currently, research in the areas of social computing is being done by many well-known labs owned by Microsoft and MIT. The team at Microsoft has a mission statement of *"to research and develop software that contribute to compelling and effective social interactions."* Their main focus is on user-centered design processes. Microsoft also added rapid prototyping combined with rigorous science to bring forth complete projects and research that can impact the social computing field. MIT, however, has a goal of creating sociotechnical systems that shape the urban environments.

- **Social Network:** Analysis is now one of the major paradigms in contemporary sociology, and it is also employed in several other social and formal sciences. Together with other complex networks, it forms part of the nascent field of network science (Borgatti, 2009; Easley, 2010).
- **Cognitive Modeling:** Describes how people's thoughts and perceptions influence their lives. Cognitive modeling historically developed within cognitive psychology and cognitive science (including human factors) and has received contributions from the fields of machine learning and artificial intelligence.

Modeling and Simulation: The primary objective of this field or domain is to build and use models for physical, mathematical, or otherwise logical representation of a system, entity, phenomena, or process, and to emulate that model to extract information for technical or managerial decision making. This is an emerging field and still growing.

- **Augmented Reality:** AR is a technology that layers computer-generated enhancements atop an existing reality to make it more meaningful through human ability to interact with it. Even though the applications area first emerged within the military, industrial, and medical applications, its scope has expanded to the areas in the visual arts, commerce and marketing, education, emergency management, serious gaming, broadcasting, and industrial design. Microsoft's HoloLens augmented reality headset is one of the recent AR accomplishments.
- **Virtual Reality:** VR is an artificial, computer-generated simulation or recreation of a real-life environment or situation. It lets the user experience the virtual environment as

a real one. Google's affordable and accessible Cardboard, Facebook's Oculus, and Sony's Play Station are some VR examples. Application areas are almost similar to AR.

- **Serious Gaming:** Refers to video games (but not for the entertainment purpose only) used by industries like defense, education, scientific exploration, health care, emergency management, city planning, engineering, and politics (Aldrich, 2009) for training, education, practice, as well as for experimentation.

Health and Medical: The focus of medical HCI and UE (Usability Engineering) research is on ordering the mass of information of increasing importance in Medicine and Health Care (Holzinger, 2007). Together, they provide an emerging potential to assist the daily workflows in the realm of medicine and health care. Recently, Ahmidi et al. (2017) showed the first systematic and uniform evaluation of surgical activity recognition techniques on the benchmark database in Robotic Surgery.

Visualization: It is the process of representing a concept or abstract data as images that can aid in understanding the meaning of the idea or data. At IBM, graphics and visualization research addresses the problem of converting data into compelling, revealing, and interactive graphics that suit users' needs. Computer visualization techniques, such as computer graphics, animation and virtual reality have been pioneered with NSF support. The area also includes visible language programming, improvements in screen layout, windows, icons, typography, and animation.

- **Graphics:** Computer graphics for graphic design, industrial design, advertising, and interior design can be 2D or 3D depending on the dimensional representation of geometric data.

- **Data:** Any data can be visualized with the help of a computer to understand the meaning and interpret the meaning for general purpose.
- **Big Data:** The term “big data” often refers simply to the use of predictive analytics, user behavior analytics, or certain other advanced data analytics methods that extract value from data, and seldom to a particular size of data set. *“There is little doubt that the quantities of data now available are indeed large, but that’s not the most relevant characteristic of this new data ecosystem”* (Boyd, 2011). Analysis of data sets can find new correlations to spot business trends, prevent diseases, combat crimes, and in many other applications.

Information and Collaborative Systems: HCI is also taking place in information systems as well as in collaborative systems by computer-assisted business tasks to computer-mediated human activities.

Learning and Education: In education, the goal is to integrate better usability experience in computers for students or learners to foster learning experience. A significant part of HCI courses covers usability concepts and usability evaluations. The aim is not only at usable solutions but also at solutions that enhance quality of interaction. The narrow orientation to prototyping and usability evaluations does not motivate students to be creative. Such an approach often lacks for methods that invent better solutions and designs (Wong et al., 2007). In class or distance learning, students or learners can benefit by using interactivity-based learning systems.

Autonomous Vehicle: This term commonly refers to autonomous cars or self-driving cars, and in recent years, has gotten much attention from various research groups and industries. Self-navigating drones are also in this domain. In terms of FAA and state regulations, the applicability may be limited at present.

Computer Interface and Architecture: This domain deals with the design part of computation systems that allows HCI to be more sophisticated and user friendly. Some latest HCI developments within the "decision making" domain are as follows:

- **Decision Support System for VAD (2016) at HCII:** This project developed a decision support tool that mines medical histories and makes recommendations on when a person suffering from stage three or four heart failure should consider having a ventricular assist device (VAD) implanted. The work focuses on developing interfaces for medical teams and for patients by addressing the challenges in how people incorporate information from intelligent systems into a complex and high stress decision process.
- **Crowd-Augmented Cognition:** CAC includes designing of crowdsourcing frameworks to combine the best qualities of machine learning and human intelligence. CAC allows distributed groups of workers to perform complicated cognitive tasks.
- **Tech-Giants:** Companies like Google, Microsoft, Amazon, Facebook, and Samsung are investing and researching into new projects directly related to human-computer interactions.

Regardless of the ongoing research and major development within and surrounding human and machine intelligence, mostly in the application level, there has been little to no work in either transferring knowledge gained in machine to human applications or in the decision interactions between cognitively intelligent humans and artificially intelligent machines. At the same time, there has been little to no research conducted toward establishment of governance ontologies in other disciplines. In parallel, search of the governance literature produced only the following few corporate, information technology, and knowledge governance taxonomies:

- In order to maintain the integrity of the specifications, Weimer and Pape (1999) proposed a system of corporate governance taxonomy based on eight characteristics– (1) prevailing firm concept and mission, (2) the board of directors system, (3) ability of salient stockholders to influence managerial decision making, (4) importance of stock markets in the relevant national economy, (5) presence or absence of external market controls on corporations, (6) ownership structure, (7) extent that executive compensation is dependent on corporate performance, and (8) the time horizon of economic relationships.
- Keenan and Aggestam (2001) overlaid Weimer and Pape's systems of corporate governance with an intellectual capital paradigm to create a composite taxonomy of corporate/intellectual-capital governance styles. The taxonomy mapped the use of intellectual capital along two dimensions– (1) Internal-External, by identifying and applying internal intellectual capital assets to set intra-organizational direction versus identifying and applying external intellectual capital assets to set extra-organizational direction. (2) Stability-Change, by identifying and applying intellectual capital assets embedded in institutionalized roles, structures, and processes to maintain stability versus identifying and applying intellectual capital assets oriented toward change and renewal.
- Donahue (2004) proposed eight potential dimensions for corporate collaborative governance– (1) formal versus informal, (2) short versus long term duration, (3) specific issue versus broad focus, (4) public versus private institutional diversity, (5) valence defining the number of distinct entities linked together, (6) stable interests versus

volatile interests, (7) allocation of the initiative among participants, and (8) problem-driven versus opportunity-driven.

- Hua et al. (2006) identified two additional taxonomies to corporate governance based on China’s transition from Communist Party ownership of all enterprises to a mix of market ownership and State-Owned Enterprises. They proposed a hybrid taxonomy of strong versus weak state-centered governance against a strong versus weak open-entrepreneurial systems governance.
- Von Nordenflycht (2010) proposed a taxonomy of four types of knowledge-intensive firms based on capital intensity, knowledge intensity, and workforce professionalization– (1) technology developers, (2) neo-professional service firms, (3) professional campuses, and (4) regulated professional service firms.
- Wilkin and Chenhall (2010) developed a taxonomy of research encompassing the focus areas of strategic alignment, risk management, resource management, and value delivery identified by the IT Governance Institute. They based their taxonomy on a review of four hundred and ninety-six papers in ten IS/AIS and two Management Accounting journals over the period of 1998 to 2008.
- Simonsson et al. (2010) studied the relationship between IT governance maturity using the thirty-four IT processes defined in the Control Objectives for Information and related Technology (COBIT) taxonomy and actual IT governance from case studies of thirty-five organizations.
- Lampathaki et al. (2010) presented a taxonomy classifying research themes and research areas and subareas based on the European Union’s CORDIS Information and Communications Technologies (ICT) Governance and Policy Modeling.

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- De Haes et al. (2013) noted that although it is a good-practice framework there has been limited academic research linking the core elements and principles of COBIT 5 to outcomes in the IT-related and general management literature.
- DeNardis and Raymond (2013) developed a disaggregated Internet governance taxonomy along the dimensions of control of critical Internet resources, setting Internet standards, access and interconnection coordination, cyber security governance, information intermediation, and architecture-based intellectual property rights enforcement.
- Stout and Love (2015) presented a governance typology with four dominant types named as Institutional, Holographic, Atomistic, and Fragmented governance based on Western political theory and also proposed a more articulated one as Integrative Governance derived from relational process ontology. Their argument on this particular governance type is that it captures sustainability and provides better grounding for global governance by capturing mutual influence as well as dynamic political process.

2.2 Limitations of Existing Studies

Even with HCI's expansion in human and computer interactions, there still exists a semantic gap between the human's and computer's understandings towards mutual behaviors and actions. Ontology, as a formal representation of domain-specific knowledge, can be used to address this problem, through solving the semantic ambiguities between the two parties (Dong et al., 2010). The general governance literature that has been identified can be summarized as being comprised of taxonomic classifications of best practices and/or standards dependent on the context and the researcher's objectives. These best practices and/or standards differ from organization to organization, government to government, and thus lack systematic continuity and universal approach. Conversely, the proposed research seeks to develop a universal HI-MI decision governance ontology as the basis for a body of knowledge in a universal set of HI-MI decision domains.

From the methodological standpoint, proposed methodology (Figure 4) facilitates two things in parallel– (i) developing a foundational formal ontology for HI-MI decision governance systems (left-hand side of Figure 4) and (ii) establishing a grounded theory based foundational body of knowledge (BoK) for human-intelligence (HI) and machine-intelligence (MI) decision governance (right-hand side of Figure 4). Ontology development essentially requires having an expert reference or knowledge base acquired from human experts and/or existing knowledge base. In contrary, absence of an expert reference base or body of knowledge (BoK) in HI-MI decision governance systems, it is needed to have such a reference base first so that based on that an ontology can be built. Unlike domain or application level ontologies where expert panels or human subjects can be interviewed to accumulate required knowledge, foundational ontology lacks similar subject matter experts to adopt such an interview-based knowledge acquiring approach. This research thus utilizes a parallel tied-up approach of building a BoK by synthesizing meta-knowledge from existing peer-reviewed literature entailing to be the expert reference base and then constructing a foundational ontology relying on this reference base. Rigorous systematic verifications and validations are implemented, so as the necessary conditions, to support proposed formal foundational ontology.

CHAPTER 3

METHODOLOGY

3.1 Integrative Approach

The integrative approach toward developing the general HI-MI decision governance theory and body of knowledge was first proposed by Cotter (2015) and then modified (Mahmud and Cotter, 2017) to capture the overall picture in developing different levels of ontology with corresponding cross-validation against a theoretical body of knowledge (BoK) (Figure 3).

The general research approach shown here proposes integration of existing socio-technical systems knowledge with decision theory and AI declarative and procedural knowledge into a human-intelligence and machine-intelligence systems theoretical framework and body of knowledge and then validates it through causal modeling of specific organizational decision instances.

This research only addresses the establishing of the formal foundational ontological basis of human-intelligence and machine-intelligence (HI-MI) decision governance to form the theoretical foundation of a systemic HI-MI decision governance body of knowledge.

Figure 3 shows the modified integrative approach to HI-MI decision governance theory and BoK.

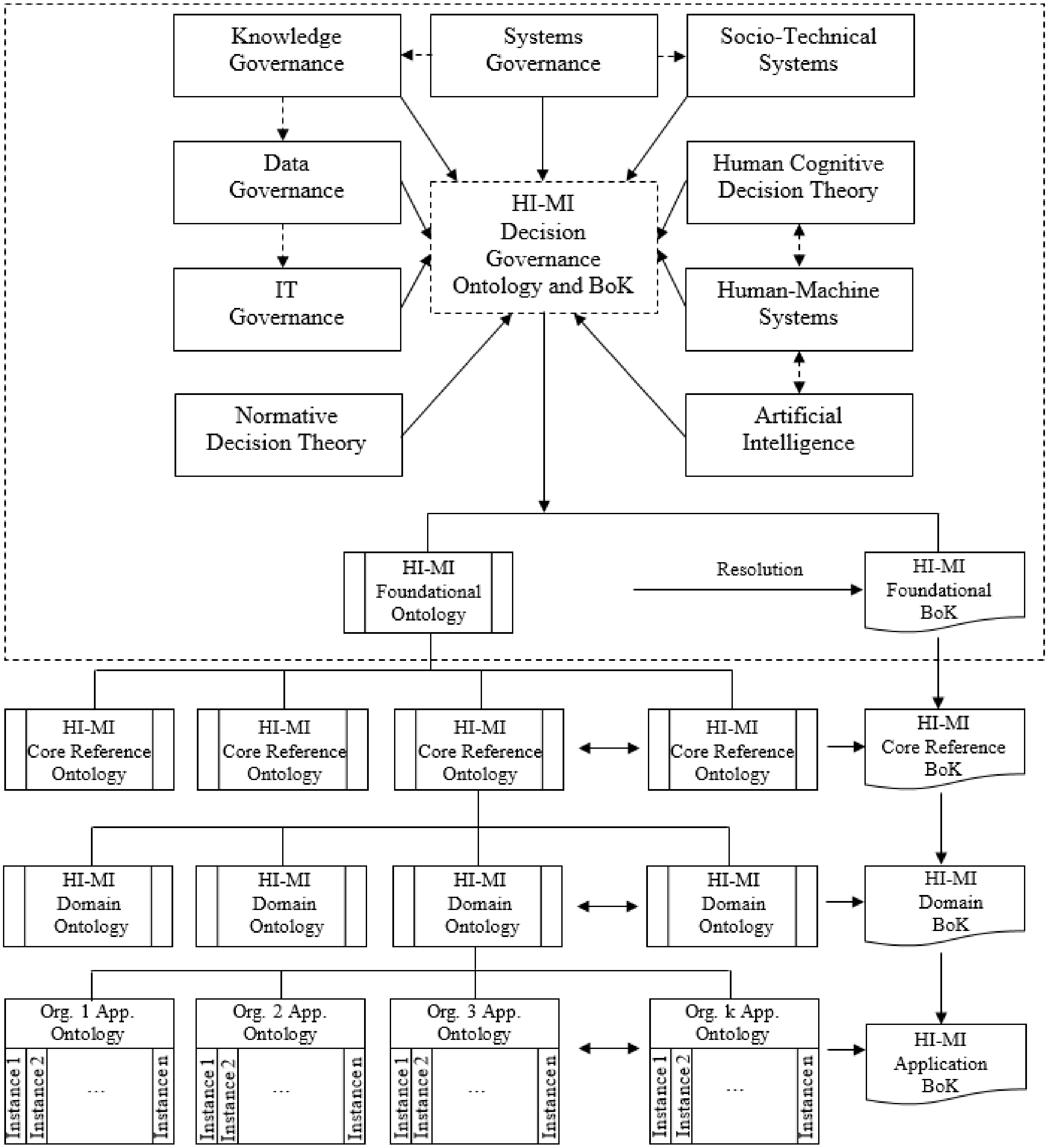

Knowledge Governance
Systems Governance
Socio-Technical Systems
Data Governance
HI-MI Decision Governance Ontology and BoK
Human Cognitive Decision Theory
IT Governance
Human-Machine Systems
Normative Decision Theory
Artificial Intelligence
HI-MI Foundational Ontology
Resolution
HI-MI Foundational BoK
HI-MI Core Reference Ontology
HI-MI Core Reference Ontology
HI-MI Core Reference Ontology
HI-MI Core Reference Ontology
HI-MI Core Reference BoK
HI-MI Domain Ontology
HI-MI Domain Ontology
HI-MI Domain Ontology
HI-MI Domain Ontology
HI-MI Domain BoK
Org. 1 App. Ontology
Org. 2 App. Ontology
Org. 3 App. Ontology
Org. k App. Ontology
Instance 1
Instance 2
...
Instance n
HI-MI Application BoK

Figure 3: Integrative Approach to HI-MI Decision Governance Theory and BoK.

3.2 Knowledge Generation Ontological Engineering Model

Since new or extended knowledge is not considered valid until it has passed a peer review process(s) and been published, this current research on knowledge generation ontological engineering process is based on gathering and jointly modeling a given body of peer reviewed works traced to their supporting seminal knowledge while simultaneously engineering the supporting ontology. The knowledge generation approach to ontological engineering integrates– (i) the theoretical construction and development methods of grounded theory and synthesizing meta-knowledge as the foundation for building the validated body of knowledge, (ii) the appropriate ontological design method for the target ontology's level and type, and (iii) text mining and content analysis to support concept extraction and concept relationships extraction for body of knowledge development and ontology engineering. The knowledge generation approach to ontological engineering seeks to mitigate the incomplete knowledge emergence limitation by integrating and validating theory and ontology development against each other.

3.3 Grounded Theory

Grounded theory provides a rigorous qualitative basis for systematically identifying the theoretical constructs, themes, and patterns evidenced in a literature corpus. Originally developed by Glaser and Strauss (Glaser and Strauss; 1965, 1967) to systematically generate social behavioral theory from observations of human decisions and actions, grounded theory has been extended to content analysis of textual data. For textual data, the first stage is to gather documents covering the spectrum of the research question(s) as completely as possible. During the document gathering stage, emergent anchor codes and natural key categories are identified from key words, phrases, and research questions. The term "code" means a named concept. The objective of the initial coding is to produce codes that relate directly to the original authors' conceptual perspectives. Anchoring codes also permit the assessment of saturation, that is, completeness of the corpus in breadth and depth. Once the document corpus is assembled, work proceeds to open coding in which the literature are comparatively decomposed into natural conceptual categories. Next, axial coding identifies spatial, temporal, cause-effect, and means-ends relationships within and among the natural axial categories. The output of axial coding is a synthesis of the natural axial categories into a core concept that explains the phenomenon of interest. Finally, selective coding refines the natural axial categories and their relationships by recoding the data with the core concept guiding the coding. If the natural axial categories and their relationships have been adequately specified, one of the axial categories should explain the central phenomenon of the core concept with all other axial categories characterized by their relationships with the core concept category.

3.4 Ontological Engineering Methodology

3.4.1 General Ontology Development Methodology

Ontology development process has varied methods depending on the ontology level and type. The fundamental ontology life cycle is:

1. Pre-design addresses scoping, the environment, and feasibility. Scoping is to find out overall scope of the ontology. The environment study identifies the platforms on which the ontology will run and the applications with which it must interface. The feasibility study addresses whether or not it is possible or even suitable to build the ontology.

2. Design addresses requirements development, ontological analysis, ontology design, and system design. Requirements development establishes the ontology conceptualization, context, and scope resulting in a set of initial specifications of the ontology's purpose, end users, intended uses, and relevant knowledge models. Ontological analysis identifies key conceptual classes and relationships within and among them for the relevant knowledge models. Ontology design translates the conceptual classes and relationships into a selected ontology language. System design addresses the software and hardware integration of the ontology into the larger information system.
3. Development addresses the ontology production, system production, and deployment. Ontology production transforms the conceptualized knowledge models into formal or semi-formal computable models suitable for deployment and re-use in the selected ontology language. Ontology system production produces the system software and hardware components necessary to support the ontology and integrate it into the larger information system. Deployment activities pilot the ontology in a test environment and scales it up with necessary improvements and extensions for the operational environment.
4. Maintenance tracks ontology performance and corrects or updates the knowledge models in the selected language as needed to maintain consistency, completeness, uniqueness, and to enable re-use.

3.4.2 The Integrated Knowledge Generation Ontological Engineering Methodology

The knowledge generation approach to ontological engineering integrates the development of a body of knowledge and its supporting ontology. The methodology begins by assembling a corpus of peer reviewed works traced to their supporting seminal knowledge about the phenomenon of interest. Initially, the corpus is categorized based on research focus by applying the grounded theory open coding process. The corpus is judged to reach saturation when the identified conceptual categories span and describe the dimensions of the body of knowledge of the phenomenon of interest, and the literature within each category achieves redundancy (i.e., reaches diminishing returns in that the inclusion of additional works provide no new or only minor information) (Bowen, 2008). Next, text mining and content analysis are applied as exploratory tools to extract manifest and latent concepts. Text mining provides lexical information on key term clusters and their distributions. Separation between clusters indicates their exclusiveness as a manifest or latent category, and the distributional properties indicate coverage of the body of knowledge. Content analysis is applied to analyze information patterns within clusters. The structure of the patterns within categories suggests manifest and latent subcategories and how completely they specify knowledge within the category. Identified categories and subcategories are applied as the initial codes for grounded theory open coding and tested to determine the degree to which they describe knowledge concepts, theories, and principles of the phenomenon. Resultant category and subcategory codes are adjusted and become the taxonomic seed categories and subcategories for the ontology and the core concepts categories and subcategories for the body of knowledge.

Content analysis is applied to examine concept relationship patterns among subcategories within categories and among categories. These concept relationship patterns are applied as the initial relationships for grounded theory axial coding, or research synthesis models, and tested for fit to the relationships among knowledge concepts, theories, and principles of the phenomenon. Concept categories, subcategories, and relationships are refined through selective coding based on fit to concepts, theories, and principles and become the axioms and functions for the ontology and body of knowledge. The ontology, finally, is published for review and refinement before being released for use.

It is the identification of latent categories and subcategories and the synthesis of relationships among and within them that admits knowledge generation in this methodology. In the historical knowledge representation methods of ontology development, all knowledge is assumed to be manifest and only extracted from experts in the field. This research extends the HCI and human-machine intelligence paradigms to the study of cognitive interactions of humans and intelligent machines in systemic decision-task processes. The foundational body of knowledge for HI-MI decision governance must be synthesized from expert knowledge in the disparate domains of systems governance, knowledge governance, data governance, artificial intelligence, decision theory, socio-technical systems as well as HCI and HMI. In order to synthesize these disparate bases of knowledge, a mixed research method is followed with quantitative text mining and content analyses being overlaid on a qualitative grounded theory analysis framework. The knowledge generation ontology development methodology for this study is shown in Figure 4 and summarized in the following steps:

1. **Data gathering:** Create corpus of peer reviewed journal articles of the identified knowledge domains,
2. **Concept extraction:** Perform text mining for concept extraction to identify structural commonalities and differences in the literature corpus,

3. **Open coding:** Using the identified structural commonalities and differences, conduct open coding in grounded theory analysis in order to establish concept classes/categories for the HI-MI decision governance body of knowledge,
4. **Taxonomy development:** Follow ontology design method and specifications to develop taxonomy classes/categories,
5. **Content analysis:** Perform content analysis to identify taxonomical relationships within and between structural relationships,
6. **Axial coding:** Using the taxonomical relationships, conduct axial coding in grounded theory analysis to establish axiomatic relationships,
7. **Ontological relationships:** Follow ontology design method and specifications to develop ontological relationships,
8. **Content refinement:** Perform content refinement to refine taxonomical structure and axiomatic relationships,
9. **Selective coding:** Apply grounded theory selective coding to refine taxonomical structure and axiomatic relationships,
10. **Ontology refinement:** Follow ontology design method to conduct taxonomy-ontological refinement,
11. **Evaluation:** Validate the foundational ontology against the developed foundational HI-MI theoretical body of knowledge.

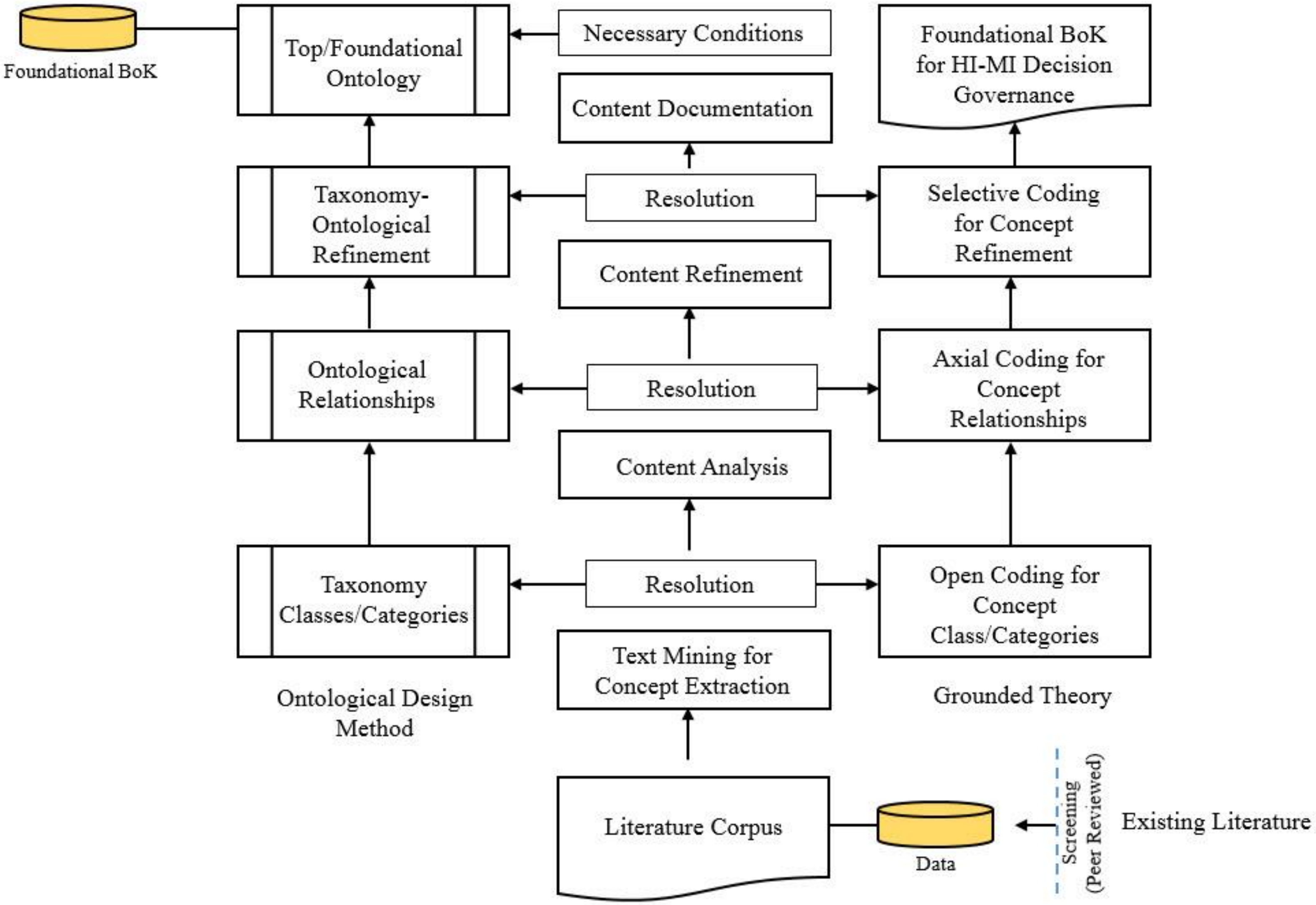

Foundational BoK
Top/Foundational Ontology
Necessary Conditions
Foundational BoK for HI-MI Decision Governance
Content Documentation
Taxonomy-Ontological Refinement
Resolution
Selective Coding for Concept Refinement
Content Refinement
Ontological Relationships
Resolution
Axial Coding for Concept Relationships
Content Analysis
Taxonomy Classes/Categories
Resolution
Open Coding for Concept Class/Categories
Text Mining for Concept Extraction
Ontological Design Method
Grounded Theory
Literature Corpus
Data
Screening (Peer Reviewed)
Existing Literature

Figure 4: Research Methodology.

3.5 Data Collection Source and Data Type

Data collection is an acute step for any research. Considering the source and types of data, research findings and significance may divaricate. Therefore, care must be given in selecting data source(s) as well as the types of data being used for the research. For this study, data is collected from the World Wide Web (WWW or W3), which is a major information space, and so far, the largest collection of public and private websites as well as a system of Internet servers that supports specially formatted documents. Retrieving data from the W3 is also convenient and faster. Conjointly, other obtainable sources such as library, printed journals, and books are also contemplated. Restricted or classified governmental data is excluded from this study. The W3 is attested as the primary data source.

The data used and analyzed for this inquiry are qualitative in nature and text based that are comprised of Portable Document Format (pdf) file of peer reviewed articles, journal papers, seminal books, and book chapters.

3.6 Saturation: General Overview

Saturation is a key term in qualitative research and can be found in various forms, with its origination being theoretical saturation as developed in grounded theory (Guest et al., 2006). Other variations of the concept for other qualitative methods include data saturation (Francis et al., 2010; Guest et al., 2006), thematic saturation (Guest et al., 2006), and in some cases simply saturation (Starks and Trinidad, 2007), as noted in the history of saturation (O’Reilly and Parker, 2012).

Despite the significance of the term “saturation” and its applicability within grounded theory based study, there are some misconceptions about how to achieve it. There appear to be no strict standard rules, criteria, or practical guidance on how to attain saturation. Glaser and Strauss (1967) first outlined saturation as the point at which "…*no additional data are being found whereby the researcher can develop properties of the category. As the researcher sees similar instances over and over again, the researcher becomes empirically confident that a category is saturated* . . . *when one category is saturated, nothing remains but to go on to new groups for data on other categories, and attempt to saturate these categories also*."

Further, Bowen (2008) noted that data saturation entails bringing new data continually into the study until the data set is complete, as indicated by data replication or redundancy. In other words, saturation is reached when the researcher gathers data to the point of diminishing returns, when nothing new is being added. Charmaz (2003) explained that saturation calls for fitting new data into categories already devised. For their part, Morse et al. (2002) pointed to the purpose of data saturation as "…*saturating data ensures replication in categories; replication verifies and ensures comprehension and completeness*." Therefore, in grounded theory, the notion of saturation does not refer to the point at which no new ideas emerge, but rather means that categories are fully accounted for, the variability between them are explained, and the relationships between them are tested and validated and thus a theory can emerge (Green and Thorogood, 2004).

Another known question about data saturation often identifies the "quantity" or "numbers" on data collection and how that impacts overall saturation. In fact, this can vary from one research to another, and even within the same research from one theme or category to another. There are two key considerations that guide the sampling methods in qualitative research– appropriateness and adequacy (Morse and Field, 1995). Marshall (1996) argued that the researcher should be pragmatic and flexible in their approach to sampling and that an adequate sample size is one that sufficiently answers the research question. In this sense, generalizability is not sought by the researcher and the focus is less on sample size and more on sample adequacy (Bowen, 2008). Bowen (2008) also argues that adequacy of sampling relates to the demonstration that saturation has been reached, which means that depth as well as breadth of information is achieved. Thus, the quality of data over quantity or numbers must be prioritized. Researchers must always ensure that the data source is valid and collected data possess high standards as well as quality to uphold the research potency to maintain the soundness and robustness of the study.

Despite all the debates and arguments, saturation as a concept still remains nebulous, and the process lacks systemization (Bowen, 2008). Therefore, the best way to formally maintain this integral part of any qualitative research is not just merely mentioning in a single statement that saturation is achieved but clearly explaining how the saturation is achieved along with any related issues or limitations (if occurs). Precise documentation must also be provided for a clear picture of attaining saturation. Researcher(s) must also state what systematic checks and quality assurances are made in obtaining saturation.

3.7 Documentation for Saturation

The subsequent sections explain how saturation is accomplished for this study. It is noteworthy to mention about the data source validation in conjunction with the ways data is collected. Sufficient and necessary reasoning behind this process are also included in the documentation.

3.7.1 Source Validation

For any research, especially in qualitative type, the data source must ensure quality, trustworthiness, and robustness. Source validity identifies any limitations or issues regarding the data source that may pose a concern for quality of data resulting in a negative impact to the overall research.

The documents used and analyzed for this inquiry were collected from the WWW and specifically from peer reviewed articles, journal papers, seminal books, and book chapters. The WWW is an open source information space and allows a fast, easy, and efficient access to the required documents. Some journal papers and articles required special university access permission to retrieve. As already mentioned, documents used herein had already passed through review processes, thus providing a layer of confidence about content validity, quality, as well as maturity. These documents carry more weight than mere opinions, blogs, newspaper articles, and any other personal thoughts.

3.7.2 Concept Dictionary

To manage, organize, and analyze collected documents, primarily for open coding, a data dictionary in the form of a concept dictionary was created (Appendix A) within Microsoft Word with some reasonable parameters such as– (1) corpus title, (2) author(s), (3) publication year, (4) publication source, (5) keywords, (6) primary research question(s), (7) secondary research question(s), (8) open categorical coding theme, and (9) axial relationships theme. The primary goal for this concept dictionary was to extract themes or concepts from compiled data. The secondary goal of this concept dictionary was to ensure whether a particular theme or concept or category are fully accounted for to achieve saturation.

3.8 Open Coding

The purpose of open coding is to arrange any qualitative data in a more manageable format for categorizing and to assist with further analysis into axial and selective coding. The term “code” entails a named concept. The objective of coding is to produce codes that relate directly to the original authors’ conceptual perspectives. Codes also permit the assessment of saturation; that is completeness of the corpus in breadth and depth. Once the document corpus is assembled, work proceeds to open coding in which the literature are comparatively decomposed into natural conceptual categories. After completing the concept dictionary, criteria in Table 1 are specified for open coding.

Table 1: Open Coding Specifications.

Phases	**Goals and Steps**
Phase 1:	**Goal 1: To identify emerging concepts from relevant literature**
Steps for identifying emerging concepts/categories	Step 1: Read papers. Step 2: Check for theme or concept implication. Step 3: Identify emerging concept classes/categories. Step 4: Document as emerging concept classes/categories.
Phase 2:	**Goal 2: To identify core-emerging classes/categories**
Steps for identifying core-emerging concepts/categories	Step 1: Look up for similar concepts and their consistency. Step 2: Cross-check for relevancy. Step 3: Identify and merge similar concepts. Step 4: Document as core-emerging concept classes/categories.
Phase 3:	**Goal 3: To identify secondary classes/categories**
Steps for identifying secondary classes/categories	Step 1: Identify core-emerging concept classes/categories to fit into secondary concept classes/categories. Step 2: Document as secondary category. Step 3: Documentation of relevant literature by paper title, lead author, and year under secondary category.
Phase 4:	**Goal 4: To identify primary concept classes/categories**
Steps for identifying primary concept classes/categories	Step 1: Identify secondary concept classes/categories to fit into primary concept classes/categories. Step 2: Documentation by primary concept category.

Based on the conditions and steps set in Table 1, literature relevant to similar themes are first sorted within secondary and then eventually under primary classes/categories. Figure 5 shows how primary classes/categories evolved from the concept dictionary.

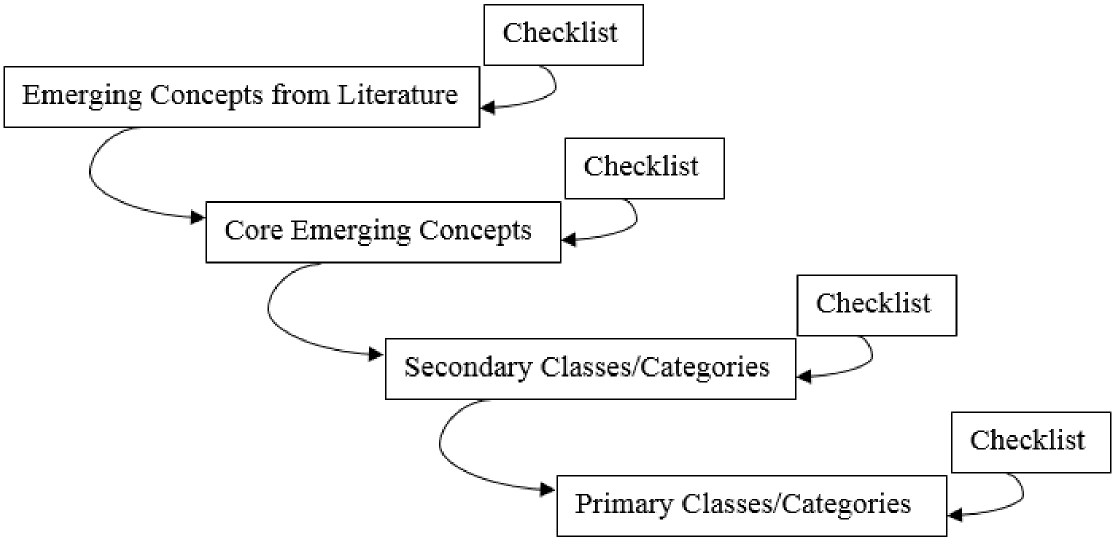

Checklist
Emerging Concepts from Literature
Checklist
Core Emerging Concepts
Checklist
Secondary Classes/Categories
Checklist
Primary Classes/Categories

Figure 5: Schematic Approach for Identifying Categories.

Collected data are gathered into various secondary categories that eventually fall into different primary or top categorical themes. For example, literature related to “Governance” has nine different secondary categories. In each secondary category, the number of related literature for saturation varied. Before conducting data analysis, the systematic approach depicted in Figure 6 is followed to convert pdf files of the literature corpus into cleaned text format. Issues encountered during text cleaning are remarked in Appendix B.

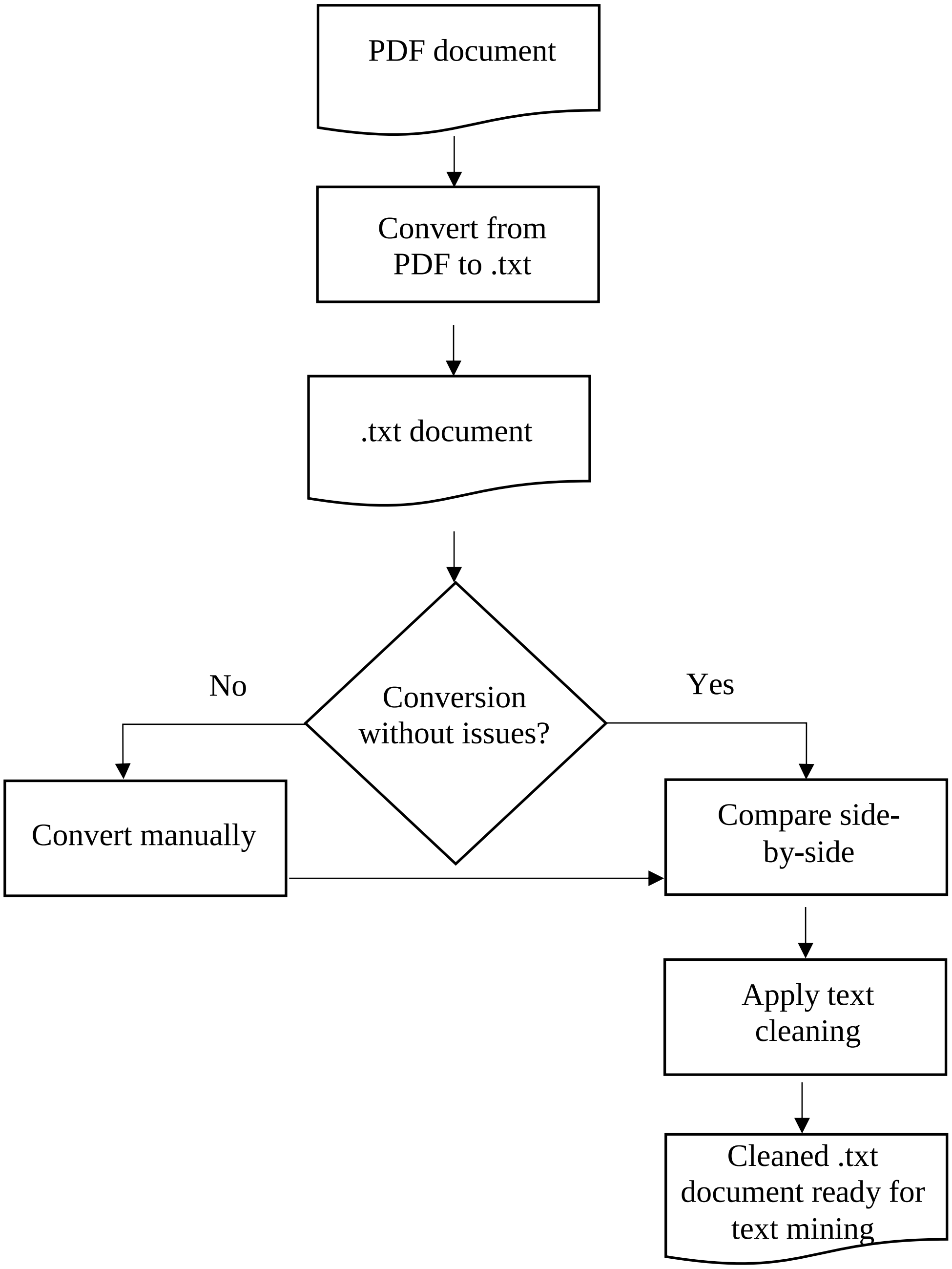

PDF document
Convert from PDF to .txt
.txt document
Conversion without issues?
No
Yes
Convert manually
Compare side-by-side
Apply text cleaning
Cleaned .txt document ready for text mining

Figure 6: Flow Diagram from Pdf to Text Mining Ready Document.

3.9 Axial Coding

The purpose of axial coding is to find the relationships among categorized classes or terms. For the analysis, a column is added in the concept dictionary (Appendix A) to identify axial relationships. Identified foundational categories are connected based on the context of axial relationships. Axial relationships coding in grounded theory provides the foundation for body of knowledge theory development.

3.10 Selective Coding

The purpose of selective coding is to find the central category or core category by concept refinement. Whereas open and axial coding are top-down categorization and relationships building, selective coding is a bottom-up re-synthesis in which the researcher carefully examines and realigns categories and relationships in order to identify and refine the core category to explain the overall body of knowledge theory.

3.11 Data Analysis

Data analysis is conducted in the open, axial, and selective coding phases based on the specifications and structured guidelines that already have been discussed. In each phase, researchers must carefully code for as many categories as fit successive, different incidents. New categories thus emerge, and new incidents fit into existing categories (Holton, 2007).

3.12 Design-Specific Method for Developing Foundational Ontology

3.12.1 Ontology Design Method

Cross-validation/resolution between ontology development and grounded theory body of knowledge development addresses the need for internal consistency rigor. As can be seen from Figure 4, in each phase of the ontology development, cross-validation checks are made to establish that the necessary conditions for categories and axioms are achieved to support the foundational ontology. For example, in Phase 1, text mining was conducted for concept extraction. Open coding was performed in grounded theory for concept classes/categories. On the parallel side, following the SUMO ontological development method, taxonomy classes/categories were established. The taxonomic categories are cross-validated against those that are supported by the grounded theory concept classes/categories. This validation cycle continued until the taxonomic and grounded theory concept classes/categories converged.

In comparison to other existing top-level ontology development methods, the SUMO ontology development method is more suitable for this research. SUMO has some key components that are directly helpful and beneficial for this ontology development. Some key features of existing top ontologies are shown in Table 2 (adapted from Mascardi et al., 2007).

Table 2: Key Features of Some Top Ontologies.

Name	Dimensions	Languages	Alignment with the WordNet	Modularity	Developed Applications	Motivated by Focus Area-Theory or Pragmatic?	Other Key Points
DOLCE	About 100 concepts and 100 axioms	First Order Logic, KIF, OWL	Only for DOLCE-Lite-Plus version	Not divided into modules	Multiple applications including linguistics	Theory focus	- has a clear cognitive bias, aims at capturing the ontological categories underlying natural language and human commonsense - an “ontology of particulars”; it has limited universals (classes and properties)
BFO	36 classes related to *is_a* relation	OWL	Not supported	Consists in two sub-ontologies-SNAP and SPAN modules	Biomedical domain Goldberg, L., (2004); also used in building an ontology for clinic-genomic trials on cancer	Theory focus	- designed for use in supporting information retrieval, analysis, and integration in scientific and other domains
GFO	79 classes, 97 subclasses-relations, 67 properties	First Order Logic, KIF, OWL	Not supported	Abstract top level, abstract core level, basic level	Biomedical science, conceptual modeling	Theory focus	- GFO includes elaborations of categories like objects, processes, time and space, properties, relations, roles, functions, facts, and situations
SUMO	20,000 terms and 60,000 axioms (including domain ontologies)	SUO-KIF, OWL	SUMO has been mapped to all of the WordNet v2.1 by hand	Divided into SUMO itself, MILO, and domain ontologies	Multiple applications-linguistics, reasoning, academic, government, and industry	Pragmatic focus	- one of the largest formal public ontologies in existence today - an ontology of both particulars and universals

Other central features of SUMO that made this development method broadly accepted are:

- It maps to the WordNet,
- It possesses language generation templates for multiple languages,
- It provides tool support for browsing and editing,
- It is the largest, free, open source, top, and formal ontology available,
- It is more than a taxonomy; it has rich axiomatization,
- Its terms are formally defined. Meanings are not dependent on a particular inference implementation,
- It is the only top-level ontology consistent with the Institute of Electrical and Electronics Engineers (IEEE) standard,
- It was created by merging publicly available ontological content into a single, comprehensive, and cohesive structure,
- It has a hierarchy of properties as well as classes. This is a very important feature for practical knowledge engineering as it allows common features like transitivity to be applied to a set of properties, with an axiom that is written once and inherited by those properties, rather than having to be rewritten, specific to each property.

Building an ontology also requires certain procedural steps or phases that allow rigorousness. As noted by Uschold (1995), these ontological building phases may impose some challenges like:

- **Ontology Capture:** Identification of the key concept classes/categories and the relationships in the domain of interest.

- **Definitions:** Production of precise unambiguous text definitions for each concept and relationship.
- **Terms:** Identification of the terms to refer to such concepts and relationships.
- **Coding:** Explicitly representing the knowledge acquired in ontology capture phase.
- **Integration:** During either or both of the capture and coding processes, there is the question of how and whether to use ontologies that already exist.

The knowledge generation ontology development methodology specified in Figure 4 addresses these challenges.

3.12.2 Design Specifications for OWL

Integrated Definition for Ontology Description Method (IDEF5) is considered as a reference for specifications to map developed ontology with Web Ontology Language (OWL 2.0). These specifications also ensure ontology usability and extendibility by aligning developed ontology with the World Wide Web Consortium (W3C). IDEF5 referenced specifications are integrated with Fluent Editor to directly map developed ontology to OWL 2.0 specifications.

3.12.3 Necessary Conditions in the Ontology and Body of Knowledge

Both inductive reasoning (Evans, 1996; Harman, 1999; Heit, 2000) and abductive reasoning (Peirce, 1958; Paul, 1993; Aliseda, 1997; Magnani, 2001; Lipton, 2004; Soler-Toscano et al., 2013) begin with observations. Inductive reasoning assumes or constrains the reasoning space to complete information, whereas abductive reasoning relaxes the assumption of complete information. Conversely, the taxonomic structure of ontology requires monotonic mutual exclusivity and exhaustiveness of complete information. The logic of the abductive-deductive grounded theory based body of knowledge development (Figure 4 right-hand side BoK development) versus the inductive-deductive ontology development (Figure 4 left-hand side ontology development) is that it counter balances the pure abductive arguments and deductive interpretations necessary in grounded theory supported BoK development with inductive-deductive logic necessary for establishment of the taxonomic and axiomatic structures in ontology design. That is, it forces proof of abductive-deductive knowledge theories by inductive-deductive logic.

Now, first analyzing how the abductive-deductive logic holds good for the BoK development. Unlike inductive and deductive inferences, abductive reasoning can be specified by infinite constraints set by the research seeking various alternative solutions to a problem. As noted by Klarman et al. (2011) *"…the space of abductive solutions can be in principle infinite, it is common to employ additional constraints to narrow it down, at least by excluding obviously unacceptable solutions."* These constraints delimit the reasoning space for complete information and act as necessary or minimal conditions to uphold an abductive explanation, in this research, the abductive explanation of the HI-MI decision governance body of knowledge. Based on Aliseda's (1997) abduction requirements, elsewhere identified as the most intuitive and universal requirements (Klarman et al., 2011), Elsenbroich et al. (2006) affirmed on the similar constraints (as listed below) to employ and support the integration of non-monotonic abductive reasoning into the deductive monotonic ontology design:

- **Consistency:** This criterion allows only consistent solutions by discarding solutions inconsistent with the knowledge base. In this study, it means to ensure whether taxonomic classes, their relationships, and overall ontological structure are consistent with the foundational BoK. The consistency requirement will be checked by Fluent Editor.
- **Minimality:** The Minimality criterion checks that solutions do not contain any irrelevant or superfluous information by not abducing more than what is necessary. Minimality condition may be considered as a sufficient one to explain a solution, however, can be extended to a necessary condition by deploying even stronger assertion on top of the minimal one.
- **Relevancy:** This criterion checks further whether a solution is relevant or not in conjunction with the knowledge base. A query must not entail the solution by its own unless engaging the union of BoK. A joint body of knowledge and query should entail a solution to be relevant. Relevancy check prevents accepting ad hoc solutions that avoid problems itself rather solving it (Klarman, 2008).
- **Explanatoriness:** To ensure developed ontology prevails explanations by taking into account both relevancy and consistency. Explanations must be relevant and consistent with the BoK. This criterion will also be tested by Fluent Editor checks.

The second thing to clarify is the deductive proof/interpretations of the aforementioned abductive explanations. This analysis will be confirmed by providing axiomatic support from the abductive logic programing (ALP) context (Esposito et al., 1996; Lamma et al., 2000). Kakas et al. (1993) provided an extension of logic programing (LP) to perform abductive reasoning, later supported by an algorithmic update (Esposito et al., 2007). ALP is an extension of LP to support abductive reasoning with logic programs that incompletely describe their problem domain (Esposito et al., 2007). By utilizing any relevant tool, a minimal set of axioms can be identified to be inserted into a knowledge base for a certain entailment to hold in abduction (Bada et al., 2008). In this research, Fluent Editor is used to insert and manipulate a minimal set of axioms.

Gruber's (1995) ontology design criteria imposes necessary conditions of ontology design. Aliseda's (1997) and Elsenbroich's (2006) necessary constraints on abductive reasoning establishes logical supports by delimiting problem space for consistency, minimality, relevancy, and explanatoriness. Further, a minimal set of axioms in abductive logic programing will provide further support for deductive interpretations. By integrating Gruber's (1995) ontology design criteria with necessary abductive constraints and axiomatic support, the foundational HI-MI decision governance ontology will satisfy required necessary conditions as shown in Figure 4. The following table summarizes the necessary conditions to support proposed foundational ontology.

Table 3: Necessary Conditions.

Purpose	**Necessary Conditions**
Ontology Design (Gruber, 1995)	Clarity
	Coherency
	Extensibility
	Minimal encoding bias
	Minimal ontological commitment

Table 3: Continued.

Purpose	**Necessary Conditions**
Abductive Constraints (Aliseda, 1997; Elsenbroich, 2006)	Consistency
	Minimality
	Relevancy
	Explanatoriness

Now that both abductive explanations and deductive proof are explained, we may consider the ontological structure as a set $\boldsymbol{\{A, D\}}$ which provides a deductive structure $\boldsymbol{D}$ and abductive meaning $\boldsymbol{A}$. The foundational ontology provides a primarily deductive structure $\boldsymbol{D}$ with minimal abductive explanation $\boldsymbol{A}$ from the associated body of knowledge. Additional deductive structure $\boldsymbol{D_S}$ will be provided in subsumed core reference, domain, and knowledge application ontologies through addition of refined subsumed minimal abductive explanations $\boldsymbol{A_S}$. Full deductive structure plus abductive explanation $\boldsymbol{\{A, D\}} \subset \boldsymbol{\{A_S, D_S\}}$ can be derived only from examination of the full foundational, core reference, domain, and application ontological structure.

3.13 Ontology Verification and Validation

3.13.1 Verification

Ontology verification checks the correctness of building of the ontology following ontology design criteria. The resultant ontology will be verified by Fluent Editor that uses Gomez-Perez's (1996, 1999, and 2001) criteria such as consistency, completeness, conciseness, expandability, and sensitiveness for evaluating and verifying taxonomies and ontologies. As explained before and shown earlier in Table 3, the necessary conditions are taken into account to explain deductive structure and inductive meaning in the ontological structure. Further, Fluent Editor is used to test the verification. Table 4 shows the listing of necessary conditions with verification criteria.

Table 4: Necessary Conditions with Verification Criteria.

Purpose	**Necessary Conditions**	**Verification Criteria**	**Verification Meet**
Ontology Design (Gruber, 1995)	Clarity	Conciseness	By Fluent Editor using Gomez-Perez's (1996, 1999, and 2001) criteria.
	Coherency	Consistency	
	Extensibility	Expandability	
	Minimal encoding bias	Completeness	
	Minimal ontological commitment	Sensitiveness	
Abductive Constraints (Aliseda, 1997; Elsenbroich, 2006)	Consistency		
	Minimality		
	Relevancy		
	Explanatoriness		

3.13.2 Validation/Resolution

Validation/resolution is an integral part of ontology development. This study addressed both short-term and long-term validations/resolutions. Short term validation/resolution is achieved in each phase of the research methodology summarized in Figure 4. As set forth earlier, in Phase 1, text mining is conducted for concept extraction. Open coding is performed in grounded theory for concept classes/categories. On the parallel side, following the SUMO ontological design method, taxonomy classes/categories are established. As a validation/resolution, established taxonomic classes/categories are checked to support by the grounded theory concept classes/categories. On the grounded theory BoK development side, it is cross-checked whether the concept classes/categories found by open coding are supported by the taxonomy classes/categories established following the SUMO ontological design method. The cross-validation/resolution is maintained in each phase of the methodology. This process thus satisfies consistency and relevancy check with theoretical BoK. After acceptance by the W3C, long-term validation will be maintained by ontology refinements. All ontologies are dynamic entities requiring revisions and refinements. As new knowledge emerges, all extensible ontologies must be refined to maintain long-term validation and extensibility. This long-term validation will conform Gruber's (1995) extendibility design criteria in ontology development.

3.14 Tools

Different tools are utilized at different stages of this research:

Data Collection: Computer with Internet connection.

Data Managing and Arranging: Folder structure in Windows operating system, MS Excel, and MS Word.

Data Analysis: R statistical software (RStudio version 3.4.2, 64 bit) for automated portion of text cleaning. Fluent Editor for ontology edits and manipulation.

Formal Concept Analysis: Concept Explorer (ConExp) tool (version 1.3) for context editing, building concept lattices from context, finding bases of implications that are true in context, finding bases of association rules that are true in context, and performing attribute exploration.

Ontology development is a tedious process which requires time, resources, and thoroughness. The aforementioned tools and software thus are handy to build, edit, and manipulate ontologies. Out of many tools available, the Fluent Ontology Editor is used for ontology development in this research. A researcher must first carefully review and identify which tool would be a suitable and better fit for the type of research under consideration. Further, not all tools come with the same capabilities. Some of the features and highlights for using Fluent Editor are:

- Fluent is the W3 standard,
- It supports Web Ontology Language 2.0 (OWL 2.0), Web Ontology Language-Descriptive Logic (OWL-DL), Resource Description Framework (RDF), and functional rendering,
- It handles complex ontologies,
- It uses Controlled Natural Language (CNL),
- It exports from the CNL format to OWL,
- Fluent has unlimited imports and built-in reasoning services,
- It supports R language package for statistical analysis. Combining ontology and statistics opens an efficient way for quantitative-qualitative analysis of data.

To recapitulate, the developed foundational ontology is highly formal (meaning machine readable, having IDEF5 specifications to map OWL 2.0), rigorous, exhaustive, and is built following ontology design criteria (Gruber, 1995), supported by Aliseda’s (1997) and Elsenbroich’s (2006) abductive learning arguments with formal validation, and Gomez-Perez’s (1996, 1999, and 2001) verification methods. The overall research is carried out in a structured and systematic framework to overcome any challenges, either from scholarly or methodological points of view.

للاستشارات المنارة

CHAPTER 4

RESULTS

4.1 Open Coding Concept Classes/Categories

The initial concept classes/categories are shown in Figure 7 (Mahmud, 2017). Concept classes are derived from open coding specifications (Table 1) and development of an HI-MI concept dictionary (Appendix A). Open coding specification was set forth in Section 3.7.2 (Chapter 3).

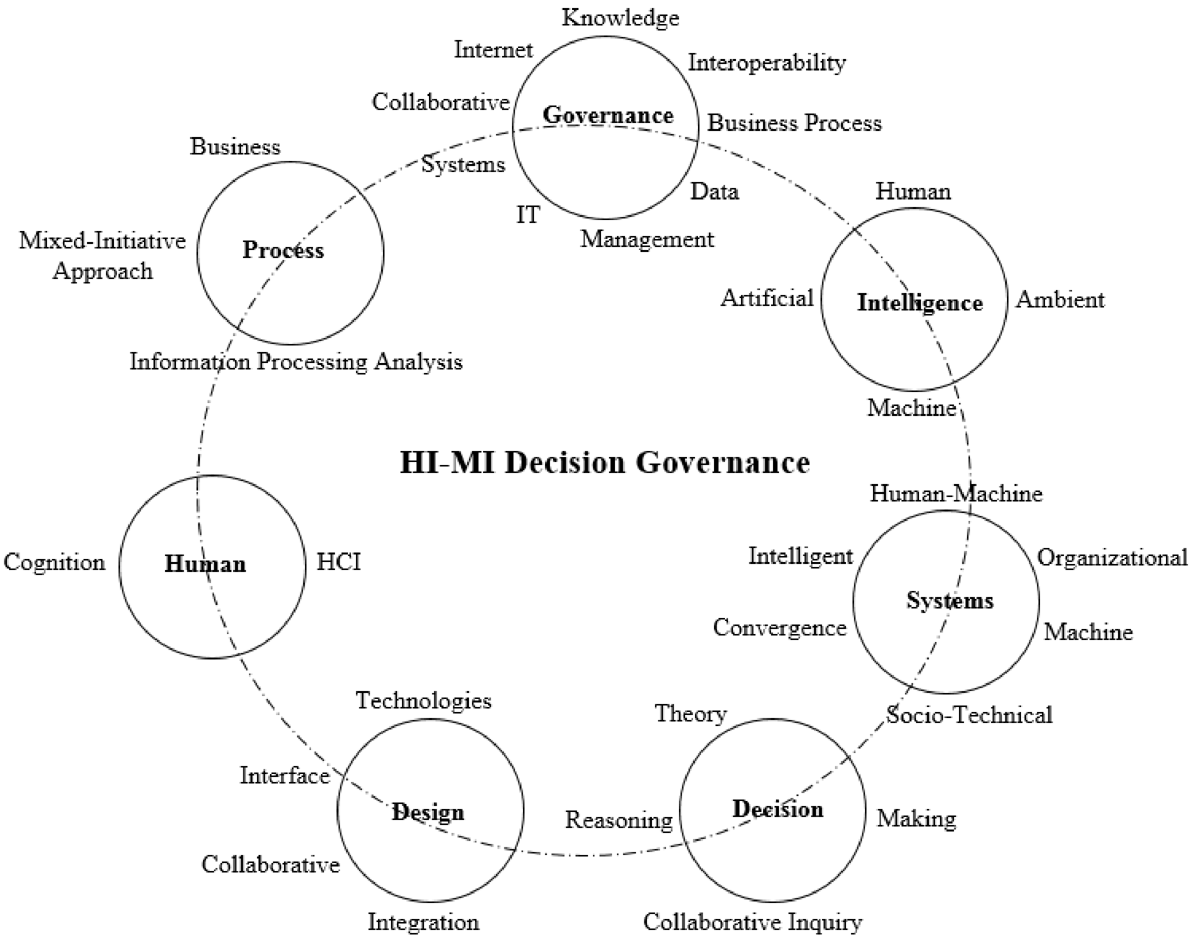

Knowledge
Internet
Interoperability
Collaborative
Governance
Business Process
Business
Systems
Data
Human
IT
Management
Mixed-Initiative Approach
Process
Artificial
Intelligence
Ambient
Information Processing Analysis
Machine
HI-MI Decision Governance
Human-Machine
Cognition
Human
HCI
Intelligent
Organizational
Systems
Convergence
Machine
Technologies
Theory
Socio-Technical
Interface
Design
Reasoning
Decision
Making
Collaborative
Integration
Collaborative Inquiry

Figure 7: Initial Concept Categories from Grounded Theory Open Coding.

Seven primary or core categories (Governance, Intelligence, Systems, Decision, Design, Human, and Process) emerged from the grounded theory based open coding analysis. In each primary category, open coding identified a number of secondary categories. For an example, “Governance” has nine secondary categories and these are– “knowledge governance,” “interoperability governance,” “business process governance,” “data governance,” “management governance,” “information technology (IT) governance,” “systems governance,” “collaborative governance,” and “Internet governance.” “Human” has only two secondary categories such as “human cognition” and “human-computer interactions (HCI).” It is apparent from Figure 7 that not all primary or core categories has equal number of secondary categories, and the number of literature corpus for each of these categories to identify also varied in numbers (so as the saturation point). Detailed concept dictionary and open categorical coding theme documentation can be found in Appendix A.

4.2 Taxonomy Classes/Categories

In parallel to the open coding concept, taxonomy classes/categories are identified by text mining (with “tm” package) using R statistical software. A systematic text cleaning method (Figure 6, Chapter 3) is followed before starting the text mining. Detailed R code and term explanations relevant to the text mining as well as content analysis can be found in Appendix C.

The most frequent terms that appeared from the text mining are:

- Systems– 10834,
- Governance– 9115,
- Process– 8344,
- Information– 7498,

- Model– 7207, and
- Decision– 6897.

However, this information is not adequate to compare and contrast with the open coding concept classes. In order to get more detailed information, frequency terms are carefully analyzed and observed in text mining with an increment of 500 (lower frequency set to 500; lowfreq=500) and stopped at 5000 (lowfreq=5000).

Table 5: Appeared Terms and Frequency.

Frequency (lowfreq)	**Appeared Terms**
5000	Data, decision, design, development, information, knowledge, management, model, process, research, systems, and governance.
4500	Data, decision, design, development, information, intelligence, internet, knowledge, management, model, organization, process, research, state, systems, technology, governance, and human.
4000	Data, decision, design, development, information, intelligence, internet, knowledge, management, model, organization, process, research, state, systems, technology, governance, human, study, and theory.
3500	Active, collaboration, computer, data, decision, design, development, information, intelligence, internet, knowledge, management, model, network, organization, process, relation, research, state, study, systems, technology, theory, user, governance, and human.
3000	Active, business, collaboration, computer, control, data, decision, design, development, individual, information, intelligence, internet, knowledge, management, model, network, operation, organization, perform, process, public, relation, research, state, study, systems, technology, theory, user, task, governance, human, learn, policy, social, and game.

Terms appeared at 5000 are– data, decision, design, development, information, knowledge, management, model, process, research, systems, and governance. To further analyze and also to ensure robustness of the analysis, all the terms from lowfreq= 3000 to lowfreq=5000 (with an increment of 500) are compared and contrasted to identify potential taxonomic classes from text mining (Table 5). Subsequently, to create a taxonomic structure for the ontology, hclust (cluster dendrogram) and CLUSPLOT are plotted and analyzed. By changing the sparsity of the document-term matrix, various plots are visualized to better interpret and analyze the results in text mining and content analysis.

The hierarchical clustering (hclust) as shown in Figures 8, 9, and 10 are based on agglomerative hierarchical clustering strategy that works with the following logic:

Step 1: First, assigning each document to its own cluster.

Step 2: Identifying the pair of clusters that are closer to each other by Euclidian distance and then merging them. This means there is now one cluster less than before.

Step 3: Computing the Euclidian distance between the new cluster and each of the old clusters.

Step 4: Repeating step 2 and step 3 until it reaches to a single cluster containing all the documents.

The complete-link clustering method here used the distance between clusters as the maximum distance between their members to achieve maximum separation. Details of other distance measures are given in Appendix G.

In Figure 8, the dendrogram shows an hclust plot at 20% non-sparsity. This means 20 percent zero terms are removed from the document-term matrix (dtm). Total number of objects shown here are 103. Following Euclidean distance method and “complete” method in hclust plot, this figure shows hierarchical plot of nodes and leaves. As the sparse terms removed from 20% to 25% (Figure 9), more terms appeared in the diagram (from 103 to 162). Further removing the sparse terms from 25% to 30% (Figure 10) gave even more terms to visualize (from 162 to 219). Sparse terms were removed up to 45% to further identify hierarchical clusters and terms. However, at this point it was a little difficult to read all the terms. Therefore, the plots for 35%, 40%, and 45% are made in 11 inches by 17 inches paper to carefully analyze and interpret. An hclust plot for 45% (number of objects 446) is shown in Figure 11. In order to make the term readable, terms are hanged from 0.05 ((plot (fit, hang = 0.05)) instead of -1 position (as done in Figures 8, 9, and 10). A modified and simplified hclust (Mahmud, 2018) for core terms is redrawn in Figure 12. Additional diagrams for such analysis can be found in Appendix D.

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	103	20% (0.20)

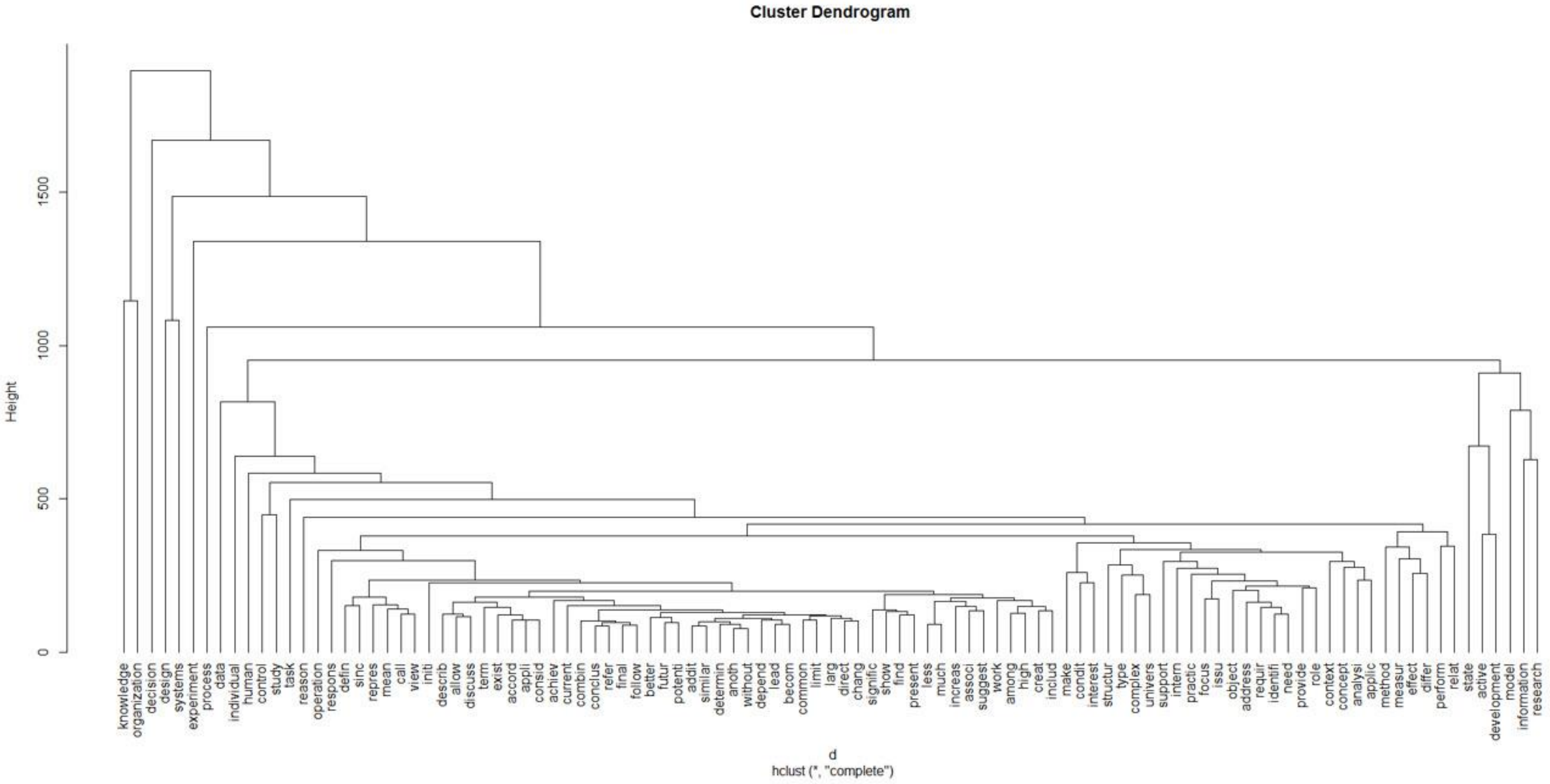


Figure 8: Cluster Dendrogram for 20% Non-Sparsity.

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	162	25% (0.25)

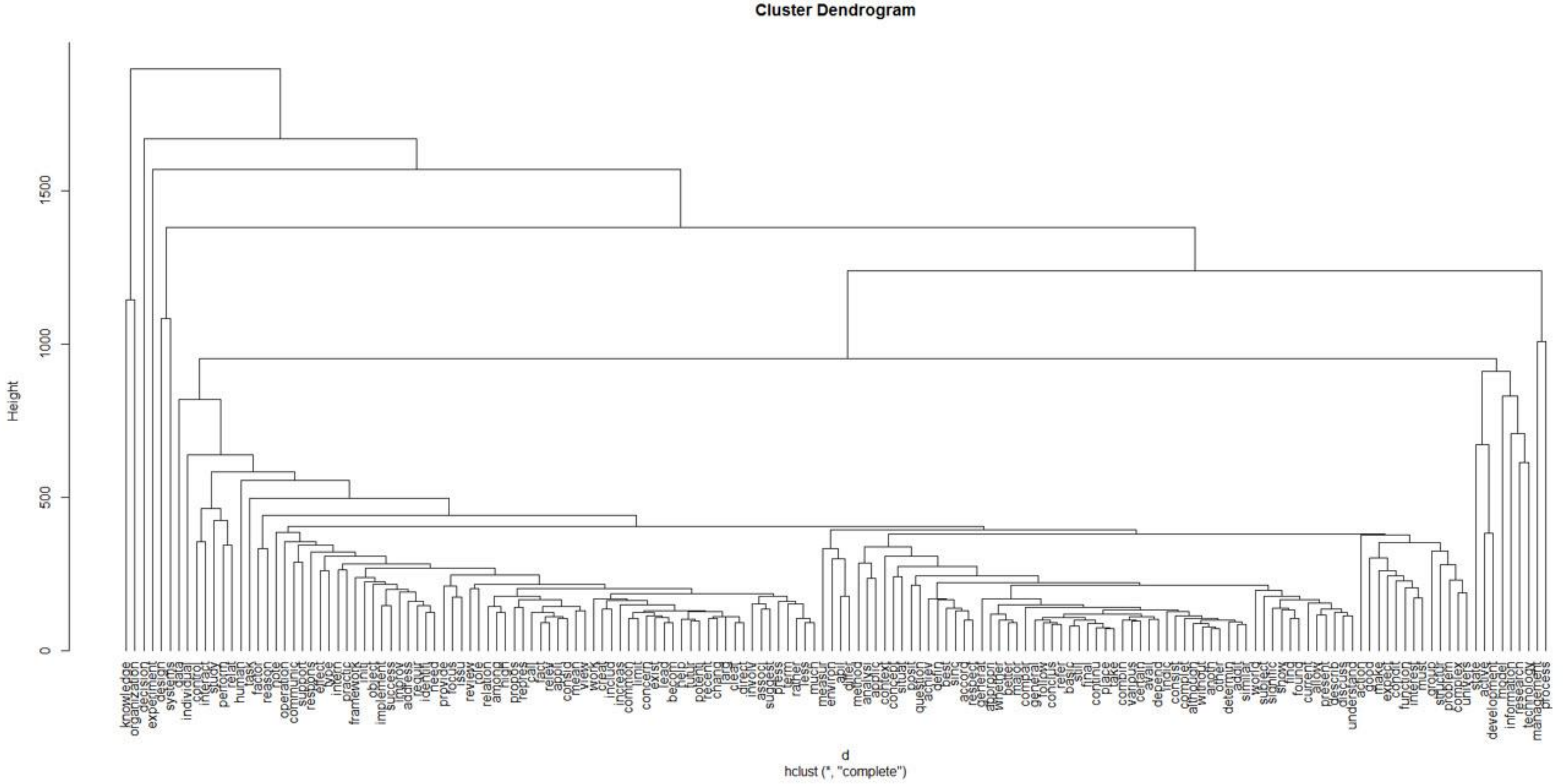


Figure 9: Cluster Dendrogram for 25% Non-Sparsity.

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	219	30% (0.30)

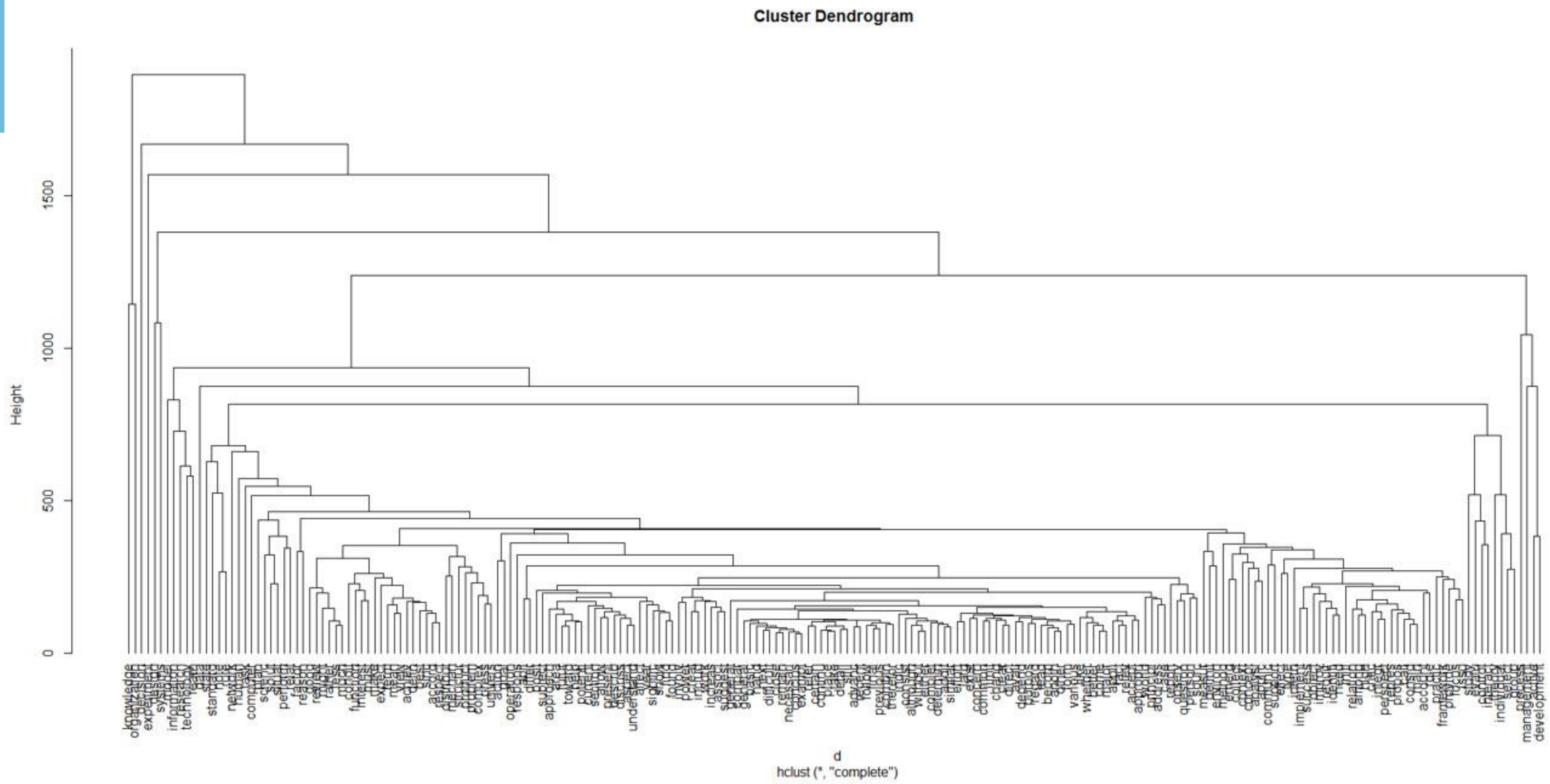


Figure 10: Cluster Dendrogram for 30% Non-Sparsity.

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	446	45% (0.45)

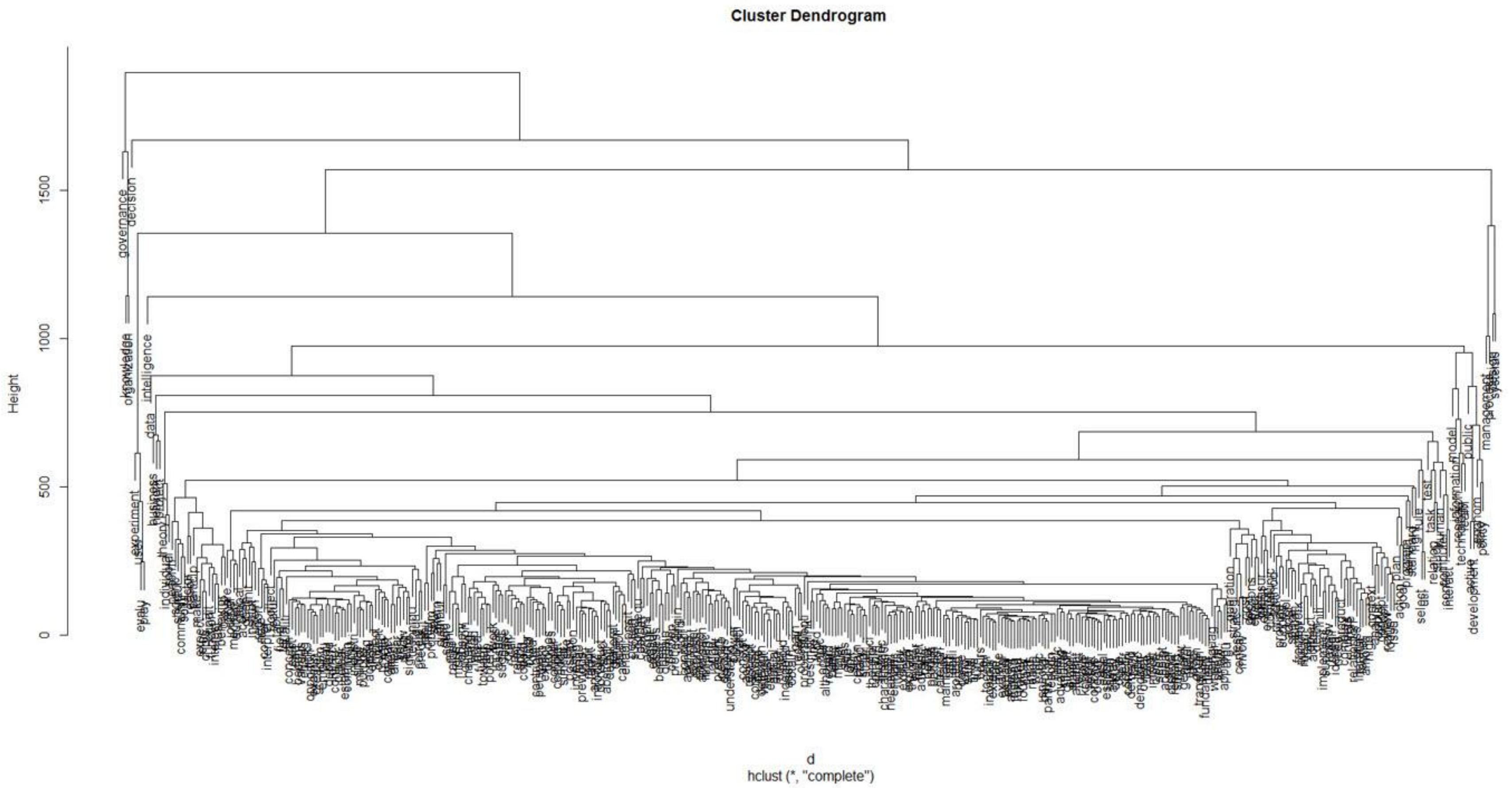


Figure 11: Cluster Dendrogram for 45% Non-Sparsity.

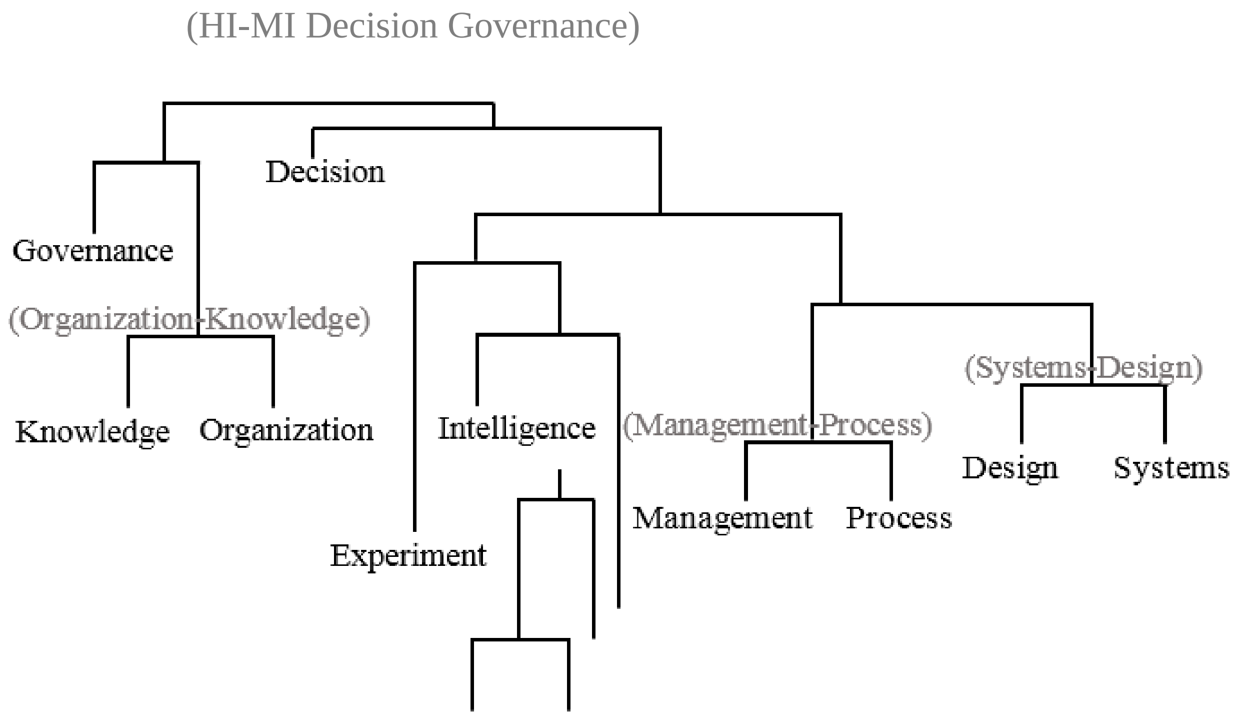

(HI-MI Decision Governance)
Decision
Governance
(Organization-Knowledge)
Knowledge
Organization
Intelligence
Experiment
(Management-Process)
Management
Process
(Systems-Design)
Design
Systems

Figure 12: Modified Cluster Dendrogram.

In hierarchical clustering, the number of clusters are not specified upfront and can be determined only after completing the analysis and then evaluating the diagram. Thus, further analyses are required in another form such as K-means clustering where number of clusters are defined upfront. This analysis generates K-corpus clusters in a way that ensures the within-cluster distances from each cluster member (to the centroid or geometric mean) of the cluster being minimized. The logic and algorithm behind this can be explained as below:

Step 1: Assigning the document randomly to k bins.

Step 2: Computing the location of the centroid of each bin.

Step 3: Computing the distance between each document and each centroid.

Step 4: Assigning each document to the bin corresponding to the centroid closest to it.

Step 5: Terminating the computation if no document is moved to a new bin. Otherwise, go to step 2.

Figures 13, 14, 15, and 16 show K-means clustering for the analyzed corpus for 2, 3, 4, and 5 clusters (K-means) respectively. The cluster plots shown in these four figures work in a mathematical space whose dimensionality equals the number of terms in the corpus (in this analysis we have a total of 69019 terms). From a practical standpoint, this is not feasible and also impossible to visualize. Thus, Principle Component Analysis (PCA) is applied to reduce the number of dimensions to two (component 1 and component 2) for 2, 3, 4, and 5 clusters (in this analysis) in such a way that the reduced dimensions capture as much of the variability as possible among the clusters (variability was 96.28% for this analysis).

Figure 13 has only two clusters and most of the core terms appeared in the first cluster (the bigger one). Figure 14 has three clusters, and the first two (from left-hand side) clusters captured the core terms. Figure 15 has four clusters and a few terms are distributed in between third and fourth clusters (from left-hand side). Figure 16 has five clusters and a few terms are distributed in between fourth and fifth clusters (from left-hand side). Comparing and contrasting these plots allows the exploration of taxonomic core terms, their association, and potential relationships. For K=2, CLUSPLOT gives only two clusters, one being the noise and the other one containing the core-terms. For K=3, CLUSPLOT becomes more informative. For K=4, the noise cluster and one of the major clusters from K=3 is divided into two resulting in redundant information in terms of information content. For K=5, the last two clusters (from left-hand side) in K=4 is further divided into two. The major taxonomic categories stabilized in the first cluster from K=3 forward.

Diagram	K means	Point Variability
CLUSPLOT	(d , 2)	96.28%

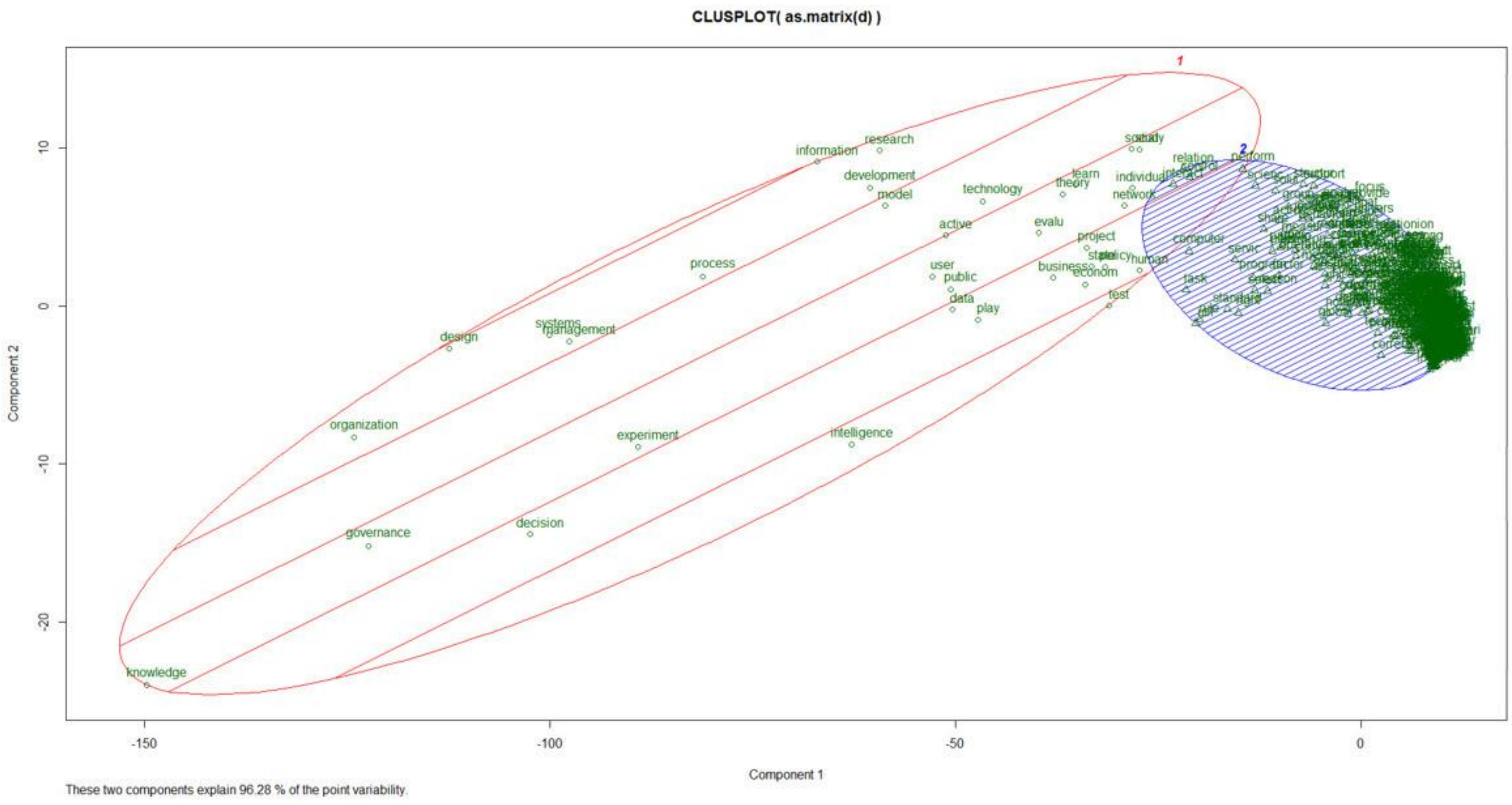


Figure 13: CLUSPLOT for K=2.

Diagram	K means	Point Variability
CLUSPLOT	(d , 3)	96.28%

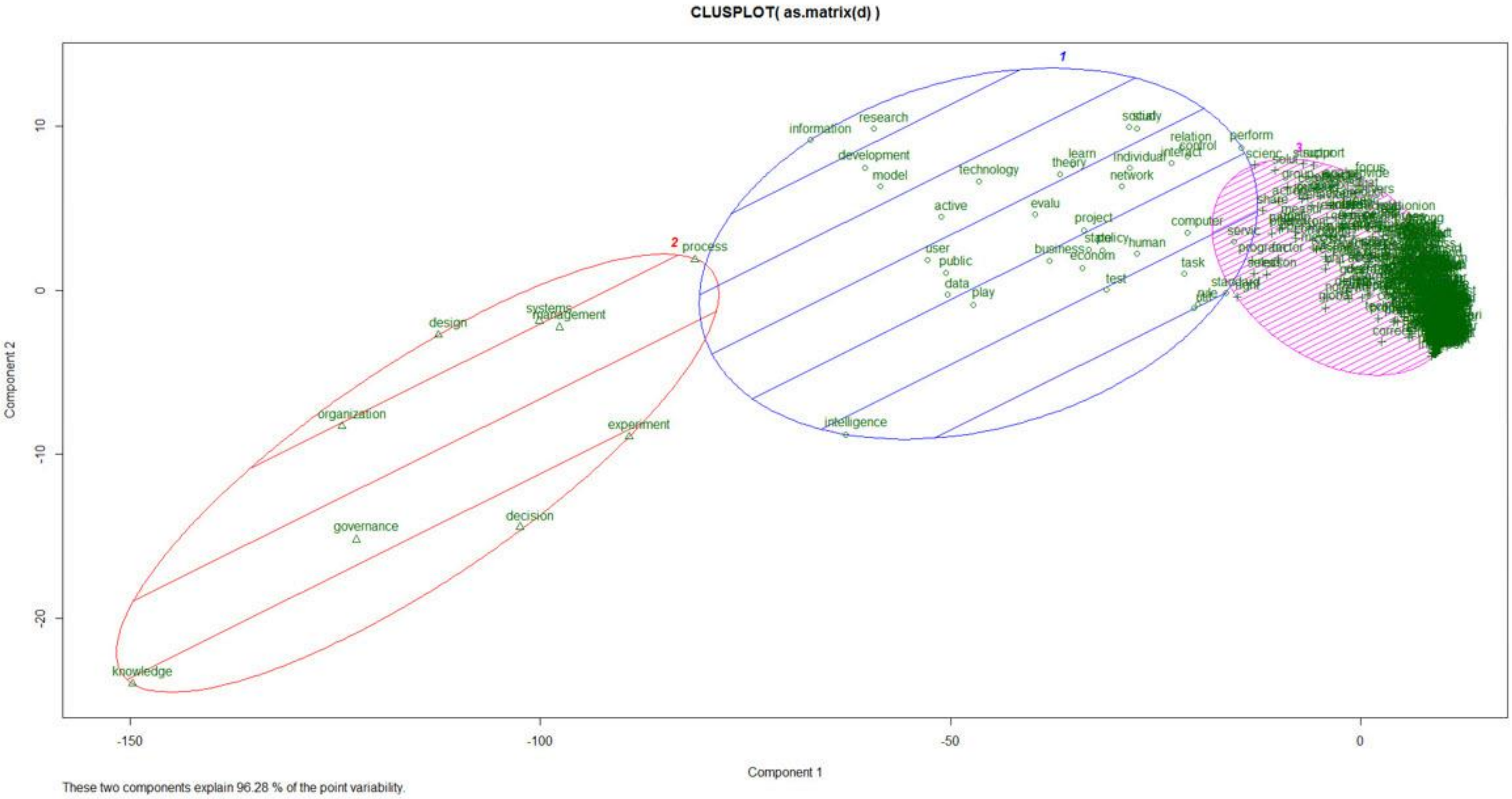


Figure 14: CLUSPLOT for K=3.

Diagram	K means	Point Variability
CLUSPLOT	(d , 4)	96.28%

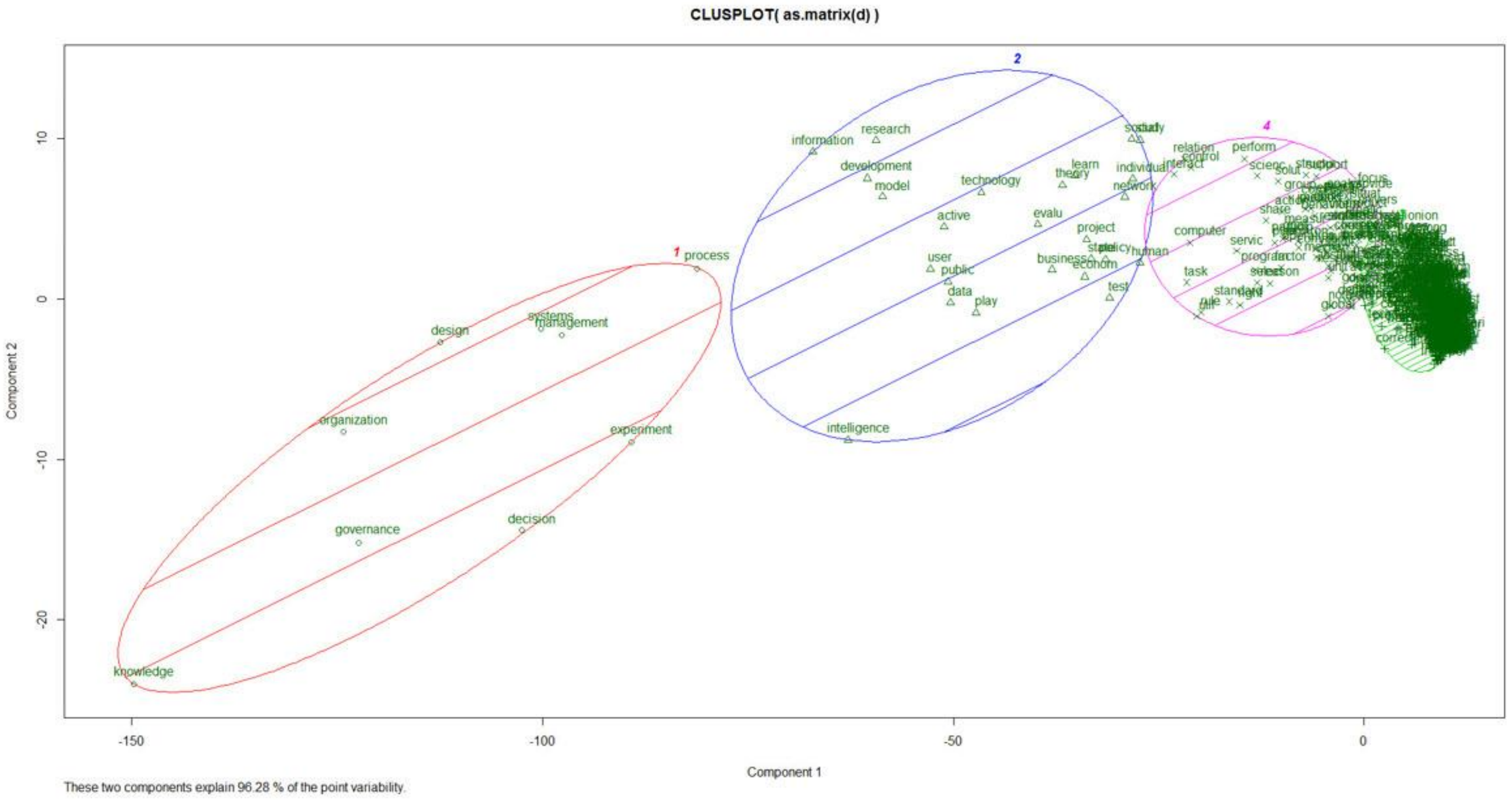


Figure 15: CLUSPLOT for K=4.

Diagram	K means	Point Variability
CLUSPLOT	(d , 5)	96.28%

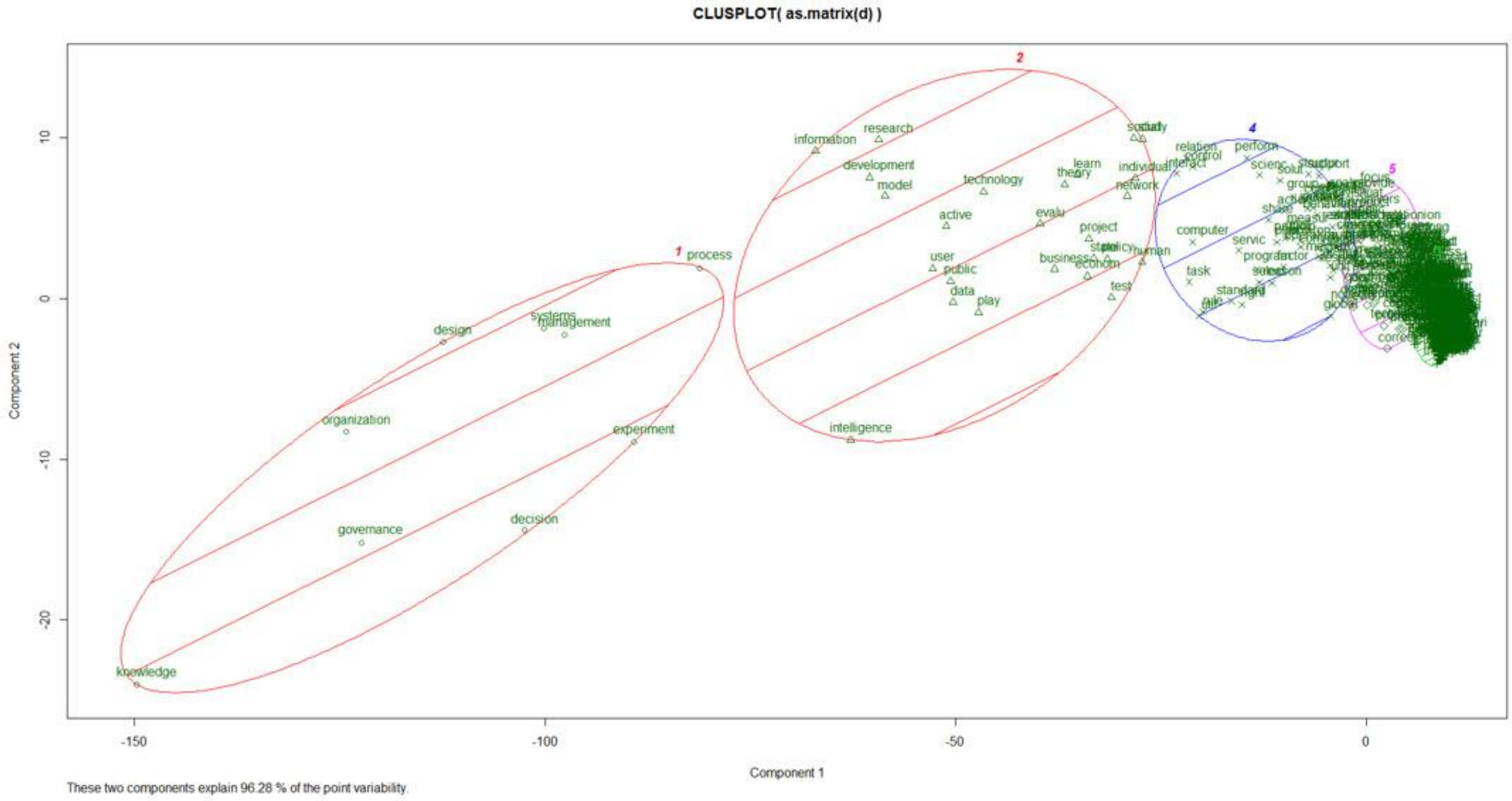


Figure 16: CLUSPLOT for K=5.

Figures 13 to 16 analyses show that the first two clusters (from left-hand side) contain all the major terms. In order to create the taxonomic hierarchy, both cluster dendrogram and CLUSPLOT were evaluated side-by-side. This also contributed– (i) to identify potential association of the core terms and (ii) to find potential relationships among the terms (within the same and different clusters). The cluster dendrogram provides an overall picture of the terms appearing in the corpus in hierarchy (and possible clusters to form). On the other hand, CLUSPLOT suggests the major clusters from the content analysis not only explore the core-terms and their order but also suggest potential axiomatic relationships. These two analyses are followed by formal text mining (where frequent terms are already identified) and carefully analyzed to find the taxonomic classes/categories for building the ontology. However, before that, the differences between the taxonomic terms in text mining and concept terms in open coding need to be resolved.

4.3 Resolution for Taxonomy Categories

The criteria applied to resolve the differences between the taxonomic terms in text mining and concept terms in grounded theory open coding are as follows:

Specification 1: Terms are abstract or general in concept. To ensure terms are not too specific or refined for domain or application level. Foundational ontologies specify only terms that are general in concept and can be reused across all core-reference and domain ontologies (Standard Upper Ontology Working Group Website: http://suo.ieee.org/).

Specification 2: Terms must be clear and concise. The definition for each term therefore needs to be clear, concise, and objective. This also meets Gruber’s (1995) ontology design criteria for clarity.

Specification 3: Terms must be consistent with the knowledge base. This meets consistency criteria (Uschold and King, 1995; Gómez-Pérez, 1999).

Specification 4: Terms should be able to answer competency questions (Gruninger and Fox, 1995). The competency questions for the ontology are listed in Appendix E. A list of definitions for the taxonomic terms can be found in Appendix F.

Following the above specifications, and comparing-contrasting with the concept categories in open coding, the taxonomic terms identified for building the foundational HI-MI decision governance ontology are:

- Decision,
- Governance,
- Organization-Knowledge (from Organization and Knowledge),
- Experiment,
- Systems-Design (from Systems and Design),
- Management-Process (from Management and Process),
- Intelligence, and
- Social-Technical (from Social and Technical comprised of Data, Business, Model, Public, and Technology).

These terms are general in concept, therefore, can be reused in core-reference and domain ontologies. The terms definitions (see Appendix F) are denoted clearly, concisely, and objectively from their attributes level following triangulation approach. Furthermore, a list of competency questions are documented in Appendix E so that developed ontology based on these taxonomic terms can answer the competency questions.

4.4 Axial Coding Concept Relationships

Concept relationships are identified (Appendix A) by axial coding in grounded theory. Axial relationships coding in grounded theory provides the foundation for body of knowledge theory development. These relationships show how the concept terms (identified in open coding) are related to each other. Following the resolution in section 4.3, the taxonomic terms are used for building the foundational HI-MI decision governance ontology. At this stage, concept relationships need to be documented. Table 6 shows the axial coding concept relationships only for the taxonomic terms noted in a previous section. It must be mentioned that, these relationships appeared from grounded theory axial coding. Language is simplified in the table to show the relationships of those taxonomic terms refined in section 4.3. For an example, considering the very first line of the table "*Decision is influenced by Knowledge*." From the axial coding it was identified that "Decision" and "Knowledge" are related in a way that "Knowledge" has some kind of impact on "Decision." Thus, in a simplified first order logic, it is acclaimed in Table 6 as "*Decision is influenced by Knowledge*." Like in any literature, the author's use of verb phrases or verbiage varies. However, the intended core meaning should remain the same if simplified for such analysis. Therefore, the relationships shown in Table 6 used simplified English predicative expressions while keeping the core meaning intact as appeared in the collected corpus. Taxonomic terms from section 4.3 are shown in capital letters in Table 6 to easily identify related relationships among terms. Details of the concept dictionary can be found in Appendix A.

Table 6: Grounded Theory Axial Coding Concept Relationships.

Concept Classes	**Concept Relationships from Grounded Theory Axial Coding**
Decision	Decision is influenced by Knowledge. Decision is made by Public. Decision requires Systems and Process. Decision is required for Design. Decision is enhanced by Intelligence and Technology. Decision is used by Governance.
Governance	Governance is a form of Systems. Governance involves and helps Public. Governance assists Decision. Governance is indispensable for Knowledge creation and dissemination. Governance hold accountable by Technology. Governance helps Management and Organization. Governance implements Process. Governance utilizes Data. Governance assists Business Process.
Organization	Organization adopts Systems, Governance, and Management. Organization Knowledge helps Governance. Organization uses Data, Model, Design, Technology, and Process. Organization involves Public and makes Decision.
Knowledge	Knowledge is accumulated by Public through learning Process and Experiment. Knowledge triggers Intelligence. Knowledge assists Decision, Design, and Business. Knowledge in Organization helps Management. Knowledge helps Governance. Knowledge in Systems level provides better understanding to Public. Knowledge is transferred through Technology.
Experiment	Experiment allows Knowledge gain for Public. Experiment is conducted in Organization by Public and Management. Experiment can be done in Systems level for Process Design. Experiment helps Decision.

Table 6: Continued.

Concept Classes	**Concept Relationships from Grounded Theory Axial Coding**
Systems	Systems is built by Public and interacts with Public. Systems go through Process. Systems integration assist Public and helps Governance. Systems Decision can be taken by Public. Systems collaboration utilizes Knowledge and thus helps Organization. Systems can have Intelligence. Systems can make Decision with gained Intelligence and Knowledge. Systems approach triggers growth of Organization. Systems development is affiliated with Model and Technology. Social-Technical comprised of Systems.
Design	Design is benefitted from Knowledge. Design may be considered as a Process. Design of Model and Systems help Public. Design can be collaborated by Public and Technology. Design needs Knowledge assimilation. Design is evaluated for Systems.
Management	Management is governed by Public. Management in Organization needs Governance for Systems Process. Management make Decision in Organization. Management requires Knowledge and Intelligence. Management is needed for Business.
Process	Process is essential for Business. Process integration helps Organization Systems. Process is needed for Knowledge strengthen. Process has role in Design. Processes can be improved by Intelligence.
Intelligence	Intelligence allows developing Knowledge and Process. Intelligence assists in Decision. Intelligence benefits Public and Systems. Intelligence helps Process.

Table 6: Continued.

Concept Classes	**Concept Relationships from Grounded Theory Axial Coding**
Social-Technical	Data contributes to Systems, Technology, and Model. Data exchanges take place in Governance. Data regulates Process in Organization. Data is used by Management and Public. Data helps in Decision. Business requires Management. Business involves Public and Decision. Business has Data and Governance. Business forms Organization. Business involves Knowledge and Process. Business benefits from Technology. Business has Process Model. Model helps Public and Management. Model is built for Intelligence, Business, and Systems. Model includes Design Process. Model uses Data to enable Process. Model helps refinement of Knowledge. Model assists Organization. Public interacts with Public. Public helps to form Social-Technical discipline. Public takes Decision. Public influences Governance in Organization. Public creates Governance for better Management. Public earns Knowledge and thus gains Intelligence. Public collaborates within Organization. Public assists Systems. Public Designs Technology and Systems. Public uses Knowledge, Intelligence, and Governance for Systems Design and Business Process. Technology assists in Public, Design, Knowledge, and Decision. Technology uses Data. Technology is used for artificial Intelligence. Technology requires Governance. Technology is essential for Organization.

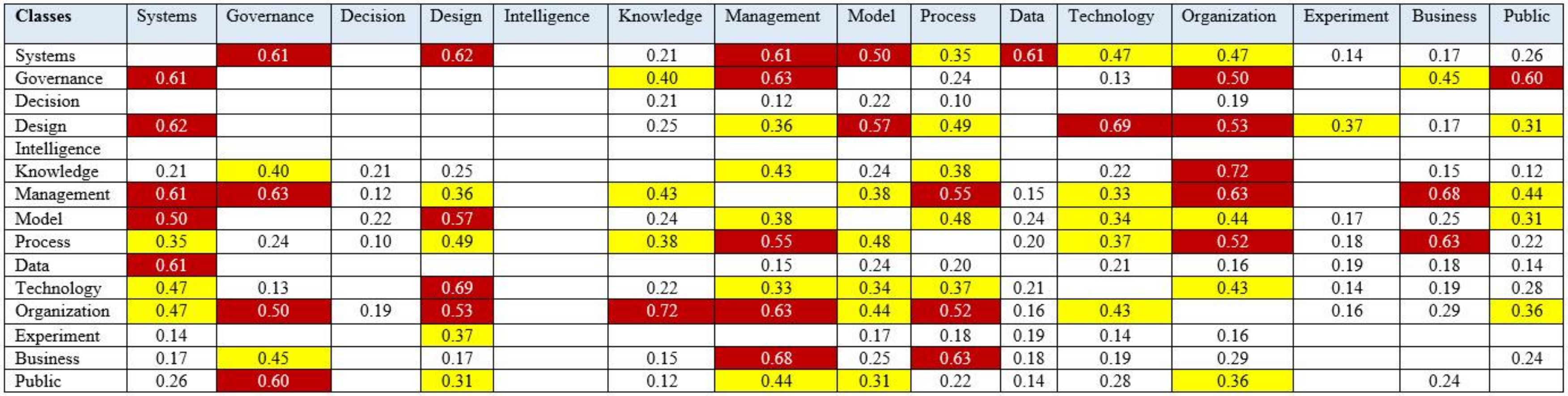
These concept relationships must be further evaluated and then formalized for Fluent Editor in the form of Controlled Natural Language (CNL) before building the formal foundational ontology.

4.5 Ontological Relationships

Now that foundational taxonomic terms are identified, the next step is to find the taxonomic relationships among the terms within and outside of the clusters. For that, a relationship matrix was created to find the terms associations (Table 7).

Correlation co-efficient 0.50 to 1 in the table is strongly correlated (being +1 is perfect positively correlated and –1 perfect negatively correlated). Correlation 0.5 to 1 is marked with red and 0.30 to 0.49 is marked with yellow. Weakly correlations are in between 0.01 to 0.29. For an example, “Systems” and “Governance” are strongly correlated with a correlation co-efficient of 0.61. In parallel to this matrix, a careful analysis was conducted from the axial coding. In grounded theory axial coding, it was already identified how concept terms (from open coding) are related to each other (referring to Table 6). The taxonomic relationships now should be resolved against the concept relationships before creation of axioms for the foundational ontology.

Table 7: Association Matrix from Content Analysis.



Classes	Systems	Governance	Decision	Design	Intelligence	Knowledge	Management	Model	Process	Data	Technology	Organization	Experiment	Business	Public
Systems		0.61		0.62		0.21	0.61	0.50	0.35	0.61	0.47	0.47	0.14	0.17	0.26
Governance	0.61					0.40	0.63		0.24		0.13	0.50		0.45	0.60
Decision						0.21	0.12	0.22	0.10			0.19			
Design	0.62					0.25	0.36	0.57	0.49		0.69	0.53	0.37	0.17	0.31
Intelligence															
Knowledge	0.21	0.40	0.21	0.25			0.43	0.24	0.38		0.22	0.72		0.15	0.12
Management	0.61	0.63	0.12	0.36		0.43		0.38	0.55	0.15	0.33	0.63		0.68	0.44
Model	0.50		0.22	0.57		0.24	0.38		0.48	0.24	0.34	0.44	0.17	0.25	0.31
Process	0.35	0.24	0.10	0.49		0.38	0.55	0.48		0.20	0.37	0.52	0.18	0.63	0.22
Data	0.61						0.15	0.24	0.20		0.21	0.16	0.19	0.18	0.14
Technology	0.47	0.13		0.69		0.22	0.33	0.34	0.37	0.21		0.43	0.14	0.19	0.28
Organization	0.47	0.50	0.19	0.53		0.72	0.63	0.44	0.52	0.16	0.43		0.16	0.29	0.36
Experiment	0.14			0.37				0.17	0.18	0.19	0.14	0.16			
Business	0.17	0.45		0.17		0.15	0.68	0.25	0.63	0.18	0.19	0.29			0.24
Public	0.26	0.60		0.31		0.12	0.44	0.31	0.22	0.14	0.28	0.36		0.24	

4.6 Resolution for Ontological Relationships

The resolution for ontological relationships attained by considering both the taxonomic terms association (Table 7) and axial coding relationships (Table 6) found in grounded theory. On top of that, CLUSPLOTs explain the whole variability of the data, describe the terms with their interrelations, and at the same time show the clusters. This helps to picture the size and shape of the clusters, as well as their relative position.

Axial coding relationships stated in Table 6 are documented in simplified natural English language that has a subject and a predicate. A subject in natural English language can be identified by asking the question of either "who" or "what", i.e. the subject of a sentence is who or what the sentence is about. And the predicate in the sentence tells about the subject. For an example, the sentence "*Decision is influenced by Knowledge*" has subject *"Decision"* and predicate "*is influenced by Knowledge*."

Correlation matrix as shown in Table 7 indicates whether terms are strongly, moderately, weakly, and not-related to each other. Now, the information from Table 6 and 7 needs to consider simultaneously to identify refined ontological relationships consistent with the theoretical body of knowledge. Given that taxonomic terms are already inserted in Fluent, terms relationships can be established using Controlled Natural Language (CNL). In Fluent Editor, the ontology is established following CNL (Controlled Natural Language). The Controlled English is a subset of English with restricted grammar and vocabulary in order to reduce the ambiguity and complexity of the natural English language.

Fluent Editor has a built-in validator for modal expressions and it gives instant feedback if there is any violation of rules or expressions. Thus, ontological relationships are first translated into CNL and then validated in Fluent using built-in validator.

4.7 Concept Refinement

The purpose of selective coding concept refinement is to find the central category or core category. Whereas open and axial coding are top-down categorization and relationships building, selective coding is a bottom-up re-synthesis in which the researcher carefully examines and realigns categories and relationships in order to identify the core category to explain the overall body of knowledge theory.

As seen from the Figure 7, even though a total thirty-nine concept categories emerged from open coding (seven top categories and thirty-two secondary categories), only fifteen categories are confirmed that actually explained the overall body of knowledge. It should be noted that out of these fifteen categories, only eight being evaluated as the foundational concept classes/categories. Decision, Governance, Experiment, and Intelligence appeared to be individual classes/categories. Organization and Knowledge formed “Organization-Knowledge”; Systems and Design formed “Systems-Design”; Management and Process formed “Management-Process” classes/categories. Social-Technical class/category comprised of Data, Business, Model, Public, and Technology.

4.8 Taxonomy-Ontological Refinement

Taxonomy-Ontological refinement is to ensure whether target ontology will be built in consistent and relevant to the overall body of knowledge. After another round of careful consideration, “Experiment” term was excluded from the foundational ontology. This term is too specific to be included in subsumed ontological levels. While revisiting the open and axial coding from grounded theory, the term “Experiment” appeared as “experimental method” or similar type of applications for a technique or test indicating that the term should be rooted for either domain or task ontology.

During the text mining and content analysis, taxonomic terms and their relationships were identified in consistent with the overall foundational body of knowledge (BoK). At this point it was carefully evaluated what terms and their relationships must support foundational ontology.

4.9 Resolution for Taxonomy-Ontological relationships

At this stage, the overall ontology is already built in Fluent Ontology Editor and ready to be materialized. The materialized ontology contains all the reasoned relations between entities. Materialization is performed by tandem of the Reasoner (HermiT) and Rule Engine (Jena), and can be done in two modes– (i) OWL-DL (Full) and (ii) OWL2 RL+ profile (Hybrid). In case of OWL-DL (Full) materialization, all the calculations are performed by the Reasoner (HermiT). This always gives the sound and complete results compared to the incomplete, but fast, OWL2 RL+ profile (Hybrid) materialization mode.

4.10 Foundational BoK for HI-MI Decision Governance

Foundational BoK for HI-MI decision governance includes– (i) an expert reference base or knowledge base for the domain of discourse, (ii) core concept terms for the KB, (iii) the relationships of the core concept terms, and (iv) a theoretical body of knowledge for HI-MI decision governance.

4.11 Foundational Ontology for HI-MI Decision Governance

From a systematic approach and rigorous analysis supplemented by exhaustive checks and validations/resolutions, the foundational ontology for human-intelligence and machine-intelligence decision governance can be visualized from Figure 17. The foundational classes/categories are marked with red boxes. Black dotted boxes are for individual terms that clustered together to form their own foundational class. This taxonomic structure is necessary (referring to the conditions set forth in Table 3 and 4) to succinctly specify HI-MI decision governance body of knowledge and also assessed by the ontological design criteria of clarity, coherency, extendibility, minimal encoding bias, and minimal ontological commitment (Gruber, 1995).

In addition to the taxonomic structure, foundational ontology should have the axiomatic relationships exhibiting the correlations among the taxonomic terms. Table 8 and 9 list taxonomic class relationships (parent-child order) and axiomatic relationships (role and correlational). Figure 18 shows the axiomatic structure of the foundational ontology, essentially displaying how terms are related to each other. Red arrow means strongly correlated and blue arrow means moderately correlated.

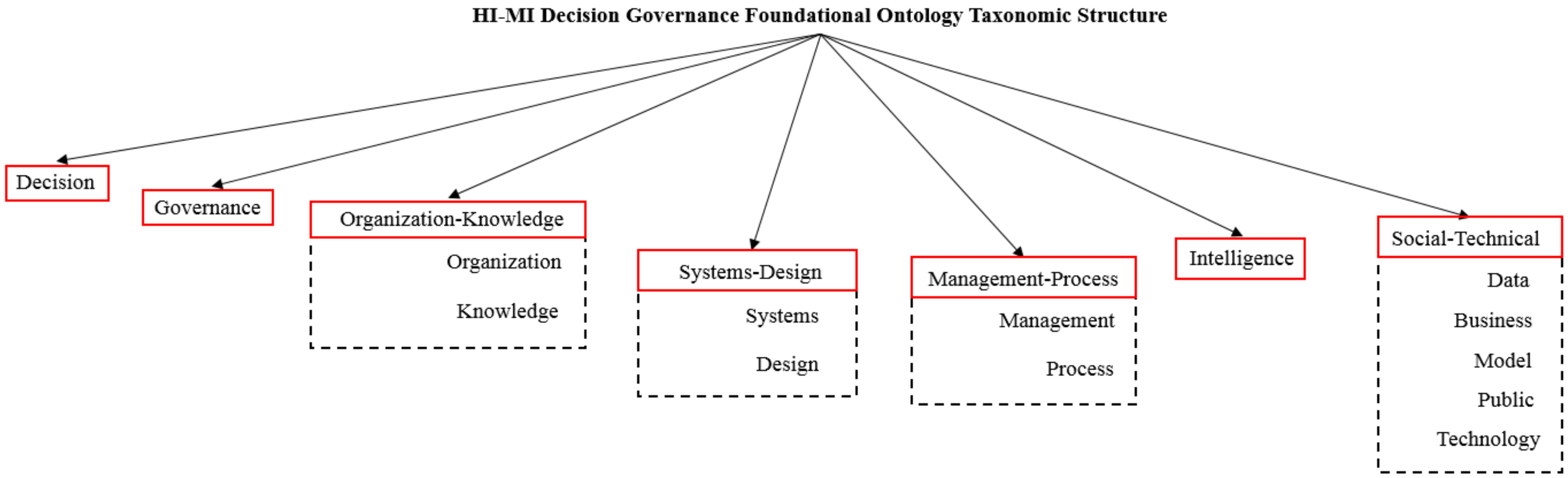

HI-MI Decision Governance Foundational Ontology Taxonomic Structure
Decision
Governance
Organization-Knowledge
Organization
Knowledge
Systems-Design
Systems
Design
Management-Process
Management
Process
Intelligence
Social-Technical
Data
Business
Model
Public
Technology

Figure 17: HI-MI Decision Governance Foundational Ontology Taxonomic Structure.

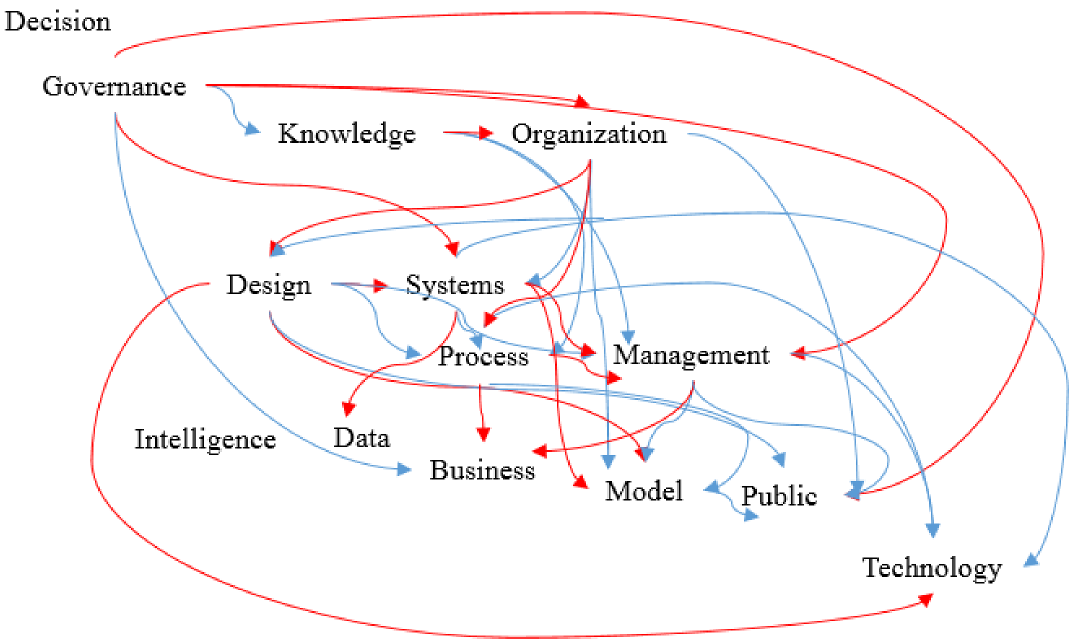

Decision
Governance
Knowledge
Organization
Design
Systems
Process
Management
Intelligence
Data
Business
Model
Public
Technology

Figure 18: HI-MI Decision Governance Foundational Ontology Axiomatic Structure.

The above figure is a simplistic visualization, compared to the complex one as shown in Figure 19, to show axiomatic relationships of the taxonomic terms for the foundational HI-MI decision governance.

As part of the research question, the axioms need to be specified for the HI-MI decision governance body of knowledge and thus listed in the following Table 8 and 9. The difference between Table 6 (axial relationships from grounded theory) and Table 8 and 9 is that, Table 6 used simplified English predicative expressions (derived from Appendix A) while keeping the core meaning intact as appeared in the collected corpus. Conversely, Table 8 and 9 are formalized in a way that these relationships succinctly show– (i) taxonomic relationships (Table 8), (ii) role relationships (Table 9), as well as (iii) correlational relationships (Table 9) among the foundational terms. Furthermore, Table 8 and 9 relationships will be formalized in Description Logic (DL) in order to generalize the taxonomic terms relationships.

Table 8 listed only those taxonomic terms that have parent-child relationships.

Table 8: Foundational Taxonomic Classes and Relationships.

Foundational Taxonomic Classes	**Taxonomic Relationships (Parent)**	**Taxonomic Relationships (Child)**
Organization-Knowledge (collectively from Organization and Knowledge)	Organization-Knowledge is-composed-of Organization and Knowledge.	Organization is-a-part-of Organization-Knowledge. Knowledge is-a-part-of Organization-Knowledge.
Systems-Design (collectively from Systems and Design)	Systems-Design is-composed-of Systems and Design.	Systems is-a-part-of Systems-Design. Design is-a-part-of Systems-Design.
Management-Process (collectively from Management and Process)	Management-Process is-composed-of Management and Process.	Management is-a-part-of Management-Process. Process is-a-part-of Management-Process.
Social-Technical (collectively from Data, Business, Model, Public, and Technology)	Social-Technical is-composed-of Data, Business, Model, Public, and Technology.	Data is-a-part-of Social-Technical. Business is-a-part-of Social-Technical. Model is-a-part-of Social-Technical. Public is-a-part-of Social-Technical. Technology is-a-part-of Social-Technical.

In comparison to Table 8, Table 9 listed those taxonomic terms that have role as well as correlational relationships.

Table 9: Foundational Taxonomic Classes and Axiomatic Relationships.

Foundational Taxonomic Classes	**Role Relationships**	**Correlational Relationships**
Decision	Decision is used by Organization.	Decision is-weakly-correlated-with Organization.
	Decision uses Knowledge.	Decision is-weakly-correlated-with Knowledge.
	Decision is used by Management.	Decision is-weakly-correlated-with Management.
	Decision involves Process.	Decision is-weakly-correlated-with Process.
	Decision utilizes Model.	Decision is-weakly-correlated-with Model.
		Decision is-not-correlated-with Systems, Governance, Design, Intelligence, Data, Technology, Business, and Public.
Governance	Governance is required for Organization.	Governance is-strongly-correlated-with Organization.
	Governance uses Knowledge.	Governance is-moderately-correlated-with Knowledge.
	Governance is required for Management.	Governance is-strongly-correlated-with Management.
	Governance involves Process.	Governance is-weakly-correlated-with Process.
	Governance functions within Systems.	Governance is-strongly-correlated-with Systems.
	Governance is required for Business.	Governance is-moderately-correlated-with Business.
	Governance helps Public.	Governance is-strongly-correlated-with Public.
	Governance holds accountable by Technology.	Governance is-weakly-correlated-with Technology.
		Governance is-not-correlated-with Decision, Intelligence, Design, Model, and Data.

Table 9: Continued.

Foundational Taxonomic Classes	**Role Relationships**	**Correlational Relationships**
Organization	Organization needs Systems.	Organization is-moderately-correlated-with Systems.
	Organization needs Governance.	Organization is-strongly-correlated-with Governance.
	Organization needs Knowledge.	Organization is-strongly-correlated-with Knowledge.
	Organization needs Management.	Organization is-strongly-correlated-with Management.
	Organization makes Decision.	Organization is-weakly-correlated-with Decision.
	Organization utilize Process.	Organization is-strongly-correlated-with Process.
	Organization utilizes Design.	Organization is-strongly-correlated-with Design.
	Organization uses Data.	Organization is-weakly-correlated-with Data.
	Organization serves Business.	Organization is-weakly-correlated-with Business.
	Organization uses Model.	Organization is-moderately-correlated-with Model.
	Organization has Public.	Organization is-moderately-correlated-with Public.
	Organization uses Technology.	Organization is-moderately-correlated-with Technology.
		Organization is-not-correlated-with Intelligence.

Table 9: Continued.

Foundational Taxonomic Classes	Role Relationships	Correlational Relationships
Knowledge	Knowledge helps Systems.	Knowledge is-weakly-correlated-with Systems.
	Knowledge helps Governance.	Knowledge is-moderately-correlated-with Governance.
	Knowledge helps Organization.	Knowledge is-strongly-correlated-with Organization.
	Knowledge helps Management.	Knowledge is-moderately-correlated-with Management.
	Knowledge helps Decision.	Knowledge is-weakly-correlated-with Decision.
	Knowledge is accumulated through Process.	Knowledge is-moderately-correlated-with Process.
	Knowledge helps Design.	Knowledge is-weakly-correlated-with Design.
	Knowledge helps Business.	Knowledge is-weakly-correlated-with Business.
	Knowledge helps Model.	Knowledge is-weakly-correlated-with Model.
	Knowledge is accumulated by Public.	Knowledge is-weakly-correlated-with Public.
	Knowledge is transferred through Technology.	Knowledge is-weakly-correlated-with Technology.
		Knowledge is-not-correlated-with Data and Intelligence.
Systems	Systems needs Design.	Systems is-strongly-correlated-with Design.
	Systems helps Governance.	Systems is-strongly-correlated-with Governance.
	Systems helps Organization.	Systems is-moderately-correlated-with Organization.
	Systems uses Knowledge.	Systems is-weakly-correlated-with Knowledge.
	Systems helps Management.	Systems is-strongly-correlated-with Management.
	Systems uses Process.	Systems is-moderately-correlated-with Process.
	Systems uses Data.	Systems is-strongly-correlated-with Data.
	Systems helps Business.	Systems is-weakly-correlated-with Business.
	Systems uses Model.	Systems is-strongly-correlated-with Model.
	Systems helps Public.	Systems is-weakly-correlated-with Public.
	Systems utilizes Technology.	Systems is-moderately-correlated-with Technology.
		Systems is-not-correlated-with Decision and Intelligence.

Table 9: Continued.

Foundational Taxonomic Classes	**Role Relationships**	**Correlational Relationships**
Design	Design is evaluated for Systems.	Design is-strongly-correlated-with Systems.
	Design helps Organization.	Design is-strongly-correlated-with Organization.
	Design helps Management.	Design is-moderately-correlated-with Management.
	Design benefits from Knowledge.	Design is-weakly-correlated-with Knowledge.
	Design helps Process.	Design is-moderately-correlated-with Process.
	Design helps Business.	Design is-weakly-correlated-with Business.
	Design is used in Model.	Design is-strongly-correlated-with Model.
	Design is utilized by Public.	Design is-moderately-correlated-with Public.
	Design utilizes Technology.	Design is-strongly-correlated-with Technology.
		Design is-not-correlated-with Governance, Decision, Intelligence, and Data.
Management	Management is utilized by Organization.	Management is-strongly-correlated-with Organization.
	Management needs Knowledge.	Management is-moderately-correlated-with Knowledge.
	Management makes Decision.	Management is-weakly-correlated-with Decision.
	Management needs Governance.	Management is-strongly-correlated-with Governance.
	Management uses Systems.	Management is-strongly-correlated-with Systems.
	Management utilizes Design.	Management is-moderately-correlated-with Design.
	Management runs through Process.	Management is-strongly-correlated-with Process.
	Management utilizes Data.	Management is-weakly-correlated-with Data.
	Management helps Business.	Management is-strongly-correlated-with Business.
	Management uses Model.	Management is-moderately-correlated-with Model.
	Management consists of Public.	Management is-moderately-correlated-with Public.
	Management benefits from Technology.	Management is-moderately-correlated-with Technology.
		Management is-not-correlated-with Intelligence.

Table 9: Continued.

Foundational Taxonomic Classes	**Role Relationships**	**Correlational Relationships**
Process	Process is needed for Organization.	Process is-strongly-correlated-with Organization.
	Process is needed for Knowledge.	Process is-moderately-correlated-with Knowledge.
	Process is utilized for Decision.	Process is-weakly-correlated-with Decision.
	Process is used in Governance.	Process is-weakly-correlated-with Governance.
	Process helps Systems.	Process is-moderately-correlated-with Systems.
	Process has a role in Design.	Process is-moderately-correlated-with Design.
	Process utilizes Data.	Process is-weakly-correlated-with Data.
	Process involves in Business.	Process is-strongly-correlated-with Business.
	Process helps Model.	Process is-moderately-correlated-with Model.
	Process helps Public.	Process is-weakly-correlated-with Public.
	Process utilizes Technology.	Process is-moderately-correlated-with Technology.
		Process is-not-correlated-with Intelligence.
Intelligence		Intelligence is-not-correlated-with Systems, Governance, Design, Decision, Knowledge, Management, Model, Process, Technology, Organization, Business, Public, and Data.

Table 9: Continued.

Foundational Taxonomic Classes	**Role Relationships**	**Correlational Relationships**
Social-Technical (Data, Business, Model, Public, and Technology)	Data contributes to Business.	Data is-weakly-correlated-with Business.
	Data contributes to Model.	Data is-weakly-correlated-with Model.
	Data is used by Public.	Data is-weakly-correlated-with Public.
	Data contributes to Technology.	Data is-weakly-correlated-with Technology.
	Business uses Data.	Business is-weakly-correlated-with Data.
	Business has Model.	Business is-weakly-correlated-with Model.
	Business is run by Public.	Business is-weakly-correlated-with Public.
	Business benefits from Technology.	Business is-weakly-correlated-with Technology.
	Model uses Data.	Model is-weakly-correlated-with Data.
	Model is used for Business.	Model is-weakly-correlated-with Business.
	Model is used by Public.	Model is-moderately-correlated-with Public.
	Model benefits from Technology.	Model is-moderately-correlated-with Technology.
	Public uses Data.	Public is-weakly-correlated-with Data.
	Public runs Business.	Public is-weakly-correlated-with Business.
	Public uses Model.	Public is-moderately-correlated-with Model.
	Public benefits from Technology.	Public is-weakly-correlated-with Technology.
	Technology utilizes Data.	Technology is-weakly-correlated-with Data.
	Technology helps Business.	Technology is-weakly-correlated-with Business.
	Technology helps Model.	Technology is-moderately-correlated-with Model.
	Technology helps Public.	Technology is-weakly-correlated-with Public.
		Intelligence is-not-correlated-with Social-Technical.

The role relationships shown in Table 9 are formed with– (i) a subject, (ii) role (such as use, involve, utilize, require, help, part of, can be, holds accountable, function, composed of, need, make, accumulated by, transfer through, evaluated for, benefitted by/from, run through, consist of, component of, has/have, and contribute), and (iii) an object. The representation of these axioms can be explained from Resource Description Framework (RDF) which is a lightweight and flexible way to represent metadata on the web. Table 9 documented the axiomatic relationships in a way that each statement has a subject, predicate, and object triple < s, p, o > which is a syntactic variant of traditional binary predicates p (s, o). The assertion of such a triple means that predicate p is a relation between subject s and object o. Each part of the triple, i.e. each RDF name, denotes a resource (Hoekstra, 2009).

A sentence in natural English language have both syntax and semantics. Syntax deals with the structure of the sentence (arrangement of words and phrases) whereas semantic expresses the meaning of it. On the contrary, the role connectors (Table 9) even though they seem different (syntax wise), semantically they are not. The core relationships can easily be understood by the semantic relationships. For example, considering this– “*Data contributes to Model.*” This sentence tells that “Data” is a subject (s) and related to an object (o) “Model” by the role connector predicate p “contributes to” to express semantic relationship or connection between s and o.

In RDF, reification is expressed using the rdf : Statement construct. A resource of type rdf : Statement can explicitly refer to the subject, predicate, and object of some property relation using the rdf : subject, rdf : predicate, and rdf : object properties, respectively. It must be noted that Table 8 and 9 listed the relations in between the identified taxonomic terms and how they form the relationships with each other using a connector. Their property level designations are not specified herewith. Subsequent ontological development in the refined levels can explore those traits for these taxonomic terms. Table 10 has listed an example of rdf structure and corresponding OWL meaning. For example, the relationships can be formally expressed as below:

USE (Organization, Decision) → Organization uses Decision or Decision is used by Organization.

HELP (Governance, Public) → Governance helps Public or Public is helped by Governance.

HAS (Business, Model) → Business has Model.

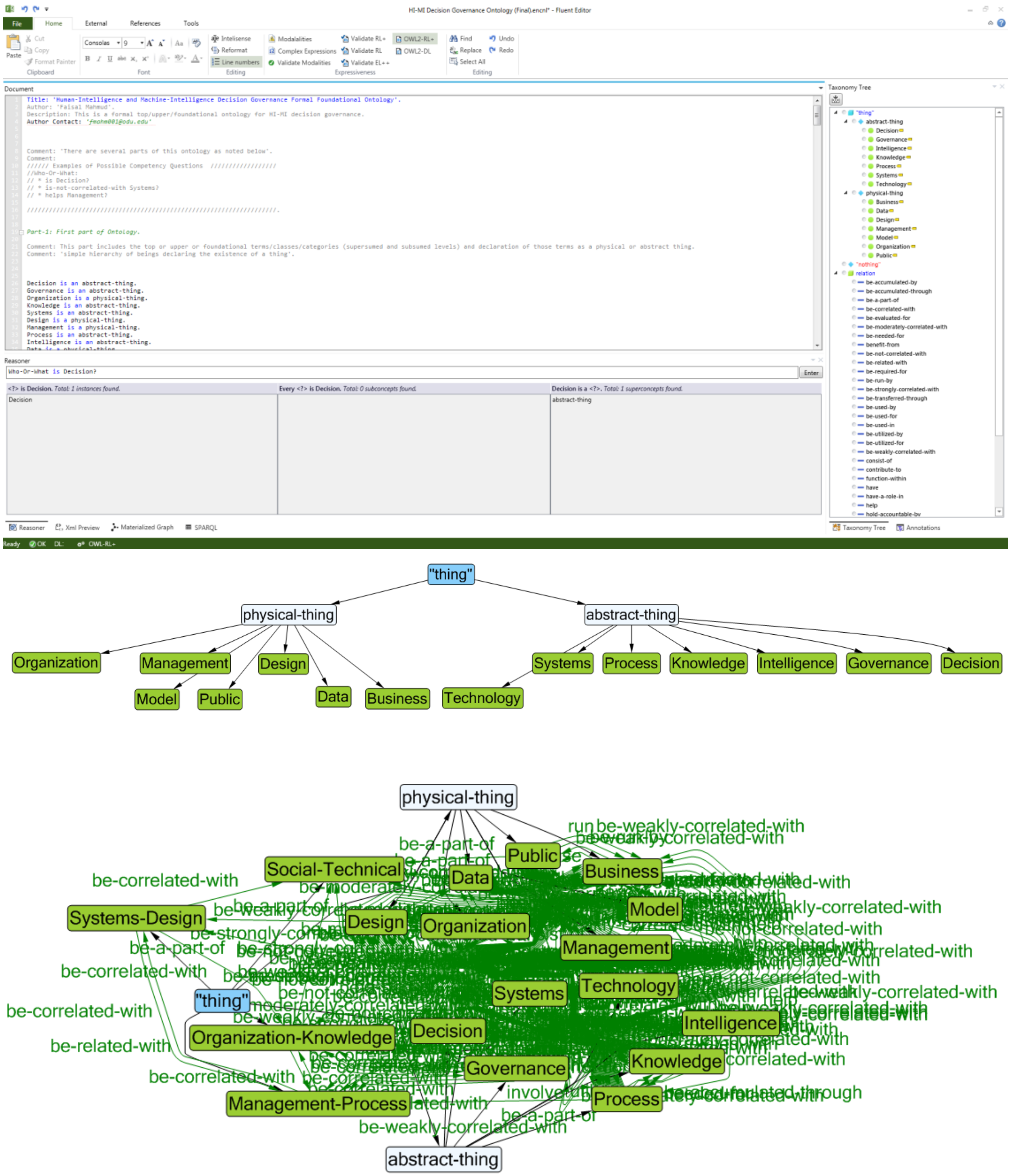
Therefore, if the connector phrase or predicate is p, taxonomic term as a subject is s_T and taxonomic term as an object is o_T , the relationship can be generalized as:

$$p\ (s_T\ ,\ o_T\ )$$

It must be reiterated that, the relationships addressed and noted in Tables 8 and 9 only show the correlations between the identified taxonomic terms. None of the relations are expressed in terms of a single taxonomic term. Also, no relationship is listed in such a way that it describes only the property of the term. For example, Business is Big or Data is Complex. These properties or attributes are explained in later Section 4.14 and shown in the form of concept lattice.

4.12 Ontology Development in Fluent Editor

The taxonomic and axiomatic relationships shown in Table 8 and 9 are also validated in Fluent Editor and supported by the knowledge base established in this research. These relationships are translated into Controlled Natural Language (CNL) prior to validating in Fluent Editor. However, these relationships must be demonstrated in the logical form to explain the domain of discourse. The formalisms (documented in Section 4:15) ensure robustness and universal relationships of developed ontology.



HI-MI Decision Governance Ontology (Final).encnl* - Fluent Editor
File
Home
External
References
Tools
Paste
Cut
Copy
Format Painter
Clipboard
Consolas
9
Font
Intelisense
Reformat
Line numbers
Editing
Modalalities
Complex Expressions
Validate Modalities
Validate RL+
Validate RL
Validate EL++
Expressiveness
OWL2-RL+
OWL2-DL
Find
Replace
Select All
Undo
Redo
Editing
Document

```
Title: 'Human-Intelligence and Machine-Intelligence Decision Governance Formal Foundational Ontology'.
Author: 'Faisal Mahmud'.
Description: This is a formal top/upper/foundational ontology for HI-MI decision governance.
Author Contact: 'fmahm001@odu.edu'



Comment: 'There are several parts of this ontology as noted below'.
Comment:
////// Examples of Possible Competency Questions  //////////////////
//Who-Or-What:
// * is Decision?
// * is-not-correlated-with Systems?
// * helps Management?

///////////////////////////////////////////////////////////////////.


Part-1: First part of Ontology.

Comment: This part includes the top or upper or foundational terms/classes/categories (supersumed and subsumed levels) and declaration of those terms as a physical or abstract thing.
Comment: 'simple hierarchy of beings declaring the existence of a thing'.



Decision is an abstract-thing.
Governance is an abstract-thing.
Organization is a physical-thing.
Knowledge is an abstract-thing.
Systems is an abstract-thing.
Design is a physical-thing.
Management is a physical-thing.
Process is an abstract-thing.
Intelligence is an abstract-thing.
Data is a physical-thing.
```

```
Who-Or-What is Decision?
```

<?> is Decision. *Total: 1 instances found.*	Every <?> is Decision. *Total: 0 subconcepts found.*	Decision is a <?>. *Total: 1 superconcepts found.*
Decision		abstract-thing

Reasoner
Xml Preview
Materialized Graph
SPARQL
Ready
OK
DL:
OWL-RL+
Taxonomy Tree

- "thing"
  - abstract-thing
    - Decision
    - Governance
    - Intelligence
    - Knowledge
    - Process
    - Systems
    - Technology
  - physical-thing
    - Business
    - Data
    - Design
    - Management
    - Model
    - Organization
    - Public
- "nothing"
- relation
  - be-accumulated-by
  - be-accumulated-through
  - be-a-part-of
  - be-correlated-with
  - be-evaluated-for
  - be-moderately-correlated-with
  - be-needed-for
  - benefit-from
  - be-not-correlated-with
  - be-related-with
  - be-required-for
  - be-run-by
  - be-strongly-correlated-with
  - be-transferred-through
  - be-used-by
  - be-used-for
  - be-used-in
  - be-utilized-by
  - be-utilized-for
  - be-weakly-correlated-with
  - consist-of
  - contribute-to
  - function-within
  - have
  - have-a-role-in
  - help
  - hold-accountable-by

Taxonomy Tree
Annotations
"thing"
physical-thing
abstract-thing
Organization
Management
Design
Model
Public
Data
Business
Technology
Systems
Process
Knowledge
Intelligence
Governance
Decision
physical-thing
be-a-part-of
Public
Data
Social-Technical
Business
Systems-Design
Design
Organization
Model
Management
"thing"
Systems
Technology
Organization-Knowledge
Decision
Intelligence
Governance
Knowledge
Management-Process
Process
abstract-thing
be-correlated-with
be-weakly-correlated-with
be-moderately-correlated-with
be-strongly-correlated-with
be-not-correlated-with
be-related-with
involve
be-a-part-of

Figure 19: Fluent Editor Views for Ontology.

Figure 19 shows three different views from Fluent Editor. The top portion of the figure is the ontology developing window. On the left-hand side of this window, taxonomic and axiomatic relationships were inserted following Controlled Natural Language (CNL). On the right-hand side of this window, taxonomic terms and relations are shown. The middle portion of Figure 18 shows Taxonomic hierarchy from “thing.” A “thing” can be either a “physical-thing” or an “abstract-thing.” A physical-thing has presence in time and space whereas an abstract-thing does not have such presence. Bottom part of Figure 18 shows complete connections of axiomatic relationships among taxonomic terms.

The following table is a snippet from developed ontology that is OWL compatible (meets Gruber’s (1995) ontology design criteria of extendibility) and is shown in SPARQL (SPARQL Protocol and RDF Query Language). SPARQL is an RDF query language, that is, a semantic query language for databases. RDF stands for Resource Description Framework.

Table 10: Terms in OWL.

Querying on: select ?x ?y {?x rdf : type ?y}	
x	**y**
Decision	OWL: Thing
Is-influenced-by	OWL: Object Property
Governance	OWL: Thing
Is-strongly-correlated-with	OWL: Object Property

4.13 Semantics Analysis

This section will first demonstrate semantics analysis in combination of– (i) WordNet®, (ii) existing expert definitions from the relevant domains, and (iii) the use of identified taxonomic terms within collected corpus.

A list of synonyms and semantic relations are listed below following WordNet 3.1. WordNet® is a large lexical database of English words developed by the Cognitive Science Laboratory of Princeton University under the direction of psychology professor George Armitage Miller (https://wordnet.princeton.edu/). In this lexical database, nouns, verbs, adjectives, and adverbs (depending on the nature) are grouped into sets of cognitive synonyms, also known as "Synsets", where each of them expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations.

In the WordNet® database, "S:" refers to show Synset (semantic) relations. The intended meaning is given in the parentheses. The word relations to the meanings are listed for all the foundational taxonomic terms only for the nouns and adjectives into sets of cognitive synonyms:

WordNet Synsets:

Decision:

- S: (n) **decision**, determination, conclusion (the act of making up your mind about something)
- S: (n) **decision**, determination, conclusion (a position or opinion or judgment reached after consideration)
- S: (n) **decision** ((boxing) a victory won on points when no knockout has occurred)
- S: (n) **decision** (the outcome of a game or contest)

- S: (n) decisiveness, **decision** (the trait of resoluteness as evidenced by firmness of character or purpose)

Governance:

- S: (n) administration, **governance**, governing body, establishment, brass, organization, organisation (the persons (or committees or departments etc.) who make up a body for the purpose of administering something)
- S: (n) government, governing, **governance**, government activity, administration (the act of governing; exercising authority)

Organization-Knowledge:

Organization:

- S: (n) **organization**, organisation (a group of people who work together)
- S: (n) arrangement, **organization**, organisation, system (an organized structure for arranging or classifying)
- S: (n) administration, governance, governing body, establishment, brass, **organization**, organisation (the persons (or committees or departments etc.) who make up a body for the purpose of administering something)
- S: (n) **organization**, organisation (the act of organizing a business or an activity related to a business)
- S: (n) **organization**, organisation, system (an ordered manner; orderliness by virtue of being methodical and well organized)

- S: (n) **organization**, organisation (the activity or result of distributing or disposing persons or things properly or methodically)
- S: (n) constitution, establishment, formation, **organization**, organisation (the act of forming or establishing something)

Knowledge:

- S: (n) cognition, **knowledge**, noesis (the psychological result of perception and learning and reasoning)

Systems-Design:

Systems:

- S: (n) **system** (instrumentality that combines interrelated interacting artifacts designed to work as a coherent entity)
- S: (n) **system**, scheme (a group of independent but interrelated elements comprising a unified whole)
- S: (n) **system** ((physical chemistry) a sample of matter in which substances in different phases are in equilibrium)
- S: (n) **system**, system of rules (a complex of methods or rules governing behavior)
- S: (n) arrangement, organization, organisation, **system** (an organized structure for arranging or classifying)
- S: (n) **system** (a group of physiologically or anatomically related organs or parts)
- S: (n) **system** (a procedure or process for obtaining an objective)

- S: (n) **system** (the living body considered as made up of interdependent components forming a unified whole)
- S: (n) organization, organisation, **system** (an ordered manner; orderliness by virtue of being methodical and well organized)

Design:

- S: (n) **design**, designing (the act of working out the form of something (as by making a sketch or outline or plan))
- S: (n) **design**, plan (an arrangement scheme)
- S: (n) blueprint, **design**, pattern (something intended as a guide for making something else)
- S: (n) **design**, pattern, figure (a decorative or artistic work)
- S: (n) purpose, intent, intention, aim, **design** (an anticipated outcome that is intended or that guides your planned actions)
- S: (n) **design** (a preliminary sketch indicating the plan for something)
- S: (n) invention, innovation, excogitation, conception, **design** (the creation of something in the mind)

Management-Process:

Management:

- S: (n) **management**, direction (the act of managing something)
- S: (n) **management** (those in charge of running a business)

Process:

- S: (n) procedure, **process** (a particular course of action intended to achieve a result)
- S: (n) **process**, cognitive process, mental process, operation, cognitive operation((psychology) the performance of some composite cognitive activity; an operation that affects mental contents)
- S: (n) summons, **process** (a writ issued by authority of law; usually compels the defendant's attendance in a civil suit; failure to appear results in a default judgment against the defendant)
- S: (n) **process**, unconscious process (a mental process that you are not directly aware of)
- S: (n) **process**, outgrowth, appendage (a natural prolongation or projection from a part of an organism either animal or plant)
- S: (n) **process**, physical process (a sustained phenomenon or one marked by gradual changes through a series of states)

Intelligence:

- S: (n) **intelligence** (the ability to comprehend; to understand and profit from experience)
- S: (n) **intelligence**, intelligence service, intelligence agency (a unit responsible for gathering and interpreting information about an enemy)
- S: (n) **intelligence**, intelligence information (secret information about an enemy (or potential enemy))
- S: (n) news, **intelligence**, tidings, word (information about recent and important events)

- S: (n) **intelligence**, intelligence activity, intelligence operation (the operation of gathering information about an enemy)

Social-Technical:

Social:

- S: (n) sociable, **social**, mixer (a party of people assembled to promote sociability and communal activity)
- S: (adj) **social**, societal (relating to human society and its members)
- S: (adj) **social** (living together or enjoying life in communities or organized groups)
- S: (adj) **social** (relating to or belonging to or characteristic of high society)
- S: (adj) **social** (composed of sociable people or formed for the purpose of sociability)
- S: (adj) **social** (tending to move or live together in groups or colonies of the same kind)
- S: (adj) **social** (marked by friendly companionship with others)

Technical:

- S: (n) **technical** (a pickup truck with a gun mounted on it)
- S: (n) technical foul, **technical** ((basketball) a foul that can be assessed on a player or a coach or a team for unsportsmanlike conduct; does not usually involve physical contact during play)
- S: (adj) **technical**, proficient (of or relating to technique or proficiency in a practical skill)
- S: (adj) **technical** (characterizing or showing skill in or specialized knowledge of applied arts and sciences)

- S: (adj) **technical**, technological (of or relating to a practical subject that is organized according to scientific principles)
- S: (adj) mechanical, mechanically skillful, **technical** (relating to or concerned with machinery or tools)
- S: (adj) **technical** (according to strict interpretation of the law or set of rules)
- S: (adj) **technical**, expert (of or relating to or requiring special knowledge to be understood)
- S: (adj) **technical** (resulting from or dependent on market factors rather than fundamental economic considerations)

Exploring Hypernym for the Taxonomic Terms:

To uncover the list of Synsets, the very first terminological meaning (which has the highest frequency counts, implying most of the time this is how a term is used) in each taxonomic term is explored to reckon Direct Hypernym. A hyponym is a word that is more specific than a given word. Conversely, a hypernym is a word that is more generic than a given word. As the goal here is to identify the words that are more generic than specific, inclusion of hypernym will assist us to proceed with further analysis.

Decision:

Direct Hypernym:

- S: (n) choice, selection, option, pick (the act of choosing or selecting)

Governance:

Direct Hypernym:

- S: (n) body (a group of persons associated by some common tie or occupation and regarded as an entity)

Organization-Knowledge:

Direct Hypernym:

Organization:

- S: (n) social group (people sharing some social relation)

Knowledge:

- S: (n) psychological feature (a feature of the mental life of a living organism)

Systems-Design:

Direct Hypernym:

Systems:

- S: (n) instrumentality, instrumentation (an artifact (or system of artifacts) that is instrumental in accomplishing some end)

Design:

- S: (n) creating by mental acts (the act of creating something by thinking)

Management-Process:

Direct Hypernym:

Management:

- S: (n) social control (control exerted (actively or passively) by group action)

Process:

- S: (n) activity (any specific behavior)

Intelligence:

Direct Hypernym:

- S: (n) ability, power (possession of the qualities (especially mental qualities) required to do something or get something done)

Social-Technical:

Direct Hypernym:

Social:

- S: (n) party (a group of people gathered together for pleasure)
- S: (adj) social, societal (relating to human society and its members)

Technical:

- S: (n) pickup, pickup truck (a light truck with an open body and low sides and a tailboard)
- S: (adj) technical, proficient (of or relating to technique or proficiency in a practical skill)

Having the hypernyms from WordNet, the next step is to look at the expert definitions from the relevant domains. For each of the primitive concepts (terms), existing definitions are identified based on frequent citations and therefore listed here:

Expert Definitions from the Relevant Domains:

Decision:

"…as a systematic process with clearly defined elements and in a distinct sequence of steps." (Drucker, 1967)

"Decision is described as a series of steps, starting with information output and analysis and culminating in resolution, namely a selection from several available alternatives." (Eilon, 1969)

"Decision focuses on how we (human) use our freedom and thus it has some aspects of human activity with goal-directed behavior in the presence of options." (Hansson, 1994)

"…conditions of dual equipoise, dealing with options including, where reasonable, the option of taking no action." (Elwyn, 2009)

"Decision theory is concerned with the reasoning underlying an agent's choices." (Streel, 2015)

Governance:

"Governance is ultimately concerned with creating the conditions for ordered rule and collective action." (Stoker, 1998)

"Governance refers to all processes of governing, whether undertaken by a government, market, or network; whether over a family, tribe, corporation, or territory; and whether by laws, norms, power, or language. Governance is a broader term than government because it

focuses not only on the state and its institutions but also on the creation of rule and order in social practices." (Bevir, 2013)

"Governance entails the formulation and implementation of public policies across organizational and sectoral boundaries through coalitions, contracts, and networks." (Page, 2013)

Organization:

"Organization is the arrangement of personnel for facilitating the accomplishment of some agreed purpose through the allocation of functions and responsibilities…a system of consciously coordinated activities or forces of two or more persons." (Selznick, 1948)

"Organization is a systems of coordinated action among individuals who differ in the dimensions of interests, preferences and knowledge." (March and Simon, 1958)

"…social units of people with recognizable boundary to meet certain goals." (Robbins, 1990)

"Organizations exist when people interact with one another to perform essential." (Daft, 2007)

"Organizations are the unities composed of mental activities of member with same goals and technologies and operate in the certain relationship mode." (Liu, 2007)

Knowledge:

"Knowledge is justified true belief." (Gettier, 1963)

"Knowledge is a particularly successful or valuable form of belief." (Sosa, 1999)

"Knowledge is the most general factive mental state." (Williamson, 2000)

"Knowledge involves complex cognitive processes: perception, communication, and reasoning." (Dekel, 2006)

Systems:

“A system is a complex of interacting elements.” (Von Bertalaffy, 1956)

“An entity that is adaptable for the purpose of surviving in its changing environment.” (Beer, 1972)

“A framework with which we can investigate phenomena from a holistic approach.” (Capra, 1997)

“System elements are rationally connected.” (Luhmann, 1990)

“A system can be defined as an entity, which is a coherent whole such that a boundary is perceived around it in order to distinguish internal and external elements and to identify input and output relating to and emerging from the entity.” (Ng, 2009)

“Systems components are aimed towards a shared purpose.” (Golinelli, 2009)

Design:

“…a specification of an object, manifested by an agent, intended to accomplish goals, in a particular environment, using a set of primitive components, satisfying a set of requirements, subject to constraints.” (Ralph and Wand, 2009)

“…a roadmap or a strategic approach for someone to achieve a unique expectation.” (Kumaragamage, 2011)

Management:

“To manage is to forecast and to plan, to organize, to command, to co-ordinate and to control.” (Fayol, 1930)

"Management is the art of getting things done through and with people in formally organized groups." (Koontz, 1961)

"Management is defined as the process by which a cooperative group directs action towards common goals." (Massie, 1971)

"Management is a multi-purpose organ that manages business and manages managers and manages workers and work." (Druker, 1973)

"Management is a social and technical process which utilizes, resources, influences, human action and facilitates changes in order to accomplish organizational goals." (Haimann and Scott, 1978)

Process:

"…a structured, measured set of activities designed to produce a specific output for a particular customer or market." (Davenport, 1993)

"Process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer." (Hammer and Champy, 1993)

"…a set of linked activities that take an input and transform it to create an output." (Johansson et al., 1993)

"A process is the definition of the tasks and the sequence of those tasks necessary to fulfill an objective." (Davis, 2009)

Intelligence:

"The aggregate or global capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment." (Wechsler, 1944)

"...the resultant of the process of acquiring, storing in memory, retrieving, combining, comparing, and using in new contexts information and conceptual skills." (Humphreys, 1979)

"Intelligence is the ability to deal with cognitive complexity." (Gottfredson, 1998)

"Intelligence is sensation, perception, association, memory, imagination, discrimination, judgement and reasoning." (Sternberg, 2000)

"Intelligence measures an agent's ability to achieve goals in a wide range of environments." (Legg and Hutter, 2007)

Social:

"Human social environments encompass the immediate physical surroundings, social relationships, and cultural milieus within which defined groups of people function and interact." (Barnett and Casper, 2001)

"Social can be evaluated in terms of three central images of thought: 'unity,' 'purity,' and 'order'." (Albertsen and Diken, 2003)

"In its broadest sense, social means association. Thus, social (connections, interactions) may include plants, animals and material artefacts as well as humans. In a narrower sense, social is used in a restrictive manner to refer primarily to human aggregates or humans-among-themselves." (Dolwick, 2009)

Technical:

"...two distinctive meanings– one the teaching of a specific art or trade; the other instruction in elementary science bearing on all arts or trades and the training of hand and eye." (Davenport-Hill, 1888)

"…distinct 'inputs', such as knowledge and labor, and 'outputs', referred to as material culture and modified environments." (McOmber, 1999)

"…a system created by humans that uses knowledge and organization to produce objects and techniques for the attainment of specific goals." (Volti, 2009)

"…techne as a word-root is traditionally understood to refer to "art" or "skill"." (Skrbina, 2015)

"…involving or needing special skills or knowledge, esp. in science or engineering." (Cambridge Dictionary, 2018)

Now, on the basis of (i) hypernyms from WordNet, (ii) existing expert definitions from the relevant domains, and (iii) terms appearance and use within collected corpus, attributes for foundational taxonomic terms are determined into two categories– (i) Existential attributes and (ii) State-Modification attributes. Table 11 listed both types of attributes. The triangulation among these three contexts is visualized in Figure 20.

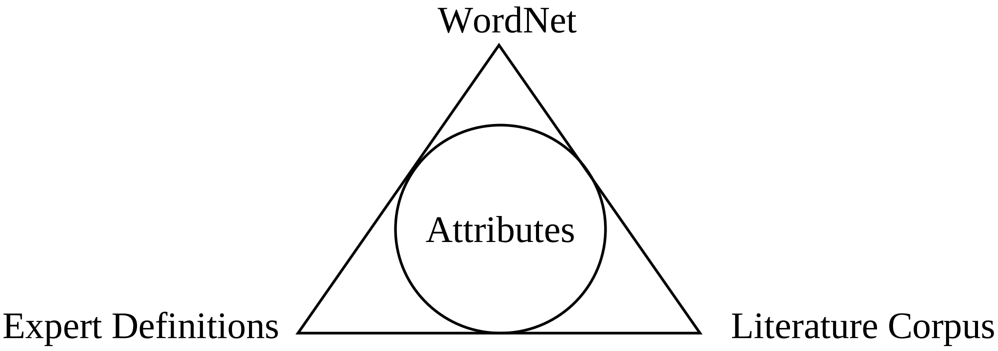


Figure 20: Triangulation of the Contexts.

Existential Attributes:

Existential attributes are those attributes of a concept (object) that are essential for the existence of that concept. In absence of any of these attributes, the concept cannot hold true. These attributes are associated with "is-a" relationships with the concept.

State-Modification Attributes:

State-Modification attributes are those attributes of a concept (object) that are required to explain a certain state of the concept. These attributes are not essential for the existence of a concept and associated with "has-a" relationships with the concept.

For each of the foundational taxonomic term, a list of attributes are documented here:

Table 11: Foundational Taxonomic Terms and Attributes.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**State-Modification Attributes (has-a relations)**
Decision	Actions Choice Human Impacts Outcomes Prediction Purposeful	Boundary Method Problem Reasoning Risk Uncertainty
Governance	Administration Pluralism Policies Purposeful	Accountability Actions Choice Coordination Interactions Pluralism

Table 11: Continued.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**State-Modification Attributes (has-a relations)**
Organization	Arrangement Human Interactions Purposeful	Actions Association Coordination Structure Transformations
Knowledge	Learning Perception Representation	Information Structure Understanding
Systems	Hierarchy Interactions Purposeful Transformations	Actions Boundary Coordination Complexity Coupling Dynamic Environment Homeostasis Information Inputs Interdependency Outputs Pluralism Wholeness
Design	Creation Plan Purposeful	Actions Application Coordination Function Information Representation

Table 11: Continued.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**State-Modification Attributes (has-a relations)**
Management	Actions Control Human Interactions Purposeful	Administration Plan Coordination Outcomes Structure
Process	Actions Control Inputs Outputs Purposeful	Events Information Sequence Tasks
Intelligence	Analysis Human Reasoning Synthesis	Dynamic Emotional Information Learning Perception Rational Representation Understanding
Social	Actions Association Human Interactions Purposeful Reasoning	Complexity Emotional Information Interdependency Learning Partnership Perception Rational Representation Understanding

Table 11: Continued.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**State-Modification Attributes (has-a relations)**
Technical	Actions Control Engineering Purposeful	Applications Coordination Function Information Outcomes Representation

As mentioned earlier, the context of triangulation technique is followed to pinpoint these attributes. The above table has few attributes that may sound similar but actually have different meanings. Conversely, some attributes are contending and needs to expound more. For example, “Decision” taxonomic term has *Choice* and *Reasoning* attributes. *Choice* and *Reasoning* intersect only in the sense of “logical motivation,” *Reasoning* requires only logic (deductive, inductive, and abductive). Logic provides the structural framework for making choices, but logic alone cannot make decisions. A decision requires a choice among alternative, and choice requires motivation toward an outcome potentially provided by an outcome of one of the alternatives. The motivation for a choice must arise from a problem. The problem structure changes the required logical reasoning and relevant choices. Thus, *Choice* is listed as “is-a” attribute and *Reasoning* as “has-a” attribute.

Another example is *Arrangement* and *Association* that are transitive and appeared in “Organization” taxonomic term. An association requires only links among entities. An arrangement requires ordered links among entities. Accordingly, association subsumes arrangement. An organization requires hierarchical ordered links among its people (humans) in order to accomplish its purpose. In this case, the more restrictive meaning is required. Therefore, *Arrangement* is listed as “is-a” attribute and *Association* as “has-a” attribute.

Under “Systems” taxonomic term, *Interactions* and *Interdependency* are transitive. Interdependence is a mutual link between at least two entities. Interactions is the particular way that the two entities affect each other through their respective actions or some external mutual action on them by a third entity. *Interdependency* ¬ → *Interactions*, but *Interactions* → *Interdependency*. Interdependencies exist within a system and between systems but are not sufficient for system existence and viability. Interactions produce the necessary and sufficient conditions for a system to exist and be viable. In this case, the more restrictive meaning is required and thus *Interactions* is listed as “is-a” attribute and *Interdependency* as “has-a” attribute.

Now that semantics analysis are performed, the next analysis is to conduct Formal Concept Analysis (FCA) based on the identified attributes. Formal Concept analysis (hereinafter FCA) is a method to analyze data for deriving implicit relationships between objects (concepts) and their attributes in a way that objects are described through a set of attributes. FCA is based on mathematical order theory, in particular on the theory of lattices (Willie and Ganter, 1999). The lattice structure is built upon objects (concepts) and their attributes and can demonstrate if there is a closure on the overall concept analysis or not. In this research, concepts are the foundational taxonomic terms such as– Decision, Governance, Organization-Knowledge, Systems-Design, Management-Process, Intelligence, and Social-Technical.

4.14 Formal Concept Analysis of Taxonomic Concept-Attribute Relationships

The union of taxonomic concept "is-a" attribute relationships provide the primitive structural information sufficient to fulfill Gruber's (1995) ontology design criteria and provide explicitness and modularity necessary for ontology re-use, maintainability, and evolution in knowledge representation. Taxonomies that are explicit are said to be proper, and taxonomies that have been normalized are said to be modular. The objective of taxonomy development is to create taxonomies that are both proper and modular. (Note: Taxonomic concept "has-a" state modification attributes provide additional restrictions necessary only to specify domain and application instances of the concept "is-a" attribute primitives. As such, the concept "has-a" attributes are not necessary for concept existence and properness. Thus, the concept "has-a" attribute relationships were not verified in this work. HI-MI decision governance concept "has-a" attribute relationships will be verified in future work through extension of the foundational ontology semantics and structure to HI-MI decision governance core reference, domain, and application instances.)

Guarino and Welty (2000) and Welty and Guarino (2001) set forth explicit, disciplined subsumption criteria for concept "is-a" attributes. They focus on the concept "is-a" attributes subsumption rather than the semantics describing of the subsumption itself. For arbitrary properties ψ and ϕ, they take the statement "ψ subsumes ϕ, to mean that, necessarily:

$$\forall x\ \phi(x) \rightarrow \psi(x) \tag{1}$$

(Welty and Guarino, 2001; p. 53)." They base their criteria on philosophical ideas of *rigidity*, *identity*, *unity*, and *dependence*. Concept "is-a" attribute subsumption that meet the constraints imposed by these criteria are sufficient to assure Gruber's clarity, coherence, minimal encoding bias, and minimum ontological commitment. The difference between identity and unity is that identity is related to the problem of distinguishing a specific concept of a certain class from other concepts of this class by means of its characteristic attributes, which are unique for it. Unity, on the other hand, is related to the problem of distinguishing the attributes of a concept from the rest of the world by means of unifying relations that binds the concept attributes, and only the concept attributes together. As an example, if the question is what is the difference between "Governance" and "Management?" Then, with the identity criteria we must be able to tell what makes these two concepts different from each other based on the union of their respective attributes. On the other hand, with the unity criteria, we must be able to say what are the attributes that binds together to form the wholeness of each concept. Welty and Guarino (2001) distinguish between *extrinsic* and *intrinsic* concept-attribute dependence. Intrinsic dependence is inherent to the concept itself. That is, an intrinsic concept is one that is inherent in the union of its "is-a" attributes and is not dependent on the union of other concepts "is-a" attributes. For an example, John "is-a" human does not depend on any other entities state of being or not being human. Extrinsic concepts are those that depend on "has-a" relationships with other concepts. For an example, John "has-a" son depends only on the external parent-child relationship.

The attribute property of rigidity relies on the notion of essentiality. An essential attribute of a concept is an attribute property that is necessary for the concept's existence. Welty and Guarino (2001, p. 57) define three levels of rigidity:

Definition 1: A *rigid property* is a property that is essential to *all* its (concept's) instances, i.e., a property ϕ: $\Box(\forall xt\ \phi(x, t) \rightarrow \Box\forall t'\ \phi(x, t'))$. This rigidity is marked as +R attribute.

Definition 2: A *non-rigid property* is a property that is not essential to *some* of its (concept's) instances, i.e., a property ϕ: $\Diamond(\exists x, t\ \phi(x, t) \cap \Diamond\ (\exists t'\ \neg\ \phi(x, t'))$. Therefore, –R attribute.

Definition 3: An *anti-rigid property* is a property that is not essential to *all* its (concept's) instances, i.e., a property ϕ: $\Box(\forall xt\ \phi(x, t) \rightarrow \Diamond(\exists t'\ \neg\ \phi(x, t'))$. Therefore, ~R attribute.

Welty and Guarino define $\Box\phi$ as necessarily true in all possible worlds and $\Diamond\phi$ as possibly true in at least one possible world. As a meta-property, rigidity is not inherited by sub-properties of properties.

Further, Welty and Guarino (2011, pp. 58-59) define "… an *identity condition* (*IC*) for an arbitrary attribute property ϕ …as a suitable relation ρ satisfying":

$$\phi(x) \cap \phi(y) \rightarrow (\rho(x, y) \leftrightarrow x = y) \tag{2}$$

Which leads to the following definitions:

Definition 4: An IC is a *sameness* formula Σ that satisfies either of the following conditions assuming the predicate E for actual existence.

$$\Box(E(x, t) \cap \phi(x, t) \cap E(y, t') \cap \phi(y, t') \cap x = y \rightarrow \Sigma(x, y, t, t') \tag{3}$$

$$\Box(E(x, t) \cap \phi(x, t) \cap E(y, t') \cap \phi(y, t') \cap \Sigma(x, y, t, t') \rightarrow x = y) \tag{4}$$

Definition 5: Any property *carries* an IC iff it is subsumed by a property supplying this IC, including the case where it supplies the IC itself. This property is marked as +I attribute.

Definition 6: A property ϕ *supplies* and IC iff (i) it is rigid, (ii) there is an IC for it, and (iii) the same IC is not carried by *all* the properties subsuming ϕ. Therefore, +O attribute.

Definition 7: Any property carrying and IC is called a *sortal*.

For an example, the attribute *Person* for the concept *Human* may have the identity condition “has-a” social security number (i.e., person:⇔ SSN) and by definitions 4-7, is a *sortal*. An attribute property carrying an IC is designated as +I (−I otherwise), and any property supplying an IC is designated as +O (−O otherwise).

Furthermore, Welty and Guarino (2011, pp. 59-60) define unity as:

Definition 8: An object *x is a whole under ω* iff ω is a relation such that all the members of a certain division *x* are linked by *ω*, and nothing else is linked by *ω*.

Definition 9: A property *ϕ carries a unity condition* (UC) iff there exists a single relation *ω* such that each instance of *ϕ* is *necessarily* a whole under *ω*.

Definition 10: A property has *anti-unity* if every instance of the property is not necessarily a whole.

Welty and Guarino recognize three types of unity– (1) Topological unity based on a topological or physical relationship, (2) Morphological unity based on some combination of topological unity and shape, and (3) Functional unity based on functional purpose. Any attribute property carrying an UC is designated as +U (–U otherwise). Any attribute property that has anti-unity is designated as ~U, but ~U implies –U.

The final attribute property specified by Welty and Guarino (2011, p. 60) is that of dependence:

Definition 11: A property ϕ is externally dependent on a property ψ if, for all its instances x, necessarily some instances of ψ must exist, which is neither a part nor a constituent of x:

$$\forall x \, \square(f(x) \rightarrow \exists y \, \psi(y) \cap \neg P(y, x) \cap \neg C(y, x)) \tag{5}$$

An externally dependent attribute property is designated as +D (–D otherwise).

Welty and Guarino apply combinations of *rigidity*, *identity*, *unity*, and *dependence* to specify ontological property kind necessary to produce a proper taxonomy. An ontological property kind is a specification of how a combination of properties specify ontological components. Table 12 presents the ontological property kind criteria for foundational ontologies.

Table 12: Foundational Ontological Property Kinds.

Meta-Property	**Property Combination**			
Category	¬O	¬I	+R	+D
				¬D
Role	¬O	¬I	~R	+D
Attribution	¬O	¬I	~R	¬D
			¬R	+D
				¬D

Rector (2003) notes that even if a taxonomy’s property kinds fulfills the Guarino and Welty’s criteria for a proper taxonomy, the taxonomy may not be a primitive taxonomy. A primitive taxonomy is one that has *“... independent disjoint skeleton ... restricted by simple trees”* (Rector, 2003; p. 1). Further, Rector defines a non-primitive taxonomy as “tangled” in that it is not easily maintained, is not extensible to other taxonomies, and is difficult to update. To achieve the state of being a primitive taxonomy, Rector adds the requirement of modularity to

Guarino and Welty's explicitness criteria. Rector defines a primitive taxonomy as one that meets the criteria for explicitness and is modular from being "normalized."

Rector's criteria are based on the hierarchical "is-kind-of" relationship. Is-kind-of relationships distinguish among members of a class or category. The members must be already specified by "is-a" and "has-a" class or category subsumption. Thus, membership is explicit but not necessarily normalized within the taxonomic hierarchy. That is, $\forall x\ B(\phi(x)) \rightarrow A(\psi(x))$ says that "all B's are A's. This extension to "is-kind-of" formalism admits– (1) primitive concepts described by necessary conditions, (2) defined concepts specified by necessary and sufficient conditions, (3) properties which relate concepts within a subsumption hierarchies, (4) restrictions constructed as quantified "role-concept" pairs, and (5) axioms which declare concept either to be disjoint or imply other concepts (Rector, 2003; p. 2). Rector's criteria *"… for normalization is that the primitive …Ontology should consist of disjoint trees."* The criteria for disjoint trees are:

- No concept should have more than one primitive parent.
- Each branch of the primitive skeleton should be homogeneous and logical.
- The primitive skeleton should clearly distinguish:
  - Self-standing concepts.
  - Partitioning refining concepts.
- Any primitive concept may be subsumed by one and only one other primitive concept.

A taxonomy that is explicitly proper and modular is a taxonomy that meets Gruber's ontological criteria. However, proper and modular do not address the issues of whether a taxonomy is complete and closed (i.e., it spans its knowledge space). Therefore, this work applied the definitions of complete lattices and closure operators from Formal Concept Analysis (Ganter and Wille, 1999). Formal Concept Analysis (FCA) is an applied branch of mathematical lattice theory that enables concept-attribute knowledge discovery, development, representation, and verification formalisms.

Basic Theorem on Concept Lattice: The concept lattice B (O objects, A attributes, I relations) is a complete concept lattice in which infimum and supremum are given by:

$$\wedge_{t \in T} (O_t, A_t) = (\cap O_t , (\cup A_t)'') \tag{6}$$

$$\wedge_{t \in T} (O_t, A_t) = ((\cup O_t)'', \cap A_t) \tag{7}$$

A complete lattice C is isomorphic to B(O, A, I) if and only if there are mappings $\gamma : O \rightarrow C$ and $\mu : A \rightarrow C$ such that $\gamma(O)$ is supremum-dense in C, $\mu(A)$ is infimum-dense in C, and $\mathrm{o}I\mathrm{a}$ is equivalent to $\gamma\mathrm{o} \leq \mu\mathrm{a}$ for all $\mathrm{o} \in O$ and all $\mathrm{a} \in A$.

Complete Lattice Definition: An ordered set $V := (V, \trianglelefteq)$ is a lattice if for any two elements x and y in V the supremum $x \vee y$ and the infimum $x \wedge y$ always exist. V is called a complete lattice if the supremum $\vee X$ and the infimum $\wedge X$ exist for any subset of X of V (Ganter and Wille, 1999; p. 5).

Closure Operator Definition: A closure system on a set G is a set of subsets which contains G and is closed under intersections. Formally, $U \subseteq B(G)$ is a closure system if $G \in U$ and $X \subseteq U \Rightarrow \cap X \in U$. A closure operator u on G is a map assigning a closure $uX \subseteq G$ to each subset $X \subseteq G$ under the following conditions (Ganter and Wille, 1999; p. 8):

- $X \subseteq Y \Rightarrow uX \subseteq uY$, monotony.
- $X \subseteq uX$, extensity.
- $uuX = uX$, idempotency.

Applying the above criteria, the HI-MI taxonomy may be shown to be proper, normalized, complete, and closed. The explicitness of the HI-MI taxonomy concept “is-a” attribute relationships is demonstrated in Table 13.

Table 13: Foundational Taxonomy Concept “is-a” Attribute Relationships.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**Attribute Property**	**Property Combination**			
Decision	Actions	Activities determined by making a choice at a decision node.	–O	–I	+R	+D
	Choice	Selecting an action at a decision node.	–O	–I	+R	+D
	Human	Homo sapiens that make choices and acts on those choices.	–O	–I	+R	+D
	Impacts	Outcome effect on the homo sapiens.	–O	–I	+R	+D
	Outcomes	Result of chance events and actions.	–O	–I	+R	+D
	Prediction	Expected outcomes given chance events and actions.	–O	–I	+R	+D
	Purposeful	Homo sapiens intent.	–O	–I	+R	–D
Governance	Administration	Oversight and application of policies.	–O	–I	+R	+D
	Pluralism	Distribution of governance.	–O	–I	+R	+D
	Policies	A course or principle of action.	–O	–I	+R	+D
	Purposeful	Governance intent.	–O	–I	+R	–D

Table 13: Continued.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**Attribute Property**	**Property Combination**			
Organization	Arrangement	Ordered structure of entities.	–O	–I	+R	+D
	Human	Subset of homo sapiens comprising an organization.	–O	–I	+R	–D
	Interactions	Particular way entities affect each other.	–O	–I	+R	+D
	Purposeful	Organizational intent.	–O	–I	+R	–D
Knowledge	Learning	Acquisition of knowledge or skills.	–O	–I	+R	+D
	Perception	Awareness and interpretation of sensory information.	–O	–I	+R	–D
	Representation	Organization of sensory information to explain phenomena.	–O	–I	+R	+D
Systems	Hierarchy	Ranked order.	–O	–I	+R	+D
	Interactions	Particular way entities affect each other.	–O	–I	+R	+D
	Purposeful	Systems intent.	–O	–I	+R	–D
	Transformations	Change in inputs' form and appearance into functional output.	–O	–I	+R	+D
Design	Creation	Bringing something into existence.	–O	–I	+R	+D
	Plan	A detailed proposal for brining something into existence.	–O	–I	+R	+D
	Purposeful	Design intent.	–O	–I	+R	–D

Table 13: Continued.

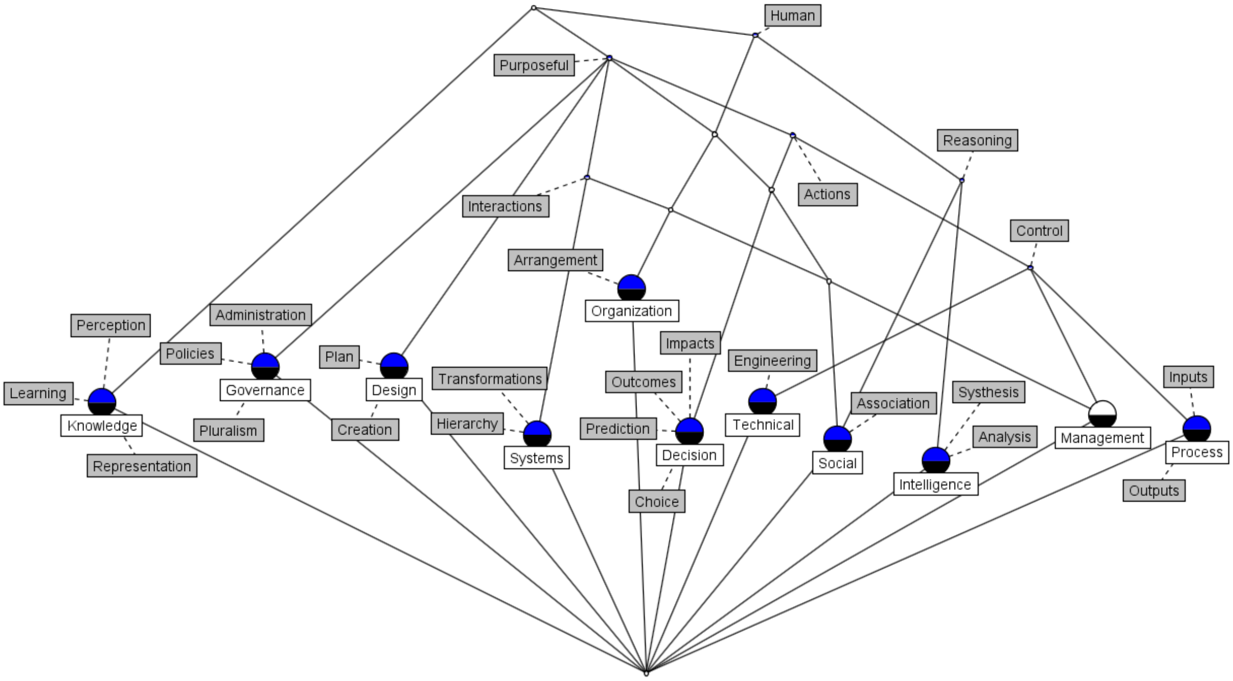
Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**Attribute Property**	**Property Combination**			
Management	Actions	Activities determined by management.	–O	–I	+R	+D
	Control	Direction of behavior to achieve outcomes.	–O	–I	+R	+D
	Human	Subset of homo sapiens being managed.	–O	–I	+R	–D
	Interactions	Particular way managed entities affect each other.	–O	–I	+R	+D
	Purposeful	Management intent.	–O	–I	+R	–D
Process	Actions	Activities determined by process order.	–O	–I	+R	+D
	Control	Direction of behavior by process order.	–O	–I	+R	+D
	Inputs	Entities taken in.	–O	–I	+R	+D
	Outputs	Entities produce.	–O	–I	+R	+D
	Purposeful	Process intent.	–O	–I	+R	–D
Intelligence	Analysis	Separating a phenomenon into its components.	–O	–I	+R	+D
	Human	Homo sapiens exhibiting intelligence.	–O	–I	+R	–D
	Reasoning	Thinking logically.	–O	–I	+R	–D
	Synthesis	Integrating the components of a phenomenon.	–O	–I	+R	+D
Social	Actions	Activities determined by social association.	–O	–I	+R	+D
	Association	Links among homo sapiens.	–O	–I	+R	+D
	Human	Homo sapiens.	–O	–I	+R	–D
	Interactions	Particular way homo sapiens affect each other.	–O	–I	+R	+D
	Purposeful	Homo sapiens intent.	–O	–I	+R	–D
	Reasoning	Thinking logically.	–O	–I	+R	+D

Table 13: Continued.

Foundational Taxonomic Terms	**Existential Attributes (is-a relation)**	**Attribute Property**	**Property Combination**			
Technical	Actions	Activities determined by scientific and mathematical properties.	–O	–I	+R	+D
	Control	Direction of behavior by scientific and mathematical properties.	–O	–I	+R	+D
	Engineering	Application of scientific and mathematical methods to produce technical outputs.	–O	–I	+R	+D
	Purposeful	Technical intent.	–O	–I	+R	–D

Since the HI-MI decision governance ontology is a foundational ontology, its attributes properties cannot carry or supply an identity condition and are classified as –O and –I. Likewise, at the foundational level, each property has a one-to-one mapping to its respective attribute and is therefore essential to its attribute, hence classified as +R. Within each category, there is at least one –D independent property with the remaining +D properties dependent only the –D independent property. The property definitions are restricted such that dependence holds within each category making the categories independent. Likewise, since there is a one-to-one mapping between each attribute and its property, the unity condition holds. Thus, the HI-MI decision governance taxonomy is proper.

Next, modularity, completeness, and closure can be assessed by concept lattices. Now evaluating Figure 21, the concepts (objects) are marked in the white boxes, whereas the attributes are in the grey boxes. When a concept node contains blue filled upper semicircle, it means that there is an attribute attached to this concept. When there is black filled lower semicircle, it means that there is only a concept attached. In FCA, a pair *(O, A)*, is such that *O* is a set of objects (categories) and *A* is a set of attributes so that *A* contains all attributes defining *O*. That is each object *O* has only one set of attributes *A*, and *O* contains all objects that describe the *C* concept context. Set of objects *O* is called *extent* of concept *(O, A)* and set of attributes *A* is called *intent* of concept *(O, A)* (Ganter and Wille, 1999; p. 18).


Human
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Control
Arrangement
Organization
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Governance
Design
Transformations
Outcomes
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Learning
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Association
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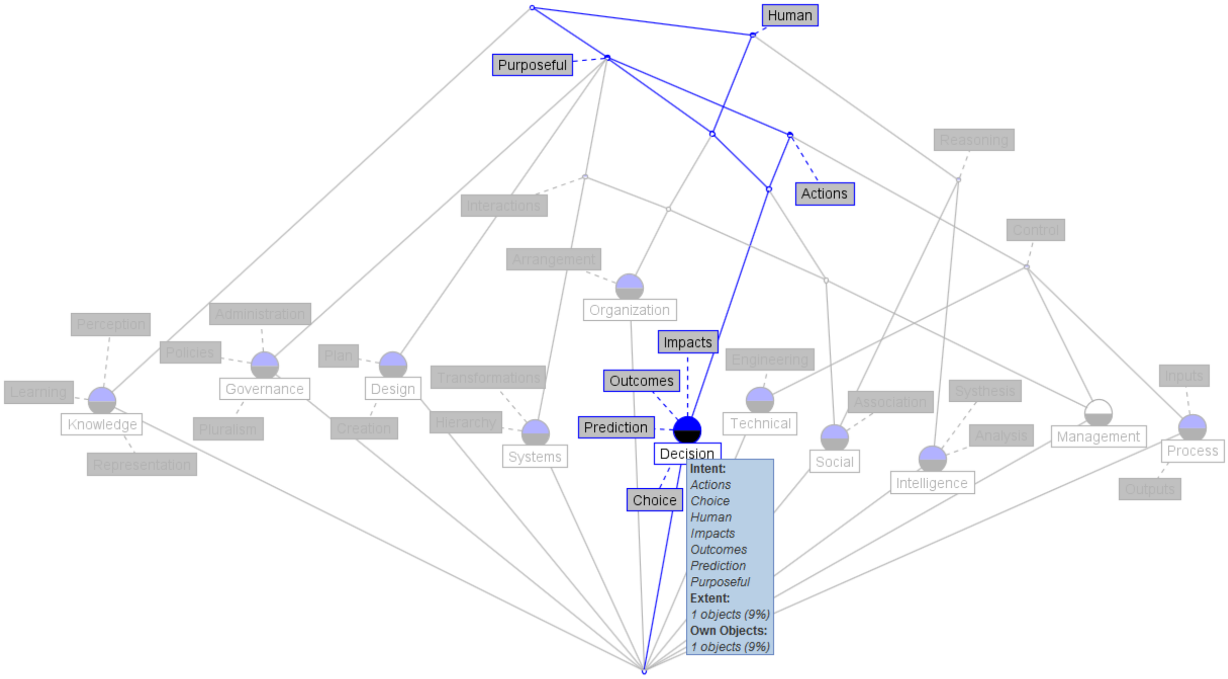
Technical
Management
Analysis
Prediction
Decision
Process
Pluralism
Creation
Systems
Social
Intelligence
Outputs
Representation
Choice

Figure 21: Primitive Concept Lattice for Existential Attributes.

Examination of Figure 21 demonstrates that the HI-MI decision governance taxonomy meets the conditions of complete lattice and closure. All categories support a single unified parent concept, and there are no intersections of attributes with unspecified categories. The single unified confirms Rector’s (2003) criteria (1) that no concept should have more than one primitive parent.

Next, examination of the lattice path for each category concept confirms Rector’s (2003) criteria (2) through (4) for being in normal form necessary and sufficient for modularization. As observed in Figure 22 to 32, the way to read the figures is, starting from the very bottom node and follow ascending path all the way to the top through connecting nodes. For example, in Figure 22, Decision has existential attributes (intents) such as Actions, Choice, Human, Impacts, Outcomes, Prediction, and Purposeful. Figures 22 through 32 demonstrate that the HI-MI decision governance taxonomy is proper, modular, complete, and closed.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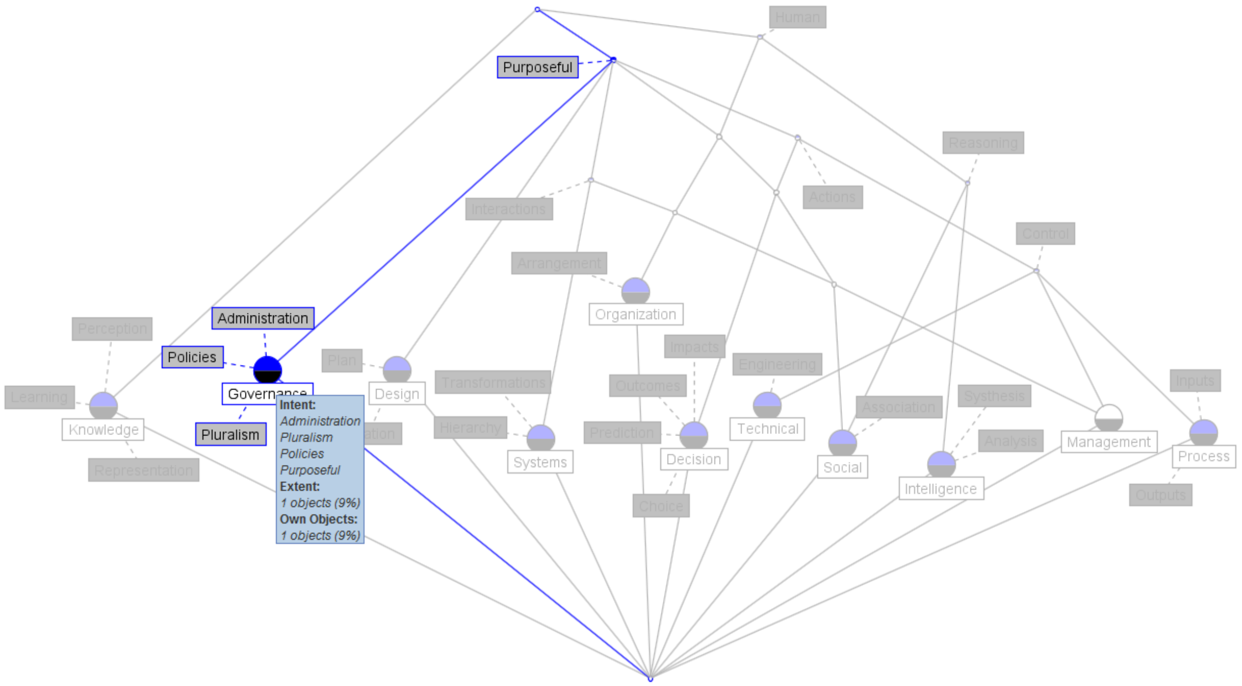
Outcomes
Synthesis
Association
Knowledge
Pluralism
Creation
Hierarchy
Prediction
Technical
Analysis
Management
Process
Systems
Decision
Social
Representation
Intelligence
Choice
Outputs
Intent:
Actions
Choice
Human
Impacts
Outcomes
Prediction
Purposeful
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 22: Lattice Path for Decision.


Human
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Impacts
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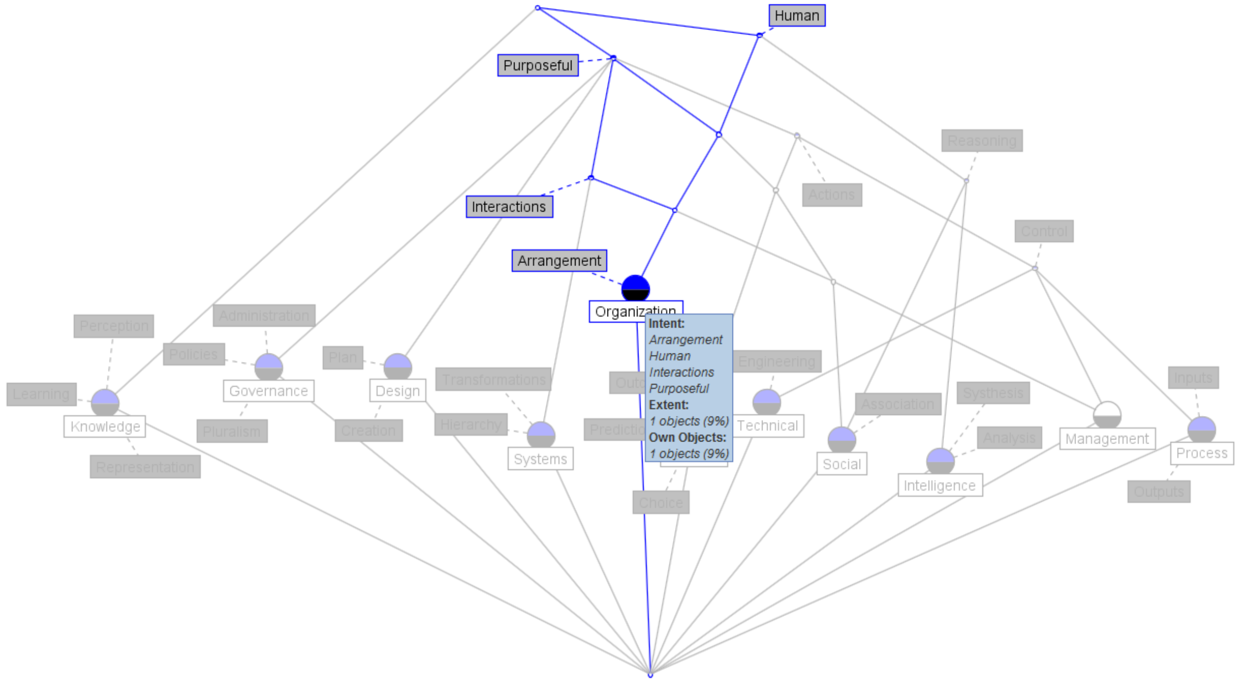
Governance
Design
Transformations
Outcomes
Inputs
Learning
Synthesis
Association
Technical
Knowledge
Hierarchy
Prediction
Management
Pluralism
Decision
Analysis
Systems
Social
Process
Intelligence
Representation
Choice
Outputs
Intent:
Administration
Pluralism
Policies
Purposeful
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 23: Lattice Path for Governance.


Human
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Reasoning
Actions
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Control
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Organization
Perception
Administration
Policies
Plan
Engineering
Governance
Design
Transformations
Inputs
Learning
Synthesis
Technical
Knowledge
Association
Hierarchy
Pluralism
Creation
Management
Analysis
Systems
Social
Process
Intelligence
Representation
Choice
Outputs
Intent:
Arrangement
Human
Interactions
Purposeful
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 24: Lattice Path for Organization.

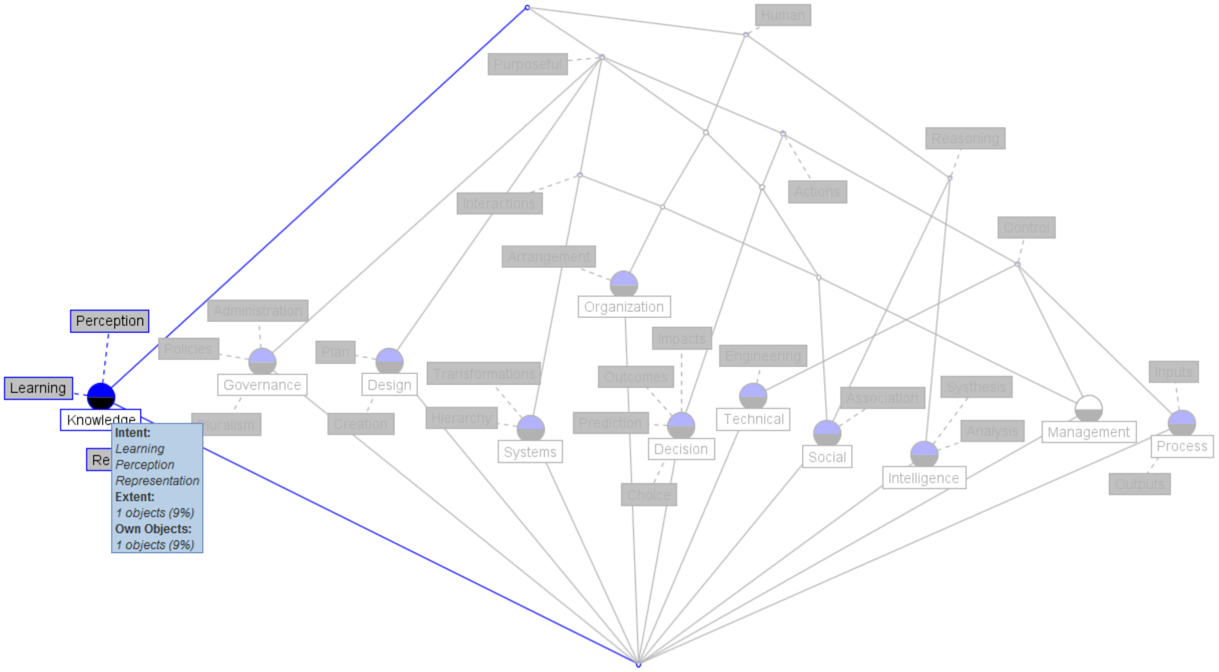
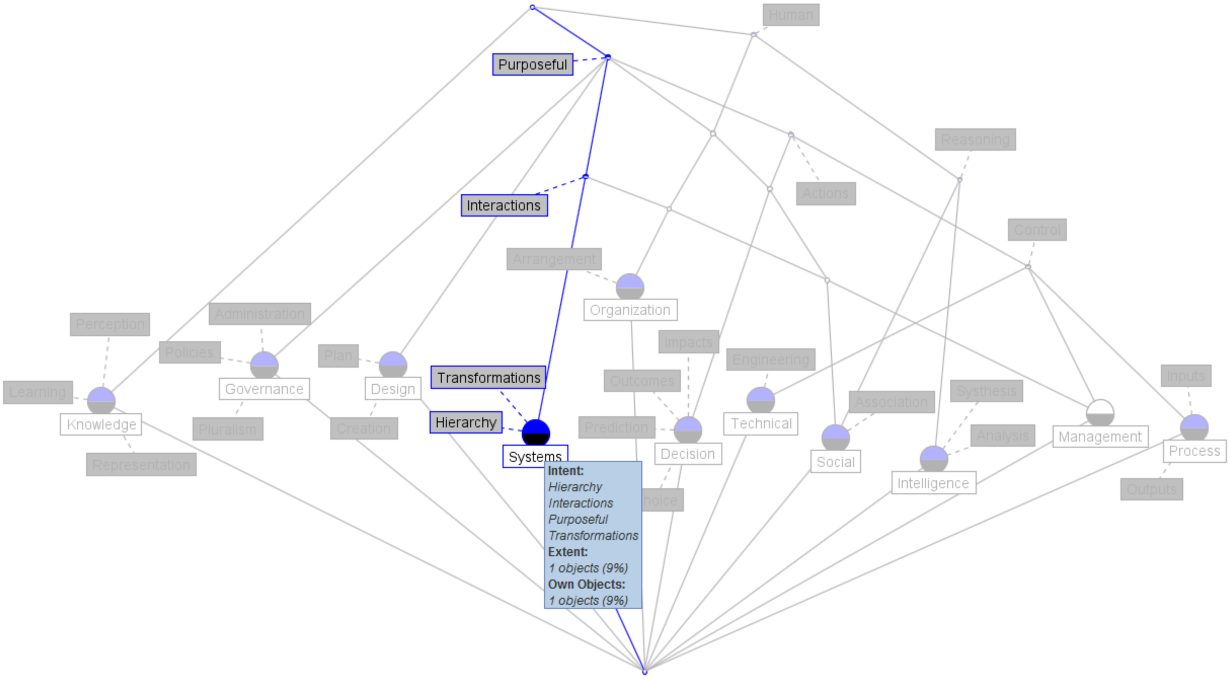

Human
Purposeful
Reasoning
Actions
Interactions
Control
Arrangement
Organization
Perception
Administration
Impacts
Engineering
Inputs
Policies
Plan
Transformations
Outcomes
Synthesis
Learning
Governance
Design
Association
Knowledge
Technical
Management
Process
Pluralism
Creation
Hierarchy
Prediction
Analysis
Re
Systems
Decision
Social
Intelligence
Outputs
Choice
Intent:
Learning
Perception
Representation
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 25: Lattice Path for Knowledge.


Human
Purposeful
Reasoning
Actions
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Organization
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Engineering
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Outcomes
Synthesis
Learning
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Creation
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Systems
Decision
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Intent:
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Interactions
Purposeful
Transformations
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 26: Lattice Path for Systems.

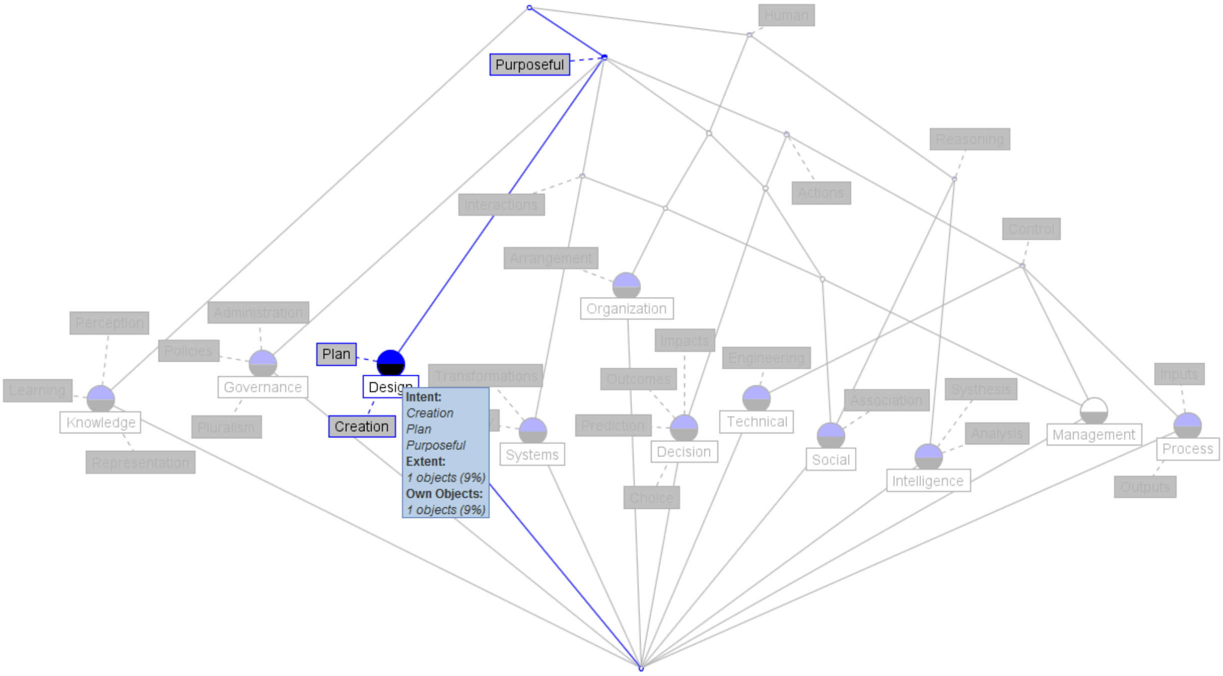
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Figure 27: Lattice Path for Design.

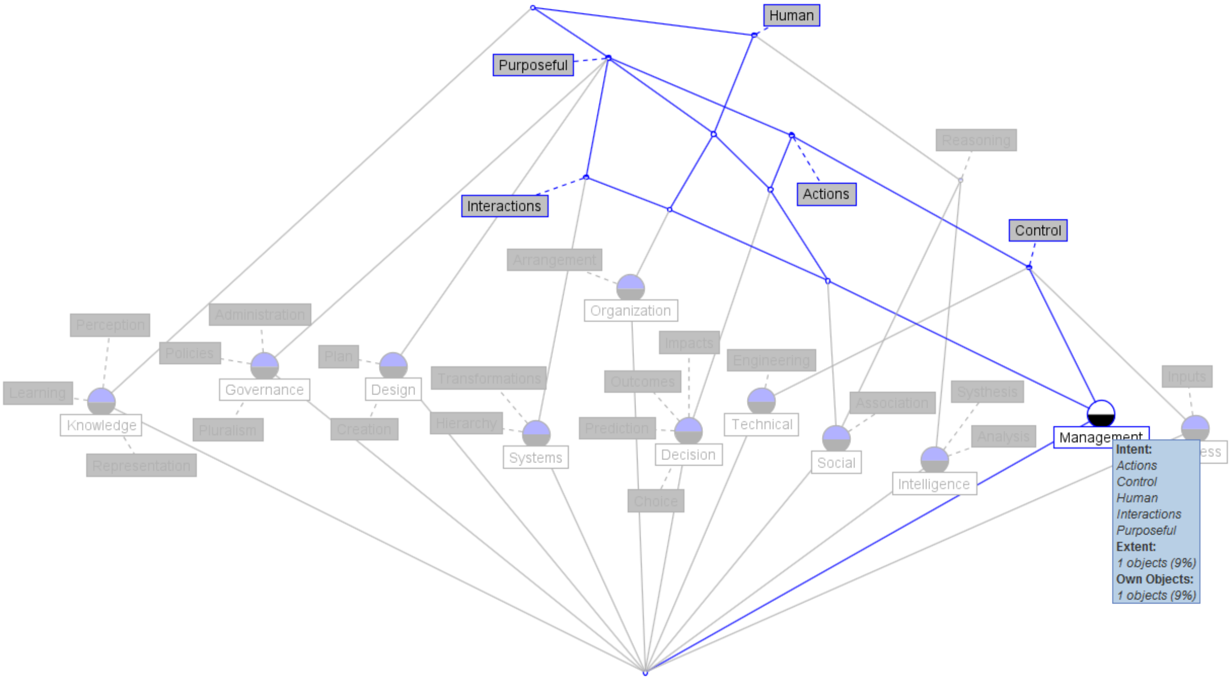
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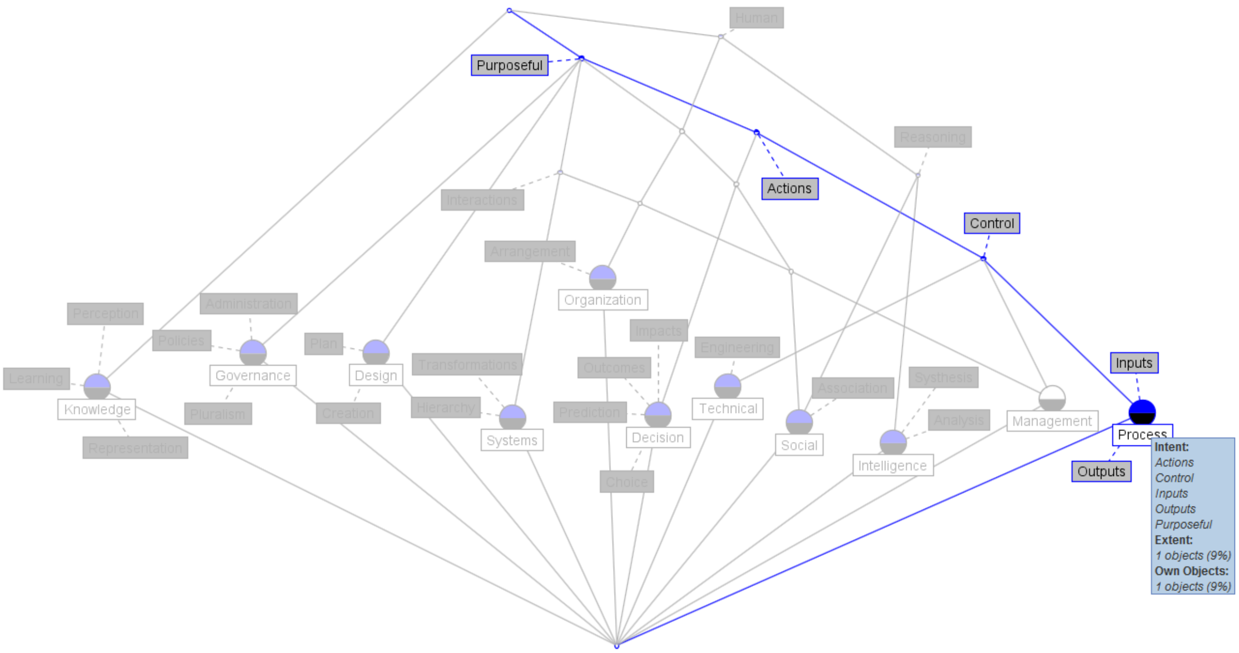
Figure 28: Lattice Path for Management.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1 objects (9%)
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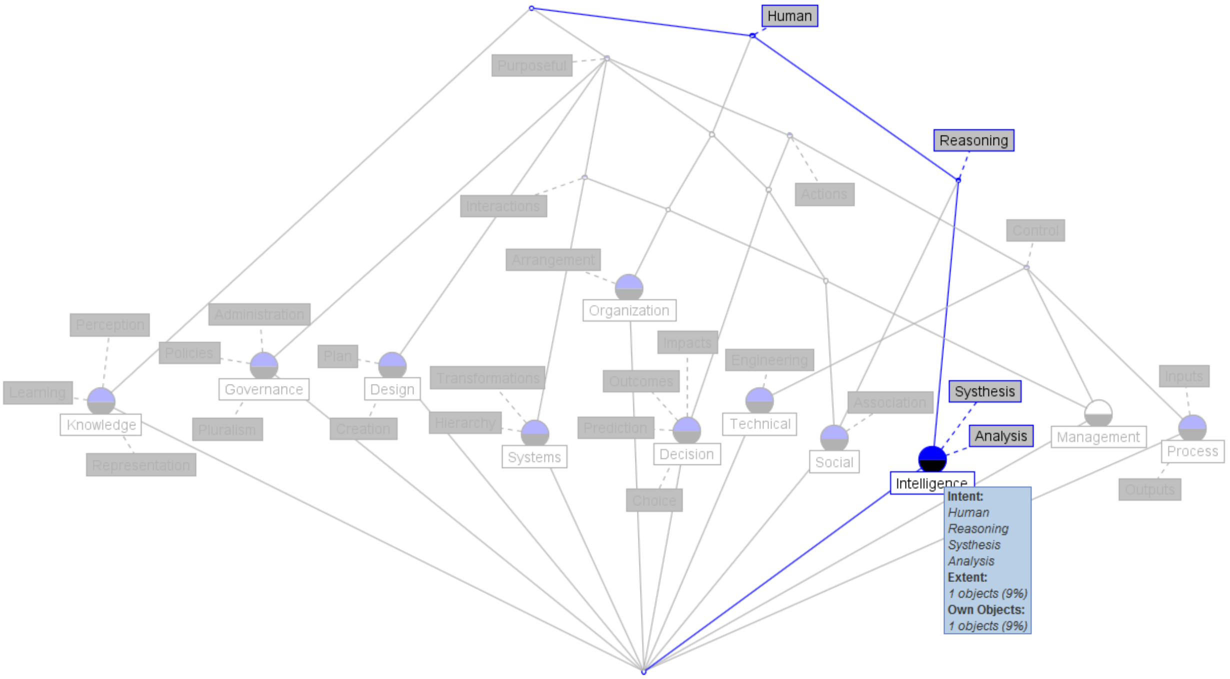
Figure 29: Lattice Path for Process.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1 objects (9%)
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Figure 30: Lattice Path for Intelligence.

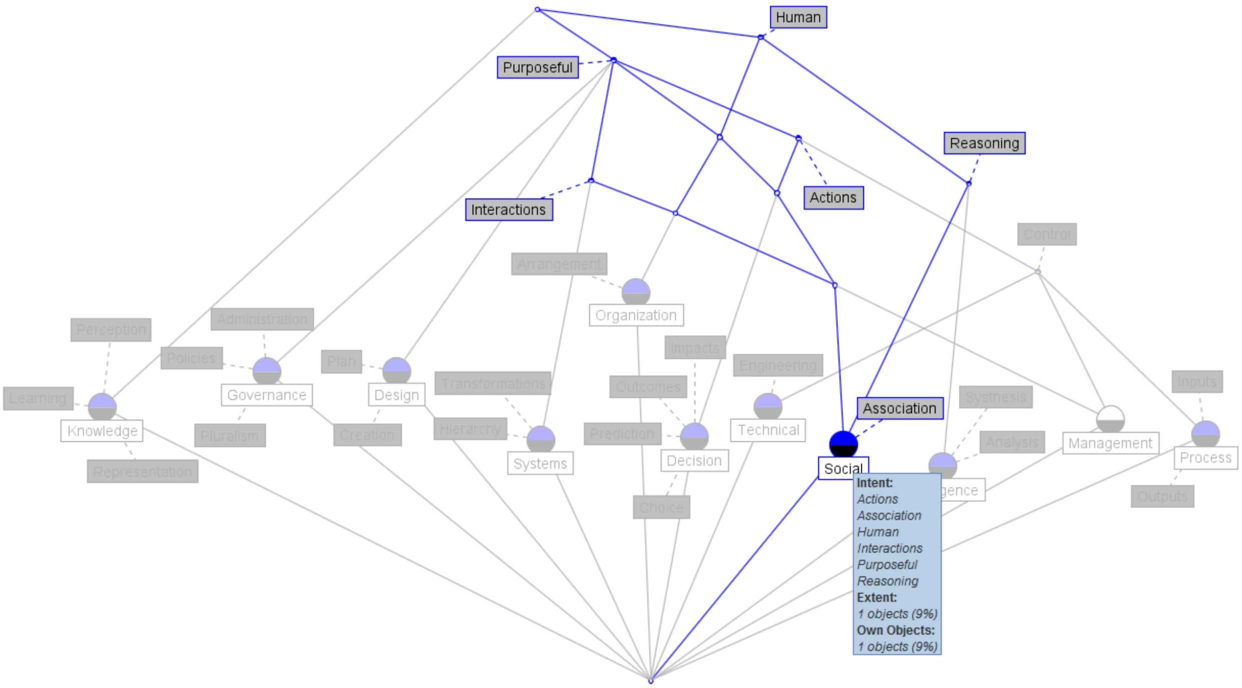
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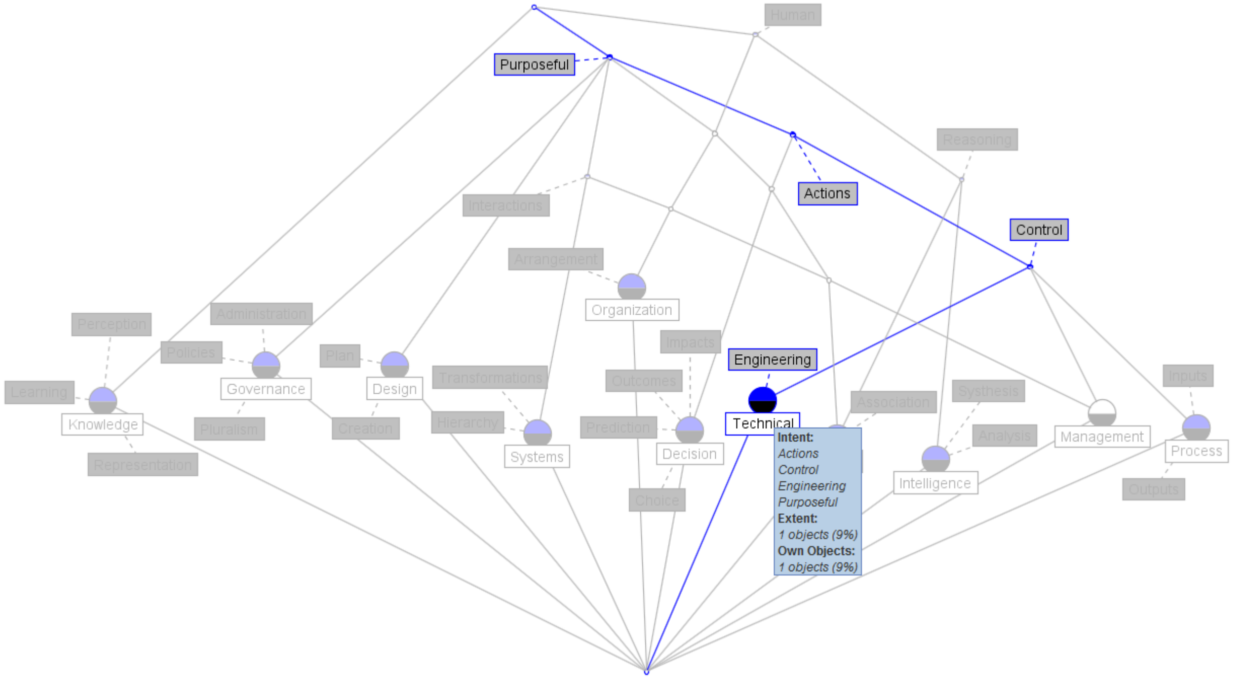
Figure 31: Lattice Path for Social.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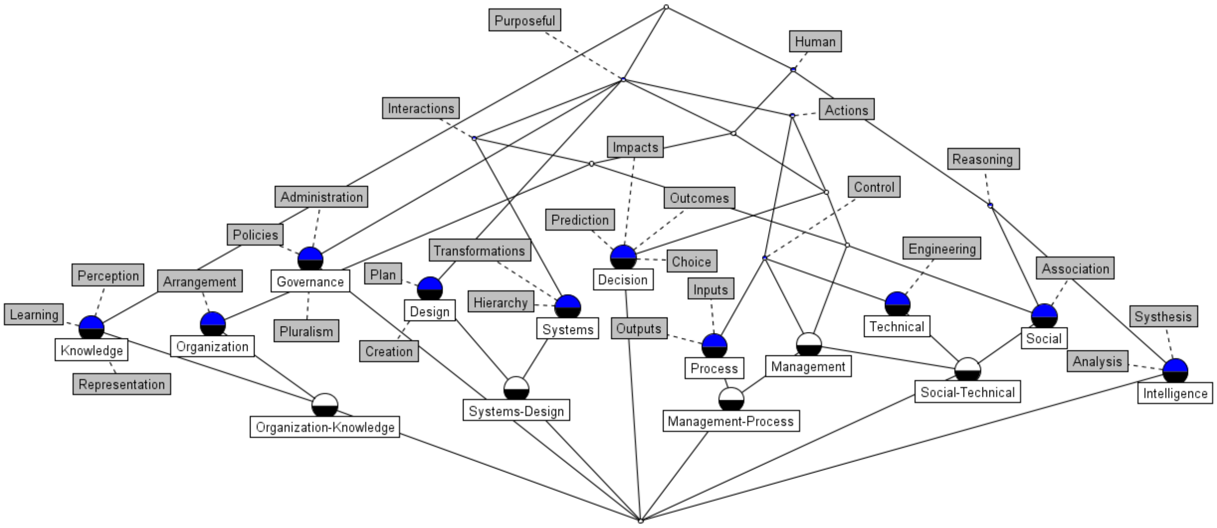
Extent:
1 objects (9%)
Own Objects:
1 objects (9%)

Figure 32: Lattice Path for Technical.

Now, the composite FCA lattices from Figures 33 through 37 demonstrate that the composite categories of Organizational-Knowledge, Management-Process, Systems-Design, and Social-Technical of Figure 17 are just the union of the primitive categories' respective attributes and attribute properties. Note in Figure 37 that joint Engineering Management is required for socio-technical systems, which is theoretically where the joint requirement should be. The composite taxonomy is proper, modular, complete, and closed thorough the union of primitives.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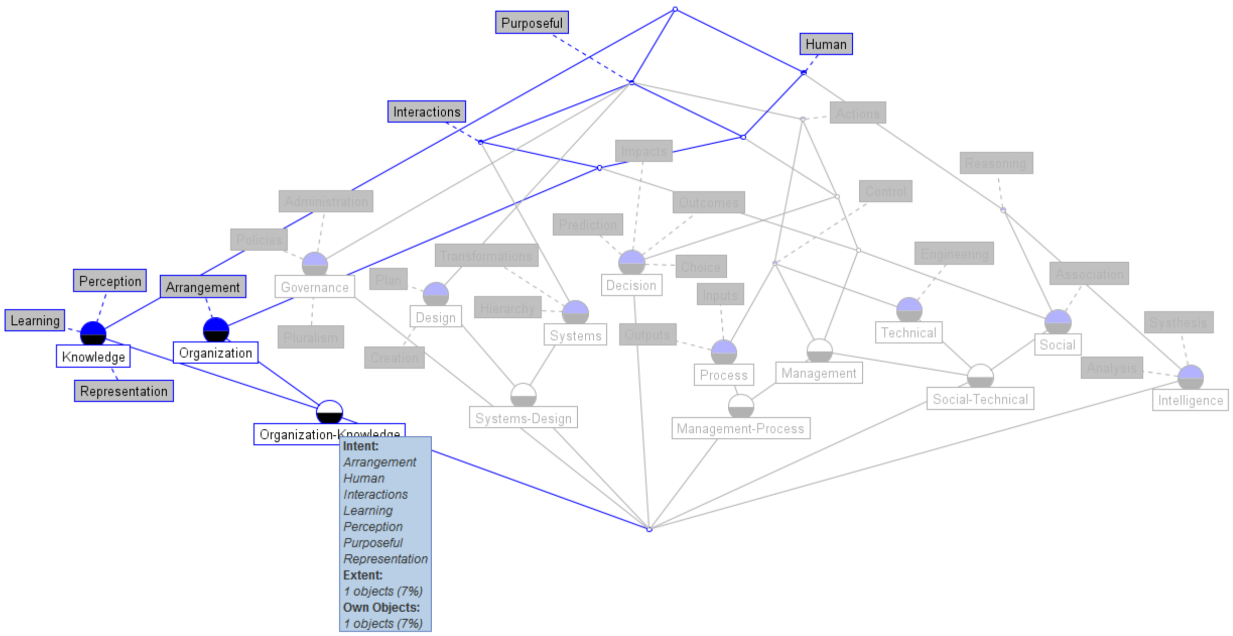
Organization-Knowledge
Management-Process

Figure 33: Composite Concept Lattice for Existential Attributes.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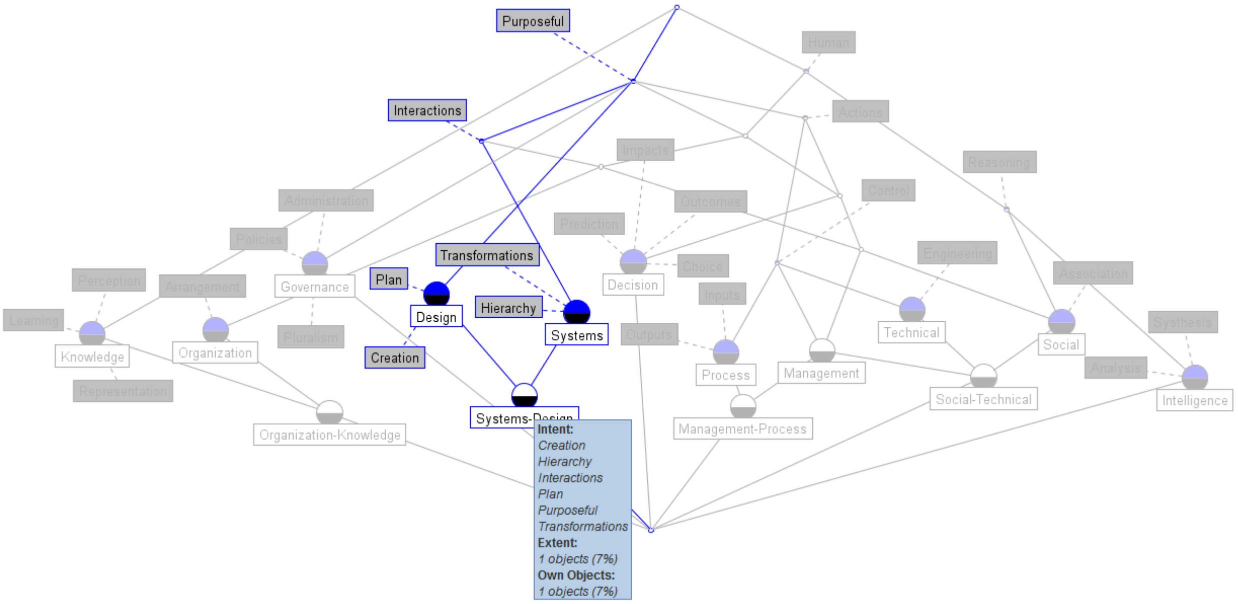
Extent:
1 objects (7%)
Own Objects:
1 objects (7%)

Figure 34: Composite Concept Lattice Path for Organization-Knowledge.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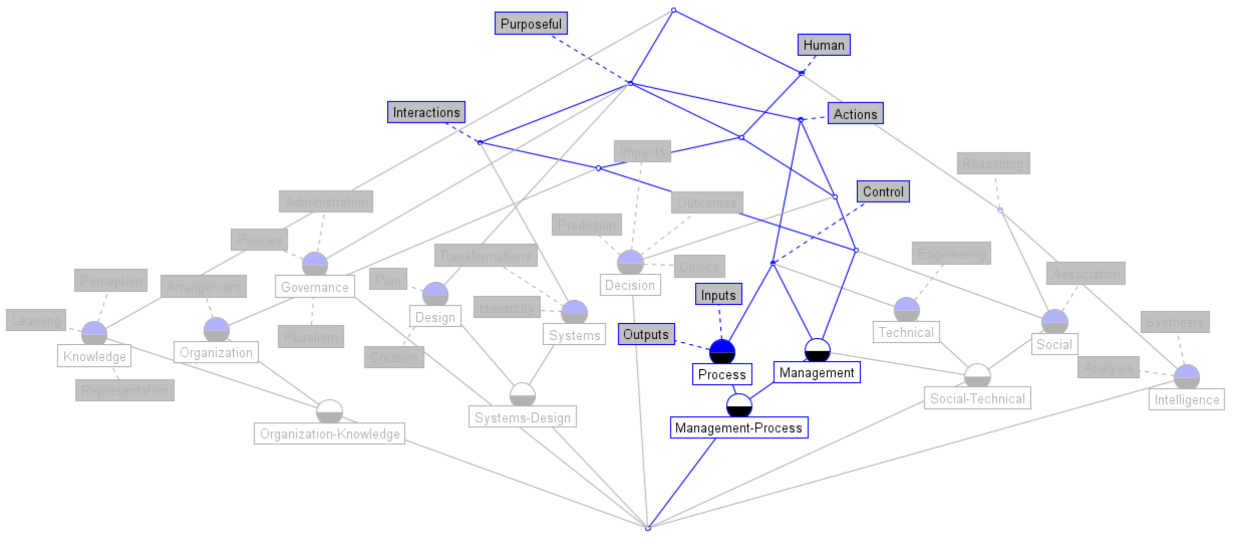
1 objects (7%)
Own Objects:
1 objects (7%)

Figure 35: Composite Concept Lattice Path for Systems-Design.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Pluralism
Knowledge
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Representation
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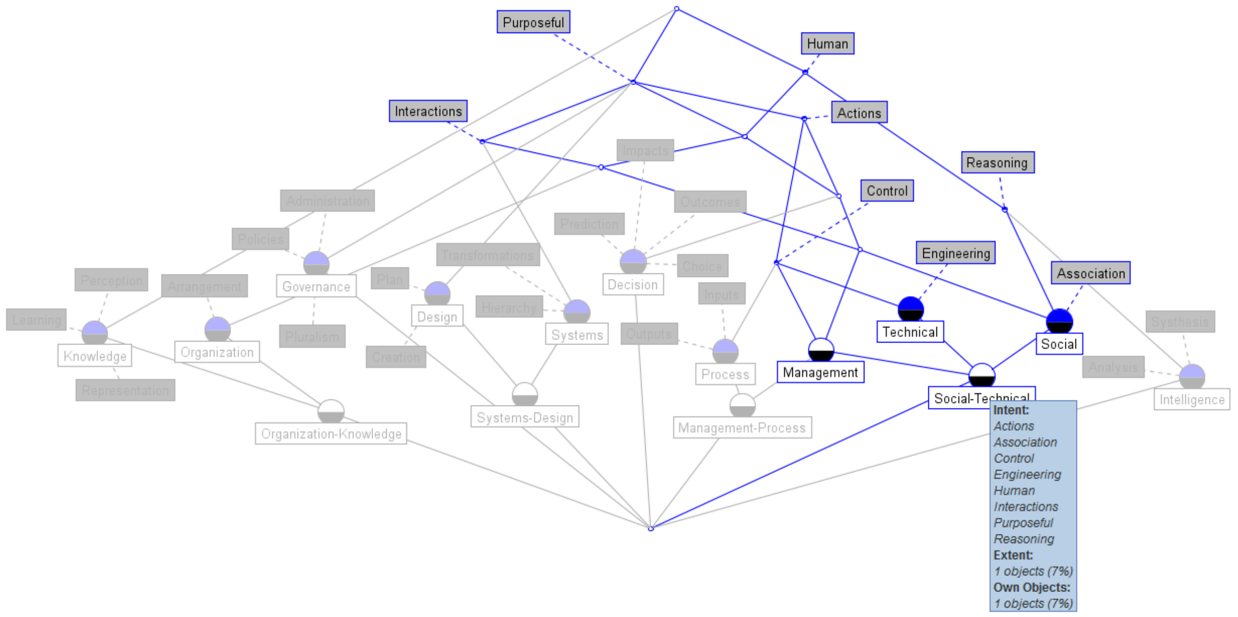
Systems-Design
Management-Process
Organization-Knowledge

Figure 36: Composite Concept Lattice Path for Management-Process.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Management-Process
Organization-Knowledge
Intent:
Actions
Association
Control
Engineering
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Extent:
1 objects (7%)
Own Objects:
1 objects (7%)

Figure 37: Composite Concept Lattice Path for Social-Technical.

In summary, the developed ontology is written in Web Ontology Language (OWL 2) which is a universal language in web semantics and thus meets semantic extendibility criteria. Also, with the IDEF5 ontology development specifications and as specified in the integrative approach (Chapter 3), this foundational ontology can be reused across all core-reference ontology and for subsequent ontological development. Therefore, semantic extendibility criteria is met in addition to modular extendibility. This foundational ontology avoids encoding bias and not written in symbol levels. OWL 2 and RDF language formally meet this criteria to overcome any encoding bias. The ontological commitment that is made is only for formal foundational ontology for HI-MI decision governance. This is delimited and solely focused on this area. Therefore, superfluous ontological commitments are not made with this research.

4.15 Formalism of Foundational Ontology

Foundational Taxonomic Terms (FTT):

Considering $\forall$ T: T is a “thing” that can be “physical” or “abstract” (i.e. physical-thing or abstract-thing). A physical-thing (PT) has presence in time and space whereas an abstract-thing (AT) does not have such presence.

Thus, FTT = ({Decision}, {Governance}, {Organization}, {Knowledge}, {Systems}, {Design}, {Management}, {Process}, {Intelligence}, {Social}, {Technical}).

$$PT \subseteq T$$

$$AT \subseteq T$$

$$FTT \subseteq T$$

Foundational Axiomatic Relationships (FAR):

Axiomatic Relationships Theorem:

Let a composite entity (thing) EE be a set $EE \setminus \{E_1 \cup E_2 \cup \ldots \cup E_j\}$ with a composite conceptualization mapping $\forall\ M(EE)) \rightarrow CC(\{C_1 \cup C_2 \cup \ldots \cup C_j\})$.

Then for $\exists\ EE \setminus \{E_i\ R(E_j)\}$ [X] $CC \setminus \{C_i\ R(C_j)\}$ there exists $EE \setminus \{E_i\{x_1, x_2, \ldots, xj\}R(E_j\{x_1, x_2, \ldots, xj\})\}$ [X] $CC \setminus \{C_i\{a_1, a_2, \ldots, a_j\}R(C_j\{a_1, a_2, \ldots, a_j\})\}$.

Disjoint Concepts Theorem:

Two concepts $\{C_i, C_j\}$ are disjoint if and only if the entity's corresponding $\{E_i(\{x_1, x_2, \ldots, x_j\}), E_j(\{x_k, x_l, \ldots, x_z\})\}$ attributes are disjoint; that is, there is no relationship mapping $E_i(\{x_1, x_2, \ldots, x_j\}) \neg \rightarrow E_j(\{x_k, x_l, \ldots, x_z\}$ between any attributes. Otherwise, there can only be a relationship between two concepts if and only if there is at least one relationship mapping between the entity's attributes $E_i(\{x_1, x_2, \ldots, x_j\}) \geq 1 \rightarrow E_j(\{x_k, x_l, \ldots, x_z\}$.

Physical Relationships Definition:

A concept relationship may take on one, and only one, type of physical form:

Causal: X causes Y (sufficiency) and Y is caused by X (necessity). The relationship between X and Y is supported by scientific laws or theory. X and Y can be measured with a high degree of accuracy.

Causal-Correlation: Only causal relationships exist between $X \leftrightarrow Y$, but the existence of the particular causal relationship has a conditional probability of X on an observable third parent variable Z, that is $Z \rightarrow X$, with given probability distribution. Specifically, $Y \leftarrow P(Xi|Zi)\ P(Zi)$ with Y independent Z.

Stochastic-Correlational: A BoK is not sufficiently mature to establish causal or causal-correlation relationships, but X and Y can be observed to be correlated due to an unknown causal relationship of $Z \rightarrow X$ and $Z \rightarrow Y$. Specifically, $P(Y) \sim \mathrm{Sum}(i)\ P(X|Zi)\ P(Zi) <= \mathrm{Cor}(Y, X)$.

Fuzzy-Correlational: A BoK is not sufficiently mature to establish at minimum stochastic-correlations between an observable Y and members in a fuzzy association X, because X cannot be observed or measured accurately. Rather X can be observed only through a fuzzy qualitative membership. Specifically, $P(Y) <= \mathrm{Cor}(Y, X = \{x \text{ fuzzy member } U(x) \mid u(x) = 1\})$.

Fuzzy-Associational: A BoK is not sufficiently mature to establish at minimum stochastic-correlations between an observable fuzzy Y and members in a fuzzy association X, because Y and X cannot be observed or measured accurately. Rather Y and X can be observed only through qualitative membership. Specifically, $P(Y) <= \mathrm{Cor}(Y = \{y \text{ fuzzy member } U(y) \mid u(y) = 1\}, X = \{x \text{ fuzzy member } U(x) \mid u(x) = 1\})$.

As already shown in Table 9 of the foundational taxonomic classes and their axiomatic relationships, further, a concept-concept correlation matrix can be shown based on the formerly identified association matrix in Table 7:

Table 14: Concept-Concept Correlation Matrix.

	Decis.	**Gover.**	**Organ.**	**Knowl.**	**Syste.**	**Desig.**	**Manag.**	**Proce.**	**Intel.**	**Socia.**	**Techn.**
Decis.	1	¬	W	W	¬	¬	W	W	¬	¬	¬
Gover.	¬	1	S	M	S	¬	S	W	¬	S	W
Organ.	W	S	1	S	M	S	S	S	¬	M	M
Knowl.	W	M	S	1	W	W	M	M	¬	W	W
Syste.	¬	S	M	W	1	S	S	M	¬	W	M
Desig.	¬	¬	S	W	S	1	M	M	¬	M	S
Manag.	W	S	S	M	S	M	1	S	¬	M	M
Proces.	W	W	S	M	M	M	S	1	¬	W	M
Intel.	¬	¬	¬	¬	¬	¬	¬	¬	1	¬	¬
Socia.	¬	S	M	W	W	M	M	W	¬	1	W
Techn.	¬	W	M	W	M	S	M	M	¬	W	1

Notions:

S = Strongly, M = Moderately, W = Weakly, and ¬ = Not

Table 14 can be treated as an extension of Table 7 to demonstrate concept-concept correlations. The taxonomic terms of the foundational ontology for HI-MI decision governance only show stochastic-correlational relationships. It is expected that subsumed core reference, domain, and application ontological development will reveal necessary refinements to subsumption and axiomatic relationships.

CHAPTER 5

DISCUSSION

5.1 Overview of the Foundational Ontology

A foundational ontology also refers to as a top or upper ontology and contains only the core terms/classes/categories for a domain of discourse. These terms are general in concept and abstract in nature (means not specific to any domain or application level). Foundational ontological terms can be reused to core-reference ontology. The scope of a foundational ontology is to specify the general or universal classifications or categories, the relationships among the terms, and axioms for a body of knowledge such that these concepts are reusable across core reference areas of the body of knowledge.

This research identified foundational taxonomic terms and their structure that specify a human-intelligence and machine-intelligence foundational ontology and how those terms are correlated with each other. The research question for this study was "*What foundational ontological structure and axioms are necessary to succinctly specify the HI-MI decision governance body of knowledge as assessed by the ontological design criteria of clarity, coherency, extendibility, minimal encoding bias, and minimal ontological commitment (Gruber, 1995)?* This question is answered with the provided supportive evidences and systematic rigorous analysis.

The foundational HI-MI decision governance ontological structure is shown in Figure 17 and 18. The taxonomic and axiomatic relationships are specified in Table 8 and 9. The ontology also meets Gruber's (1995) ontology design criteria as noted with the research question. This foundational ontology for HI-MI decision governance lays the foundation for subsequent development of core-reference, domain, and application level ontologies, and their associated bodies of knowledge.

5.2 Research Implications

The artificial intelligence community’s ambitious goal of completely modeling and replicating human cognition in computers is still in its infancy, regardless of progress in the invention of strongly sophisticated tools and technologies to roughly represent human cognition abilities in machines. With this singular objective, developed AI applications fundamentally treat humans as discontinuities to be avoided or as objects in human-centered smart service systems. There has been a lack of research into cognitively cooperative human-machine decision making systems. Further, in absence of an expert reference base or body of knowledge (BoK), integrated with an ontological framework, decision makers must rely on the best practices or standards that differ from organization to organization and government to government, contributing to systems failure in complex mission critical situations. It is still debatable whether and when human or machine decision capacity should govern or when a joint human-intelligence and machine-intelligence (HI-MI) decision capacity is required in any given decision situation.

To begin addressing these deficiencies, this research developed a formal, top level foundational ontology for HI-MI decision governance in parallel with a grounded theory based foundational body of knowledge which forms the theoretical foundation of a systemic HI-MI decision governance framework. Integrated HI-MI systemic decisions and actions are required to achieve a specified set of mission outcomes under evolving states of human-intelligence and machine-intelligence responses to dynamic environmental constraining forces. The foundational ontology developed in this research is substantial in that it spans the systemic HI-MI decision governance body of knowledge and provides the framework for subsequent systemic HI-MI decision governance core reference, domain, and application ontologies and knowledge representation. As the state of relevant artificial intelligence and human-machine interaction knowledge increases over the time, the systemic HI-MI decision governance ontology constructed out of this research must be refined to achieve reduced risk and uncertainty in systemic mission outcomes.

5.3 Research Limitations

Traditional ontology development methodology follows a life-cycle of– (i) pre-design and scoping, (ii) design, (iii) development, and (iv) maintenance. In its design and development, traditional ontology articulation relies on an existing knowledge base extracted from either interviewing experts or synthesizing meta-knowledge from the seminal works of the tangential domains by reviewing and integrating them into a literature corpus (Uschold and King, 1995; Gómez-Pérez, 1999). Since this research did not have HI-MI experts or an existing body of knowledge, it relied on synthesizing meta-knowledge from admitted peer reviewed works of identified tangential domains into a literature corpus. For this systemic HI-MI decision governance foundational ontology formulation, the existing collections of relevant knowledge were synthesized from the domains of the general systems, governance, decision theory, socio-technical systems, human-machine interaction, and artificial intelligence. Peer reviewed works outside of the identified tangential domains were not included in the systemic HI-MI decision governance ontology development. Further, restricted or classified governmental data is excluded from this study. Thus, the resultant systemic HI-MI decision governance foundational ontology may reflect only academic knowledge of identified tangential domains and not fully span governmental or military interface of humans and machines toward mission accomplishment.

An ontology and its associated knowledge base are dynamic entities in that they must change with the addition of new knowledge. Long term validation of an ontology requires ontology refinement which is triggered by updating the existing body of knowledge with the addition of new knowledge into the knowledge base. The systemic HI-MI decision governance foundational ontology developed in this research is only the first version of what is expected to be a sequence of version updates as new knowledge will be added from supporting core reference, domain, and application specific ontologies and their associated bodies of knowledge.

Another point of assessment is that, this research did not seek to answer questions in governance that relates or considers “fairness”, “justification”, or “ethical obligation”. Therefore, whether it is Jeremy Bentham’s (1843) “Utilitarianism” for “greater goodness or happiness” or Immanuel Kant’s (2004) “Categorical Imperative” for “moral obligation” and thus to relate decision governance with “morality” or “justice” is beyond the scope of this research. The ethical obligation or “justice” in philosophical domain also raised this question with much debate– “*What is the right thing to do?”* Or especially for this research– “*Should decision governance include the ethical or moral perspective?”* These questions are also out of scope of the current research. However, questions like these certainly set off interesting future research ideas and topics in the field of artificial intelligence or research relevant to decision making governance.

CHAPTER 6

CONCLUSIONS

6.1 Primary Contributions of this Study

Primary contribution of this study can be summarized as below:

Theoretical: This research produced a grounded theory based foundational body of knowledge for systemic HI-MI decision governance. This foundational body of knowledge is comprised of peer-reviewed journals, articles, synthesized book chapters, and books. Further, this research produced a systemic HI-MI decision governance formal foundational ontology that meets Gruber's (1995) ontology design criteria and is extendible to the W3C by Web Ontology Language (OWL). This extendibility fulfills ontology design criteria.

Methodological: A unique methodology has been introduced by this research which is based on abductive-deductive logical inferences for ground theory based BoK development with the inductive-deductive interpretations of necessary conditions for ontology design. This methodology employed cross-validation and resolution of the foundational ontology against its foundational body of knowledge.

6.2 Widening the Scope

The scope of this research includes:

1. A foundational formal ontology for HI-MI decision governance within a systems context.
2. A grounded theory based foundational body of knowledge (BoK) for human-intelligence (HI) and machine-intelligence (MI) decision governance.

These scopes can be widened by taking the outcomes of this research and extend that to build supporting core-reference, domain, and application ontologies. Having a completed structure of HI-MI decision governance full ontology, i.e. spanning from foundational to application level ontology, we can make systematic and reliable human-machine decisions across mission critical situations.

6.3 Suggestions for Future Research

A foundational ontology lays the foundation for subsequent ontological development such as core-reference, domain, and application ontologies. The classes/categories/terms and axioms identified for foundational ontology by this research can be re-used to build core-reference ontologies. Additionally, the knowledge base created with this research for systemic HI-MI decision governance gives a reference base for other relevant studies. The major suggestions for future research are:

1. Continue building the core-reference, then domain, and then application level ontologies for systemic HI-MI decision governance.
2. The ontology built here is the W3C extendible (with OWL). Integrating this with SUMO top ontology for the purpose of knowledge sharing and re-use will be highly beneficial.
3. Updating and extending the knowledge base when new knowledge will emerge.
4. Updating the developed foundational ontology with the updates of existing knowledge base. Ontology maintenance is a major part of ontological life-cycle.

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APPENDIX

A. CONCEPT DICTIONARY

Table 15: Concept Dictionary.

Corpus Title	**Author(s)**	**Publication Year**	**Publication Source**	**Keywords**	**Primary Research Question(s)**	**Secondary Research Question(s)**	**Open Categorical Coding Theme**	**Axial Relationship Theme**
Corporate Governance and Intellectual Capital: Some Conceptualizations	James Keenan and Maria Aggestam	2001	Blackwell Publishers Ltd	Corporate governance and intellectual capital.	What is corporate governance and intellectual capital paradigm?	How can the members, processes, and structures of corporate governance be aligned with paradigms concerning intellectual capital?	Knowledge Governance	Relationship of intellectual capital governance to financial and physical capitals.
Exploring Knowledge Governance	Nicolai J. Foss and Joseph T. Mahoney	2010	International Journal of Strategic Change Management	Governance, knowledge management, and theories of the firm.	How to characterize the knowledge governance field?	What are the key knowledge governance issues?	Knowledge Governance	Knowledge governance is an important part of strategic management and international business.
Knowledge Governance, Innovation and Development	Leonardo Burlamaqui	2010	Revista de Economia Política	Globalization, governance, competition, intellectual property, and antitrust.	Why we need better understanding of the interaction among innovation, competition and intellectual property policies from an evolutionary-developmental	Where do knowledge and innovations come from in the developed nations?	Knowledge Governance	Knowledge governance approach and a public policy/public interest perspective.

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					perspective?			
The Emerging Knowledge Governance Approach: Challenges and Characteristics	Nicolai J. Foss	2007	SAGE	Governance, knowledge management, and organizational economics.	Why to characterize knowledge governance emerging approach?	What is the knowledge governance approach trying to accomplish?	Knowledge Governance	Knowledge and business administration.
Knowledge Governance: Processes and Perspectives	Nicolai J. Foss and Snejina Michailova	2009	Oxford University Press	Knowledge, governance, processes, and management.	Which knowledge processes are influenced by governance mechanisms?	Is whether knowledge governance primarily aims at optimizing the cost of the processes of managing knowledge or whether there is more to it?	Knowledge Governance	The role of organization in the creation of knowledge-based competitive advantage.
Knowledge Governance: An Exploration of Principles, Impact, and Barriers	Alwin L. Gerritsen, Marian Stuiver, and Catrien J. A. M. Termeer	2013	Oxford University Press	Innovation, learning, green growth, agenda setting, and complexity	- What are the main principles underlying knowledge governance? - What is its impact on the realization of societal objectives?	What barriers to its functioning can be revealed?	Knowledge Governance	Knowledge governance involves knowledge production engaging in the collaborative production by individuals and organizations.
Knowledge Governance	Chong Ju Choi, Philip Cheng, Brian Hilton, and Edwar	2005	Journal of Knowledge Management	Knowledge transfer, governance, and exchange.	How to broaden the scope of existing knowledge management research through a greater	What the role of different governance structures on knowledge transfers and flows?	Knowledge Governance	Knowledge management benefits more from incorporating more of the research methodolo

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
	d Russell				integration with social science methodologies, especially social anthropology.			gies of social anthropology.
A Conceptualization of Knowledge Governance in Project-Based Organizations	Sofia Pemsel, Anna Wiewiora, Ralf Müller, Monique Aubry, and Kerry Brown	2014	International Journal of Project Management	Knowledge governance, project-based organizations, knowledge governance definition, and conceptualization.	How can knowledge governance be conceptualized in project-based organizations?	How is knowledge governance defined in relation to project-based organizations?	Knowledge Governance	Knowledge and learning processes are vital for survival and improved business performance.
Neither Hierarchy nor Identity: Knowledge-Governance Mechanisms and the Theory of the Firm	Anna Grandori	2001	Journal of Management and Governance	Knowledge, governance, firm, and theory.	Why should a hierarchical arrangement be superior for governing the simultaneous occurrence of assets' specificity and uncertainty?	Is knowledge-governance any different out of the aegis of firm governance?	Knowledge Governance	Knowledge-based theory of the firm.
Exploring the Complex Interaction between Governance and Knowledge in Education	Mihály Fazekas and Tracey Burns	2012	OECD Publishing	Governance, knowledge, systems, and model.	How do governance and knowledge mutually constitute and impact on each other in complex	How best to bridge the various literatures and possible next steps for knowledge and governance?	Knowledge Governance	Knowledge is crucial for governance and governance is indispensable for knowledge creation

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
					education systems?			and dissemination.
Thinking Clearly about Multistakeholder Internet Governance	Laura DeNardis and Mark Raymond	2013	Eighth Annual GigaNet Symposium	Internet governance and interoperability	What types of administration are optimal for promoting a balance of interoperability, innovation, free expression and operational stability in any particular functional and political context?	What are the potential for gains from the study of multi-stakeholder governance?	Internet governance	Internet governance should take multi-stakeholder.
Zero-Rating in Emerging Economies	Helani Galpaya	2017	Centre for International Governance Innovation and Chatham House	Economy, data, Internet, and regulation.	Do zero-rating violates net neutrality rules?	What are the arguments for and against zero-rating?	Internet Governance	Options-theory approach to regulation and policy making.
Critical Infrastructure and the Internet of Things	Tobby Simon	2017	Centre for International Governance Innovation and Chatham House	Infrastructure, Internet of Things, risks, and governance.	What are the emerging risks to critical infrastructure with the rise of the Internet of Things (IoT)?	What are the cyber threats to business and governments in the face of an expanding IoT?	Internet Governance	The integration of the IoT with critical infrastructure means new growth opportunities for organizations and

Corpus Title	**Author(s)**	**Publication Year**	**Publication Source**	**Keywords**	**Primary Research Question(s)**	**Secondary Research Question(s)**	**Open Categorical Coding Theme**	**Axial Relationship Theme**
								governments.
Corporate Accountability for a Free and Open Internet	Rebecca MacKinnon, Nathalie Maréchal, and Priya Kumar	2016	Centre for International Governance Innovation and Chatham House	Accountability, open Internet, technology, and systems.	What is the evolving role of corporations in international governance and accountability systems beyond the information communications technology?	How public benchmarking of companies, in concert with other initiatives and mechanisms, might foster greater corporate accountability for a free and open Internet?	Internet Governance	Internet and related technologies hold governments and other institutions accountable.
Internet Intermediaries as Platforms for Expression and Innovation	Anupam Chander	2016	Centre for International Governance Innovation and Chatham House	Internet intermediaries, governance, liability, and online.	How to encourage Internet intermediaries to help people find what they are looking for, share with each other what they want to share?	Why to educate people in ways that are consistent with both local and international law?	Internet Governance	Internet intermediaries fosters freedom online.
Increasing Internet Connectivity While Combatting Cybercrime: Ghana as a Case Study	Caroline Baylon and Albert Antwi-Boasiako	2016	Centre for International Governance Innovation and Chatham House	Economic development, Internet connectivity, and Internet infrastructure.	How to promote the growth of Internet infrastructure in the region, looking at the current state of Internet connectivity in Ghana?	- What is the link between increased Internet connectivity and a growth in cybercrime? - How to combat cybercrime?	Internet Governance	Policy making and strategy for tackling cybercrimes.
Unlocking Affordable Access in	Steve Song	2016	Centre for International	Strategies, regulation, development, and	Why we need to lower the barriers to	Do existing mobile network economic	Internet Governance	Policy making and shifting for better

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
Sub-Saharan Africa			Governance Innovation and Chatham House	affordability.	access innovation?	models is affordable to access in Sub-Saharan Africa?		development.
Multi-Stakeholderism: Anatomy of an Inchoate Global Institution	Mark Raymond and Laura DeNardis	2016	Centre for International Governance Innovation and Chatham House	Governance, multi-stakeholderism, and enterprise.	What is multi-stakeholderism to Internet Governance?	Are all Internet governance tasks and functions accomplished via multi-stakeholder modalities?	Internet Governance	Multi stakeholderism engages in a governance enterprise concerning public issues.
Standards, Patents and National Competitiveness	Michael Murphree and Dan Breznitz	2016	Centre for International Governance Innovation and Chatham House	Standards, intellectual property, patents, and Internet.	What is the impact of standards-essential patents (SEPs)?	How firms are able to shape the terms of competition through their control of standards-essential IP?	Internet Governance	Product standardization clears prospective buyer or user what they are acquiring, as well as its capabilities.
Ethics in the Internet Environment	Rolf H. Weber	2016	Centre for International Governance Innovation and Chatham House	Internet, governance, ethics, and accountability.	What is the importance of ethics in the Internet governance?	Why there is a lack of appropriate accountability for ethical standards in Internet governance?	Internet Governance	Ethical standards require to protect users' privacy.
One Internet: An Evidentiary Basis for Policy Making on Internet	Laura DeNardis	2016	Centre for International Governance Innova	Internet, policy making, universality, and fragmentation.	Whether cyberspace will continue to expand into a single, universal	How this choice resolves in the contemporary context will have	Internet Governance	Systems of Internet infrastructure and governance are recognized

Corpus Title	**Author(s)**	**Publication Year**	**Publication Source**	**Keywords**	**Primary Research Question(s)**	**Secondary Research Question(s)**	**Open Categorical Coding Theme**	**Axial Relationship Theme**
Universality and Fragmentation			tion and Chatham House		network, or fragment into disjointed segments based on geographical borders or proprietary ecosystems?	considerable implications for the future of global economic development, national security and counterterrorism, and for the nature of free expression and access to knowledge online?		as critical points of control for achieving market advantage or carrying out geopolitical or global economic objectives.
When Are Two Networks Better than One? Toward a Theory of Optimal Fragmentation	Christopher S. Yoo	2016	Centre for International Governance Innovation and Chatham House	Internet, fragmentation, legal principles, and governance.	What is the fragmentation in the Internet's physical architecture, address space and protocols, and in the legal principles governing the Internet?	Whether and when fragmentation is good or bad?	Internet Governance	Fragmentation and legal principles governing the Internet.
How to Connect the Other Half: Evidence and Policy Insights from Household Surveys in Latin America	Hernán Galperin	2016	Centre for International Governance Innovation and Chatham House	Policy, Internet, users, regulation, and connectivity.	How to connect the next billion Internet users?	How socio demographic characteristics affect Internet adoption?	Internet Governance	Policy towards infrastructure re-deployment initiatives and regulatory reforms will connect the unconnected.
Internet Openness and Fragmentation: Toward	Sarah Box	2016	Centre for International Gover	Internet, openness, fragmentation, economy,	How do we measure Internet openness, or, indeed,	When the concept of Internet openness itself is so	Internet Governance	Global data flows enabled by Internet openness.

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
Measuring the Economic Effects			nance Innovation and Chatham House	and data flows.	measure Internet fragmentation?	broad, encompassing technical, economic, political and societal aspects?		
A Framework for Understanding Internet Openness	Jeremy West	2016	Centre for International Governance Innovation and Chatham House	Internet, openness, framework, and economics.	How changes in openness affect economies and societies and how various stakeholder actions and inactions affect openness?	What do we understand by the open internet versus Internet openness?	Internet Governance	Large and diverse set of circumstances and stakeholder actions influence Internet openness.
Market-driven Challenges to Open Internet Standards	Patrik Fältström	2016	Centre for International Governance Innovation and Chatham House	Open Internet standards, and interoperability.	What are the basic Internet principles that have enabled innovation and interoperability?	How market economy forces have shaped the evolution of Internet standards, including a resurgence of proprietary and anti-competitive approaches?	Internet Governance	Public procurement to encourage openness.
Governance of International Trade and the Internet: Existing and Evolving Regulatory Systems	Harsha Vardhana Singh, Ahmed Abdel-Latif and L. Lee Tuthill	2016	Centre for International Governance Innovation and Chatham House	Governance, trade, Internet, systems, and regulation.	What are the new trade-related concerns that need to be addressed, including the difficulty of determining jurisdiction	Why we need effective participation by the private sector in developing appropriate regulatory regimes?	Internet Governance	Overlap between Internet and trade governance.

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					and rules of origin?			
Tracing the Economic Impact of Regulations on the Free Flow of Data and Data Localization	Matthias Bauer, Martina F. Ferracane, and Erik van der Marel	2016	Centre for International Governance Innovation and Chatham House	Economy, regulations, data, localization, and Internet.	How the economic costs of data localization and associated regulations on the free flow of data affect downstream economies in a group of emerging economies and the European Union?	What is the recent developments in policies regarding data localization and associated data regulations?	Internet Governance	The regulation in data services and domestic downstream economic performance.
Looking Back on the First Round of New gTLD Applications: Implications for Trademarks and Freedom of Expression	Jacqueline D. Lipton	2016	Centre for International Governance Innovation and Chatham House	Internet, domain, freedom of expression, trademark, and governance.	Whether the advantages of the new gTLD system outweigh its costs in the new domain spaces, given the significant resources expended by applicants and opposers in the context of the application process?	Why to balancing interests in trademarks against interests in free expression?	Internet Governance	Balancing commercial interests and freedom of expression in the domain space.
Patents and Internet Standards	Jorge L. Contreras	2016	Centre for International Gover	Patents, law, policy, and	Why the patenting and litigation trends	What is relevance of patents to the web?	Internet Governance	New developments will require new standards

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			nance Innovation and Chatham House	interoperability.	observed among network technologies not affected the Internet?			and common protocols.
Jurisdiction on the Internet: From Legal Arms Race to Transnational Cooperation	Bertrand de La Chapelle and Paul Fehlinger	2016	Centre for International Governance Innovation and Chatham House	Internet, jurisdiction, law, and policy.	Why jurisdiction issues represent a growing concern for all stakeholders, who are under pressure to find rapid solutions as the uses and misuses of the Internet Increase?	- Why to fill the institutional gap in Internet governance? - How to move toward transnational cooperation Frameworks?	Internet Governance	Operational governance frameworks guarantee procedural interoperability and due process?
Education 3.0 and Internet Governance: A New Global Alliance for Children and Young People’s Sustainable Digital Development	Divina Frau-Meigs and Lee Hibbard	2016	Centre for International Governance Innovation and Chatham House	Digital transition, education, Internet governance, policy, and information.	What are the gaps and opportunities for schools by making media and information literacy (MIL) combined with Internet governance principles and processes?	What are the evolving ecosystem of state and non-state actors beyond the education system?	Internet Governance	Future of education and its digital transition for Internet governance.
A Pragmatic Approach to the Right to Be Forgotten	Kieron O’Hara, Nigel Shadbolt and Wendy Hall	2016	Centre for International Governance Innovation	Law, Internet, data, web, privacy, and policy.	What is the nature of the balance between free speech and privacy on the Internet?	What is the moral and political issues, and raises technical and	Internet Governance	Data protection and technological contribution to a relatively

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			and Chatham House			institutional problems?		controversial process.
The Digital Trade Imbalance and Its Implications for Internet Governance	Susan Ariel Aaronson	2016	Centre for International Governance Innovation and Chatham House	Digital trade, Internet, governance, and policy.	How governments use trade agreements and policies to address cross-border Internet issues and to limit digital protectionism?	What is “protectionist” and what comprises a legitimate national policy?	Internet Governance	Policy makers should encourage interoperability.
The Privatization of Human Rights: Illusions of Consent, Automation and Neutrality	Emily Taylor	2016	Centre for International Governance Innovation and Chatham House	Privatization, human rights, automation, and neutrality.	What is the intersection of human rights with online life?	Why there is a need for the cooperation of all stakeholders in arriving at realistic and robust processes for Internet governance?	Internet Governance	Processes need to be more transparent; the decision makers and their freedom from conflicts of interest need to be clearly identified.
Combatting Cyber Threats: CSIRTs and Fostering International Cooperation on Cybersecurity	Samantha Bradshaw	2015	Centre for International Governance Innovation and Chatham House	Cyber-attacks, Internet, governance, information, and regulation.	What is the role of CSIRTs in the emerging cyber regime complex?	What might be driving the lack of trust and information sharing within the community?	Internet Governance	International cooperation and coordination is necessary to fight cyber-attacks.
One in Three: Internet Governance and	Sonia Livingstone, John Carr,	2015	Centre for International Gover	Internet, governance, children,	Why Internet governance bodies should be	What are the issues of child protection in the online	Internet Governance	Internet governance and children’s rights.

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Children's Rights	and Jasmina Byrne		nance Innovation and Chatham House	policy, and rights.	given consideration to children’s rights?	space, policy and governance?		
The Dark Web Dilemma: Tor, Anonymity and Online Policing	Eric Jardine	2015	Centre for International Governance Innovation and Chatham House	TOR, dark web, policy, online, and regulation.	Is shuttering anonymity networks a viable solution?	What is to be done in term of policing?	Internet Governance	The networks of the Dark Web need to be more actively policed.
The TOR Dark Net	Gareth Owen and Nick Savage	2015	Centre for International Governance Innovation and Chatham House	TOR, Internet, privacy, and contents.	What is the type and popularity of the Onion Router (Tor) content?	Is it good or bad to have TOR Net legality?	Internet Governance	The issues and contents in the Dark Net.
The Strengths and Weaknesses of the Brazilian Internet Bill of Rights: Examining a Human Rights Framework for the Internet	Carolina Rossini, Francisco Brito Cruz, and Danilo Doneda	2015	Centre for International Governance Innovation and Chatham House	Internet, bill of rights, human rights, and framework.	What is the Marco Civil da Internet (MCI) as a human rights framework for the Internet?	- Why the MCI cannot be seen in isolation? - What are the strengths and weaknesses of MCI?	Internet Governance	Human rights framework for the Internet.
Landmark EU and US Net Neutrality Decisions: How Might	Ben Scott, Stefan Heumann, and Jan-	2015	Centre for International Governance	Net neutrality, decisions, Internet, and policy.	How might pending decisions impact internet	What the Internet looks like with and without net neutrality	Internet Governance	The greater the difference between the implementa

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Pending Decisions Impact Internet Fragmentation?	Peter Kleinhans		Innovation and Chatham House		fragmentation?			tion of the net neutrality rules, the more likely the markets will develop in significantly different ways.
The Emergence of Contention in Global Internet Governance	Samantha Bradshaw, Laura DeNardis, Fen Osler Hampson, Eric Jardine, and Mark Raymond	2015	Centre for International Governance Innovation and Chatham House	Emergence of contention, governance, Internet, and regime.	What does the emerging contention in Internet governance look like?	-Why has contention in the Internet governance regime increased? - Why there has been a shift in the underlying problem structure of the Internet governance regime.	Internet Governance	The emergence of contention of Internet influences global governance.
Net Neutrality: Reflections on the Current Debate	Pablo Bello and Juan Jung	2015	Centre for International Governance Innovation and Chatham House	Net neutrality, Internet, regulations, and policy.	What is the need to preserve the Internet as a space that is open to innovation, and the freedom of users to access content and services?	Why the regulatory principles should be balanced between the different actors of the value chain?	Internet Governance	Technological and commercial innovation on the Internet is essential to maximize consumer welfare.
Solving the International Internet Policy Coordination Problem	Nick Ashton-Hart	2015	Centre for International Governance Innovation and	Internet, policy, problems, and solutions.	How serious is the problem of digital policy development dispersion?	Why have we not seen a holistic response to the problem?	Internet Governance	International policy-making process to deliver better policy results.

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			Chatham House					
Connected Choices: How the Internet is Challenging Sovereign Decisions	Melissa E. Hathaway	2015	Centre for International Governance Innovation and Chatham House	Choice, Internet, decisions, and sovereignty.	How the Internet is challenging sovereign decisions?	What is the current debate concerning the control and governance of the Internet?	Internet Governance	Control and governance of the Internet.
A Primer on Globally Harmonizing Internet Jurisdiction and Regulations	Michael Chertoff and Paul Rosenzweig	2015	Centre for International Governance Innovation and Chatham House	Internet, jurisdiction, regulations, and governance.	What are the jurisdiction problems for internet regulations?	What is needed is to harmonize existing rules within an agreed-upon framework of law?	Internet Governance	Multilateral agreement on a choice-of-law framework is essential to the continuing growth of the network.
ICANN: Bridging the Trust Gap	Emily Taylor	2015	Centre for International Governance Innovation and Chatham House	ICANN, IANA, accountability, multi-stakeholder, and governance.	How the technical architecture of critical Internet resources has certain governance implications?	How the IANA transition was recognized to be dependent on ICANN's wider accountability?	Internet Governance	Multi-stakeholder membership in ICANN to bridge the trust gap.
Understanding Digital Intelligence and the Norms That Might Govern It	David Omand	2015	Centre for International Governance Innovation and Chatham House	Digital intelligence, Internet, governance, law, and policy.	What is the nature of digital intelligence?	Why we need international norms for the safe practice of digital intelligence?	Internet Governance	Intelligence activity and model of security activity on the Internet.

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On the Nature of the Internet	Leslie Daigle	2015	Centre for International Governance Innovation and Chatham House	Internet, invariants, and policy.	How can one distinguish between helpful and healthy adjustments to the Internet and actions that will undermine the nature of the Internet?	How can one engage in meaningful dialogue across stakeholders, including those more versed in how the Internet works and those who understand the needs of the world's communities?	Internet Governance	Technology drives the Internet.
The Impact of the Dark Web on Internet Governance and Cyber Security	Michael Chertoff and Tobby Simon	2015	Centre for International Governance Innovation and Chatham House	Dark Web, Internet, cyber security, and governance.	What is the impact of the dark web on Internet governance and cyber security?	Why do we need the governance of the "deep Web" and the "dark Web"?	Internet Governance	Strategies and policies need for governing the Internet and safeguard cyberspace.
Innovations in Global Governance: Toward a Distributed Internet Governance Ecosystem	Stefaan G. Verhulst, Beth S. Noveck, Jillian Raines, and Antony Declercq	2014	Centre for International Governance Innovation and Chatham House	Governance, Internet, system, and multi-stakeholder.	- What is open governance and how does it inform distributed internet governance? - What are the key functions of distributed internet governance?	- How does distributed internet governance build on the internet's architecture? - How is distributed governance different from multi-stakeholder governance?	Internet Governance	Experiments in distributed governance approaches to learn what works and what does not.

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Legal Interoperability as a Tool for Combatting Fragmentation	Rolf H. Weber	2014	Centre for International Governance Innovation and Chatham House	Interoperability, models, legal rules, and governance.	What is legal Interoperability?	What the different regulatory models available in order to make legal rules interoperable	Internet Governance	Interoperability for technologies and social exchange.
Legal Mechanisms for Governing the Transition of Key Domain Name Functions to the Global Multi-stakeholder Community	Aaron Shull, Paul Twomey and Christopher S. Yoo	2014	Centre for International Governance Innovation and Chatham House	Governance, ICANN, multi-stakeholder, and Internet.	If ICANN, the current IANA functions operator, is no longer accountable to the US government, then who should it be accountable to?	What form should that accountability take?	Internet Governance	Multi-stakeholder to Internet governance.
Tipping the Scale: An Analysis of Global Swing States in the Internet Governance Debate	Tim Maurer and Robert Morgus	2014	Centre for International Governance Innovation and Chatham House	Internet governance, swing states, and policy.	What is the conceptualization of swing states in Internet governance?	How the behavior of swing states can help to understand the systemic shift in international relations?	Internet Governance	Aspects of international relations with Internet governance.
The Regime Complex for Managing Global Cyber Activities	Joseph S. Nye, Jr.	2014	Centre for International Governance Innovation and Chatham House	Cyberspace, interconnected systems, government, and regime theory.	What is cyber governance using regime Theory?	What are the challenges for managing internet governance?	Internet Governance	Development of normative structures for the governance of cyberspace.

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Collaborative Governance	John D. Donahue and Richard J. Zeckhauser	2011	Princeton University Press	Collaboration, governance, and rationale.	What are the promise, rationales, and problems of collaboration?	What is the art of collaboration?	Collaborative Governance	Collaboration provides public benefits.
Collaborative Governance in Theory and Practice	Chris Ansell and Alison Gash	2007	Journal of Public Administration Research and Theory	Collaborative governance, theory, and practice.	What are the critical variables to influence whether or not governance will produce successful collaboration?	Why to develop a contingency approach to collaboration?	Collaborative Governance	Collaborative governance can avoid adversarial policy making.
Teaching Collaborative Governance: Phases, Competencies, and Case-Based Learning	Ricardo S. Morse and John B. Stephens	2015	Journal of Public Affairs Education	Collaborative governance, learning, and public administration.	Why we need ground education and training for collaborative governance?	What kinds of questions focus attention on phase-specific Competencies?	Collaborative Governance	Collaborative governance is becoming a primary motif in public administration.
Collaborative Public Management: Where Have We Been and Where Are We Going?	Rosemary O'Leary and Nidhi Vij	2012	The American Review of Public Administration	Collaboration, collaborative public management, research, and practice.	What are the most important issues, concepts, and ideas in collaborative public management?	What it means to be a collaborative thinker, on-the-ground challenges, and paradoxes of collaboration?	Collaborative Governance	Collaborative public management needs aggregation of knowledge.
Collaborative Public Management: New Strategies for Local Government	Robert Agranoff and Michael McGuire	2003	Georgetown University Press	Collaborative management, strategies, and government.	How to manage the process in inter-organizational management?	What are the skills for collaborative public management?	Collaborative Governance	Collaboration is required in management and government.

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An Integrative Framework for Collaborative Governance	Kirk Emerson, Tina Nabatchi, and Stephen Balogh	2011	Journal of Public Administration Research and Theory	Governance, framework, and collaboration.	Why we need an integrative framework for collaborative governance?	What is the scope of collaborative governance?	Collaborative Governance	Collaborative governance in a larger system's context.
A Grounding for Global Governance	Margaret Stout and Jeannine M. Love	2015	Administration & Society	Governance, ontology, relational, process, and typology.	Why integrative governance is needed for sustainability?	What is governance typology and how to find the suitable one?	Collaborative/integrative governance	Integrative governance for development.
COBIT 5 and Enterprise Governance of Information Technology: Building Blocks and Research Opportunities	Steven De Haes, Wim Van Grembergen, and Roger S. Debreceny	2013	Journal of Information Systems	Enterprise governance of IT, IT governance, COBIT, business/IT alignment, balanced scorecard, organizational systems, and IT controls.	Why to narrow the gap between academic research and practice concerning information technology?	What are the COBIT 5 processes and related practices in enterprise governance?	IT Governance	Information technology is essential in organizations.
Governance Strategies for Living Technologies: Bridging the Gap between Stimulating and Regulating Technoscience	Rinie van Est and Dirk Stemerding	2013	Artificial Life, MIT Press	Governance, living technology, technology assessment, regulation, NBIC convergence, bioethics, and bio-politics.	How to deal with innovation promotion and risk regulation for living technologies?	Why to bridge the gap between stimulating and regulating technologies?	IT Governance	Governance strategies for living technologies.
Coordinating Technology Governance	Gary E. Marchant and	2015	Issues in Science And	Emerging technologies, governanc	Why to coordinating technology	What is the social implication of	IT Governance	Technologies need to be governed.

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	Wendell Wallach		Technology	e, and social implications.	governance?	technologies and their governance?		
Governance Challenges of Technological Systems Convergence	Jim Whitman	2006	Bulletin of Science, Technology & Society, Sage Publications	Technological systems convergence, nanotechnology, regulation, governance, and risk.	What are the prospects for exercising governance over the technological systems and the uses to which they might be put?	What will it mean to speak of “global governance” where the technological promise of converging technologies (CT) has been fulfilled?	IT Governance	Converging technologies for better development.
Board Briefing on IT Governance	IT Governance Institute	2003	IT Governance Institute	IT, governance, enterprise, organization, and management.	How critical is IT to sustaining the enterprise and how critical is IT to growing the enterprise?	How far the enterprise should go in risk mitigation and is the cost justified by the benefit?	IT Governance	IT governance should be integrated within enterprise governance.
IT Governance: Developing a Successful Governance Strategy	The National Computing Centre	2005	The National Computing Centre	IT, governance, strategy, and development.	How to develop a successful IT governance strategy?	What is IT governance best practice?	IT Governance	IT governance assists business and organization.
Don't Just Lead, Govern: How Top Performing Firms Govern IT	Peter Weill	2004	MIS Quarterly Executive	Governance, IT, design, and assessment.	How top IT governance performers govern IT?	Is it the leadership of management or good governance?	IT Governance	Good governance ensures to make the key IT decisions.
Decision Support Framework for the Implementation of IT-Governance	Kerstin Fink and Christian Ploder	2008	Proceedings of the 41st Hawaii International	Decision, IT, governance, and organization.	What is the issue of implementing IT governance into the organizatio	How to describe IT governance and corporate governance decisions?	IT Governance	IT governance Impacts to decision making processes in the

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			Conference on System Sciences, IEEE		nal context by a decision support framework?			organization.
Norms as a Basis for Governing Sociotechnical Systems	Munindar P. Singh,	2013	ACM Transactions on Intelligent Systems and Technology	Governance, sociotechnical systems, and adaptation.	Do traditional approaches simply scale up to large socio-technical systems?	Why we need a measure of correctness in governance that emphasizes interactions?	Systems Governance	Self-governance of multi-stakeholder sociotechnical systems.
A Systems Theory of Good Governance	Henrik Bang and Anders Esmark	2013	ICPP	Systems, governance, strategy, policy, and organization.	What is the strategy of good governance for public governance policy and organization?	What are the critical responses to good governance based on deliberative and radical democracy?	Systems Governance	Relation between power and freedom involved in good governance.
System-of-Systems Governance: New Patterns of Thought	Ed Morris, Pat Place, and Dennis Smith	2006	Software Engineering Institute, Carnegie Mellon University	Systems, governance, and information technology.	What are the key characteristics of good IT governance affected by the autonomy of individual systems in a system of systems?	What is the purpose of system-of-systems governance?	Systems Governance	Governance models must change when acquiring, developing, and operating a system of systems.
An Empirical Taxonomy of SOE Governance in Transitional China	Jinyang Hua, Paul Miesing, and Mingfang Li	2006	Journal of Management Governance, Springer	Capitalism with Chinese characteristics, governance taxonomy, institutionalism,	How should the enterprises deal with the tension between the old and new corporate	What are the unique characteristics of governance approaches in transitional China?	Systems Governance	Governance structures, systems, and process.

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				state-owned enterprises, and transition economies.	leadership systems?			
Governance and Intelligence In Research and Innovation Systems	Stefan Kuhlmann	2002	Universiteit Utrecht	Governance, intelligence, research, innovation, and systems.	To which extent can the institutional settings of research and innovation be deliberately shaped?	Under which conditions can the institutional settings of research and innovation be deliberately shaped?	Systems Governance	Heuristic models help to understand the emergence of new knowledge.
The Governance of Business Processes	M. Lynne Markus and Dax D. Jacobson	2015	Handbook on Business Process Management, Springer	Governance, business, process, organization, and performance.	What are the various governance mechanisms, their advantages and disadvantages?	How governance mechanisms can contribute to improved business process performance?	Business Process Governance	Increase of business processes necessitates and challenges governance.
The Governance of Business Process Management	Andrew Spanyi	2015	Handbook on Business Process Management, Springer	Governance, business, process, and performance.	What are the management practices of BPM governance?	What organizations need to do to effectively execute and sustain improvements to operational performance?	Business Process Governance	BPM governance for business performance.
Business Process Standardization	Roger Tregear	2015	Handbook on Business Process Management, Springer	Business, process, standardization, and organization.	What are the complex issues about process standardization?	What to consider-globally consistent or locally relevant?	Business Process Governance	Standardization of common processes across an organization.

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Organizational Governance	Nicolai J. Foss and Peter G. Klein	2008	The Handbook of Rational Choice Social Research	Rational choice, organizational economics, governance structures, and governance mechanisms.	What are the rational-choice approaches to organizational governance?	What firms are, what firms do, and how firms are structured?	Management Governance	Theories of organizational governance to solve issues in organization and management.
Rethinking Governance in Management Research	Laszlo Tihanyi, Scott Graffin, and Gerard George	2014	Academy of Management Journal	Governance, management, and organization.	What is the comparative performance of various approaches to governance?	What are the limits to inter-organizational coordination in the execution of the fundamental duties of governance?	Management Governance	Interrelation among governance, organization, and management.
The Management of Project Management: A Conceptual Framework for Project Governance	Eric G. Too and Patrick Weaver	2014	International Journal of Project Management	Project governance, multi project environment, strategic alignment, enterprise project management, and business value.	How to improve the performance of projects and hence create value for organizations?	What is the relationship between governance and management?	Management Governance	Guidance to organizations in the development of effective project governance to optimize the management of projects.
A Framework for Development of Integrated Intelligent Knowledge for Managemen	Antonio Martín, Carlos León, Joaquín Luque, Iñigo	2012	Expert Systems with Applications	Intelligent agents, expert system, GDMO, MIB, TMN, artificial intelligent, and	What is integrated intelligent management?	Why we need to formalize knowledge management descriptions?	Management Governance	Development of integrated intelligent knowledge for management.

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t of Telecommunication Networks	Monedero			network management.				
Governance of Interoperability in Intergovernmental Services: Towards an Empirical Taxonomy	Herbert Kubicek	2008	Systemics, Cybernetics and Informatics	E-Government, E-Services, Centralization, Governance, Integration of information system, intergovernmental cooperation, intergovernmental information systems, interoperability, and standardization.	How interoperability (IOP) is achieved and maintained for E-Government services?	Why interoperation needs to be standardization and centralization?	Governance Interoperability	Governance interoperability and exchange of data between two or more government agencies.
The Relationship between Modes of Governance and Relational Tie in New Product Development Relationships	Ebrahim Teimoury, Mehdi Fesharaki, and Afshar Bazyar,	2010	Journal of Strategy and Management	Governance, trust, product development, and strategic alliance.	What is the impact of trust and norm of information sharing?	What ae key modes of governance through which relational ties are influenced?	Governance Interoperability	Trust and norms of information sharing are positively related to relational ties.
Governance, Growth, and Development Decision-Making	Douglass North, Daron Acemoglu, Francis Fukuy	2008	The International Bank for Reconstruction and	Governance, development, and decision making.	What diverse strategic choices are available to development decision-makers?	What do we know about the relationship between the political and economic dimensions of	Governance Interoperability	Interactions between governance and development.

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	ama, and Dani Rodrik		Development/ The World Bank			development?		
Addressing the Impact of Data Location Regulation in Financial Services	James M. Kaplan and Kayvaun Rowshankish	2015	Centre for International Governance Innovation and Chatham House	Data governance, regulation, and financial services.	What is the impact and implications of data location regulation?	What the financial institutions should consider for data location regulation?	Data Governance	Data location regulation in organizations and technology.
The Compelling Case for Data Governance	Douglas Blair et al. (ECAR Working Group)	2015	Educause Center for Analysis and Research	Data governance, information technology, systems, and management.	Why is data governance necessary?	Who should be involved in data governance, and how?	Data Governance	Data governance, management, and key processes.
One Size Does Not Fit All- A Contingency Approach to Data Governance	Kristin Weber, Boris Otto, and Hubert Oesterle	2009	ACM Journal of Data and Information Quality	Data governance, IT governance, data quality management, data governance model, and contingency theory.	- How a flexible data governance model is composed of? - What are the key elements?	Why companies need data quality management (DQM)?	Data Governance	Relation between IT governance and data governance.
Designing a Data Governance Framework	Erkka Niemi	2013	ResearchGate	Data governance, data quality, data management, data strategy, enterprise	What is our understanding of data governance in complex enterprise environments?	Why we need data governance framework for globally operating companies?	Data Governance	Design research and data governance.

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				systems, ES, business-IT alignment, and action design research.				
Key Dimensions for Cloud Data Governance	Majid Al-Ruithe, Elhadj Benkhelifa, and Khawar Hameed	2016	IEEE 4th International Conference on Future Internet of Things and Cloud	Data governance, cloud computing, E-government, adoption, and data management.	What are the key dimensions for cloud data governance?	Why to increase awareness about data governance and cloud computing?	Data Governance	Data governance and its relation to models, management, and processes.
Human-Computer Super-Intelligence	Alexander A. Antonov	2010	American Journal of Scientific and Industrial Research	Mind and brain, human intelligence, human thinking, human knowledge, artificial intelligence, technological singularity, super-intelligence, and super-knowledge.	Can artificial intelligence serve as the basis for ‘computer super-intelligence’?	- What is actually super-knowledge - In what way will the new super-knowledge differ from human knowledge?	Human Intelligence	Human-computer super-intelligence allows developing super-knowledge on significant multiple-factor processes.
Intelligence: New Findings and Theoretical Developments	Richard E. Nisbett, Joshua Aronson, Clancy	2012	American Psychologist	Intelligence, fluid and crystallized intelligence, environme	Can we capture the complexity of human intelligence?	What is the relationship between environmental factors and intelligence?	Human Intelligence	Intelligence and theoretical development of knowledge.

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	Blair, William Dickens, James Flynn, Diane F. Halpern, Eric Turkheimer			ntal and genetic influences, heritability, race and sex differences.				
Genetics of Intelligence	Ian J Deary, Frank M Spinath, and Timothy C Bates	2006	European Journal of Human Genetics	IQ, intelligence, heritability, environment, twins, and adoption.	What do we know about the genetic polymorphisms implied by the heritability?	What happens to genetic and environmental contributions to intelligence in old age?	Human Intelligence	Cognitive differences and genetic intelligence.
Assessing the Competence and Credibility of Human Sources of Intelligence Evidence: Contributions from Law and Probability	David A. Schum and Jon R. Morris	2007	Law, Probability and Risk, Oxford University Press	Testimonial evidence, HUMINT, witnesses, competence, credibility, Bayes' rule, and Baconian probability.	When we obtain an item of human intelligence, to what extent can we believe it?	Should we be concerned about the sources of human intelligence?	Human Intelligence	Human sources of intelligence and credibility assessment.
Race and IQ in the Postgenomic Age: The Microcephaly Case	Sarah S. Richardson	2011	BioSocieties	Evolutionary cognitive genetics, genomics, human population genetics, neurogenetics, race, and IQ.	How postgenomic is changing the race and IQ landscape?	What are theoretical frameworks of the intersecting fields of evolutionary cognitive genetics?	Human Intelligence	Intelligence, cognition, and objective knowledge.
Collective Intelligence, The	Jean-François Noubel	2004	TheTransitioner.org	Intelligence, organization,	What is the key concepts underlying	How modern organizations and	Human Intelligence	Collective intelligence and the guidelines

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Invisible Revolution				technologies, and governance.	collective intelligence?	individuals can concretely learn how to increase their collective intelligence?		of a universal governance.
On the Collective Nature of Human Intelligence	Alex Pentland	2007	International Society for Adaptive Behavior	Theory of mind, cognitive science, evolution, socio-scope, network intelligence, and individual intelligence	What is the causality of the social cues in determining behavior?	What is human network intelligence?	Human Intelligence	Information aggregation and decision-making using intelligence.
Collective Intelligence in Organizations: Tools and Studies	Antonietta Grasso and Gregorio Convertino	2012	Computer Supported Cooperative Work, Springer	Intelligence, collaboration, organizational, and tools.	- What defines the forms of large-scale collaboration that emerge in specific organizations? - What are the organizational processes that are best suited to bottom-up emerging collaboration?	- How do quality, customer input, and timing affect work outcomes in organizations? - What mix of research methods, such as field studies and logs analysis, are suitable for CI research and design?	Human Intelligence	Collective intelligence research, design, and development in organizations.
Human Super Intelligence	Alexander A. Antonov	2011	International Journal of Emerging Sciences	Intelligence, thinking, knowledge, technological singularity	How human super intelligence can be implemented in the	How human super intelligence enable people to successfully solve multi-factor tasks?	Human Intelligence	Human super intelligence results in the emergence of the new human-

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				, super intelligence, and super knowledge.	near future?			computer civilization.
Increasing Emotional Intelligence through Training: Current Status and Future Directions	Nicola S. Schutte, John M. Malouff, and Einar B. Thorsteinsson	2013	International Journal of Emotional Education	Emotional intelligence, training, intervention, and adaptive emotions.	What is the impact of training in emotional-intelligence skills?	How to improve the outcomes of emotional intelligence?	Human Intelligence	Training increases emotional intelligence.
Relational Frame Theory and Human Intelligence	Sarah Cassidy, Bryan Roche, and Denis O'Hora	2010	European Journal of Behavior Analysis	Intelligence, relational frame theory, multiple exemplar training, derived relational responding, and stimulus equivalence.	What is the effect of relational interventions?	Can we frame the analysis of "intelligent" behaviors?	Human Intelligence	Intelligence using relational frame theory (RFT).
Collective Intelligence in Humans: A Literature Review	Juho Salminen	2012	Collective Intelligence Proceedings	Intelligence, human, and knowledge.	What scientific community means by the notion of collective intelligence in human context?	What is global behavior of the complex adaptive system?	Human Intelligence	Understanding of cognition to improve conceptual models and the design frameworks of collective intelligence.
Machine Intelligence	Alex S. Taylor	2009	CHI 2009 ~ Studying Intellig	Intelligence and intelligent machines.	Can we rethink intelligence as both a topic of	How intelligence is seen and enacted in things can	Machine Intelligence	Human interactions with machines

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			ent Systems		inquiry and a resource for design in HCI?	profoundly influence the interactions between human and machine?		to treat as intelligent.
Measuring the Machine Intelligence Quotient (MIQ) of Human–Machine Cooperative System	Hee-Jun Park, Byung Kook Kim, and Kye Young Lim	2001	IEEE Transactions on Systems, Man, And Cybernetics-Part A: Systems And Humans	Human computer interaction, intelligent system, machine intelligence, machine intelligence quotient (MIQ), measurement, and mental workload.	What are the issues about definition and measurement of machine intelligence not formulated?	How can we narrow the gap between the numerically expressed MIQ and the degree of machine intelligence users feel?	Machine Intelligence	Measuring machine intelligence for human-machine cooperative systems.
Revealing the Autonomous System Taxonomy: The Machine Learning Approach	Xenofontas Dimitropoulos, Dmitri Krioukov, George Riley, and KC Claffy	2006	The SAO/ NASA Astrophysics Data System (ADS)	Networking and Internet architecture.	Why we need autonomous system taxonomy?	Can we apply a machine learning approach for building a taxonomy?	Machine Intelligence	Expanding the understanding by creating models.
Toward Human Level Machine Intelligence- Is It Achievable? The Need for a Paradigm Shift	Lotfi A. Zadeh	2009	International Journal of Advanced Intelligence	Machine intelligence; theory of perceptions; fuzzy logic.	Is it possible to achieve human level machine intelligence?	What is the need for mechanization of natural language understanding?	Machine Intelligence	Understanding of preciseness of meaning for machine intelligence.
Universal Intelligence: A Definition	Shane Legg	2007	Minds & Machines	AIXI, complexity theory, intelligenc	What is our knowledge about intelligence	How to develop a concept of intelligence	Machine Intelligence	Definition of intelligence modelled

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of Machine Intelligence				e, theoretical foundations, Turing test, intelligence definitions, and intelligence tests.	, particularly on machine intelligence?	that is applicable to all kinds of systems?		on expert definitions of human intelligence, to generalize and formalize it for machine intelligence.
Artificial Intelligence And Administrative Discretion: Implications for Public Administration	Thomas J. Barth	1999	American Review Of Public Administration, SAGE Publications, Inc.	Artificial intelligence, public administration, judgment, and knowledge.	Whether the emergence of AI makes administrative discretion arguments moot?	What are the implications of using AI in public policy decision making?	Artificial Intelligence	AI systems can be a great benefit as advisers or tools to humans.
Artificial Intelligence and Consciousness	Drew McDermott	2007	The Cambridge Handbook of Consciousness, Cambridge University Press	Computational system, artificial intelligence, and consciousness.	How a computational system can exhibit intentionality?	Why and how symbols inside the system can refer to things?	Artificial Intelligence	Artificial intelligence to achieve consciousness.
Artificial Intelligence for Decision Making	Gloria Phillips-Wren and Lakhmi Jain	2006	Springer-Verlag Berlin Heidelberg 2006	Artificial intelligence, information, knowledge-based systems, and decision making.	Can artificial intelligence be used for decision making?	How artificial intelligence provides information to the user and suggests courses of action?	Artificial Intelligence	Artificial intelligence enhances decision making.

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Artificial Legal Intelligence	Stephen M. McJohn	1998	Harvard Journal of Law & Technology	Artificial intelligence, legal reasoning, and theory.	What is artificial legal intelligence?	How the forces of natural selection shape our cognitive abilities?	Artificial Intelligence	Artificial legal intelligence benefits legal system.
Artificial Psychology: The Psychology of AI	James A. Crowder	2013	Systemics, Cybernetics and Informatics	Artificial psychology, artificial cognition, emotional memory, and artificial intelligence.	What learning and reasoning have many possible meanings that the solution can easily get lost in the sea of opinions and options?	What does it mean to be artificially cognitive?	Artificial Intelligence	Technology of artificial intelligence could help humans.
Autonomy (What's it Good for?)	J. P. Gunderson and L.F. Gunderson	2007	The Association for Computing Machinery (ACM)	Artificial intelligence, autonomy, machine cognition, and reification.	Given the environment and the design goals of the intelligent system, can autonomy be enabled?	What capabilities are necessary to enable autonomy?	Artificial Intelligence	Incorporating autonomous components into a cognitive system.
Combining Human and Machine Intelligence in Large-Scale Crowdsourcing	Ece Kamar, Severin Hacker, and Eric Horvitz	2012	International Foundation for Autonomous Agents and Multi-agent Systems	Crowdsourcing, consensus tasks, complementary computing, and decision-theoretic reasoning.	How machine learning and inference can be harnessed to leverage the complementary strengths of humans and computational agents to solve crowdsourcing tasks?	How learned probabilistic models can be used to fuse human and machine contributions and to predict the behaviors of workers?	Artificial Intelligence	System that combines machine learning and decision-theoretic planning to guide the allocation of human effort in consensus tasks.

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Intention is Choice with Commitment	Philip R. Cohen and Hector J. Levesque	1990	Artificial Intelligence, Elsevier Science Publishers	Choice, artificial intelligence, and theory.	How intentions can be adopted relative to a background of relevant beliefs and other intentions or goals?	How an agent is committed to its goals?	Artificial Intelligence	Principles governing the rational balance among an agent's beliefs, actions, and intentions.
On Seeing Things	M. B. Clowes	1971	Artificial Intelligence, North-Holland Publishing Company	Intelligence, knowledge, syntax, and semantics.	- What is the knowledge of semantics? - What is the distinction between syntax and semantics, and the concept of denotation?	How to characterize the knowledge of the world?	Artificial Intelligence	System and formalization of knowledge.
Planning in a Hierarchy of Abstraction Spaces	Earl D. Sacerdoti	1974	Artificial Intelligence, North-Holland Publishing Company	Problem space, process, intelligence, and planning.	What is the approach to augmenting the power of the heuristic search process?	Why using abstraction spaces in problem solving?	Artificial Intelligence	Information and details in the problem space.
Sustainable Policy Making: A Strategic Challenge for Artificial Intelligence	Michela Milano, Barry O'Sullivan, Marco Gavanelli	2014	Association for the Advancement of Artificial Intelligence	Policy, artificial intelligence, decision support, and process.	Can artificial intelligence techniques play any role in policy-making process as well as in decision support?	Why user acceptance should be considered in policy making process?	Artificial Intelligence	Artificial intelligence helps policy making process and decision support.
The knowledge Level	Allen Newell	1982	Association for the	Knowledge, artificial	What is the nature of knowledge	What is the problem of knowledge	Artificial Intelligence	Knowledge representation,

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			Advancement of Artificial Intelligence	intelligence, and systems.	and representation?	representation?		processes, intelligence, and systems.
Unnatural Selection: Seeing Human Intelligence in Artificial Creations	Tony Veale	2015	Journal of Artificial General Intelligence	Computational creativity, language, art, ready-mades, modernism, and Twitterbots.	How AI systems explicitly model metaphor as a knowledge-driven process?	Can a metaphor generator yield results that are provocative but meaningful?	Artificial Intelligence	Knowledge based approach to intelligent content generation.
A Survey on Ambient Intelligence in Healthcare	Giovanni Acampora, Diane J. Cook, Parisa Rashidi, and Athanasios V. Vasilakos	2013	Proceedings of the IEEE	Ambient intelligence (AmI), healthcare, sensor networks, and smart environments.	How AmI technology might support people affected by various physical or mental disabilities or chronic disease?	What are the state-of-the-art artificial intelligence (AI) methodologies for developing AmI system in the healthcare domain?	Ambient Intelligence	The infrastructure and technology required for achieving the vision of AmI.
Ambient Intelligence: Concepts and Applications	Juan Carlos Augusto and Paul McCullagh	2007	Computer Science and Information Systems (ComSIS)	Ambient intelligence, information, and smart home.	What is the scope of ambient intelligence (AmI) in relationship between AmI and related areas?	What are the areas where AmI will have future impacts?	Ambient Intelligence	The flow of information in AmI system.
Ambient Intelligence: Technologies, Applications, and Opportunities	Diane J. Cook, Juan C. Augusto, and Vikramadity	2009	Pervasive and Mobile Computing	Ambient intelligence, artificial intelligence, sensors, decision making, context	What are the contributing technologies in ambient intelligence (AmI)?	What are the issues related to security and privacy for AmI systems?	Ambient Intelligence	Ambient intelligence and the relationship with technologies with applications.

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	R. Jakkulaa			awareness, and privacy				
An Ambient Intelligent Agent with Awareness of Human Task Execution	Fiemke Both, Mark Hoogendoorn , Andyvan der Mee, and Michael de Vos	2008	International Conference on Web Intelligence and Intelligent Agent Technology	Ambient intelligence, human, and knowledge.	Is there a reasoning method to enable an agent to derive what a human is doing?	Can information be expressed in the workflow about the experiences?	Ambient Intelligence	Reasoning process by human based on knowledge.
BOnSAI: A Smart Building Ontology for Ambient Intelligence	Thanos G. Stavropoulos, Dimitris Vrakas , Danai Vlachava, and Nick Bassiliades	2012	International Conference on Web Intelligence, Mining and Semantics	Ambient intelligence, semantic web, and ontologies .	Why we need smart building ontology for ambient intelligence ?	What an ontological framework for ambient intelligence will do?	Ambient Intelligence	Knowledge representation to enhance service-based intelligent applications.
The Future of Ambient Intelligence in Europe: The Need for More Everyday Life	Yves Punie	2005	Communications and Strategies	Research and development policy.	What are the challenges and bottlenecks for ambient intelligence (AmI) realization?	What are the information society technologies innovation policy questions for advancing the notion of AmI?	Ambient Intelligence	Information technologies and the relation with ambient intelligence .
A Web-based Collaborative Framework for Facilitating Decision Making on a 3D Design	Purevdorj Nyamsurena, Soo-Hong Lee, Hyun-Tae Hwang	2015	Journal of Computational Design and Engineering	Decision making, distributed environment, 3D data visualization on revision control,	What are the drawbacks for visualization of the design change and design errors on a	What are the challenges of designing process in a 3D environment in web-based framework?	Collaborative Inquiry	Designing process development and decision making.

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Developing Process	, and Tae-Joo Kim			and WebGL.	decision making process using a web technology?			
Collaborative Inquiry Learning Models, Tools, and Challenges	Thorsten Bell, Detlef Urhahne, Sascha Schanze, and Rolf Ploetzner	2010	International Journal of Science Education	Inquiry learning, collaboration, computer-based learning environments, science education, learning environment, collaborative inquiry learning, and computer assistance.	What is collaborative inquiry learning?	Are there any benefits of computerized tools in enabling and enhancing collaborative inquiry learning processes?	Collaborative Inquiry	The relationship between models, tools, and collaborative inquiry learning.
Support of the Collaborative Inquiry Learning Process: Influence of Support on Task and Team Regulation	Nadira Saab, Wouter van Joolingen, and Bernadette van Hout-Wolters	2011	Metacognition Learning	Collaborative inquiry learning, cscl, meta-cognition, task regulation, team regulation, support, and instruction.	How support of collaborative inquiry learning can influence the use of regulative activities of students?	What are the possible relations between task regulation, team regulation and learning results?	Collaborative Inquiry	Collaborative inquiry learning and communication help learning process.
A Prospect Theory-Based Interval Dynamic Reference Point Method for	Liang Wang, Zi-Xin Zhang, and Ying-Ming Wang	2015	Expert Systems with Applications	Emergency decision making, emergency response, prospect theory,	Why we need interval dynamic reference point method for emergency	What are the odds of existing decision makers (DMs) decision processes	Decision Making	Information and its relation to decision making.

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Emergency Decision Making				topsis, interval value, and dynamic reference point.	decision making?	under emergencies?		
Choice under Uncertainty	Jonathan Levin	2006	Stanford University	Choice, uncertainty, and model.	Why to develop a model of choice behavior under uncertainty?	Do people's preferences depend on a reference point?	Decision Making	Model of choice behavior and relation to uncertainty.
Decision Making Under Uncertainty: The Impacts of Emotional Intelligence and Behavioral Patterns	Malek Lashgari	2015	Academy of Accounting and Financial Studies Journal	Decision making, uncertainty, intelligence, and emotions.	What are the factors influencing and enhancing the decision-making process in financial assets?	How to improve the decision-making process?	Decision Making	Understanding, managing and regulating emotions help in the decision-making process.
Decision-Theoretic Harmony A First Step	LiangrongYi and Judy Goldsmith	2010	International Journal of Approximate Reasoning	Decision-theoretic planning, Markov decision processes, Harmony generation	Can Markov decision process lead to computational efficiency?	Why to model music generation using Markov decision processes?	Decision Making	Model, choice and decision-making process.
Enhancing the Decision Making Process: An Ontology-based Approach	Gunjan Mansingh	2014	International Conference on Information Resources Management (CONF-IRM)	Organizational decision making, Multi-criteria decision making, Ontology	Why we need an ontological approach for decision making process?	Do we need to integrate ontology into typical multi-criteria decision-making techniques?	Decision Making	Decision making process and knowledge about the alternatives.
Making Shared Decision-	Angela Coulter, Alf Collins	2011	The King's Fund	Shared decision-making, decision	- What is shared decision-making?	When is shared decision-	Decision Making	Effective shared decision-making for

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Making A Reality				support, ethics, information, and involvement.	- Why shared decision-making is important? - What shared decision-making involves?	making appropriate?		information and involvement in decisions experience.
Operational Intelligence Discovery and Knowledge-Mapping Approach In A Supply Network with Uncertainty	S.C.L. Koh and K.H. Tan	2006	Journal of Manufacturing Technology Management	Knowledge management, knowledge mapping, uncertainty management, supply chain management, and decision making.	Why knowledge mapping is difficult when there is uncertainty in a supply network?	What do we know about “knowledge” with “intelligence”?	Decision Making	An approach for discovering operational intelligence and knowledge mapping.
A Comparison of Axiomatic Approaches to Qualitative Decision Making Using Possibility Theory	Phan H. Giang and Prakash P. Shenoy	2001	Proceedings of the 17th Conference in Uncertainty in Artificial Intelligence (UAI 2001)	Approach, decision making, and theory.	Can we make qualitative decision using possibility theory?	What is the representation theorem for the unified system of axioms?	Decision Making	System of axioms for decision making.
Risk and Decision Making: The “Logic” of Probability	Manfred Borovcnik	2015	The Mathematics Enthusiast	Risk, uncertainty, risk perception, decision making, statistical errors, Bayesian	- What is risk? - What are the various meanings of risk?	- What is the statistical notions of risk? - What is the psychological aspects of risk and	Decision Making	The notion of risk as a multi-faceted concept.

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				risk, minimax principle.		perception of risk?		
Robust, Scalable Hybrid Decision Networks	Jason Scholz, Ian Dall, Don Gossink, Glen Smith, and Darryn Reid	2013	Association for the Advancement of Artificial Intelligence	Design, evaluation, and decision networks.	Can we build a framework for robust decision making at an enterprise level?	Can decision making framework assist machine intelligence?	Decision Making	Decision making with analysis and design.
Satisficing Games and Decision Making	Wynn C. Stirling	2003	Cambridge University Press	Rationality, locality, praxeology, equanimity, uncertainty, community, congruency, complexity, and meliority.	Can a notion of being “good enough” be defined that is distinct from being best?	Is it possible to formulate the concepts of being good enough for the group and good enough for the individuals that do not lead to the problems?	Decision Making	Approach to decision theory and mathematical games.
Shared Decision Making-Finding the Sweet Spot	Terri R. Fried	2016	The New England Journal of Medicine	Shared decision making, patients, and health care.	Should clinicians work against their natural impulses to tell the patient what to do when they’re certain of what’s best?	Why patients need clinicians’ assistance in making a decision?	Decision Making	Knowledge and information to assist shared decision making.
Shared Decision Making, Contextualized	Robert L. Ferrer and James M. Gill	2013	Annals of Family Medicine	Patient-centered care, decision making, shared	Is shared decision making a distinct subroutine invoked for a limited	What boundaries should be placed on shared decision making?	Decision Making	Shared decision helps knowledge refinement and make better

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					number of critical decisions?			informed decisions.
Shared Decision-Making In The Medical Encounter: What Does It Mean? (Or It Takes At Least Two To Tango)	Cathy Charles, Amiram Gafni, and Tim Whelan	1997	Elsevier Science Ltd	Shared treatment decision-making, physician/ patient communication	What does shared decision making mean in medical domain?	What is the prerequisite to shared decision-making?	Decision Making	Information sharing and its relation to shared decision making.
A Decision Theory Approach to the Business Judgment Rule: Reflections on Disney, Good Faith, and Judicial Uncertainty	Andrew S. Gold	2007	Maryland Law Revie	Business judgement rule, decision theory, and law.	Can we enforce judicial role in corporate law?	How to rule when courts do not have access to sufficient empirical data?	Decision Theory	Business judgment rule standard to review un-conflicted director conduct.
A Decision Theory of Statutory Interpretation: Legislative History by the Rules	Victoria F. Nourse	2012	The Yale law Journal	Decision theory, law, and legal process.	What is a decision theory of statutory interpretation?	What is the law of legislative procedure?	Decision Theory	Decision theory and its relation to knowledge and information.
Application of Decision Theory to the Testing of Large Systems	Peter J. Wong	1970	IEEE Transactions On Aerospace and Electronic Systems	Decision, systems, and methods.	How much of test resources should be committed to each subsystem?	What is the relative value of testing the various subsystems?	Decision Theory	Methodology, decision making, and relation to systematic process.
Behavioral Decision Theory Perspectives	Paul Slovic, Baruch Fischhoff,	1984	Acta Psychologica	Risk, safety, decision, and	Is current risk levels from hazards or competing	Should policy respond to public fears that experts	Decision Theory	Risk and relevant safety goals.

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on Risk and Safety	and Sarah Lichtenstein			technologies.	energy technologies provide meaningful benchmarks?	see as unjustified?		
Beyond Statistical Inference: A decision Theory for Science	Peter R. Killeen	2006	Psychonomic Bulletin & Review	Inferences, decision theory, and science.	Can traditional null hypothesis significance testing yield the scientific decisions?	What role does effect size play in the significant criterion?	Decision Theory	Decision theory and its relation to the expected utility of an effect.
Causal Decision Theory and EPR Correlations	Arif Ahmed and Adam Caulton	2014	Synthese, Springer	Bell's theorem, Decision Theory, Counterfactuals, Many worlds interpretation	What we should consider-purely statistical (i.e. evidential) or the causal approach to decision theory?	Where is the conflict between causal decision theory and the EPR statistics?	Decision Theory	Correlations of causal decision theory and EPR experiment.
Decision Theory and Human Behavior	Wayne L. Lee	1971	Princeton University Press.	Decision theory, human and behavior.	What is the meaning of rational action?	Why are preferences consistent?	Decision Theory	The relation of decision theory and human behavior.
Decision Theory as Practice: Crafting Rationality in Organizations	Laure Cabantous, Jean-Pascal Gond, and Michael Johnson-Cramer	2010	Organization Studies	Bricolage, calculability, decision analysis, performativity, rational decision-making	What are the underlying practices in rational choice theory achieved within organizations?	How organizational actors can make decisions in accord with the axioms of rational choice theory?	Decision Theory	Social construction of rationality and practices within organizations.
Decision Theory in Expert Systems and Artificial	Eric J. Horvitz, John S.	1988	International Journal of Appro	Artificial intelligence, belief networks,	What are the problems in representation,	What are the issues that have not been studied in detail	Decision Theory	Artificial intelligence contributes to problem solving and

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Intelligence	Breese, and Max Henrion		ximate Reasoning	decision analysis, decision theory, explanation, influence diagrams, knowledge engineering, operations research, probability, and uncertainty	inference, knowledge engineering, and explanation within the decision-theoretic framework?	within the expert-systems setting?		decision making.
Decision Theory in Maintenance Decision Making	A.T. de Almeida and G.A. Bohoris	1995	Journal of Quality in Maintenance Engineering	Decision theory, maintenance, and decision making.	How to use decision theory in maintenance engineering and management?	Why to use decision theory in maintenance engineering and management?	Decision Theory	Decision theory concepts and their applicability in maintenance.
Decision Theory Under Ambiguity	Johanna Etner, Meglena Jeleva, and Jean-Marc Tallon	2012	Journal of Economic Surveys	Ambiguity, Ambiguity aversion, Decision, and Uncertainty	What is the source of the difficulty faced when attempting to define notions and measures of ambiguity attitudes?	What existing literature are out there to address decision theory under ambiguity?	Decision Theory	Fully subjective models and models incorporating explicitly some information.
Decision Theory without Logical Omniscience: Toward an Axiomatic Framework for Bounded Rationality	Barton L. Lipman	1999	The Review of Economic Studies	Decision theory, framework, information, and model.	How to develop a decision theory which does not assume that agents are logically omniscient?	Why to develop a decision theory which does not assume that agents are logically omniscient?	Decision Theory	Axiomatic development of a tractable model of bounded rationality.

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Fuzzy Sets and Decision Theory	R. M. Capocelli and A. De Luca	1973	Information and Control	Fuzzy sets, decision theory, and information.	Can a learning system make decisions?	What is the possibility of characterizing the learning processes?	Decision Theory	Learning processes using information.
Judgment and Decision: Theory and Application	Gordon F. Pitz and Natalie J. Sachs	1984	Annual Review Psychology	Decision, information processing, and application.	What is the degree to which prescriptive models clarify the judgment or decision making (JDM) process itself?	Do inconsistent judgments indicate human failures?	Decision Theory	Decision making and the relationship to general cognitive structure.
On the Use of Bayesian Decision Theory for Issuing Natural Hazard Warnings	T. Economou, D. B. Stephenson, J. C. Rougier, R. A. Neal, and K. R. Mylne	2016	Royal Society Publishing	Natural hazards, early warning system, decision theory, ensemble forecasting, and ensemble post-processing	How Bayesian approach can be utilized for making decision Under uncertainty?	Why predictive and consequence information is helpful in uncertainty?	Decision Theory	Decision theory for constructing and evaluating hazard warnings.
Qualitative Decision Theory: From Savage's Axioms to Nonmonotonic Reasoning	Didier Dubois, Helene Fargier, and Henri Prade, Patrice Perny	2002	Journal of the ACM	Comparative uncertainty, decision theory, non-monotonic reasoning, possibility theory, preference relations, and qualitative decision theory	What extent a purely symbolic approach to decision making under uncertainty is possible?	What are the limitations of purely symbolic approaches to both rational and practically useful criteria for decision making under uncertainty?	Decision Theory	Relation of information, decision making, uncertainty, and intelligence.

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Counterfactual Reasoning and Learning Systems: The Example of Computational Advertising	Léon Bottou, Jonas Peters, Joaquin Quiñonero-Candela, Denis X. Charles, D. Max Chickering, Elon Portugaly, Dipankar Ray, Patrice Simard, and Ed Snelson	2013	Journal of Machine Learning Research	Causation, counterfactual reasoning, and computational advertising.	How to leverage causal inference to understand the behavior of complex learning systems?	What is the central role of causal inference for the design of learning systems interacting with their environment?	Reasoning	Reasoning and learning systems.
How Emotions Affect Logical Reasoning: Evidence from Experiments with Mood-Manipulated Participants, Spiderphobics, and People with Exam Anxiety	Nadine Jung, ChristinaWranke, KaiHamburger, and Markus Knauff	2014	Frontiers in Psychology	Logical reasoning, emotions, conditional reasoning, Wason selection task, spiderphobia, and exam anxiety.	How emotions affect logical reasoning and cognitive tasks?	What is the connection between logical reasoning and emotional states?	Reasoning	Emotional state and content may interact to modulate logical reasoning.
Metaphors We Think With: The Role of Metaphor in Reasoning	Paul H. Thibodeau and Lera	2011	PLoS One	Reasoning	How the metaphors influence the way we reason about	What is the influence of the metaphorical framing effect?	Reasoning	Metaphors, knowledge structures, and reasoning.

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	Boroditsky				complex issues?			
Reasoning Ability is (Little More Than) Working-Memory Capacity?!	Patrick C. Kyllonen and Raymond E. Christal	1990	Intelligence	Reasoning and working memory capacity.	What is the relationship between WM and reasoning?	Is working-memory capacity process or domain specific?	Reasoning	Reasoning is correlated comparatively strongly with general knowledge; working-memory capacity correlated comparatively strongly with processing speed.
Reasoning, Learning, and Creativity: Frontal Lobe Function and Human Decision-Making	Anne Collins and Etienne Koechlin	2012	PLoS Biology	Decision making, reasoning, creativity, and human.	How the creation of new behavioral strategies manages an expanding collection of behavioral strategies for driving action?	What the frontal lobe does for behavioral strategies for driving action?	Reasoning	Model for integrating reasoning, learning, and creative abilities in the service of executive control and decision-making.
Working-Memory Capacity Explains Reasoning Ability-and A Little Bit More	Heinz-Martin Su¨ß, Klaus Oberauer, Werner W. Wittmann, Oliver Wilhelm, and Ralf Schulze	2002	Intelligence	Working memory capacity and reasoning.	What is the role of working memory capacity in cognitive abilities?	What distinguishes working memory from intelligence test tasks?	Reasoning	The relationship between working memory and intelligence.

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A Multi-agent Approach to Collaborative Design of Modular Products	Chun-Che Huang	2004	Sage Publications	Concurrent engineering, knowledge management, modular product, collaborative design, design rules, and data mining.	Given a set of modules at a certain design stage, what initial module and consecutive modules should or should not be selected due to some design and customer constraints in a collaborative environment?	What are the design rules using a data mining technique?	Collaborative Design	Knowledge using the data mining technique to support designer decision-making using a neural network technique.
Collaborative Design: Combining Computer-Aided Geometry Design and Building Information Modelling	Shajay Bhooshan	2017	John Wiley & Sons, Ltd.	Collaborative design, CAD, information, and modelling.	How collaborative design practice has followed in the footsteps of the automotive, aircraft and shipbuilding industries in adopting a hybrid approach to design development?	Why to combine computer-aided geometry design and building information modelling?	Collaborative Design	Collaborative design for spatial expression and ordering of social processes.
Collaborative Design in Product Development Based on Product Layout Model	Y.W.Bai, Z.N.Chen, H.Z.Bin, and J.Hu	2005	Robotics and Computer-Integrated Manufacturing	Collaborative design, product layout feature, PLF model, parametric design,	What is collaborative design based on the PLF model?	Why do we need collaborative design based on the PLF model?	Collaborative Design	Collaborative design and model for product development.

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				and datum.				
Feature-based Design in a Distributed and Collaborative Environment	W.D. Li, S.K. Ong, J.Y.H. Fuh, Y.S. Wong, Y.Q. Lu, and A.Y.C. Nee	2004	Computer-Aided Design	Client/server, distributed design, and feature-based modelling.	How to effectively implement the collaborative environment methodology in a distributed design environment?	Why collaborative design needs to be integrated in a distributed environment?	Collaborative Design	Design integration for collaborative and distributed system.
Principles For Knowledge Creation In Collaborative Design Science Research	Boris Otto and Hubert Österle	2012	Thirty Third International Conference on Information Systems	Collaboration, design science, information system research, knowledge creation, and research methods/ methodology.	What knowledge creation processes are used in collaborative DSR settings?	What problems may occur during researcher-practitioner collaboration?	Collaborative Design	Knowledge creation perspective on collaborative design science research.
Cochlear Implants: System Design, Integration, and Evaluation	Fan-Gang Zeng, Stephen Rebscher, William Harrison, Xiaoan Sun, and Haihong Feng	2008	IEEE Reviews In Biomedical Engineering	Auditory brainstem, auditory nerve, auditory prosthesis, biocompatibility, biomaterials, current source, electric stimulation, electrode, fine structure, hermetic sealing, loudness,	What are the academic and industrial perspectives on the underlying research and ongoing development of cochlear implants?	What are the critical issues in cochlear implant research and development?	Design Integration	Cochlear implant as a model to design and evaluate other similar neural prostheses implants.

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				music perception, pitch, radio frequency, safety, signal processing, speech recognition, and temporal resolution.				
Describing the Creative Design Process by the Integration of Engineering Design and Cognitive Psychology Literature	T. J. Howard, S. J. Culley, and E. Dekoninck	2008	Design Studies	Design process, creative process, engineering design, and psychology.	Why we need an integrative creative design process?	How creative design process should be integrated?	Design Integration	Integration between a modernized consensus view of both the design process from engineering design and the creative process from cognitive psychology.
Design, Integration and Test of a Shopping Assistance Robot System	M. Garcia-Arroyo, L. F. Marin-Urias, A. Marin-Hernandez, and G. de J. Hoyos-Rivera	2012	7th ACM/IEEE International Conference on Human-Robot Interaction	Shopping assistance robot, mobile robots, interfaces, mobile devices, and QR codes.	How to design a (shopping assistant robot) system to keep control on buying?	Why users may benefit from a shopping assistant system?	Design Integration	Integration of support system to assist human.
Design: The Only Methodology of	P. John Williams	2000	Journal of Technology	Technology, design, knowledge, and processes.	Why it is important to utilize a range of processes	How technology should be perceived in education?	Design of Technologies	Technological knowledge and utilizing a

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Technology ?			Education		when developing technological literacy and capability?			range of processes.
Research Framework, Strategies, and Applications of Intelligent Agent Technologies (IATs) in Marketing	V. Kumar, Ashutosh Dixit, Rajshekar (Raj) G. Javalgi, and Mayukh Dass	2015	Journal of the Academy of Marketing Science	Intelligent agent technologies, marketing strategy, and grounded theory.	What are the recent developments in the field of marketing that are related to IATs, and how can they be classified based on marketing concepts?	- What are the opportunities and challenges associated with the adoption of IATs in the marketing domain, and how to conceptually link them together? - How do the marketing applications of IATs enhance firm performance?	Design of Technologies	Intelligent agent technologies and their marketing applications.
Teaching science through designing technology	Mai M. Sidawi	2009	International Journal of Technology and Design Education	Science, technology, education, design, and knowledge transfer.	How do students learn science through designing technology?	When teaching science through designing technology, what is taught first, science or technology?	Design of Technologies	Relationship between science and technology and hence knowledge transfer.
The Influence of Young Children's Use of Technology on Their Learning: A Review	Ching-Ting Hsin, Ming-Chaun Li, and Chin-Chung Tsai	2014	Educational Technology & Society	Early childhood education, young children, educational technology, and technolog	- How do technologies influence young children's learning across different developmental domains?	What are the key factors that influence children's learning with technology?	Design of Technologies	The relationships between technology use and children's learning.

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				y-assisted learning.	- What are the purposes and methods focused on by researchers when conducting studies of this topic?			
Toward Cognitive Assistants for Complex Decision Making Under Uncertainty	D.A. Schum, G. Tecuci, D. Marcu, and M. Boicu	2014	Intelligent Decision Technologies	Decision making under uncertainty, decision making under time and information constraints, intelligence analysis, decision rules, cognitive assistants, discovery, combining judgments, and proliferation of nuclear weapons.	What is at stake in terms of decision making?	What are the odds for any decision making?	Design of Technologies	Intelligence decision technology and systems.
Evaluation of hydraulic excavator Human-Machine Interface concepts using NASA TLX	Joseph Akyeampong, Silvanus Udoka, Giandomenico Caruso, and	2014	International Journal of Industrial Ergonomics	Hydraulic excavator, human-machine interface, heads-up display, coordinated control, ergonomics, and	How an augmented interaction can reduce the mental and physical workload?	How to obtain a more usable and ergonomic human-machine interface concepts?	Interface Design	Human-machine interface design concepts on subjective workload demands.

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	Monica Bordegoni			NASA TLX.				
Measurable Decision Making with GSR and Pupillary Analysis for Intelligent User Interface	Jianlong Zhou, Jinjun Sun, Fang Chen, Yang Wang, Ronnie Taib, Ahmad Khawaji, and Zhidong Li	2015	ACM Transactions on Computer-Human Interaction	Design, human factors, experimentation, decision making, GSR, eye-tracking, and machine learning.	Why decision making should be measured in real time?	How human physiological information is modeled and used to adapt both interface and decision making?	Interface Design	Decision making and intelligent user interface.
The Impact of Interface Affordances on Human Ideation, Problem Solving, and Inferential Reasoning	Sharon Oviatt, Adrienne Cohen, Andrea Miller, Kumi Hodge, and Ariana Mann	2012	ACM Transactions on Computer-Human Interaction	Experimentation, design, performance, human factors, pen interfaces, educational interfaces, thinking tools, ideational fluency, problem solving, inferential reasoning, nonlinguistic representations, diagrams, and affordances.	How computer interface affordances influence basic cognition?	What are the limitations of existing interfaces in computers?	Interface Design	Designing interface to assist human cognition and understanding.
The Study of Models of Intelligent Interfaces	Angel R. Puerta	1993	Intelligent User	Intelligent-interface modeling, self-	What is the need for models of	What are the key benefits of a model of an	Interface Design	Knowledge requirements for an intelligent

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			Interfaces	adaptation, user-interface management, and machine learning.	intelligent interfaces?	intelligent interface?		user interface.
User Interface Design Principles for Interactive Television Applications	Konstantinos Chorianopoulos	2008	International Journal of Human-Computer Interaction	User interface, design, principles, interactive TV, and media studies.	Is the usability mentality of task efficiency and of productivity goals suitable for ITV applications?	What is the design rationale for user interface?	Interface Design	User Interface design consideration and relation to applications.
Brain-Computer Interface Technologies in the Coming Decades	Brent J. Lance, Scott E. Kerick, Anthony J. Ries, Kelvin S. Oie, and Kaleb McDowell	2012	Proceedings of the IEEE	Augmented brain-computer interface (ABCI), brain-computer interaction, electroencephalographic (EEG), human-computer interaction, opportunistic BCI, opportunistic state detection, and pervasive computing.	What technologies are out there that use online brain-signal processing to influence human interactions with computers, their environment, and even other humans?	What are the current applications of brain-computer interface?	Human-Computer Interaction	Online brain-signal processing to enhance Human-computer interactions.
Indexicality: Understanding Mobile Human-Computer	Jesper kjeldskov and Jeni paay	2010	ACM Transactions on Compu	Design, human factors, mobile computing	What is the value of the indexicality Concept?	How users interpret information in a mobile computer	Human-Computer Interaction	Design and the relationship between user

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Interaction in Context			ter-Human Interaction	, indexicality, physical context, spatial context, social context, prototype systems, field evaluation, public transport, healthcare, and sociality.		user interface?		interface representations and user context.
Sustainable Making? Balancing Optimism and Criticism in HCI Discourse	David Roedl, Shaowen Bardzell, and Jeffrey Bardzell	2015	ACM Transactions on Computer-Human Interaction	Design, human factors, theory, maker culture, DIY, sustainability, and discourse analysis.	- How does HCI discourse conceptualize the maker as a subject position of interactivity? - How tropes of empowerment and progress (re)configured in this conceptualization?	What consequences does the underlying “grammar” of HCI maker discourse have for contemporary research problems?	Human-Computer Interaction	HCI in helping create sociotechnical solutions.
The Feet in HCI: A Survey of Foot-Based Interaction	Eduardo Velloso, Dominik Schmidt, Jason Alexander, Hans Gellersen, and	2015	ACM Computing Surveys	Human factors, foot interaction, feet tracking, and gestural interfaces.	- What are the characteristics of users in foot-operated computer interfaces? - How the characteristics of users affect the design of foot-	How the foot-based research prototypes and commercial systems capture input and provide feedback?	Human-Computer Interaction	Interaction between users and systems.

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	Andreas Bulling				operated computer interfaces?			
The Relationship of Action Research to Human-Computer Interaction	Gillian R. Hayes	2011	ACM Transactions on Computer-Human Interaction	Design, human factors, action research, and collaborative inquiry.	How action research impacts on human-computer interaction?	Why action research to consider for collaboration?	Human-Computer Interaction	Relationship of action research to human-computer interaction.
Bayesian Learning Theory Applied to Human Cognition	Robert A. Jacobs and John K. Kruschke	2010	John Wiley & Sons, Ltd.	Bayesian learning theory, human, and cognition.	What is the role of prior knowledge in Bayesian models?	How Bayesian models naturally address active learning?	Human Cognition	Bayesian information processing to human cognition.
Partners in Cognition: Extending Human Intelligence with Intelligent Technologies	Gavriel Salomon, David N. Perkins, and Tamar Globerson	1991	Educational Researcher	Intelligence, human cognition, and technologies.	How computer, technologies that aid in cognitive processing, can support intellectual performance and enrich individuals' minds?	Can machines make people more intelligent?	Human Cognition	Technologies and human cognitive processing.
Human-Recommender Systems: From Benchmark Data To Benchmark Cognitive Models	Patrick Shafto and Olfa Nasraoui	2016	ACM Conference on Recommender Systems	Human-recommender systems, data, cognition, and models.	What is benchmark model of human behavior and how it relates to cognitive models?	How data to present to people and the updated behavior in response to people’s observed actions impact on effective performance?	Human Cognition	Interactions between the user and the algorithm.

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New Thinking: The Evolution of Human Cognition	Cecilia Heyes	2012	Philosophical Transactions of the Royal Society	Cognition, evolution of cognition, cognitive development, social cognition, cultural evolution, and human evolution.	- When did the most important changes take place? - How did the changes happen? - What have the changes produced?	How to rethink the overall evolution of human cognition?	Human Cognition	Interactions with the physical and social environment for the development of human psychological capacities.
Socio-Cognitive Aspects of Interoperability: Understanding Communication Task Environments among Different Organizations	Gyu Hyun Kwon, Tonya L. Smith-Jackson, and Charles W. Bostian	2011	ACM Transactions on Computer-Human Interaction	Human factors, socio-cognitive, interoperability, emergency communication, and organization.	What is the socio-cognitive dimensions of interoperability?	How interoperability affects organizational decision-making and performance?	Human Cognition	Collaboration among organizations on interoperable communication systems design.
The Effects of Stress and Stress Hormones on Human Cognition: Implications for the Field of Brain and Cognition	S.J. Lupien, F. Maheu, M. Tu, A. Fiocco, and T.E. Schramek	2007	Brain and Cognition	Stress, glucocorticoid, catecholamine, memory, aging, and hippocampus.	What is the effects of stress in human?	How stress is related to human cognitive function?	Human Cognition	The processes of cognitive function in human related to stress.
Unraveling the Evolution of Uniquely Human Cognition	Evan L. MacLean	2016	Proceedings of the National Academy of Sciences of the United States of	Cognitive evolution, human evolution, comparative psychology, human uniqueness, and cognition	What makes human cognition unique?	How and why different aspects of human cognition have evolved?	Human Cognition	Processes of cognitive evolution of human.

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			America					
Working Memory Capacity and its Relation to General Intelligence	Andrew R.A. Conway, Michael J. Kane, and Randall W. Engle	2003	Trends in Cognitive Sciences	Working memory, reasoning, and intelligence.	What is working memory capacity (WMC)?	What is the relation of WMC to intelligence?	Human Cognition	Working memory capacity and its relation to intelligence.
Working Memory is (almost) Perfectly Predicted by g	Roberto Colom, Irene Rebollo, Antonio Palacios, Manuel Juan-Espinosa, and Patrick C. Kyllonen	2004	Intelligence	Working memory, g, crystallized intelligence, spatial ability, fluid intelligence, and psychometric speed.	Is working memory (WM) especially important to understand g?	What is the relationship of working memory (WM) and processing speed (PS)?	Human Cognition	Relationships among information, concurrent processing, and decision.
Business Process Change: A Study of Methodologies, Techniques, and Tools	William J. Kettinger, James T.C. Teng, and Subashish Guha	1997	MIS Quarterly	Business process redesign, reengineering, methodology, techniques, organizational process change, impact and socio-technical systems design, IS career	What are the existing methodologies, techniques, and tools to analyze business process change?	How the business process reengineering (BPR) project planners could customize methodology and select technique for their projects?	Business Process	The relationships between the key activities of the BPR project stage-activity framework and the sub-systems of the business process change model.

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				development, software tools, qualitative and quantitative method, strategy, and quality.				
Business Process Verification-Finally a Reality!	M.T. Wynn, H.M.W. Verbeek, W.M.P. van der Aalst, A.H.M. ter Hofstede, and D. Edmond	2009	Business Process Management Journal	Business process re-engineering, modelling, and programming languages.	How the reduction rules can be used to improve the efficiency of business processes?	Why there is a need for verification of process models?	Business Process	Business process verification techniques to assess the correctness of real-life models.
Research in Business Process Management: A Bibliometric Analysis	Peter Wohlhaupter	2012	Diploma thesis, University of Ulm	Business, process, and management.	Why a bibliometric analysis is essential for business process management?	How the bibliometric analysis relates to the research clusters in the various fields of business process management?	Business Process	Integration of the processes with the organizational structure of the enterprise.
The Implementation of Business Process Reengineering	Varun Grover, Seung Ryul Jeong, William J. Kettinger, and	1995	Journal of Management Information Systems	Business process reengineering, change management, and implementation of innovations.	What are the problems related to implementation of business process reengineering?	- What is the relative severity of these problems? - How do these problems relate to the success of business	Business Process	Relative severity of the various reengineering implementations problems and how these problems

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	James T.C. Teng					process reengineering?		are related to the success of reengineering projects.
Toward a Theory of Business Process Change Management	William J. Kettinger and Varun Grover	1995	Journal of Management Information Systems	Business process, management, and theory.	What is business process change (BPC)?	Is there a theory of business process change (BPC) management?	Business Process	Relationships between BPC and process efficiency, process cost reduction, customer success, and market share growth.
An Information Processing Analysis of Expert and Novice Teachers' Problem Solving	H. Lee Swanson, James E. O’Connor, and John B. Cooney	1990	American Educational Research Journal	Information, process, problem-solving, and analysis.	How expert and novice teachers solve common classroom discipline problems?	Do the instructional conditions influence the actual solution to a problem for expert and novice teacher?	Information Processing Analysis	Problem solving processes and solutions to classroom discipline problems separate expert and novice teachers.
An Information-Processing Analysis of Mindfulness: Implications for Relapse Prevention in the Treatment of Substance Abuse	F. Curtis Breslin, Martin Zack, and Shelley McMain	2002	American Psychological Association	Relapse, treatment, mindfulness meditation, addictive behaviors, and information processing.	What is the role of information processes in relapse?	How mindfulness can help prevent relapse?	Information Processing Analysis	Information processing analysis of mindfulness to prevent relapse.
Digital Visual Information Processing: Adding Vision and Graphics	Franz W. Leberl	2000	First Int’l Workshop on Image and Signal	Visual information, process, vision, and graphics.	Do the separation into vision and graphics makes any sense?	How processing of digital visual information should be considered?	Information Processing Analysis	Information processing for visual information.

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			Processing and Analysis					
Strengthening Intelligence Education with Information-Processing and Knowledge-Organization Competencies	Yejun Wu	2013	Journal of Strategic Security	Intelligence, information, process, knowledge, and organization.	- Is information processing an important part of intelligence work?	- Are information-processing and knowledge-organization competencies a part of the intelligence education?	Information Processing Analysis	Information-processing and knowledge organization competencies strengthen intelligence-education
Data-to-Model: A Mixed Initiative Approach for Rapid Ethnographic Assessment	Kathleen M. Carley, Michael W. Bigrigg, and Bouba Diallo	2012	Computational and Mathematical Organization Theory	Data, model, mixed-initiative approach, and assessment.	Is there any insights of data to model process in mixed-initiative approach?	What the key challenges are of mixed-initiative approach for rapid ethnographic assessment?	Mixed-Initiative Approach	Data-to model process enables meta-network information.
Evaluating Mixed-Initiative Systems: An Experimental Approach	Gabriella Cortelweaklya and Amedeo Cesta	2006	American Association for Artificial Intelligence	Mixed-initiative system, interaction, and evaluation.	Can mixed-initiative approach respond to a specific need of real users?	What are the different aspects and issues of the mixed-initiative paradigm?	Mixed-Initiative Approach	Experimental approach to evaluate key features of mixed-initiative systems.
Mixed-Initiative Human-Robot Interaction: Definition, Taxonomy, and Survey	Shu Jiang and Ronald C. Arkin	2015	IEEE International Conference on Systems, Man, and Cybernetics	Mixed-initiative interaction, taxonomy, survey, human-robot interaction, and human-	- What is the mixed-initiative? - When does the robot/human take the initiative?	How does the human/robot take the initiative?	Mixed-Initiative Approach	Mixed-initiative interaction is an effective collaboration strategy that enables the human and the robot to

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				robot team.				work together.
Mixed-Initiative Interface Personalization as a Case Study in Usable AI	Andrea Bunt, Cristina Conati, and Joanna McGrenere	2009	Association for the Advancement of Artificial Intelligence	Interface, Artificial intelligence, and personalization.	What issues we can encounter from the design and evaluation of a specific approach to personalization?	How a mixed-initiative customization assistance (MICA) system assists the development of usable AI?	Mixed-Initiative Approach	Design and evaluation of a system to assist users with usable AI and interface.
A Basis of Safety Design for Cooperative Human-machine System	Kohei Okabe and Hiroyasu Ikeda	2011	SICE Annual Conference	System safety design, risk management, cooperative robot, and un-prescribed event.	Is preventing the occurrence of un-prescribed events not grasped by the designer a design requirement?	What safety requirements for the cooperative human-machine system must be considered?	Human-Machine Systems	Safety design for cooperative human-machine system.
A Decision-Support Approach for the Design of Human-Machine Systems and Processes	Kenneth P. LaSala, Marvin L. Roush, and Zoran Matic	1995	Proceedings of Annual Reliability and Maintainability Symposium	Human reliability, systems engineering, concurrent engineering, and design to reliability.	Why the Reliable Human-Machine System Developer (REHMS-D) is required in manufacturing processes?	Does REHMS-D have value in system and maintenance design?	Human-Machine Systems	Relationship of human reliability model and a six-stage system engineering process.
A Framework to Classify Processes in the Field of Human-Machine Systems Engineering	Daniel Ley and Fraunhofer Fkie	2013	IEEE International Conference on Systems, Man, and	Data capturing methods, human-machine systems engineering, modeling language,	What are the relevant attributes for task decisions in human-machine systems?	What are the typical attributes of processes for discussions independent from application domains?	Human-Machine Systems	The role of processes in the field of design and evaluation of complex human-machine systems.

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			Cybernetics	process analysis, process attributes, process classification, and workflow analysis.				
A Learning-by-Metaphor Human-Machine System	Stuart H. Rubin	2006	IEEE International Conference on Systems, Man, and Cybernetics	Semantic, syntax, and systems.	How to equate distinct syntax having a common semantics in human-machine system?	Should human-machine interface delegate tasks between human and machine in accordance with the performance?	Human-Machine Systems	The role of common semantics in human-machine system.
A Survey on Human Machine Dialogue Systems	Stavros Mallios and Nikolaos Bourbakis	2016	7th International Conference on Information, Intelligence, Systems & Applications (IISA)	Dialogue systems, natural language understanding, dialogue management, and answering systems	What are the weak points and challenges in existing methodologies for dialogue systems (DSs) development?	What are the recent developments on dialogue systems?	Human-Machine Systems	Systems and its communication with a human in spoken or written form.
Abnormal Operation Diagnosis in Human-Machine Systems	Denis Berdjag, Frederic Vanderhaegen, Alexey Shumsky, and Alexey Zhirabok	2015	10th Asian Control Conference (ASCC)	Computational modeling, acceleration, presses, algebra, sensors, guidelines, and decision making	Why quick abnormal operation diagnosis (fault detection and isolation) is vital in human-machine systems performance?	What differences are out there between nondeterministic and deterministic finite state machine (FSM) representation of HMS for diagnosis?	Human-Machine Systems	Human emotional or psychological states and its relationship to corresponding behavior resulting in human performance.

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Advances in Human-Machine Systems for In-Vehicle Environments	John H. L. Hansen, Wooil Kim, and Pongtep Angkititrakul	2008	Workshop on Hands-free Speech Communication and Microphone Arrays	Robust speech recognition, in-vehicle dialog systems, driver behavior model, UTDrive.	How to utilize multimodal information from in-vehicle condition to increase the performance of human-machine interactive system?	Can multimodal information assist to improve overall safety and intelligence for smart vehicle systems?	Human-Machine Systems	Human-machine systems and the effect on driver behavior.
RECON: An Adaptive Human-Machine System for Supporting Intelligence Analysis	William Ross, Alexis Morris, Mihaela Ulieru, and Alexandre Bergeron Guyard	2013	IEEE International Conference on Systems, Man, and Cybernetics	Adaptive human-machine systems, context awareness, case-based recommendation, brain-computer interfaces, information relevance, and modelling and simulation.	What adaptive system can be designed to enhance the current intelligence capability?	How RECON will contribute for supporting intelligent analysis?	Human-Machine Systems	Integration of case-based computer simulation, implicit Brain computer interface data, and natural human-computer Interaction.
Virtual/Mixed/Augmented Reality Laboratory Research for the Study of Augmented Human and Human-Machine Systems	Kaj Helin, Jaakko Karjalainen, Timo Kuula, and Nicolas Philippon	2016	12th International Conference on Intelligent Environments	Virtual reality, mixed reality, augmented reality, augmented human, human centered design, and	What do we know about a specific Virtual/Mixed/Augmented Reality (VR/MR/AR) laboratory?	How VR/MR/AR/AH may well be employed as a premise for Augmented Human research and the design of new human-	Human-Machine Systems	Augmented Human (AH) design process and research laboratory conditions.

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				participatory design.		machine systems?		
Physiological Cognitive State Assessment: Applications for Designing Effective Human-Machine Systems	Justin R. Estepp	2011	33rd Annual International Conference of the IEEE EMBS	Cognition, design, systems, and machine.	Do physiologically-based machine learning techniques can benefit from increased collaboration?	What are the current state of cognitive state assessment in human-machine systems?	Human-Machine Systems	Physiological inputs can be applied directly to the design and implementation of augmented human-machine systems.
Collective Intelligence System Engineering	Ioanna Lykourentzou, Dimitrios J. Vergados, and Vassili Loumos	2009	Proceedings of the International Conference on Management of Emergent Digital EcoSystems	Design, standardization, collective intelligence, and system engineering.	What are the main challenges for the design and construction of a generic collective intelligence system?	Can human be able to reach unprecedented results and solutions from collective intelligence?	Human-Machine Systems	Collective intelligence to improve community processes.
Combining Decision-Making Theories With a Cognitive Theory for Intelligent Help: A Comparison	Katerina Kabassi and Maria Virvou	2015	IEEE Transactions On Human-Machine Systems	Adaptive systems, cognitive science, and user Interfaces.	Why multi-criteria decision making theories (MCDM) should be combined with cognitive theory?	What is the main advantage of combining MCDM theories with cognitive theory?	Human-Machine Systems	Integration of MCDM theories with cognitive theory provides designing better intelligent user interfaces.
Command and Control Requirements for Moving-Target Defense	Marco Carvalho, Jeffrey M. Bradshaw, Larry	2012	IEEE Computer Society	Cognitive science, human computer interaction, man-machine	What is moving-target defense?	What are the command and control requirements for moving-target defense?	Human-Machine Systems	Moving-target network defense provides a better human-centered

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	Bunch, Tom Eskridge, Paul J. Feltovich, Robert R. Hoffman, and Daniel Kidwell			systems, and employment				perspective.
Composition of Constraint, Hypothesis and Error Models to improve interaction in Human-Machine Interfaces	J. Ramon Navarro-Cerdan, Rafael Llobet, Joaquim Arlandis, and Juan-Carlos Perez-Cortes	2016	Information Fusion	Multi-source information fusion, human-machine interaction, weighted finite-state transducer composition, and interactive multimodal string correction.	Why independent error, constraint, input hypothesis, and user interaction models differ from Stochastic Parsing or Hidden Markov models?	How multisource information system improves interaction method in human-machine interfaces?	Human-Machine Systems	Combining multi source information for interaction method in human-machine interfaces.
Conceptualizing Hybrid Human-Machine Systems and Interaction	Sonja Buxbaum-Conradi, Tobias Redlich, and Jan-Hauke Branding	2016	49th Hawaii International Conference on System Sciences	Man machine systems, physiology, evolution (biology), robots, convergence, and ergonomics.	How a design question needs to be asked/addressed in terms of users?	Who and what is the user for a designed system in human-machine systems?	Human-Machine Systems	Integration of interfaces into the dynamics of human behavior and cognition.
An Adaptive Basic I/O Gain Tuning Method Based on Leveling Control Input Histogram	Mitsuhiro Kamezaki, Hiroyasu Iwata, and Shigek	2014	IEEE/ RSJ International Conference on Intelligent	Tuning, Histograms, Manipulators, Adaptive systems,	How to improve work performance in human-machine systems by improving	What extent of a lever histogram might be tuned for comfortable operability?	Human-Machine Systems	Improving work performance of human-machine systems by adjusting

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for Human-Machine Systems	i Sugano		Robots and Systems	Man machine systems, Gaussian distribution, and joints.	basic input/output gain?			tuning method.
Cooperative Problem Solving in Human-Machine Systems: Theory, Models, and Intelligent Associate Systems	Patricia M. Jones and James L. Jacobs	2000	IEEE Transactions On Systems, Man, and Cybernetics	Human-computer cooperative problem solving, and intelligent associate systems.	What theoretical foundations are out there to use models for cooperative problem solving?	What are the requirements for intelligent associate systems?	Human-Machine Systems	Relationships of theory and models for cooperative problem solving.
Creating Living Cellular Machines	Roger D. Kamm and Rashid Bashir	2013	Annals of Biomedical Engineering	Tissue engineering, Systems biology, Synthetic biology, Biobots, Vascular networks, Neuromuscular junctions, and Biological machines.	Do creation of living machines possible?	How the local rules of interaction result in global functionalities and diverse phenotypes?	Human-Machine Systems	Integration of cellular systems for the creation of ‘‘living machines’’ within human-machine systems.
Analysis and Modeling of Human Impedance Properties for Designing a Human-Machine Control System	Yoshiyuki Tanaka, Teruyuki Onishi, Toshio Tsuji, Naoki Yamada, Yuusaku Takeda, and	2007	IEEE International Conference on Robotics and Automation	Humans, impedance, man machine systems, control system synthesis vehicle dynamics foot, leg, biological system modeling, manipulator	How to integrate different variable of human impedance properties into a human-machine control system?	How to evaluate operational performance and feeling into a human-machine control system?	Human-Machine Systems	Integration of human impedance properties (lower extremities) into a human-machine control system by using the developed experimental device.

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	Ichiro Masamori			dynamics, and design methodology.				
Enhancing the Dependability of Human-Machine Systems Using Brunswikian Symmetry	Meike Jipp and Essameddin Badreddin	2006	International Conference on Computational Intelligence for Modelling Control and Automation-International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC)	Man machine systems, humans, aircraft, surveillance, airplanes, competitive intelligence, accidents, lakes, air traffic control, and computational intelligence.	How to address dependability of a system by overcoming miscommunication and deficient Interaction ?	Is there a framework to be developed to analyze communication between the operator and the technology and to determine deficiencies?	Human-Machine Systems	Dependability of a system of human users and supportive technology can be enhanced by improving man-machine communication/interaction.
Evaluating User Experience in Games: Concepts and Methods	Regina Bernhaupt	2010	Springer Publishing Company, Inc.	Use experience, games, and methods.	Does user experience matter in video games design? If so, how to measure that?	Why human-centered approach in the design and development of technology	Human-Machine Systems	User experience and design approach.

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						is important?		
Design and Modelling in Optimization of Human-Machine Systems Functioning	Mikhail G. Grif, Elena V. Geniatulina,and Natalie D. Ganelina	2015	International Siberian Conference on Control and Communications (SIBCON)	Functional-structural theory, human-machine System, the set of alternatives, the alternative graph, functional Network, the operation target binding combination of operations, pair incompatibility, and design automation.	How to optimize human-machine systems functioning process?	How algorithms can assist combinations of operations and functioning processes of human-machine systems?	Human-Machine Systems	Models and methods for automated design of human-machine systems functioning process.
Human Reliability in Man-Machine Systems	Marie Havlikova, Miroslav Jirgl, and Zdenek Bradac	2014	25th International Symposium on Intelligent Manufacturing and Automation	Man Machine System, quantitative reliability analysis, HRA, and THERP.	Does human reliability matter more in human-machine systems than machine reliability?	What to consider for technical systems in addition to the underlying reliability function of the system components?	Human-Machine Systems	Human plays more important role than hardware and software reliability in human-machine systems.
A Quantitative Measure for Information Transfer in Human-Machine Control Systems	Maxim Bakaev and Tatiana Avdeenko	2015	International Siberian Conference on Control and Comm	Interface design, throughput, Hick-Hyman law, model human processor, and	Is there a way to formulating quantitative measure for information flows in human-machine systems?	How to clarify the interface “information capacity” concept as well as the degree of Hick-Hyman’s	Human-Machine Systems	The scope of information transfer in the course of interaction in human-machine systems.

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			unications (SIBCON)	information complexity.		law applicability in this matter?		
Formal Framework for Detection of Automation Surprises in Human-machine Systems Modeled by Hybrid Automata	Daiki Ishii and Toshimitsu Ushio	2014	IEEE 3rd Global Conference on Consumer Electronics (GCCE)	Automation, user interfaces, man machine systems, automata, educational institutions, analytical models, and discrete-event systems.	How to identify automation surprises in human-machine systems?	What are the conditions for the nonexistence of the automation surprises?	Human-Machine Systems	The relationship of information for intended machine operation.
Simulation Model of the Decision-Making Support for Human-Machine Systems Operators	Rizun Nina and Taraninko Yurii	2015	IEEE Seventh International Conference on Intelligent Computing and Information Systems (ICICIS)	Simulation model, human-machine systems, Operator, motor operator’s activity, and speed	How to increase the quality of monitoring and controlling of the decision-making processes of the human-machine systems?	Can we increase the efficiency of the operator's decision-making processes?	Human-Machine Systems	Models can provide decision making support for human-machine systems operators.
Improvement of Embedded Human-Machine Interfaces Combining Language, Hypothesis and Error Models	Juan-Carlos Perez-Cortes, Rafael Llobet, J.Ramon Navarro-Cerdan	2011	22nd International Workshop on Database and Expert Systems	Hidden Markov models, optical character recognition software, transducers, stochastic	What improvements are required for embedded human-machine interfaces?	Why to improve existing models for embedded human-machine interfaces?	Human-Machine Systems	Relationships of language, hypothesis, and error model’s combination to improve human-

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
	, and Joaquim Arlandis		Applications	processes, probabilistic logic, syntactics, and computational modeling.				machine interfaces.
Optimal Modality Selection for Multimodal Human-Machine Systems using RIMAG	Mithun George Jacob and Juan P. Wachs	2014	IEEE International Conference on Systems, Man, and Cybernetics	Human-Robot Interaction, Multimodal systems, and Pareto optimization	How to determine an optimal multimodal lexicon for a specific task?	How effective combination of communication modalities (multimodal lexicon) can maximize effectiveness?	Human-Machine Systems	Collaboration of human-machine systems and utilization of diverse verbal and non-verbal communication channels.
Optimal Task Allocation for Human-Machine Collaborative Manufacturing Systems	Bin Hu and Jing Chen	2017	IEEE Robotics and Automation Letters	Discrete event dynamic automation systems, human factors and Human-in-the-loop, and Petri Nets for Automation Control.	How to model the impact of human fatigue on the dynamics of manufacturing processes?	Is there an optimal task-allocation policy that minimizes an average joint cost for human and process can be obtained? If so, how?	Human-Machine Systems	Cooperative collaboration between human operators and machines effectively combines the strengths of both the human and machine.
Theories, Models, And Human-Machine Systems	Kenneth H. Funk	1983	Mathematical Modelling	Knowledge, theory, model, and systems.	What distinction can we draw between theories and models?	How both theories and models impact knowledge development and refinement?	Human-Machine Systems	The relationship between theories and models and how it plays important roles in the development and refinement of knowledge.

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Human-Machine Cooperation to Design Intelligent Manufacturing Systems	M-Pierre Pacaux-Lemoine, Damien Trentesaux, and Gabriel Zambrano Rey	2016	42nd Annual Conference of the IEEE Industrial Electronics Society	Intelligent manufacturing systems, self-organization, human-machine cooperation, and human factors.	How can the human supervise the artificial self-organizing (ASO)-manufacturing control system (MCS)?	How can the ASO-MCS perceive the intervention of the human as help and not as a disturbance?	Intelligent Systems	Adopting a human-centered approach for the design and evaluation of assistance systems and processes.
Intelligent Control for Human-Machine Systems	Martin Buss and Hideki Hashimoto	1996	IEEE/ASME Transactions on Mechatronics	Intelligent control, man machine systems, artificial intelligence, intelligent structures, mechatronics, artificial neural networks, fuzzy logic, genetic algorithms, computer networks, and intelligent systems	What are the intelligent control (IC) system behavior models and hierarchical approaches?	What are the insights of IC models from cognitive science?	Intelligent Systems	Human interaction and the relationship with the intelligent control (IC) to achieve an intelligent cooperative manipulation system (ICMS).
Real-time Motion Planning Methods for Autonomous on-Road Driving: State-of-the-Art and	Christos Katrakazas, Mohammed Quddus, Wen-	2015	Transportation Research Part C	Path planning, obstacle detection, trajectory planning, autonomous	- What existing motion planning methods are out there for autonomous driving?	What are the limitations of the existing methods?	Intelligent Systems	Vehicular communications and incorporation of transport engineering aspects to improve

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Future Research Directions	Hua Chen, and Lipika Deka			vehicles, and V2I.	- How do they differ from one another?			the look-ahead horizon of sensing technologies.
Robotics and Intelligent Systems in Support of Society	Raj Reddy	2006	IEEE Computer Society	Intelligent robots, intelligent systems, senior citizens, robot sensing systems, speech synthesis, speech recognition, service robots, cognitive robotics, application software, and bandwidth.	What will we do with all technological power?	How will it affect the way we live and work?	Intelligent Systems	Intelligent technologies in the service of society and humanity.
Why and Why Not Explanations Improve the Intelligibility of Context-Aware Intelligent Systems	Brian Y. Lim, Anind K. Dey, and Daniel Avrahami	2009	CHI Proceedings of the SIGCHI Conference on Human Factors in Computing Systems	Intelligibility, context-aware, and explanations.	How to improve intelligibility of context-aware intelligent Systems?	Can the difference of explanations have any impact to carry out tasks?	Intelligent Systems	The effectiveness and importance of providing why and why not explanations over how to and what if.
Can Machines Intelligently Propose	Pengwei Wang, Zhongyuan	2017	International World Wide Web	Machine intelligence, hypothesis, semantic	How machines can propose novel and	If machines innovate novel hypothesis, can it then	Machine Systems	Utilizing embedding based genetic algorithm

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Novel and Reasonable Scientific Hypotheses?	Wang, Lei Ji, Jun Yan, and Lianwen Jin		Conference Committee (IW3C2)	information, and genetic algorithm.	reasonable scientific hypotheses?	efficiently accelerate scientific progress?		to learn from past data to innovate novel hypothesis.
Google’s Neural Machine Translation System: Bridging the Gap between Human and Machine Translation	Yonghui Wu, Mike Schuster, Zhifeng Chen, Quoc V. Le, Mohammad Norouzi, and et al.	2016	Cornell University Library	Neural Machine Translation (NMT), systems, and models.	How to improve automated translation system/method?	What are the critical techniques of GNMT for accuracy, speed, and robustness?	Machine Systems	GNMT system to provide good balance between the flexibility of “character”-delimited models and the efficiency of “word”-delimited models.
Hidden Technical Debt in Machine Learning Systems	D. Sculley, Gary Holt, Daniel Golovin, Eugene Davydov, Todd Phillips, and et al.	2015	Proceedings of the 28th International Conference on Neural Information Processing Systems	Machine learning, software engineering framework, and systems.	How to measure technical debt in a system, or to assess the full cost of this debt?	What are some specific machine learning (Ml) systems risk factors?	Machine Systems	Risk factors to account for in system design.
A Critical Review of the Use of System Dynamics for Organizational Consultation Projects	Alexander Zock	2004	Proceeding of the 22nd International systems dynamics	Epistemology, Luhmann’s theory of social systems, autopoiesis, structural coupling,	Can an improvement in the organizational practice of SD (systems dynamics) be achieved through a	What are the fragmented theoretical foundations of the SD methodology?	Organizational Systems	Integration of the existing SD based organizational consulting practice into the systemic

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
				organization theory, organizational intervention theory, systemic intervention, and intervention architectures.	reformulation of the theoretical framework underlying SD?			consultancy framework.
Designing Organizational Systems: An Interdisciplinary Discourse	Richard Baskerville, Marco De Marco, and Paolo Spagnoletti	2013	Springer	Organizational systems, design, and information systems.	What are the insights of organizational systems design and studies?	How organizations and its practices information systems, and managerial strategies play together for systems design?	Organizational Systems	Information systems and organization studies act as an interdisciplinary approach.
Perspectives on Organizational Change: Systems and Complexity Theories	Francis Amagoh	2008	The Public Sector Innovation Journal	Systems theory, complexity theory, organizational change, and organizational transformation	How organizations can gain competitive advantage by being able to manage and survive change?	How organizational leaders can respond and adapt to the uncertainties and demands of global change?	Organizational Systems	Systems and complexity models assist organizational leaders to address complex organizational dilemmas.
The Systems Theory of Management in Modern Day Organizations - A Study of Aldgate Congress Resort Limited Port Harcourt	Cornell C Chikere and Jude Nwoka	2015	International Journal of Scientific and Research Publications,	System, management, organization, technology, and firms.	Is systems approach to management being applied in modern day organizations?	Are there issues arising from the adoption of this systems theory to management?	Organizational Systems	Organizations should adopt systems approach to enhance corporate growth and profitability.

Corpus Title	**Author(s)**	**Publication Year**	**Publication Source**	**Keywords**	**Primary Research Question(s)**	**Secondary Research Question(s)**	**Open Categorical Coding Theme**	**Axial Relationship Theme**
Two Approaches to Organizational Analysis: A Critique and a Suggestion	Amitai Etzioni	1960	Administrative Science Quarterly	System model, goal model, and organizational analysis.	Why should consider a system model in place of a goal model for measuring the effectiveness of organizational activities?	Why goal model is not effective for an organizational analysis?	Organizational Systems	The relationships of system and goal models with organizational analysis.
Ethical and Legal Issues of the Use of Computational Intelligence Techniques in Computer Security and Computer Forensics	Bernd Stahl, David Elizondo, Moira Carroll-Mayer, Yingqin Zheng, and Kutoma Wakunuma	2010	International Joint Conference on Neural Networks (IJCNN)	Ethics.	What issues arising from the use of computational intelligence in the security and forensics computer domains?	How technology, its development and use should be treated in democratic societies?	Socio-Technical Systems	Relationship between normative disciplines (i.e. ethics, law) with computational technology.
Sociotechnical Systems Analysis in Health Care: A Research Agenda	Pascale Carayon, Ellen J. Bass, Tommaso Bellandi, Ayse P. Gurses, M. Susan Hallbeck, and	2011	IIE Transactions on Healthcare Systems Engineering	Sociotechnical systems, human factors and ergonomics, transitions of care, workload, patient safety, medical devices, health information	How designing or redesigning care systems and processes can have an impact on patient and provider outcomes?	- Under which technical and organizational conditions is patient-centered care effective? - Does patient-centered care actually constitute a way of improving patient	Socio-Technical Systems	Socio-Technical Systems Analysis (STSA) and relevant research areas.

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	Vanina Mollo			technology, risk management, and patient-centered care.		satisfaction or quality and safety of care?		
Socio-Technical Systems: From Design Methods to Systems Engineering	Gordon Baxter and Ian Sommerville	2011	Interacting with Computers	Socio-technical systems, systems engineering, and software engineering.	What pragmatic design framework of socio-technical systems engineering (STSE) bridges the gap between organizational change and system development?	- How can requirements be made richer to incorporate information about socio-technical processes? - What tool support is effective in supporting STSE processes? - How should socio-technical systems design methods evolve to cover work that is not co-located?	Socio-Technical Systems	Relationships between organizational change processes and technical systems development.
The New Stream of Socio-Technical Approach and Main Stream Information Systems Research	Vafa Ghaffarian	2011	Procedia Computer Science	Socio-technical approaches and information systems.	How socio-technical design differs from the old approach to the new one?	What (new) ICT perspective needs to be considered for designing socio-technical approach?	Socio-Technical Systems	Relationships of socio-technical design to theoretical and practical needs.
5G: The Convergence of Wireweakly Communications	Raul Chavez-Santiago, Michal Szydel	2015	Wireweakly Personal Communications	5G, radio spectrum, traffic offloading, small-cells, software	How to exploit existing radio technologies for 5G mobile	Challenges associated with converging existing technologies	Systems Convergence	Interoperability between different radio access

Corpus Title	Author(s)	Publication Year	Publication Source	Keywords	Primary Research Question(s)	Secondary Research Question(s)	Open Categorical Coding Theme	Axial Relationship Theme
	ko, Adrian Kliks, and et al.			defined radio, and software defined networking.	communications?			technologies.
Cloudlets: at the Leading Edge of Mobile-Cloud Convergence	Mahadev Satyanarayanant, Zhuo Chent, Kiryong Hat, Wenlu Hut, Wolfgang Richtert, and Padmanabhan Pillai	2014	International Conference on Mobile Computing, Applications and Services (MobiCASE)	Cloud computing	How to put technologies together to create systems that can provide real-time cognitive assistance for mobile users?	How can computers help humans be smarter?	Systems Convergence	Converged cloud system to human cognition and learning.
Convergence and Competition: The Case of Bank Regulation in Britain and the United States	Heidi Mandanis Schooner and Michael Taylor	1999	Michigan Journal of International Law	Policy convergence, competition, and regulation.	Why simple competition is comparatively unsuccessful in explaining the actual path of bank regulation?	What effect of policy convergence on regulatory systems?	Systems Convergence	Policy convergence VS regulatory systems to competitive advantage/ disadvantage.

Now, based on this concept dictionary, concept categories identified from open coding are shown in Table 16.

Table 16: Concept Categories from Open Coding.

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
Governance	Knowledge Governance	- Corporate Governance and Intellectual Capital (Keenan J, 2001) - Exploring Knowledge Governance (Foss N, 2010) - Knowledge Governance, Innovation and Development (Burlamaqui L, 2010) - The Emerging Knowledge Governance Approach: Challenges and Characteristics (Foss N, 2007) - Knowledge Governance: Processes and Perspectives (Foss N, 2009) - Knowledge Governance: An Exploration of Principles, Impact, and Barriers (Gerritsen A, 2013) - Knowledge Governance (Choi C, 2005) - A Conceptualization of Knowledge Governance in Project-Based Organizations (Pemsel S, 2014) - Neither Hierarchy nor Identity: Knowledge-Governance Mechanisms and the Theory of the Firm (Grandori A, 2001) - Exploring the Complex Interaction between Governance and Knowledge in Education (Fazekas M, 2012)
	Internet Governance	- Thinking Clearly about Multistakeholder Internet Governance (DeNardis L, 2013) - Zero-rating in Emerging Economies (Galpaya H, 2017) - Critical Infrastructure and the Internet of Things (Simon T, 2017) - Corporate Accountability for a Free and Open Internet (MacKinnon R, 2016) - Internet Intermediaries as Platforms for Expression and Innovation (Chander A, 2016) - Increasing Internet Connectivity While Combatting Cybercrime: Ghana as a Case Study (Baylon C, 2016) - Unlocking Affordable Access in Sub-Saharan Africa (Song S, 2016) - Multi-Stakeholderism: Anatomy of an Inchoate Global Institution (Raymond M, 2016) - Standards, Patents and National Competitiveness (Murphree M, 2016) - Ethics in the Internet Environment (Weber R, 2016) - One Internet: An Evidentiary Basis for Policy Making on Internet Universality and Fragmentation (DeNardis L, 2016)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- When Are Two Networks Better than One? Toward a Theory of Optimal Fragmentation (Yoo C, 2016) - How to Connect the Other Half: Evidence and Policy Insights from Household Surveys in Latin America (Galperin H, 2016) - Internet Openness and Fragmentation: Toward Measuring the Economic Effects (Box S, 2016) - A Framework for Understanding Internet Openness (West J, 2016) - Market-Driven Challenges to Open Internet Standards (Fältström P, 2016) - Governance of International Trade and the Internet: Existing and Evolving Regulatory Systems (Singh H, 2016) - Tracing the Economic Impact of Regulations on the Free Flow of Data and Data Localization (Bauer M, 2016) - Looking Back on the First Round of New gTLD Applications: Implications for Trademarks and Freedom of Expression (Lipton J, 2016) - Patents and Internet Standards (Contreras J, 2016) - Jurisdiction on the Internet: From Legal Arms Race to Transnational Cooperation (Chapelle B, 2016) - Education 3.0 and Internet Governance: A New Global Alliance for Children and Young People’s Sustainable Digital Development (Frau-Meigs D, 2016) - A Pragmatic Approach to the Right to Be Forgotten (O’Hara K, 2016) - The Digital Trade Imbalance and Its Implications for Internet Governance (Aaronson S, 2016) - The Privatization of Human Rights: Illusions of Consent, Automation and Neutrality (Taylor E, 2016) - Combatting Cyber Threats: CSIRTs and Fostering International Cooperation on Cybersecurity (Bradshaw S, 2015) - One in Three: Internet Governance and Children's Rights (Livingstone S, 2015) - The Dark Web Dilemma: Tor, Anonymity and Online Policing (Jardine E, 2015) - The Tor Dark Net (Owen G, 2015) - The Strengths and Weaknesses of the Brazilian Internet Bill of Rights: Examining a Human Rights Framework for the Internet (Rossini C, 2015) - Landmark EU and US Net Neutrality Decisions: How Might Pending Decisions Impact Internet Fragmentation? (Scott B, 2015) - The Emergence of Contention in Global Internet Governance (Bradshaw S, 2015)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Net Neutrality: Reflections on the Current Debate (Bello P, 2015) - Solving the International Internet Policy Coordination Problem (Ashton-Hart N, 2015) - Connected Choices: How the Internet is Challenging Sovereign Decisions (Hathaway M, 2015) - A Primer on Globally Harmonizing Internet Jurisdiction and Regulations (Chertoff M, 2015) - ICANN: Bridging the Trust Gap (Taylor E, 2015) - Understanding Digital Intelligence and the Norms that Might Govern It (Omand D, 2015) - On the Nature of the Internet (Daigle L, 2015) - The Impact of the Dark Web on Internet Governance and Cyber Security (Chertoff M, 2015) - Innovations in Global Governance: Toward a Distributed Internet Governance Ecosystem (Verhulst S, 2014) - Legal Interoperability as a Tool for Combatting Fragmentation (Weber R, 2014) - Legal Mechanisms for Governing the Transition of Key Domain Name Functions to the Global Multi-Stakeholder Community (Shull A, 2014) - Tipping the Scale: An Analysis of Global Swing States in the Internet Governance Debate (Maurer T, 2014) - The Regime Complex for Managing Global Cyber Activities (Nye J, 2014)
	Collaborative Governance	- Collaborative Governance (Donahue J, 2011) - Collaborative Governance in Theory and Practice (Chris A, 2007) - Teaching Collaborative Governance: Phases, Competencies, and Case-Based Learning (Morse R, 2015) - Collaborative Public Management: Where Have We Been and Where Are We Going? (O'Leary R, 2012) - Collaborative Public Management: New Strategies for Local Government (Agranoff R, 2003) - An Integrative Framework for Collaborative Governance (Emerson K, 2011) - A Grounding for Global Governance (Stout M, 2015)
	IT Governance	- COBIT 5 and Enterprise Governance of IT (De Haes S, 2013) - Governance Strategies for Living Technologies: Bridging the Gap between Stimulating and Regulating Technoscience (Est R, 2013) - Coordinating Technology Governance (Marchant G, 2015)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Governance Challenges of Technological Systems Convergence (Whitman J, 2006) - Board Briefing on IT Governance (IT Governance Institute, 2003) - IT Governance: Developing a Successful Governance Strategy (The National Computing Centre, 2005) - Don't Just Lead, Govern: How Top Performing Firms Govern IT (Weill P, 2004) - Decision Support Framework for the Implementation of IT Governance (Fink K, 2008)
	Systems Governance	- Norms as a Basis for Governing Sociotechnical System (Singh M, 2013) - A Systems Theory of Good Governance (Bang H, 2013) - System-of-Systems Governance: New Patterns of Thought (Morris E, 2006) - Empirical Taxonomy SOE Governance Transitional China (Hua J, 2006) - Governance and Intelligence in Research and Innovation Systems (Kuhlmann S, 2002)
	Business Process Governance	- The Governance of Business Processes (Markus M, 2015) - The Governance of Business Process Management (Spanyi A, 2015) - Business Process Standardization (Tregear R, 2015)
	Management Governance	- Organizational Governance (Foss N, 2008) - Rethinking Governance in Management Research (Tihanyi L, 2014) - The Management of Project Management: A Conceptual Framework for Project Governance (Too E, 2014) - A Framework for Development of Integrated Intelligent Knowledge for Management of Telecommunication Networks (Martin A, 2012)
	Governance Interoperability	- Governance Interoperability in Intergovernmental Services (Kubicek H, 2008) - The Relationship between Modes of Governance and Relational Tie in New Product Development Relationships (Teimoury E, 2010) - Governance, Growth, and Development Decision-Making (North D, 2008)
	Data Governance	- Addressing the Impact of Data Location Regulation in Financial Services (Kaplan J, 2015)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- The Compelling Case for Data Governance (Blair D, 2015) - One Size Does Not Fit All- A Contingency Approach to Data Governance (Weber K, 2009) - Designing a Data Governance Framework (Niemi E, 2013) - Key Dimensions for Cloud Data Governance (Al-Ruithe M, 2016)
Intelligence	Human Intelligence	- Human-Computer Super-Intelligence (Antonov A, 2010) - Intelligence: New Findings and Theoretical Developments (Nisbett R, 2012) - Genetics of Intelligence (Deary I, 2006) - Assessing the Competence and Credibility of Human Sources of Intelligence Evidence: Contributions from Law and Probability (Schum D, 2007) - Race and IQ in the Postgenomic Age: The Microcephaly Case (Richardson S, 2011) - Collective Intelligence, The Invisible Revolution (Noubel JF, 2004) - On the Collective Nature of Human Intelligence (Pentland A, 2007) - Collective Intelligence in Organizations: Tools and Studies (Grasso A, 2012) - Human Super Intelligence (Antonov A, 2011) - Increasing Emotional Intelligence through Training: Current Status and Future Directions (Schutte N, 2013) - Relational Frame Theory and Human Intelligence (Cassidy S, 2010) - Collective Intelligence in Humans: A Literature Review (Salminen J, 2012)
	Machine Intelligence	- Revealing Autonomous System Taxonomy (Dimitropoulos X, 2006) - Measuring the Machine Intelligence Quotient (MIQ) of Human-Machine Cooperative Systems (Park HJ, 2001) - Universal Intelligence: A Definition of Machine Intelligence (Legg S, 2007) - Machine Intelligence (Taylor A, 2009) - Toward Human Level Machine Intelligence-Is It Achievable? The Need for a Paradigm Shift (Zadeh L, 2009)
	Ambient Intelligence	- Ambient intelligence: Technologies, Applications, and Opportunities (Cook D, 2009) - The Future of Ambient Intelligence in Europe: The Need for More Everyday Life (Punie Y, 2005)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Ambient Intelligence: Concepts and Applications (Augusto J, 2007) - A Survey on Ambient Intelligence in Healthcare (Acampora G, 2013) - BOnSAI: A Smart Building Ontology for Ambient Intelligence (Stavropoulos T, 2012) - An Ambient Intelligent Agent with Awareness of Human Task Execution (Both F, 2008)
	Artificial Intelligence	- Sustainable Policy Making: A Strategic Challenge for Artificial Intelligence (Milano M, 2014) - Artificial Intelligence for Decision Making (Phillips-Wren G, 2006) - Artificial Intelligence and Consciousness (McDermott D, 2007) - The Knowledge Level (Newell A, 1982) - Planning in a Hierarchy of Abstraction Spaces (Sacerdoti E, 1974) - On Seeing Things (Clowes M, 1971) - Intention is Choice with Commitment (Cohen P, 1990) - Artificial Intelligence and Administrative Discretion: Implications for Public Administration (Barth T, 1999) - Combining Human and Machine Intelligence in Large-scale Crowdsourcing (Kamar E, 2012) - Artificial Psychology: The Psychology of AI (Crowder J, 2013) - Unnatural Selection: Seeing Human Intelligence in Artificial Creations (Veale T 2015) - Artificial Legal Intelligence (Gray P, 1997) - Autonomy (What's it Good for?) (Gunderson J, 2007)
Systems	Human-Machine Systems	- Evaluating User Experience in Games: Concepts and Methods (Bernhaupt R, 2010) - Composition of Constraint, Hypothesis and Error Models to Improve Interaction in Human-Machine Interfaces (Navarro-Cerdan J, 2016) - Command and Control Requirements for Moving-Target Defense (Carvalho M, 2012) - Improvement of Embedded Human-Machine Interfaces Combining Language, Hypothesis and Error Models (Perez-Cortes J, 2011) - Theories, Models, and Human-Machine Systems (Funk K, 1983)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Combining Decision-Making Theories with a Cognitive Theory for Intelligent Help: A Comparison (Kabassi K, 2015) - Creating Living Cellular Machines (Kamm R, 2013) - Human Reliability in Man-Machine Systems (Havlikova M, 2015) - Collective Intelligence System Engineering (Lykourentzou I, 2009) - A Basis of Safety Design for Cooperative Human-Machine System (Okabe K, 2011) - A Decision-Support Approach for the Design of Human-Machine Systems and Processes (LaSala K, 1995) - A Framework to classify Processes in the field of Human-Machine Systems Engineering (Ley D, 2013) - A Learning-by-Metaphor Human-Machine System (Rubin S, 2006) - A Survey on Human Machine Dialogue Systems (Mallios S, 2016) - Abnormal Operation Diagnosis in Human-Machine Systems (Berdjag D, 2015) - Advances in Human-Machine Systems for In-Vehicle Environments (Hansen J, 2008) - RECON: An Adaptive Human-Machine System for Supporting Intelligence Analysis (Ross W, 2013) - Virtual/Mixed/Augmented Reality Laboratory Research for the Study of Augmented Human and Human-Machine Systems (Helin K, 2016) - Physiological Cognitive State Assessment: Applications for Designing Effective Human-Machine Systems (Estepp J, 2011) - Conceptualizing Hybrid Human-Machine Systems and Interaction (Buxbaum-Conradi S, 2016) - Cooperative Problem Solving in Human-Machine Systems: Theory, Models, and Intelligent Associate Systems (Jones P, 2000) - An Adaptive Basic I/O Gain Tuning Method Based on Leveling Control Input Histogram for Human-Machine Systems (Kamezaki M, 2014) - Analysis and Modeling of Human Impedance Properties for Designing a Human-Machine Control System (Tanaka Y, 2007) - Enhancing the Dependability of Human-Machine Systems Using Brunswikian Symmetry (Jipp M, 2006) - Design and Modelling in Optimization of Human-Machine Systems Functioning (Grif M, 2015)

Concept Categories from Open Coding

Primary Category	Secondary Category	Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)
		- A Quantitative Measure for Information Transfer in Human-Machine Control Systems (Bakaev M, 2015) - Formal Framework for Detection of Automation Surprises in Human-Machine Systems Modeled by Hybrid Automata (Ishii D, 2014) - Simulation Model of the Decision-Making Support for Human-Machine Systems Operators (Nina R, 2015) - Optimal Modality Selection for Multimodal Human-Machine Systems using RIMAG (Jacob M, 2014) - Optimal Task Allocation for Human-Machine Collaborative Manufacturing Systems (Hu B, 2017)
	Machine Systems	- Can Machines Intelligently Propose Novel and Reasonable Scientific Hypotheses? (Wang P, 2017) - Google's Neural Machine Translation System: Bridging the Gap between Human and Machine Translation (Wu Y, 2016) - Hidden Technical Debt in Machine Learning Systems (Sculley D, 2015)
	Intelligent Systems	- Why and Why Not Explanations Improve the Intelligibility of Context-Aware Intelligent Systems (Lim B, 2009) - Robotics and Intelligent Systems in Support of Society (Reddy R, 2006) - Intelligent Control for Human-Machine Systems (Buss M, 1996) - Human-Machine Cooperation to Design Intelligent Manufacturing Systems (Pacaux-Lemoine M-P, 2016) - Real-Time Motion Planning Methods for Autonomous On-Road Driving: State-of-The-Art and Future Research Directions (Katrakazas C, 2015)
	Systems Convergence	- 5G: The Convergence of Wirelessly Communications (Chávez-Santiago R, 2015) - Convergence and Competition: The Case of Bank Regulation in Britain and the United States (Schooner H, 1999) - Cloudlets: At the Leading Edge of Mobile-Cloud Convergence (Satyanarayanan M, 2014)
	Socio-Technical Systems	- Socio-Technical Systems: From Design Methods to Systems Engineering (Baxter G, 2011) - The New Stream of Socio-Technical Approach and Main Stream Information Systems Research (Ghaffarian V, 2011) - Socio-Technical Systems Analysis in Health Care: A Research Agenda (Carayon P, 2011)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Ethical and Legal Issues of the Use of Computational Intelligence Techniques in Computer Security and Computer Forensics (Stahl B, 2010)
	Organizational Systems	- Designing Organizational Systems (Baskerville R, 2013) - Perspectives on Organizational Change: Systems and Complexity Theories (Amagoh F, 2008) - The Systems Theory of Management in Modern Day Organizations - A Study of Aldgate Congress Resort Limited Port Harcourt (Chikere C, 2015) - Two Approaches to Organizational Analysis: A Critique and a Suggestion (Etzioni A, 1960) - A Critical Review of the Use of System Dynamics for Organizational Consultation Projects (Zock A, 2004)
Decision	Decision Theory	- Behavioral Decision Theory Perspectives On Risk And Safety (Slovic P, 1984) - Decision Theory as Practice: Crafting Rationality in Organizations (Cabantous L, 2010) - Decision Theory in Maintenance Decision Making (Almeida A, 1995) - Beyond Statistical Inference: A Decision Theory for Science (Killeen P, 2006) - Decision Theory in Expert Systems and Artificial Intelligence (Horvitz E, 1988) - Qualitative Decision Theory: From Savage's Axioms to Non-Monotonic Reasoning (Dubois D, 2002) - Decision Theory Under Ambiguity (Etner J, 2012) - Fuzzy Sets and Decision Theory (Capocelli R, 1973) - A Decision Theory Approach to The Business Judgment Rule: Reflections on Disney, Good Faith, and Judicial Uncertainty (Gold A, 2007) - Judgment and Decision: Theory and Application (Pitz G, 1984) - Decision Theory without Logical Omniscience: Toward an Axiomatic Framework for Bounded Rationality (Lipman B, 1998) - Application of Decision Theory to the Testing of Large Systems (Wong P, 1971) - Causal Decision Theory and EPR Correlations (Ahmed A, 2014) - On the Use of Bayesian Decision Theory for Issuing Natural Hazard Warnings (Economou T, 2016)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- A Decision Theory of Statutory Interpretation: Legislative History by the Rules (Nourse V, 2012) - Decision Theory and Human Behavior (Lee W, 1971)
	Decision Making	- Decision-Theoretic Harmony: A First Step (Yi L, 2010) - Satisfying Games and Decision Making: With Applications to Engineering and Computer Science (Stirling W, 2003) - Choice Under Uncertainty (Levin J, 2006) - Shared Decision Making- Finding the Sweet Spot (Fried T, 2016) - Shared Decision Making, Contextualized (Ferrer R, 2013) - Shared Decision-Making in The Medical Encounter: What Does It Mean? (Or It Takes At Least Two To Tango) (Charles C, 1997) - Making Shared Decision-Making A Reality- No Decision about Me, Without Me (Coulter A, 2011) - Operational Intelligence Discovery and Knowledge-Mapping Approach in a Supply Network With Uncertainty (Koh S, 2006) - A Prospect Theory-Based Interval Dynamic Reference Point Method for Emergency Decision Making (Wang L, 2015) - Decision Making Under Uncertainty: The Impacts of Emotional Intelligence and Behavioral Patterns (Lashgari M, 2015) - Risk and Decision Making: The "Logic" of Probability (Borovcnik M, 2015) - A Comparison of Axiomatic Approaches to Qualitative Decision Making Using Possibility Theory (Giang P, 2001) - Robust, Scalable Hybrid Decision Networks (Scholz J, 2013) - Enhancing the Decision Making Process: An Ontology-based Approach (Mansingh, 2014)
	Reasoning	- How Emotions Affect Logical Reasoning: Evidence from Experiments with Mood-Manipulated Participants, Spider Phobics, and People with Exam Anxiety (Jung N, 2014) - Reasoning, Learning, and Creativity: Frontal Lobe Function and Human Decision-Making (Collins A, 2012) - Counterfactual Reasoning and Learning Systems: The Example of Computational Advertising (Bottou L, 2013) - Metaphors We Think With: The Role of Metaphor in Reasoning (Thibodeau P, 2011) - Reasoning Ability is (Little More Than) Working-Memory Capacity (Kyllonen P, 1990) - Working Memory Capacity Explains Reasoning Ability- and a Little Bit More (Su¨ß H-M, 2002)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
	Collaborative Inquiry	- Support of the Collaborative Inquiry Learning Process: Influence of Support on Task and Team Regulation (Saab N, 2011) - A Web-based Collaborative Framework for Facilitating Decision Making on a 3D Design Developing Process (Nyamsuren P, 2015) - Collaborative Inquiry Learning: Models, Tools, and Challenges (Bell T, 2010)
Design	Design of Technologies	- Toward Cognitive Assistants for Complex Decision Making Under Uncertainty (Schum D, 2014) - Design: The Only Methodology of Technology? (Williams P, 2000) - The Influence of Young Children's Use of Technology on Their Learning: A Review (Hsin C, 2014) - Teaching Science through Designing Technology (Sidawi M, 2009) - Research Framework, Strategies, and Applications of Intelligent Agent Technologies (IATs) in Marketing (Kumar V, 2016)
	Interface Design	- The Impact of Interface Affordances on Human Ideation, Problem-Solving and Inferential Reasoning (Oviatte S, 2012) - The Study of Models of Intelligent Interfaces (Puerta A, 1993) - User Interface Design Principles for Interactive Television Applications (Chorianopoulos K, 2008) - Evaluation of Hydraulic Excavator Human-Machine Interface Concepts Using NASA TLX (Akyeampong J, 2014) - Measurable Decision Making with GSR and Pupillary Analysis for Intelligent User Interface (Zhou J, 2015)
	Design Integration	- Cochlear Implants: System Design, Integration and Evaluation (Zeng F, 2008) - Describing the Creative Design Process by the Integration of Engineering Design and Cognitive Psychology Literature (Howard T, 2008) - Design, Integration and Test of a Shopping Assistance Robot System (Garcia-Arroya M, 2012)
	Collaborative Design	- Collaborative Design in Product Development Based on Product Layout Model (Bai Y, 2005)

Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
		- Collaborative Design: Combining Computer-Aided Geometry Design and Building Information Modelling (Bhoosan S, 2017) - Principles for Knowledge Creation in Collaborative Design Science Research (Otto B, 2012) - Feature-based Design in a Distributed and Collaborative Environment (Li W, 2004) - A Multi-Agent Approach to Collaborative Design of Modular Products (Huang C, 2004)
Human	Human Cognition	- Human-Recommender Systems: From Benchmark Data to Benchmark Cognitive Models (Shafto P, 2016) - Socio-Cognitive Aspects of Interoperability: Understanding Communication Task Environments among Different Organizations (Kwon G, 2011) - New Thinking: The Evolution of Human Cognition (Heyes C, 2012) - Unraveling the Evolution of Uniquely Human Cognition (Maclean E, 2016) - Bayesian Learning Theory Applied to Human Cognition (Jacobs R, 2011) - The Effects of Stress and Stress Hormones on Human Cognition: Implications for the Field of Brain and Cognition (Lupien S, 2007) - Partners in Cognition: Extending Human Intelligence with Intelligent Technologies (Salomon G, 1991) - Working Memory Capacity and its Relation to General Intelligence (Conway A, 2003) - Working Memory is (almost) Perfectly Predicted by g (Colom R, 2004)
	Human-Computer Interactions	- The Feet in Human-Computer Interaction: A Surveyor Foot-Based Interaction (Velloso E, 2015) - The Relationship of Action Research to Human-Computer Interaction (Hayes G, 2011) - Indexicality: Understanding Mobile Human-Computer Interaction in Context (Kjeldskov J, 2010) - Sustainable Making? Balancing Optimism and Criticism in HCI Discourse (Roedl D, 2015) - Brain-Computer Interface Technologies in the Coming Decades (Lance B, 2012)

للاستشارات المنارة

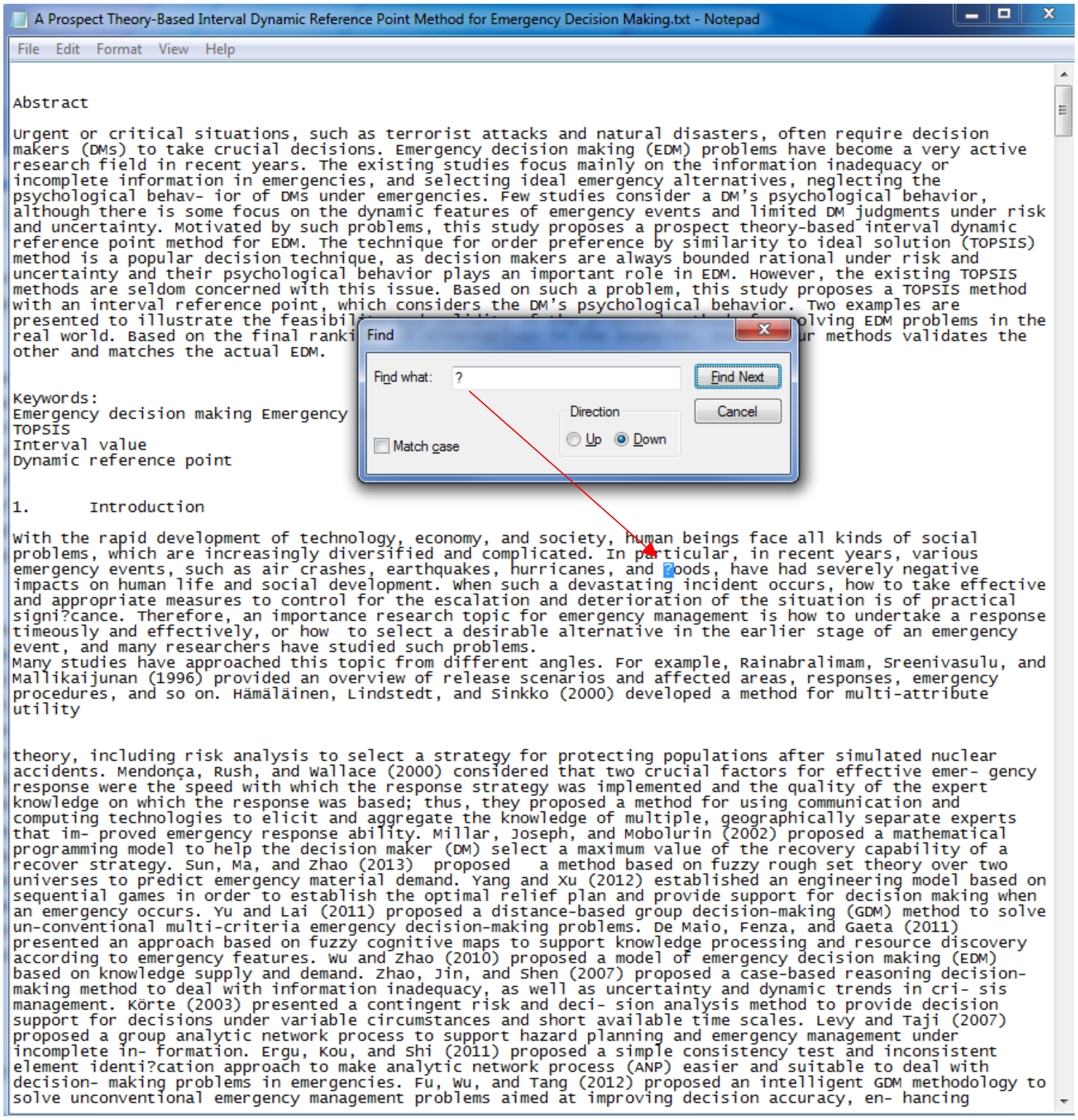
Concept Categories from Open Coding		
Primary Category	**Secondary Category**	**Data/Corpus from where categorical theme emerged (information includes: corpus title, lead author by last name and first initial, year)**
Process	Business Process	- Business Process Verification- Finally a Reality! (Wynn M, 2009) - Toward a Theory of Business Process Change Management (Kettinger W, 1995) - Research in Business Process Management: A bibliometric Analysis (Wohlhaupter P, 2012) - Business Process Change: A Study of Methodologies, Techniques, and Tools (Kettinger W, 1997) - The Implementation of Business Process Reengineering (Grover V, 1995)
	Information Processing Analysis	- An Information-Processing Analysis of Mindfulness: Implications for Relapse Prevention in the Treatment of Substance Abuse (Breslin F, 2002) - An Information Processing Analysis of Expert and Novice Teachers' Problem Solving (Swanson H, 1990) - Strengthening Intelligence Education with Information-Processing and Knowledge Organization Competencies (Wu Y, 2013) - Digital Visual Information Processing: Adding Vision and Graphics (Leberl F, 2000)
	Mixed-Initiative Approach	- Mixed-Initiative Interface Personalization as a Case Study in Usable AI (Bunt A, 2009) - Data-to-Model: A Mixed Initiative Approach for Rapid Ethnographic Assessment (Carley K, 2012) - Mixed-Initiative Human-Robot Interaction: Definition, Taxonomy, and Survey (Jiang S, 2015) - Evaluating Mixed-Initiative Systems: An Experimental Approach (Cortelweaklya G, 2006)

APPENDIX

B. ISSUES FROM PDF TO TEXT FILE CONVERSION

The following issues are encountered while converting pdf to text files:

- Characters converted into “?” sign in some words: As seen from the image below, actual word was “flood.” However, the conversion changed that into “?oods” by changing “fl” into “?” sign.


A Prospect Theory-Based Interval Dynamic Reference Point Method for Emergency Decision Making.txt - Notepad
File
Edit
Format
View
Help
Find
Find what:
Find Next
Cancel
Direction
○ Up
● Down
☐ Match case

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Abstract

Urgent or critical situations, such as terrorist attacks and natural disasters, often require decision
makers (DMs) to take crucial decisions. Emergency decision making (EDM) problems have become a very active
research field in recent years. The existing studies focus mainly on the information inadequacy or
incomplete information in emergencies, and selecting ideal emergency alternatives, neglecting the
psychological behav- ior of DMs under emergencies. Few studies consider a DM’s psychological behavior,
although there is some focus on the dynamic features of emergency events and limited DM judgments under risk
and uncertainty. Motivated by such problems, this study proposes a prospect theory-based interval dynamic
reference point method for EDM. The technique for order preference by similarity to ideal solution (TOPSIS)
method is a popular decision technique, as decision makers are always bounded rational under risk and
uncertainty and their psychological behavior plays an important role in EDM. However, the existing TOPSIS
methods are seldom concerned with this issue. Based on such a problem, this study proposes a TOPSIS method
with an interval reference point, which considers the DM’s psychological behavior. Two examples are
presented to illustrate the feasibil                                               olving EDM problems in the
real world. Based on the final ranki                                                ur methods validates the
other and matches the actual EDM.


Keywords:
Emergency decision making Emergency
TOPSIS
Interval value
Dynamic reference point


1.      Introduction

With the rapid development of technology, economy, and society, human beings face all kinds of social
problems, which are increasingly diversified and complicated. In particular, in recent years, various
emergency events, such as air crashes, earthquakes, hurricanes, and ?oods, have had severely negative
impacts on human life and social development. When such a devastating incident occurs, how to take effective
and appropriate measures to control for the escalation and deterioration of the situation is of practical
signi?cance. Therefore, an importance research topic for emergency management is how to undertake a response
timeously and effectively, or how  to select a desirable alternative in the earlier stage of an emergency
event, and many researchers have studied such problems.
Many studies have approached this topic from different angles. For example, Rainabralimam, Sreenivasulu, and
Mallikaijunan (1996) provided an overview of release scenarios and affected areas, responses, emergency
procedures, and so on. Hämäläinen, Lindstedt, and Sinkko (2000) developed a method for multi-attribute
utility


theory, including risk analysis to select a strategy for protecting populations after simulated nuclear
accidents. Mendonça, Rush, and Wallace (2000) considered that two crucial factors for effective emer- gency
response were the speed with which the response strategy was implemented and the quality of the expert
knowledge on which the response was based; thus, they proposed a method for using communication and
computing technologies to elicit and aggregate the knowledge of multiple, geographically separate experts
that im- proved emergency response ability. Millar, Joseph, and Mobolurin (2002) proposed a mathematical
programming model to help the decision maker (DM) select a maximum value of the recovery capability of a
recover strategy. Sun, Ma, and Zhao (2013)  proposed   a method based on fuzzy rough set theory over two
universes to predict emergency material demand. Yang and Xu (2012) established an engineering model based on
sequential games in order to establish the optimal relief plan and provide support for decision making when
an emergency occurs. Yu and Lai (2011) proposed a distance-based group decision-making (GDM) method to solve
un-conventional multi-criteria emergency decision-making problems. De Maio, Fenza, and Gaeta (2011)
presented an approach based on fuzzy cognitive maps to support knowledge processing and resource discovery
according to emergency features. Wu and Zhao (2010) proposed a model of emergency decision making (EDM)
based on knowledge supply and demand. Zhao, Jin, and Shen (2007) proposed a case-based reasoning decision-
making method to deal with information inadequacy, as well as uncertainty and dynamic trends in cri- sis
management. Körte (2003) presented a contingent risk and deci- sion analysis method to provide decision
support for decisions under variable circumstances and short available time scales. Levy and Taji (2007)
proposed a group analytic network process to support hazard planning and emergency management under
incomplete in- formation. Ergu, Kou, and Shi (2011) proposed a simple consistency test and inconsistent
element identi?cation approach to make analytic network process (ANP) easier and suitable to deal with
decision- making problems in emergencies. Fu, Wu, and Tang (2012) proposed an intelligent GDM methodology to
solve unconventional emergency management problems aimed at improving decision accuracy, en- hancing
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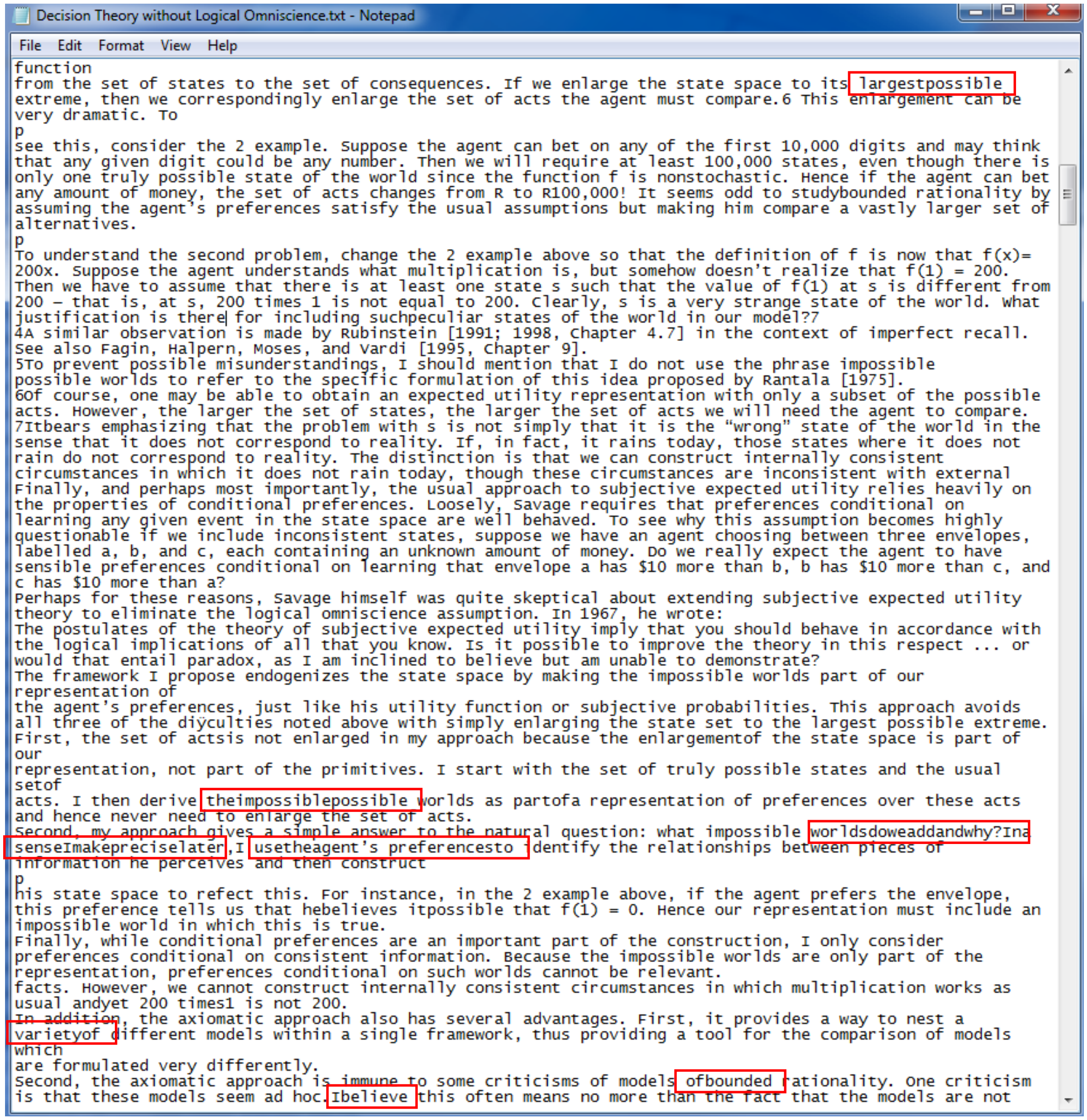
- Words combined into a single word: As seen from the image below, two or more words combined into a single word:



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function
from the set of states to the set of consequences. If we enlarge the state space to its largestpossible
extreme, then we correspondingly enlarge the set of acts the agent must compare.6 This enlargement can be
very dramatic. To
p
see this, consider the 2 example. Suppose the agent can bet on any of the first 10,000 digits and may think
that any given digit could be any number. Then we will require at least 100,000 states, even though there is
only one truly possible state of the world since the function f is nonstochastic. Hence if the agent can bet
any amount of money, the set of acts changes from R to R100,000! It seems odd to studybounded rationality by
assuming the agent's preferences satisfy the usual assumptions but making him compare a vastly larger set of
alternatives.
p
To understand the second problem, change the 2 example above so that the definition of f is now that f(x)=
200x. Suppose the agent understands what multiplication is, but somehow doesn't realize that f(1) = 200.
Then we have to assume that there is at least one state s such that the value of f(1) at s is different from
200 – that is, at s, 200 times 1 is not equal to 200. Clearly, s is a very strange state of the world. What
justification is there for including suchpeculiar states of the world in our model?7
4A similar observation is made by Rubinstein [1991; 1998, Chapter 4.7] in the context of imperfect recall.
See also Fagin, Halpern, Moses, and Vardi [1995, Chapter 9].
5To prevent possible misunderstandings, I should mention that I do not use the phrase impossible
possible worlds to refer to the specific formulation of this idea proposed by Rantala [1975].
6Of course, one may be able to obtain an expected utility representation with only a subset of the possible
acts. However, the larger the set of states, the larger the set of acts we will need the agent to compare.
7Itbears emphasizing that the problem with s is not simply that it is the "wrong" state of the world in the
sense that it does not correspond to reality. If, in fact, it rains today, those states where it does not
rain do not correspond to reality. The distinction is that we can construct internally consistent
circumstances in which it does not rain today, though these circumstances are inconsistent with external
Finally, and perhaps most importantly, the usual approach to subjective expected utility relies heavily on
the properties of conditional preferences. Loosely, Savage requires that preferences conditional on
learning any given event in the state space are well behaved. To see why this assumption becomes highly
questionable if we include inconsistent states, suppose we have an agent choosing between three envelopes,
labelled a, b, and c, each containing an unknown amount of money. Do we really expect the agent to have
sensible preferences conditional on learning that envelope a has $10 more than b, b has $10 more than c, and
c has $10 more than a?
Perhaps for these reasons, Savage himself was quite skeptical about extending subjective expected utility
theory to eliminate the logical omniscience assumption. In 1967, he wrote:
The postulates of the theory of subjective expected utility imply that you should behave in accordance with
the logical implications of all that you know. Is it possible to improve the theory in this respect ... or
would that entail paradox, as I am inclined to believe but am unable to demonstrate?
The framework I propose endogenizes the state space by making the impossible worlds part of our
representation of
the agent's preferences, just like his utility function or subjective probabilities. This approach avoids
all three of the diÿculties noted above with simply enlarging the state set to the largest possible extreme.
First, the set of actsis not enlarged in my approach because the enlargementof the state space is part of
our
representation, not part of the primitives. I start with the set of truly possible states and the usual
setof
acts. I then derive theimpossiblepossible worlds as partofa representation of preferences over these acts
and hence never need to enlarge the set of acts.
Second, my approach gives a simple answer to the natural question: what impossible worldsdoweaddandwhy?Ina
senseImakepreciselater,I usetheagent's preferencesto identify the relationships between pieces of
information he perceives and then construct
p
his state space to refect this. For instance, in the 2 example above, if the agent prefers the envelope,
this preference tells us that hebelieves itpossible that f(1) = 0. Hence our representation must include an
impossible world in which this is true.
Finally, while conditional preferences are an important part of the construction, I only consider
preferences conditional on consistent information. Because the impossible worlds are only part of the
representation, preferences conditional on such worlds cannot be relevant.
facts. However, we cannot construct internally consistent circumstances in which multiplication works as
usual andyet 200 times1 is not 200.
In addition, the axiomatic approach also has several advantages. First, it provides a way to nest a
varietyof different models within a single framework, thus providing a tool for the comparison of models
which
are formulated very differently.
Second, the axiomatic approach is immune to some criticisms of models ofbounded rationality. One criticism
is that these models seem ad hoc.Ibelieve this often means no more than the fact that the models are not
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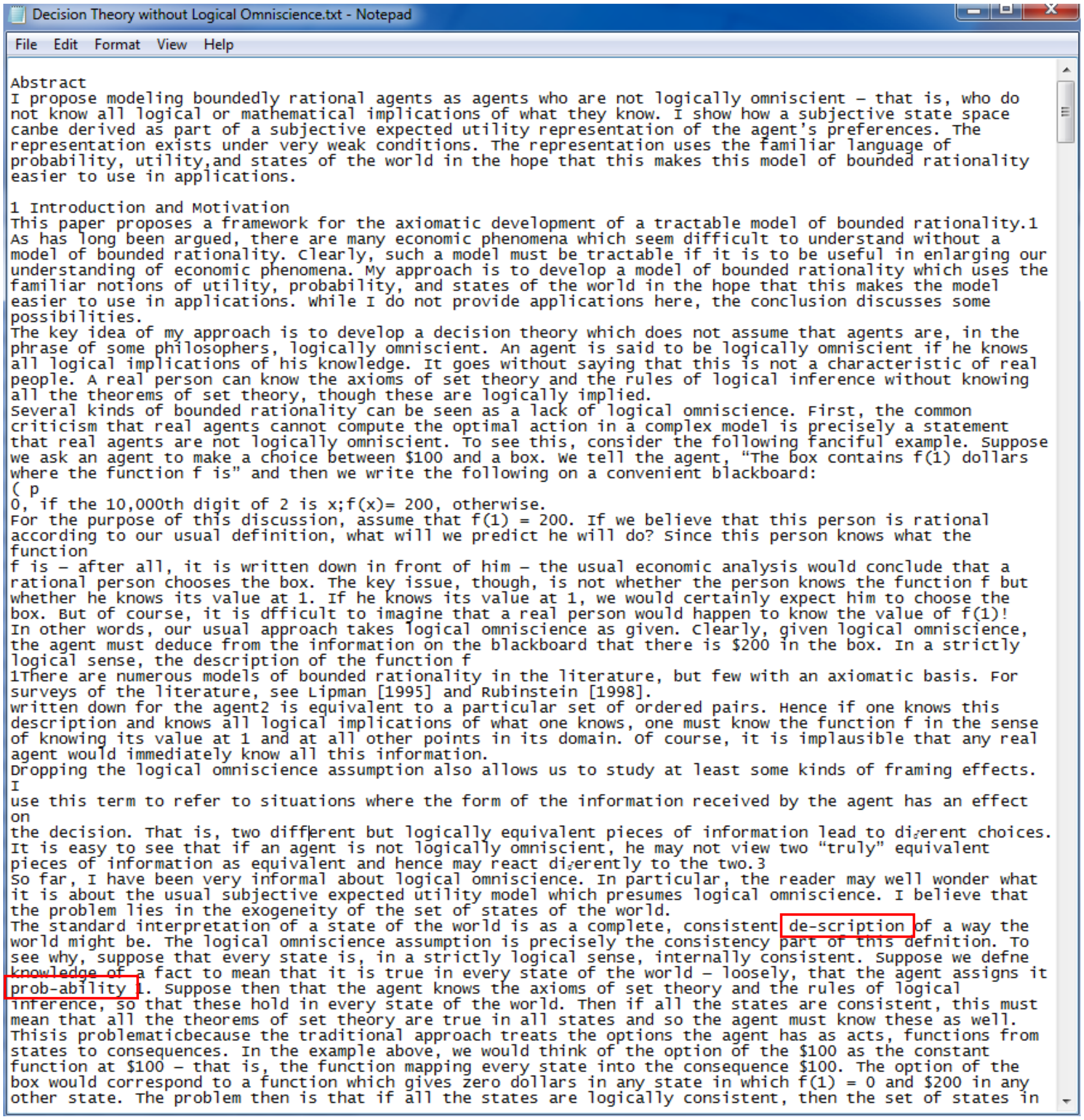
- Words got separated by hyphen: As seen from the image below, words got separated by hyphen:



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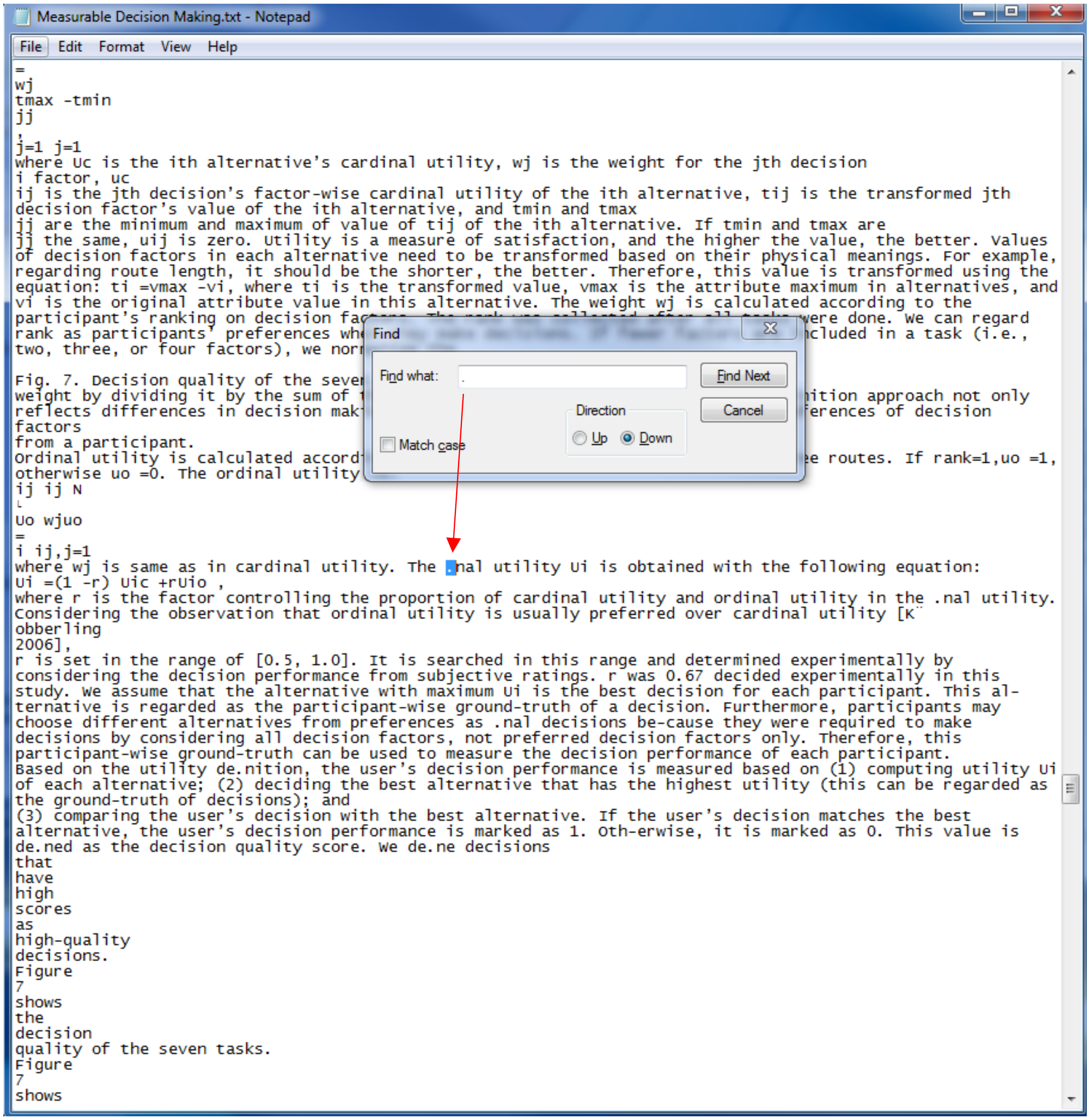
Abstract
I propose modeling boundedly rational agents as agents who are not logically omniscient – that is, who do
not know all logical or mathematical implications of what they know. I show how a subjective state space
canbe derived as part of a subjective expected utility representation of the agent’s preferences. The
representation exists under very weak conditions. The representation uses the familiar language of
probability, utility,and states of the world in the hope that this makes this model of bounded rationality
easier to use in applications.

1 Introduction and Motivation
This paper proposes a framework for the axiomatic development of a tractable model of bounded rationality.1
As has long been argued, there are many economic phenomena which seem difficult to understand without a
model of bounded rationality. Clearly, such a model must be tractable if it is to be useful in enlarging our
understanding of economic phenomena. My approach is to develop a model of bounded rationality which uses the
familiar notions of utility, probability, and states of the world in the hope that this makes the model
easier to use in applications. While I do not provide applications here, the conclusion discusses some
possibilities.
The key idea of my approach is to develop a decision theory which does not assume that agents are, in the
phrase of some philosophers, logically omniscient. An agent is said to be logically omniscient if he knows
all logical implications of his knowledge. It goes without saying that this is not a characteristic of real
people. A real person can know the axioms of set theory and the rules of logical inference without knowing
all the theorems of set theory, though these are logically implied.
Several kinds of bounded rationality can be seen as a lack of logical omniscience. First, the common
criticism that real agents cannot compute the optimal action in a complex model is precisely a statement
that real agents are not logically omniscient. To see this, consider the following fanciful example. Suppose
we ask an agent to make a choice between $100 and a box. We tell the agent, “The box contains f(1) dollars
where the function f is” and then we write the following on a convenient blackboard:
( p
0, if the 10,000th digit of 2 is x;f(x)= 200, otherwise.
For the purpose of this discussion, assume that f(1) = 200. If we believe that this person is rational
according to our usual definition, what will we predict he will do? Since this person knows what the
function
f is – after all, it is written down in front of him – the usual economic analysis would conclude that a
rational person chooses the box. The key issue, though, is not whether the person knows the function f but
whether he knows its value at 1. If he knows its value at 1, we would certainly expect him to choose the
box. But of course, it is dfficult to imagine that a real person would happen to know the value of f(1)!
In other words, our usual approach takes logical omniscience as given. Clearly, given logical omniscience,
the agent must deduce from the information on the blackboard that there is $200 in the box. In a strictly
logical sense, the description of the function f
1There are numerous models of bounded rationality in the literature, but few with an axiomatic basis. For
surveys of the literature, see Lipman [1995] and Rubinstein [1998].
written down for the agent2 is equivalent to a particular set of ordered pairs. Hence if one knows this
description and knows all logical implications of what one knows, one must know the function f in the sense
of knowing its value at 1 and at all other points in its domain. Of course, it is implausible that any real
agent would immediately know all this information.
Dropping the logical omniscience assumption also allows us to study at least some kinds of framing effects.
I
use this term to refer to situations where the form of the information received by the agent has an effect
on
the decision. That is, two different but logically equivalent pieces of information lead to diﬀerent choices.
It is easy to see that if an agent is not logically omniscient, he may not view two “truly” equivalent
pieces of information as equivalent and hence may react diﬀerently to the two.3
So far, I have been very informal about logical omniscience. In particular, the reader may well wonder what
it is about the usual subjective expected utility model which presumes logical omniscience. I believe that
the problem lies in the exogeneity of the set of states of the world.
The standard interpretation of a state of the world is as a complete, consistent de-scription of a way the
world might be. The logical omniscience assumption is precisely the consistency part of this defnition. To
see why, suppose that every state is, in a strictly logical sense, internally consistent. Suppose we defne
knowledge of a fact to mean that it is true in every state of the world – loosely, that the agent assigns it
prob-ability 1. Suppose then that the agent knows the axioms of set theory and the rules of logical
inference, so that these hold in every state of the world. Then if all the states are consistent, this must
mean that all the theorems of set theory are true in all states and so the agent must know these as well.
Thisis problematicbecause the traditional approach treats the options the agent has as acts, functions from
states to consequences. In the example above, we would think of the option of the $100 as the constant
function at $100 – that is, the function mapping every state into the consequence $100. The option of the
box would correspond to a function which gives zero dollars in any state in which f(1) = 0 and $200 in any
other state. The problem then is that if all the states are logically consistent, then the set of states in
```

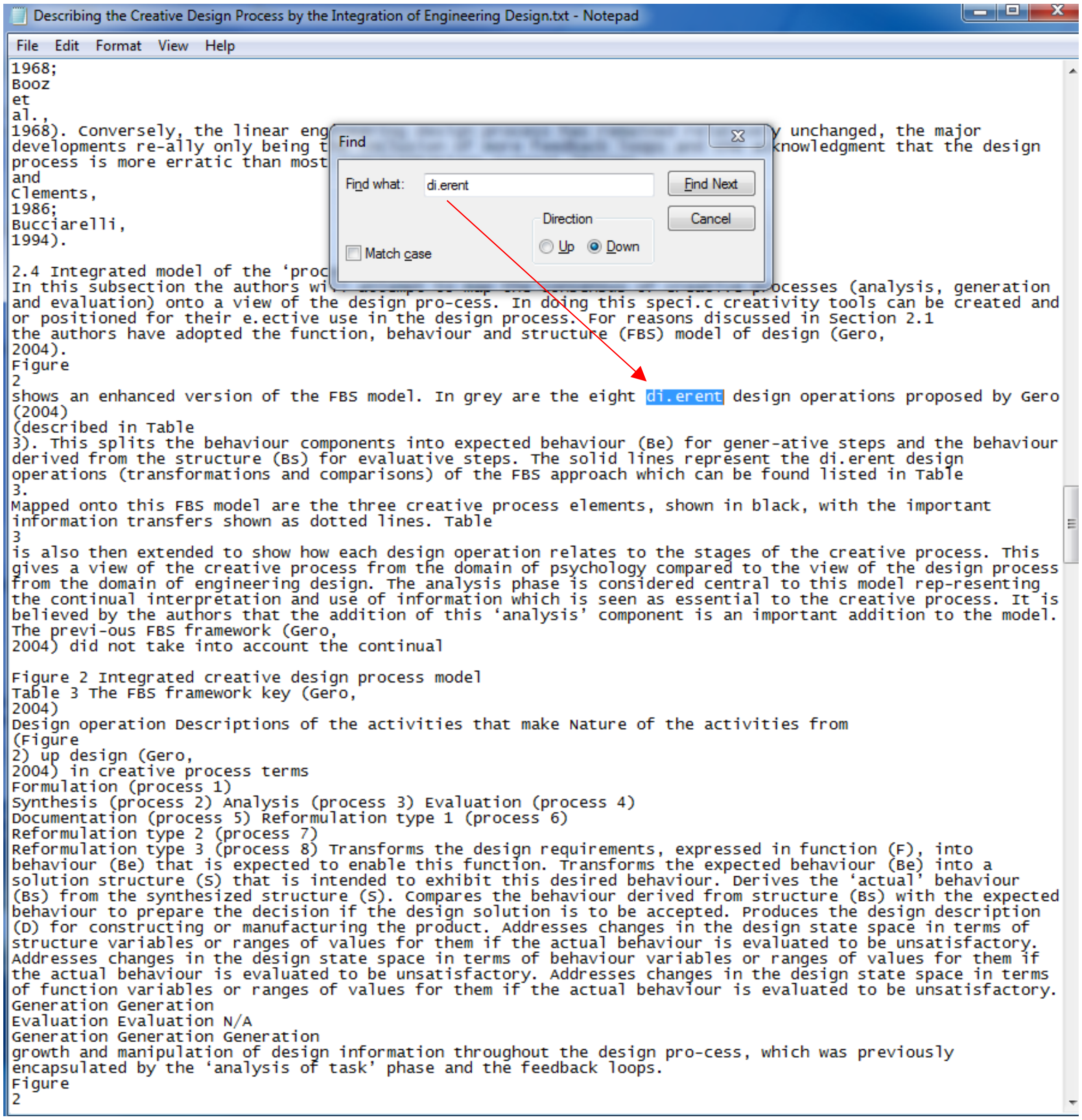
- Characters converted into “.” period sign in some words: As seen from the image below, actual word was “final.” However, the conversion changed that into “.nal” by changing “fi” into “.” sign.



```
=
wj
tmax -tmin
jj
,
j=1 j=1
where Uc is the ith alternative's cardinal utility, wj is the weight for the jth decision
i factor, uc
ij is the jth decision's factor-wise cardinal utility of the ith alternative, tij is the transformed jth
decision factor's value of the ith alternative, and tmin and tmax
jj are the minimum and maximum of value of tij of the ith alternative. If tmin and tmax are
jj the same, uij is zero. Utility is a measure of satisfaction, and the higher the value, the better. Values
of decision factors in each alternative need to be transformed based on their physical meanings. For example,
regarding route length, it should be the shorter, the better. Therefore, this value is transformed using the
equation: ti =vmax -vi, where ti is the transformed value, vmax is the attribute maximum in alternatives, and
vi is the original attribute value in this alternative. The weight wj is calculated according to the
participant's ranking on decision fa                                       were done. We can regard
rank as participants' preferences wh                                       ncluded in a task (i.e.,
two, three, or four factors), we nor

Fig. 7. Decision quality of the seve
weight by dividing it by the sum of                                        ition approach not only
reflects differences in decision mak                                       ferences of decision
factors
from a participant.
Ordinal utility is calculated accord                                       e routes. If rank=1,uo =1,
otherwise uo =0. The ordinal utility
ij ij N
L
Uo wjuo
=
i ij,j=1
where wj is same as in cardinal utility. The .nal utility Ui is obtained with the following equation:
Ui =(1 -r) Uic +rUio ,
where r is the factor controlling the proportion of cardinal utility and ordinal utility in the .nal utility.
Considering the observation that ordinal utility is usually preferred over cardinal utility [K¨
obberling
2006],
r is set in the range of [0.5, 1.0]. It is searched in this range and determined experimentally by
considering the decision performance from subjective ratings. r was 0.67 decided experimentally in this
study. We assume that the alternative with maximum Ui is the best decision for each participant. This al-
ternative is regarded as the participant-wise ground-truth of a decision. Furthermore, participants may
choose different alternatives from preferences as .nal decisions be-cause they were required to make
decisions by considering all decision factors, not preferred decision factors only. Therefore, this
participant-wise ground-truth can be used to measure the decision performance of each participant.
Based on the utility de.nition, the user's decision performance is measured based on (1) computing utility Ui
of each alternative; (2) deciding the best alternative that has the highest utility (this can be regarded as
the ground-truth of decisions); and
(3) comparing the user's decision with the best alternative. If the user's decision matches the best
alternative, the user's decision performance is marked as 1. Oth-erwise, it is marked as 0. This value is
de.ned as the decision quality score. We de.ne decisions
that
have
high
scores
as
high-quality
decisions.
Figure
7
shows
the
decision
quality of the seven tasks.
Figure
7
shows
```

Similarly, “ff” changed into “.” period sign:


Describing the Creative Design Process by the Integration of Engineering Design.txt - Notepad
File
Edit
Format
View
Help
Find
Find Next
Cancel

```
1968;
Booz
et
al.,
1968). Conversely, the linear eng                                              y unchanged, the major
developments re-ally only being t                                              knowledgment that the design
process is more erratic than most
and
Clements,
1986;
Bucciarelli,
1994).

2.4 Integrated model of the 'proc
In this subsection the authors wi                                              ocesses (analysis, generation
and evaluation) onto a view of the design pro-cess. In doing this speci.c creativity tools can be created and
or positioned for their e.ective use in the design process. For reasons discussed in Section 2.1
the authors have adopted the function, behaviour and structure (FBS) model of design (Gero,
2004).
Figure
2
shows an enhanced version of the FBS model. In grey are the eight di.erent design operations proposed by Gero
(2004)
(described in Table
3). This splits the behaviour components into expected behaviour (Be) for gener-ative steps and the behaviour
derived from the structure (Bs) for evaluative steps. The solid lines represent the di.erent design
operations (transformations and comparisons) of the FBS approach which can be found listed in Table
3.
Mapped onto this FBS model are the three creative process elements, shown in black, with the important
information transfers shown as dotted lines. Table
3
is also then extended to show how each design operation relates to the stages of the creative process. This
gives a view of the creative process from the domain of psychology compared to the view of the design process
from the domain of engineering design. The analysis phase is considered central to this model rep-resenting
the continual interpretation and use of information which is seen as essential to the creative process. It is
believed by the authors that the addition of this 'analysis' component is an important addition to the model.
The previ-ous FBS framework (Gero,
2004) did not take into account the continual

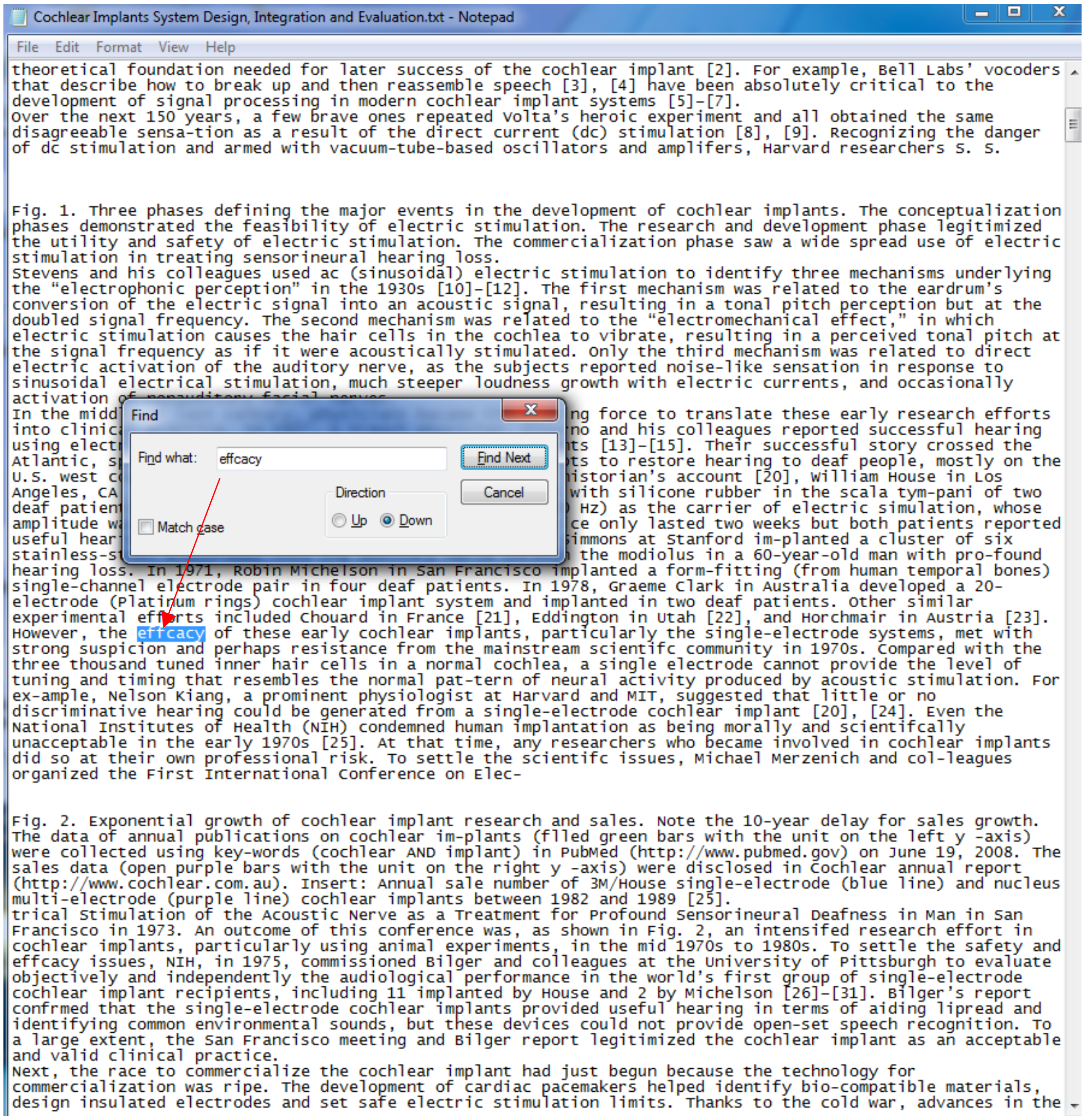
Figure 2 Integrated creative design process model
Table 3 The FBS framework key (Gero,
2004)
Design operation Descriptions of the activities that make Nature of the activities from
(Figure
2) up design (Gero,
2004) in creative process terms
Formulation (process 1)
Synthesis (process 2) Analysis (process 3) Evaluation (process 4)
Documentation (process 5) Reformulation type 1 (process 6)
Reformulation type 2 (process 7)
Reformulation type 3 (process 8) Transforms the design requirements, expressed in function (F), into
behaviour (Be) that is expected to enable this function. Transforms the expected behaviour (Be) into a
solution structure (S) that is intended to exhibit this desired behaviour. Derives the 'actual' behaviour
(Bs) from the synthesized structure (S). Compares the behaviour derived from structure (Bs) with the expected
behaviour to prepare the decision if the design solution is to be accepted. Produces the design description
(D) for constructing or manufacturing the product. Addresses changes in the design state space in terms of
structure variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.
Addresses changes in the design state space in terms of behaviour variables or ranges of values for them if
the actual behaviour is evaluated to be unsatisfactory. Addresses changes in the design state space in terms
of function variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.
Generation Generation
Evaluation Evaluation N/A
Generation Generation Generation
growth and manipulation of design information throughout the design pro-cess, which was previously
encapsulated by the 'analysis of task' phase and the feedback loops.
Figure
2
```

Find what: di.erent

☐ Match case

Direction ○ Up ● Down

- Characters got deleted: As seen from the image below, actual word was "efficacy." However, the conversion changed that into "effcacy" by deleting "i" character.


Cochlear Implants System Design, Integration and Evaluation.txt - Notepad
File Edit Format View Help
Find
Find Next
Cancel
Direction
○ Up ● Down
☐ Match case

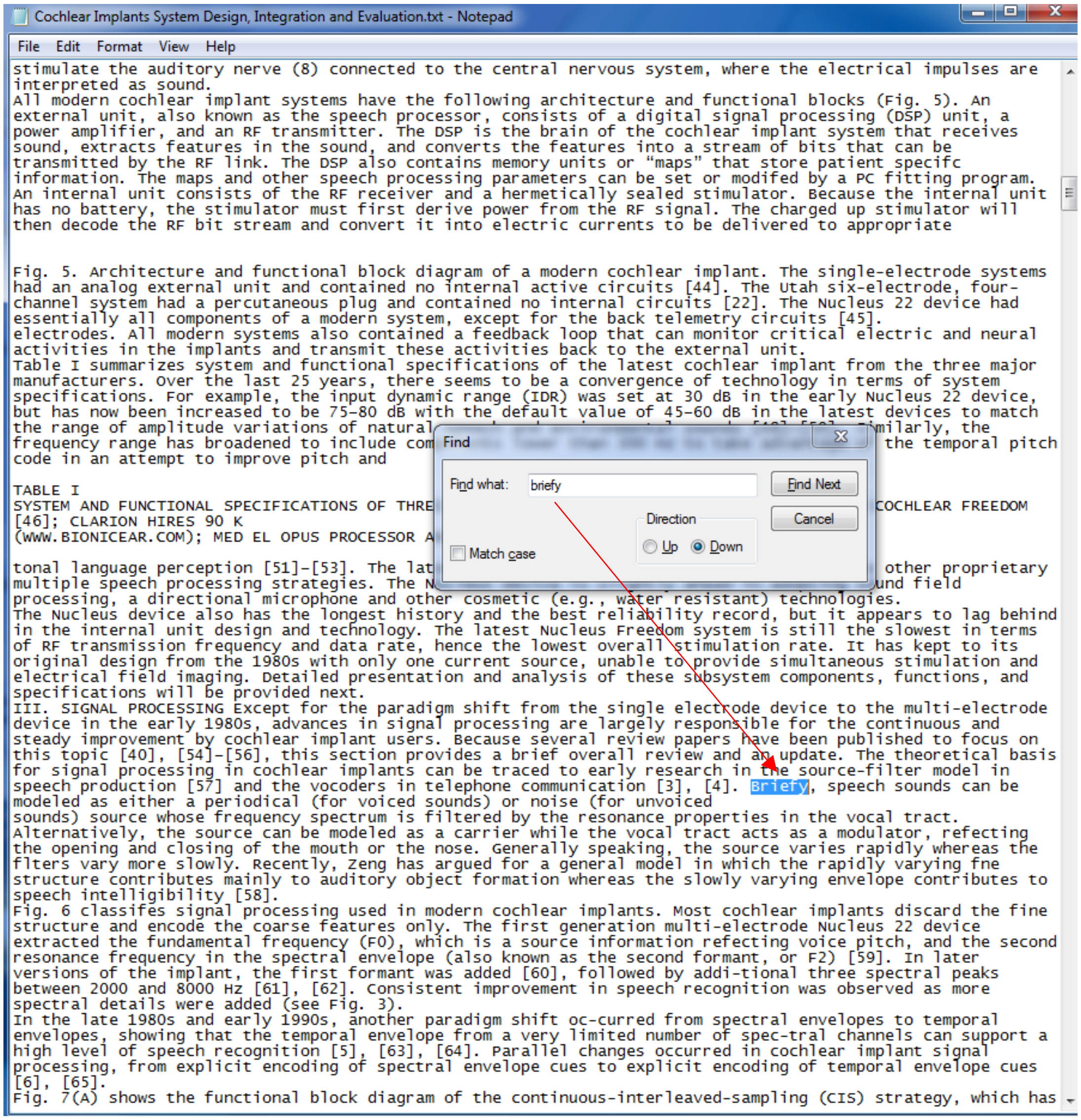
Find what: effcacy

```
theoretical foundation needed for later success of the cochlear implant [2]. For example, Bell Labs' vocoders
that describe how to break up and then reassemble speech [3], [4] have been absolutely critical to the
development of signal processing in modern cochlear implant systems [5]-[7].
Over the next 150 years, a few brave ones repeated Volta's heroic experiment and all obtained the same
disagreeable sensa-tion as a result of the direct current (dc) stimulation [8], [9]. Recognizing the danger
of dc stimulation and armed with vacuum-tube-based oscillators and amplifers, Harvard researchers S. S.


Fig. 1. Three phases defining the major events in the development of cochlear implants. The conceptualization
phases demonstrated the feasibility of electric stimulation. The research and development phase legitimized
the utility and safety of electric stimulation. The commercialization phase saw a wide spread use of electric
stimulation in treating sensorineural hearing loss.
Stevens and his colleagues used ac (sinusoidal) electric stimulation to identify three mechanisms underlying
the "electrophonic perception" in the 1930s [10]-[12]. The first mechanism was related to the eardrum's
conversion of the electric signal into an acoustic signal, resulting in a tonal pitch perception but at the
doubled signal frequency. The second mechanism was related to the "electromechanical effect," in which
electric stimulation causes the hair cells in the cochlea to vibrate, resulting in a perceived tonal pitch at
the signal frequency as if it were acoustically stimulated. Only the third mechanism was related to direct
electric activation of the auditory nerve, as the subjects reported noise-like sensation in response to
sinusoidal electrical stimulation, much steeper loudness growth with electric currents, and occasionally
activation o
In the midd                                         ng force to translate these early research efforts
into clinic                                         no and his colleagues reported successful hearing
using elect                                         ts [13]-[15]. Their successful story crossed the
Atlantic, s                                         ts to restore hearing to deaf people, mostly on the
U.S. west c                                         istorian's account [20], William House in Los
Angeles, CA                                         with silicone rubber in the scala tym-pani of two
deaf patien                                         Hz) as the carrier of electric simulation, whose
amplitude w                                         ce only lasted two weeks but both patients reported
useful hear                                         immons at Stanford im-planted a cluster of six
stainless-s                                         the modiolus in a 60-year-old man with pro-found
hearing loss. In 1971, Robin Michelson in San Francisco implanted a form-fitting (from human temporal bones)
single-channel electrode pair in four deaf patients. In 1978, Graeme Clark in Australia developed a 20-
electrode (Platinum rings) cochlear implant system and implanted in two deaf patients. Other similar
experimental efforts included Chouard in France [21], Eddington in Utah [22], and Horchmair in Austria [23].
However, the effcacy of these early cochlear implants, particularly the single-electrode systems, met with
strong suspicion and perhaps resistance from the mainstream scientifc community in 1970s. Compared with the
three thousand tuned inner hair cells in a normal cochlea, a single electrode cannot provide the level of
tuning and timing that resembles the normal pat-tern of neural activity produced by acoustic stimulation. For
ex-ample, Nelson Kiang, a prominent physiologist at Harvard and MIT, suggested that little or no
discriminative hearing could be generated from a single-electrode cochlear implant [20], [24]. Even the
National Institutes of Health (NIH) condemned human implantation as being morally and scientifcally
unacceptable in the early 1970s [25]. At that time, any researchers who became involved in cochlear implants
did so at their own professional risk. To settle the scientifc issues, Michael Merzenich and col-leagues
organized the First International Conference on Elec-


Fig. 2. Exponential growth of cochlear implant research and sales. Note the 10-year delay for sales growth.
The data of annual publications on cochlear im-plants (flled green bars with the unit on the left y -axis)
were collected using key-words (cochlear AND implant) in PubMed (http://www.pubmed.gov) on June 19, 2008. The
sales data (open purple bars with the unit on the right y -axis) were disclosed in Cochlear annual report
(http://www.cochlear.com.au). Insert: Annual sale number of 3M/House single-electrode (blue line) and nucleus
multi-electrode (purple line) cochlear implants between 1982 and 1989 [25].
trical Stimulation of the Acoustic Nerve as a Treatment for Profound Sensorineural Deafness in Man in San
Francisco in 1973. An outcome of this conference was, as shown in Fig. 2, an intensifed research effort in
cochlear implants, particularly using animal experiments, in the mid 1970s to 1980s. To settle the safety and
effcacy issues, NIH, in 1975, commissioned Bilger and colleagues at the University of Pittsburgh to evaluate
objectively and independently the audiological performance in the world's first group of single-electrode
cochlear implant recipients, including 11 implanted by House and 2 by Michelson [26]-[31]. Bilger's report
confrmed that the single-electrode cochlear implants provided useful hearing in terms of aiding lipread and
identifying common environmental sounds, but these devices could not provide open-set speech recognition. To
a large extent, the San Francisco meeting and Bilger report legitimized the cochlear implant as an acceptable
and valid clinical practice.
Next, the race to commercialize the cochlear implant had just begun because the technology for
commercialization was ripe. The development of cardiac pacemakers helped identify bio-compatible materials,
design insulated electrodes and set safe electric stimulation limits. Thanks to the cold war, advances in the
```

Similarly character “l” got deleted in some words. For an example, the following image shows how the conversion changed “Briefly” into “Briefy”:


Cochlear Implants System Design, Integration and Evaluation.txt - Notepad
File
Edit
Format
View
Help
Find
Find Next
Cancel
Direction

Find what: briefy

☐ Match case

○ Up ● Down

stimulate the auditory nerve (8) connected to the central nervous system, where the electrical impulses are
interpreted as sound.
All modern cochlear implant systems have the following architecture and functional blocks (Fig. 5). An
external unit, also known as the speech processor, consists of a digital signal processing (DSP) unit, a
power amplifier, and an RF transmitter. The DSP is the brain of the cochlear implant system that receives
sound, extracts features in the sound, and converts the features into a stream of bits that can be
transmitted by the RF link. The DSP also contains memory units or “maps” that store patient specifc
information. The maps and other speech processing parameters can be set or modifed by a PC fitting program.
An internal unit consists of the RF receiver and a hermetically sealed stimulator. Because the internal unit
has no battery, the stimulator must first derive power from the RF signal. The charged up stimulator will
then decode the RF bit stream and convert it into electric currents to be delivered to appropriate

Fig. 5. Architecture and functional block diagram of a modern cochlear implant. The single-electrode systems
had an analog external unit and contained no internal active circuits [44]. The Utah six-electrode, four-
channel system had a percutaneous plug and contained no internal circuits [22]. The Nucleus 22 device had
essentially all components of a modern system, except for the back telemetry circuits [45].
electrodes. All modern systems also contained a feedback loop that can monitor critical electric and neural
activities in the implants and transmit these activities back to the external unit.
Table I summarizes system and functional specifications of the latest cochlear implant from the three major
manufacturers. Over the last 25 years, there seems to be a convergence of technology in terms of system
specifications. For example, the input dynamic range (IDR) was set at 30 dB in the early Nucleus 22 device,
but has now been increased to be 75–80 dB with the default value of 45–60 dB in the latest devices to match
the range of amplitude variations of natural … milarly, the
frequency range has broadened to include com … the temporal pitch
code in an attempt to improve pitch and

TABLE I
SYSTEM AND FUNCTIONAL SPECIFICATIONS OF THRE … COCHLEAR FREEDOM
[46]; CLARION HIRES 90 K
(WWW.BIONICEAR.COM); MED EL OPUS PROCESSOR A

tonal language perception [51]–[53]. The lat … other proprietary
multiple speech processing strategies. The N … und field
processing, a directional microphone and other cosmetic (e.g., water resistant) technologies.
The Nucleus device also has the longest history and the best reliability record, but it appears to lag behind
in the internal unit design and technology. The latest Nucleus Freedom system is still the slowest in terms
of RF transmission frequency and data rate, hence the lowest overall stimulation rate. It has kept to its
original design from the 1980s with only one current source, unable to provide simultaneous stimulation and
electrical field imaging. Detailed presentation and analysis of these subsystem components, functions, and
specifications will be provided next.
III. SIGNAL PROCESSING Except for the paradigm shift from the single electrode device to the multi-electrode
device in the early 1980s, advances in signal processing are largely responsible for the continuous and
steady improvement by cochlear implant users. Because several review papers have been published to focus on
this topic [40], [54]–[56], this section provides a brief overall review and an update. The theoretical basis
for signal processing in cochlear implants can be traced to early research in the source-filter model in
speech production [57] and the vocoders in telephone communication [3], [4]. Briefy, speech sounds can be
modeled as either a periodical (for voiced sounds) or noise (for unvoiced
sounds) source whose frequency spectrum is filtered by the resonance properties in the vocal tract.
Alternatively, the source can be modeled as a carrier while the vocal tract acts as a modulator, refecting
the opening and closing of the mouth or the nose. Generally speaking, the source varies rapidly whereas the
flters vary more slowly. Recently, Zeng has argued for a general model in which the rapidly varying fne
structure contributes mainly to auditory object formation whereas the slowly varying envelope contributes to
speech intelligibility [58].
Fig. 6 classifes signal processing used in modern cochlear implants. Most cochlear implants discard the fine
structure and encode the coarse features only. The first generation multi-electrode Nucleus 22 device
extracted the fundamental frequency (F0), which is a source information refecting voice pitch, and the second
resonance frequency in the spectral envelope (also known as the second formant, or F2) [59]. In later
versions of the implant, the first formant was added [60], followed by addi-tional three spectral peaks
between 2000 and 8000 Hz [61], [62]. Consistent improvement in speech recognition was observed as more
spectral details were added (see Fig. 3).
In the late 1980s and early 1990s, another paradigm shift oc-curred from spectral envelopes to temporal
envelopes, showing that the temporal envelope from a very limited number of spec-tral channels can support a
high level of speech recognition [5], [63], [64]. Parallel changes occurred in cochlear implant signal
processing, from explicit encoding of spectral envelope cues to explicit encoding of temporal envelope cues
[6], [65].
Fig. 7(A) shows the functional block diagram of the continuous-interleaved-sampling (CIS) strategy, which has

APPENDIX

C. R ANALYSIS CODE

```
> #Package installation

> install.packages(“tm”)

> install.packages(“SnowballC”)

> install.packages(“ggplot2”)

> install.packages(“wordcloud”)

> library(tm)


> #Create corpus

> docs<-Corpus(DirSource(“C:/Users/fmahmud/Desktop/TextMining”))

> docs                    ***#To inspect if documents are loaded properly


> getTransformations()

> #Create the toSpace Content Transformer

> toSpace<-content_transformer(function(x,pattern){return(gsub(pattern,“”,x))})

> docs<-tm_map(docs,toSpace, “ -”)

> docs<-tm_map(docs,toSpace, “ - ”)

> docs<-tm_map(docs,toSpace, “- ”)

> docs<-tm_map(docs,toSpace, “:”)

> docs<-tm_map(docs,toSpace, “@”)

> docs<-tm_map(docs,toSpace, “'”)
> docs<-tm_map(docs,toSpace, “*”)

> docs<-tm_map(docs,toSpace, “•”)

> docs<-tm_map(docs,toSpace, “/”)

> docs<-tm_map(docs,toSpace, “//”)

> docs<-tm_map(docs,toSpace, “_”)

> docs<-tm_map(docs,toSpace, “!”)

> docs<-tm_map(docs,toSpace, “--”)

> docs<-tm_map(docs,toSpace, “]”)

> docs<-tm_map(docs,toSpace, “<”)

> docs<-tm_map(docs,toSpace, “>”)

> docs<-tm_map(docs,toSpace, “-->”)

> docs<-tm_map(docs,toSpace, “}”)

> docs<-tm_map(docs,toSpace, “^”)

> docs<-tm_map(docs,toSpace, “¶”)

> docs<-tm_map(docs,toSpace, “~”)

> docs<-tm_map(docs,toSpace, “„”)

> docs<-tm_map(docs,toSpace, “¦¦”)

> docs<-tm_map(docs,toSpace, “#”)
```

> **#Remove punctuation-replace punctuation marks with “”**

```
> docs<-tm_map(docs,removePunctuation)
> #Strip digits/numbers (std transformation, so no need for content_transformer)
> docs<-tm_map(docs,removeNumbers)

> #Transform to lower case (need to wrap in content_transformer)
> docs<-tm_map(docs,content_transformer(tolower))

> #Remove stopwords using the standard list in tm
> docs<-tm_map(docs,removeWords,stopwords(“English”))

> #Remove custom English words
> myStopwords<-c(“can”, “one”, “new”, “also”, “may”, “work”,
+“different”, “example”, “two”, “case”, “approach”,
+“many”, “however”, “use”, “using”, “used”,
+“time”, “based”, “within”, “even”, “need”,
+“well”, “set”, “see”, “level”, “number”,
+“order”, “following”, “make”, “made”, “introduction”,
+“guide”, “important”, “possible”, “will”,
+“term”, “result”, “results”, “thus”, “form”,
+“way”, “understand”, “require”, “required”, “requirement”,
+“change”, “often”, “direct”, “part”, “particular”,
+“like”, “increase”, “nature”, “exist”, “given”, “take”,
+“discuss”, “point”, “mean”, “three”, “present”,
+“general”, “specific”, “paper”, “refer”, “reference”,
+“include”, “effect”, “value”, “issue”, “several”,
+“function”, “problem”, “consider”, “perform”, “involved”,
+“â€”, “â€™â€™”, “â€™”, “â€œ”,
+“first”, “second”, “â€œonramp”, “â€œonrampâ€\u009d”, “â€œpaidâ€\u009d”,
+ “â€œsavetheinternetinâ€\u009d”, “â€œsnapchat”, “â€œsomethingâ€\u009d”)

> #Remove custom stopwords
> docs<-tm_map(docs,removeWords,myStopwords)

> #Strip whitespace
> docs<-tm_map(docs,stripWhitespace)

> #Stem document
> docs<-tm_map(docs,stemDocument)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“system”,replacement=“systems”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“inform”,replacement=“information”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“govern”,replacement=“governance”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“decis”,replacement=“decision”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“decisionionmak”,replacement=“decision”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“knowledge”,replacement=“knowledge”)
```

للاستشارات المنارة

```
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“manag”,replacement=“management”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“intellig”,replacement=“intelligence”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“organ”,replacement=“organization”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“organizationiz”,replacement=“organization”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“develop”,replacement=“development”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“technolog”,replacement=“technology”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“experi”,replacement=“experiment”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“active”,replacement=“active”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“individu”,replacement=“individual”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“studi”,replacement=“study”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“provid”,replacement=“provide”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“theory”,replacement=“theory”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern=“collabor”,replacement=“collaboration”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“comput”,replacement=“computer”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“polici”,replacement=“policy”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“oper”,replacement=“operation”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“busi”,replacement=“business”)
> docs<-tm_map(docs,content_transformer(gsub),pattern=“relationin”,replacement=“relation”)
> docs<-
tm_map(docs,content_transformer(gsub),pattern="relationship",replacement="relation")
> docs<-tm_map(docs,content_transformer(gsub),pattern="relat",replacement="relation")

> #Document-term matrix
> dtm<-DocumentTermMatrix(docs)
> dtm

> #Length should be total number of terms
> freq<-colSums(as.matrix(dtm))
> length(freq)

> #Create sort order (descending)
> ord<-order(freq,decreasing=TRUE)

> #Inspect most frequently occurring terms
> freq[head(ord)]

> #Inspect least frequently occurring terms
> freq[tail(ord)]
> dtmr<-DocumentTermMatrix(docs,control=list(wordLengths=c(4,20)))
> dtmr
> freqr<-colSums(as.matrix(dtmr))
> length(freqr)


> #Identifying terms for different frequency

> findFreqTerms(dtmr,lowfreq=500)

> findFreqTerms(dtmr,lowfreq=1000)

> findFreqTerms(dtmr,lowfreq=1500)

> findFreqTerms(dtmr,lowfreq=2000)

> findFreqTerms(dtmr,lowfreq=2500)

> findFreqTerms(dtmr,lowfreq=3000)

> findFreqTerms(dtmr,lowfreq=3500)

> findFreqTerms(dtmr,lowfreq=4000)

> findFreqTerms(dtmr,lowfreq=4500)

> findFreqTerms(dtmr,lowfreq=5000)


> #Cluster diagram

> library(cluster)

> dtmrs <- removeSparseTerms(dtmr, 0.15) *** Change the value for 0.20. 025, 0.30, 0.35, 0.40, and 0.45

> d <- dist(t(dtmrs), method="Euclidian")

> fit <- hclust(d=d, method="complete")

> fit

> plot(fit, hang=-1)

> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.20)
> d <- dist(t(dtmrs), method=“Euclidian”)
> fit <- hclust(d=d, method=“complete”)
> fit
> plot(fit, hang=-1)
> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.25)
> d <- dist(t(dtmrs), method=“Euclidian”)
> fit <- hclust(d=d, method=“complete”)
> fit
> plot(fit, hang=-1)
> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.30)
> d <- dist(t(dtmrs), method=“Euclidian”)
> fit <- hclust(d=d, method=“complete”)
> fit
> plot(fit, hang=-1)
> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.35)
> d <- dist(t(dtmrs), method=“Euclidian”)
> fit <- hclust(d=d, method=“complete”)
> fit
> plot(fit, hang=0.05)
> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.40)
> d <- dist(t(dtmrs), method="Euclidian")
> fit <- hclust(d=d, method="complete")
> fit
> plot(fit, hang=0.05)
> plot.new()
> dtmrs <- removeSparseTerms(dtmr, 0.45)
> d <- dist(t(dtmrs), method="Euclidian")
> fit <- hclust(d=d, method="complete")
> fit
> plot(fit, hang=0.05)
> groups <- cutree(fit, k=10)
> rect.hclust(fit, k=10, border="red")

> #CLUSPLOT
> install.packages("fpc")
> library(fpc)
> install.packages("cluster")
> library(cluster)
> kfit <- kmeans(d, 2)  *** Change the value for 3, 4, 5, 6, 7, 8, 9, and 10
> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)
> plot.new()
> kfit <- kmeans(d, 3)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 4)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 5)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 6)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 7)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 8)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 9)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)

> plot.new()

> kfit <- kmeans(d, 10)

> clusplot(as.matrix(d), kfit$cluster, color=T, shade=T, labels=2, lines=0)
> #Association of terms
> install.packages(“tm”)
> install.packages(“ggplot2”)
> install.packages(“NLP”)
> library(tm)
> findAssocs(dtmr, “systems”, 0.85) #for single word with other occurring words
```

APPENDIX

D. ADDITIONAL FIGURES

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	299	35% (0.35)

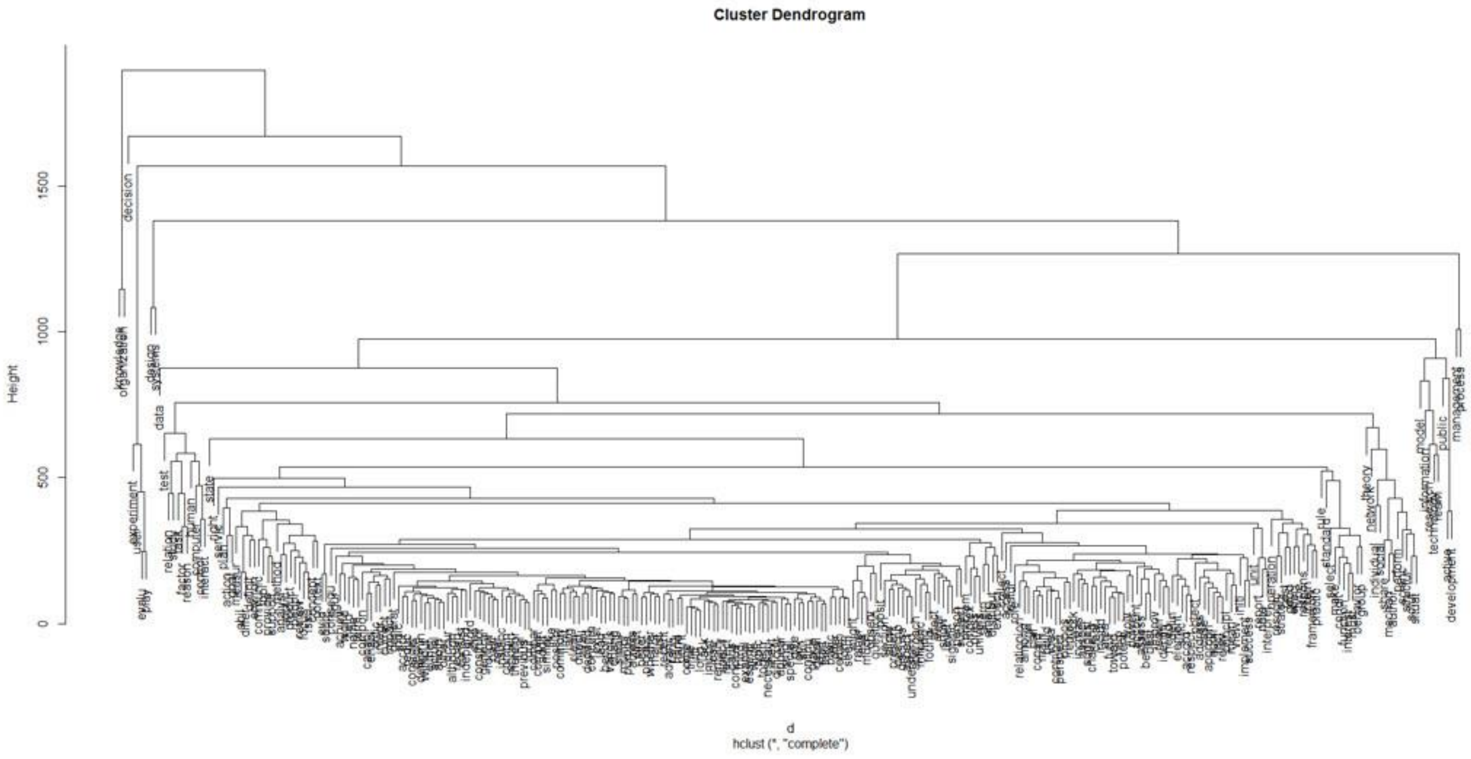


Figure 38: Cluster Dendrogram for 35% Non-Sparsity.

Diagram	Method	Distance	Number of Objects	Remove Sparse Terms
Hclust (Cluster Dendogram)	Complete	Euclidean	371	40% (0.40)

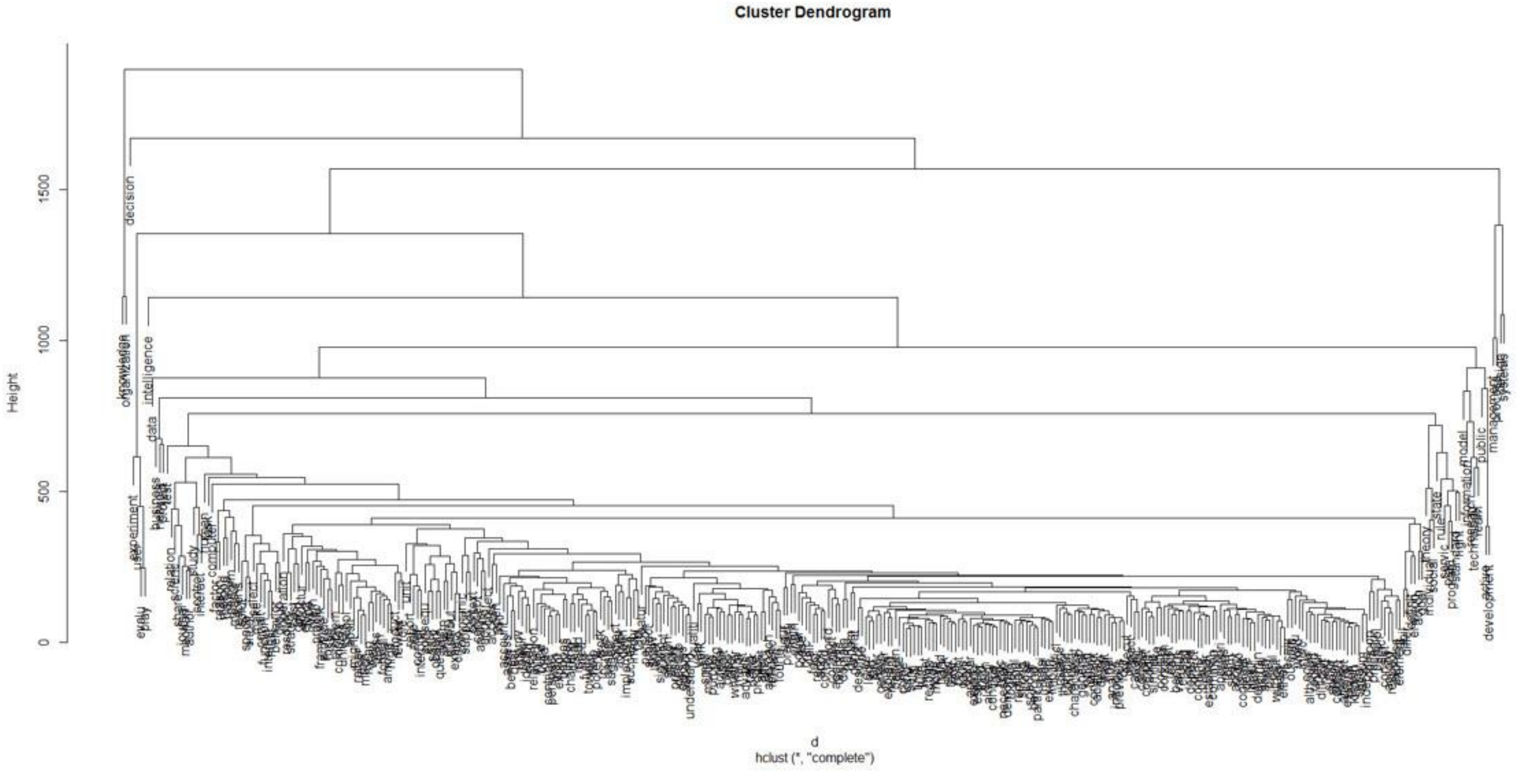


Figure 39: Cluster Dendrogram for 40% Non-Sparsity.

Diagram	K means	Point Variability
CLUSPLOT	(d , 6)	96.28%

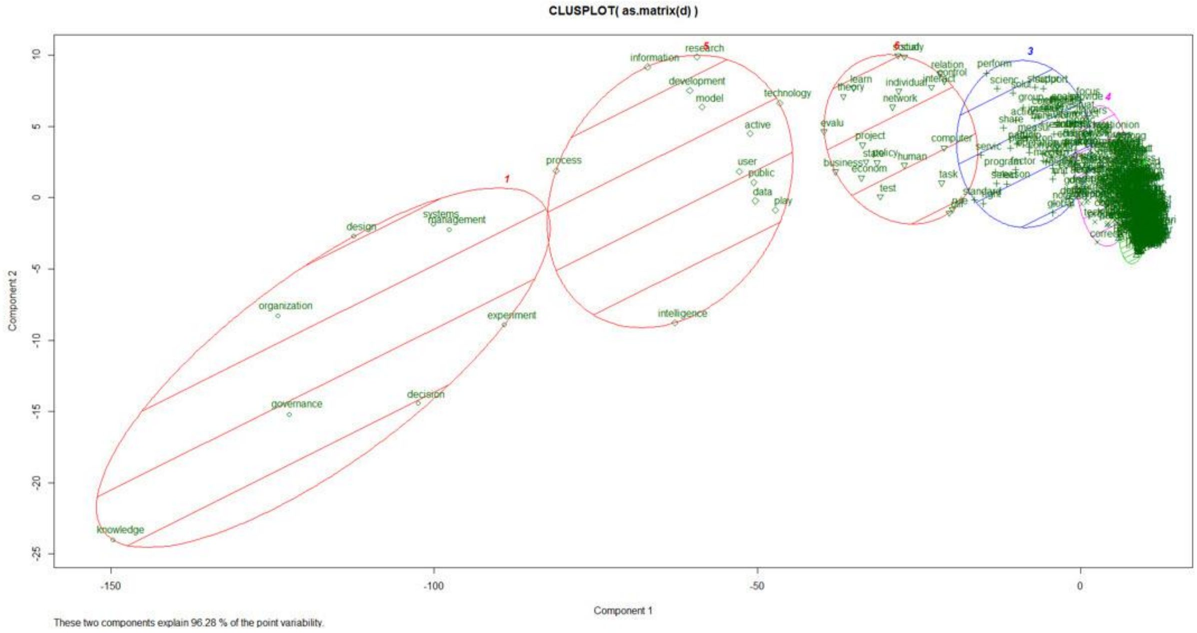


Figure 40: CLUSPLOT for K=6.

Diagram	K means	Point Variability
CLUSPLOT	(d , 7)	96.28%

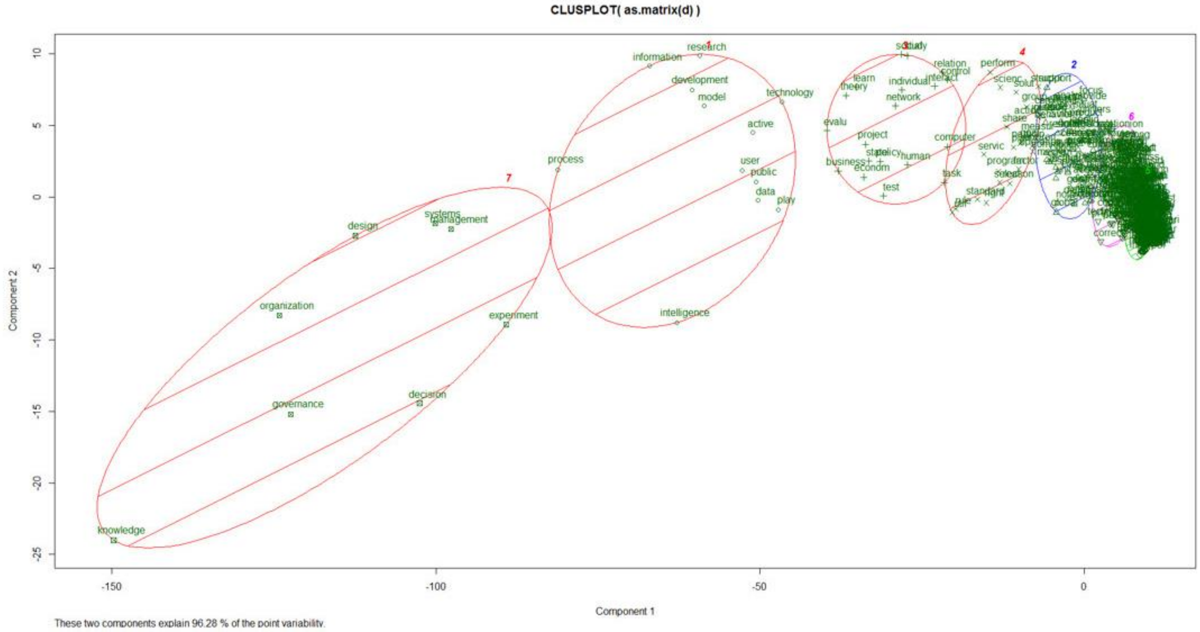


Figure 41: CLUSPLOT for K=7.

Diagram	K means	Point Variability
CLUSPLOT	(d , 8)	96.28%

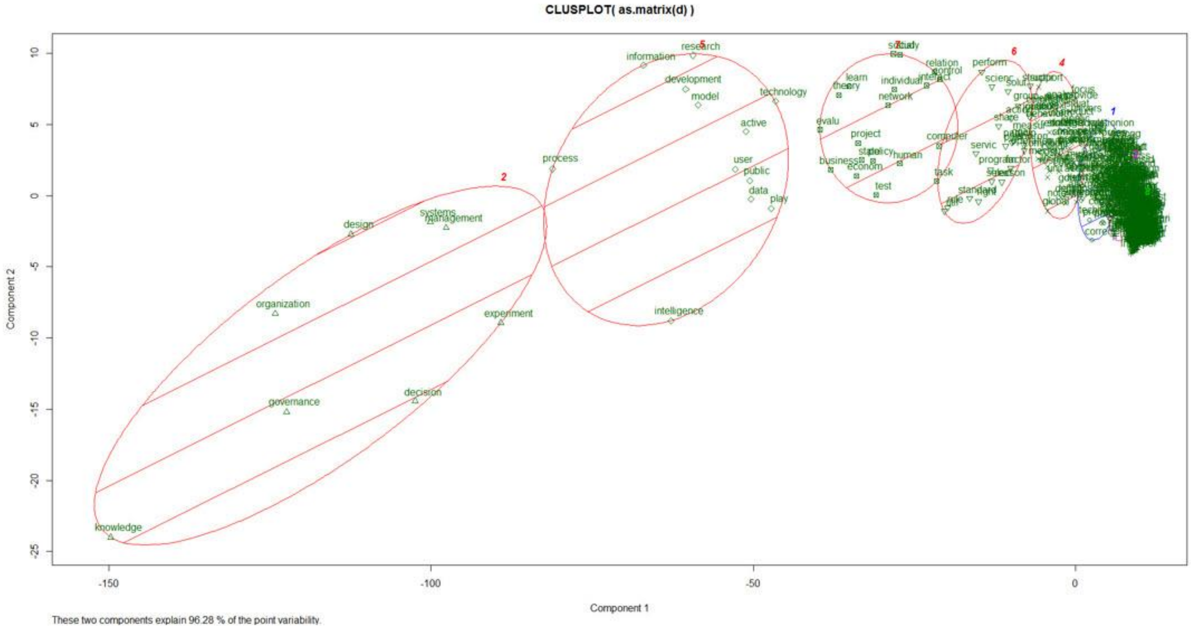


Figure 42: CLUSPLOT for K=8.

Diagram	K means	Point Variability
CLUSPLOT	(d , 9)	96.28%

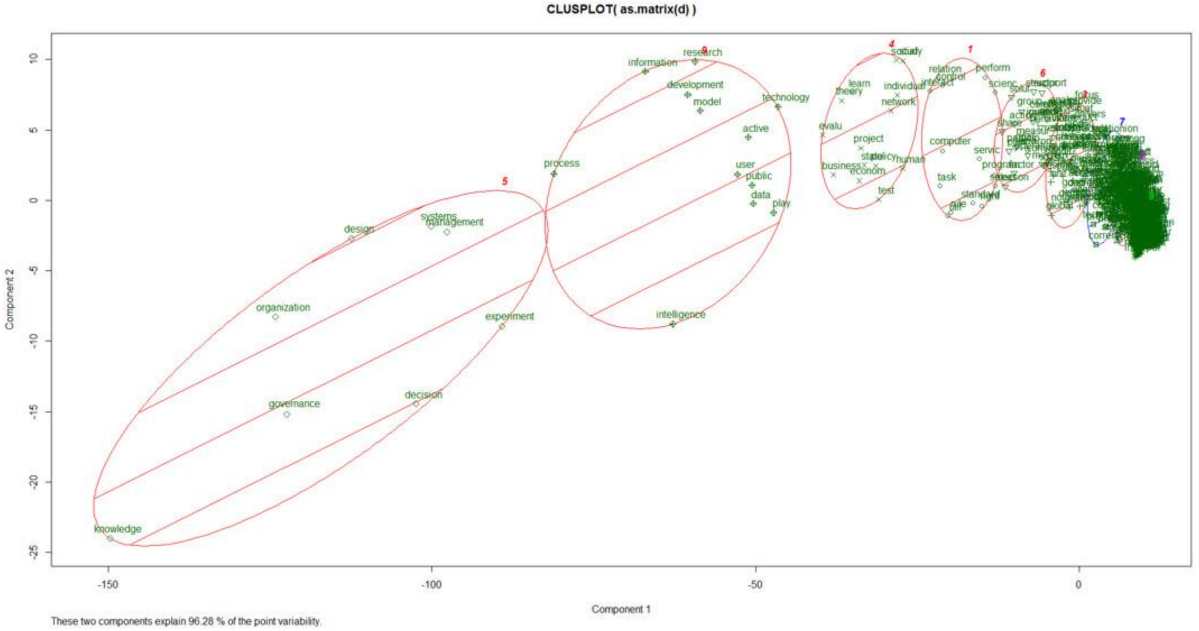


Figure 43: CLUSPLOT for K=9.

APPENDIX

E. COMPETENCY QUESTIONS

The following table listed a set of competency questions for the developed ontology. Competency questions are those questions an ontology is able to answer.

Table 17: A Set of Competency Questions.

Competency Questions (Definition level)	**Competency Questions (Role/Taxonomy and Correlational level)**
Who/What is Decision?	Who/What uses Decision?
	Who/What is used by Decision?
	Who/What is involved by Decision?
	Who/What does Decision involve?
	Who/What utilizes Model?
	What taxonomic terms are related with Decision?
	What taxonomic terms are not related with Decision?
Who/What is Governance?	Who/What is Governance required for?
	Who/What does Governance use?
	Who/What does Governance involve?
	Where does Governance function?
	Who/What does Governance help?
	Who/What holds Governance accountable?
	What taxonomic terms are related with Governance?
	What taxonomic terms are not related with Governance?
Who/What is Organization?	Who/What does Organization need?
	Who/What does Organization make?
	Who/What does Organization utilize?
	Who/What does Organization use?
	Who/What does Organization serve?
	Who/What does Organization have?
	What taxonomic terms are related with Organization?
	What taxonomic terms are not related with Organization?
Who/What is Knowledge?	Who/What does Knowledge help?
	How Knowledge is accumulated through?

Competency Questions (Definition level)	**Competency Questions (Role/Taxonomy and Correlational level)**
	How Knowledge is accumulated by?
	How Knowledge is transferred?
	What taxonomic terms are related with Knowledge?
	What taxonomic terms are not related with Knowledge?
Who/What is Systems?	Who/What does Systems need?
	Who/What does Systems help?
	Who/What does Systems use?
	Who/What does Systems utilize?
	What taxonomic terms are related with Systems?
	What taxonomic terms are not related with Systems?
Who/What is Design?	Who/What does Design evaluated for?
	Who/What does Design help?
	Who/What does Design benefit from?
	Who/What does utilize Design?
	What taxonomic terms are related with Design?
	What taxonomic terms are not related with Design?
Who/What is Management?	Who/What utilizes Management?
	Who/What does Management need?
	Who/What does Management make?
	Who/What does Management use?
	Who/What does Management utilize?
	How does Management run through?
	Who/What does Management help?
	Who/What does Management consist of?
	Who/What does Management benefit from?
	What taxonomic terms are related with Management?
	What taxonomic terms are not related with Management?
Who/What is Process?	Who/What does Process need for?
	Who/What does Process utilize for?
	Where does Process use?
	Who/What does Process help?
	Where does Process has a role?
	Who/What does Process utilize?
	Who/What does Process involve in?
	What taxonomic terms are related with Process?
	What taxonomic terms are not related with Process?
Who/What is Intelligence?	What taxonomic terms are not related with Intelligence?

Competency Questions (Definition level)	**Competency Questions (Role/Taxonomy and Correlational level)**
Who/What is Data?	Where does Data contribute?
	Who/What uses Data?
	What taxonomic terms are not related with Data?
Who/What is Business?	Who/What does Business use?
	Who/What does Business have?
	Who/What runs Business?
	Where does Business benefit from?
	What taxonomic terms are not related with Business?
Who/What is Model?	Who/What does Model use?
	Who/What does Model use for?
	Who/What uses Model?
	Where does Model benefit from?
	What taxonomic terms are not related with Model?
Who/What is Public?	Who/What does Public use?
	Who/What does Public run?
	Where does Public benefit from?
	What taxonomic terms are not related with Public?
Who/What is Technology?	Who/What does Technology utilize?
	Who/What does Technology help?
	What taxonomic terms are not related with Technology?
Who/What is Organization-Knowledge?	How does Organization-Knowledge compose of?
	Who/What is part of Organization-Knowledge?
Who/What is Systems-Design?	How does Systems-Design compose of?
	Who/What is part of Systems-Design?
Who/What is Management-Process?	How does Management-Process compose of?
	Who/What is part of Management-Process?
Who/What is Social-Technical?	How does Social-Technical compose of?
	Who/What is part of Social-Technical?

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APPENDIX

F. DEFINITIONS OF FOUNDATIONAL TAXONOMIC TERMS

Table 18: Definitions of Foundational Taxonomic Terms.

Terms	**Definitions**
Decision	A choice to make (by human) about something with prediction and purpose.
Governance	A set of policies with purpose to administer rule and actions.
Organization	A group of people in an arrangement and interactions aimed for defined purpose.
Knowledge	The perception and understanding of a thing in the form of facts.
Systems	A collection of interrelated things to function interdependently and act as a whole to accomplish specific goals.
Design	A plan or set of components to satisfy or create specified requirements.
Management	A group of people in an arrangement to administer rule and actions.
Process	A purposeful set of actions in sequence to achieve outputs from inputs.
Intelligence	The cognitive ability of human for reasoning, synthesizing, and analyzing something.
Social	An association of people having interactions and interdependency with partnership for specific goals.
Technical	A purposeful set of actions and applications having engineering manifestation.
Data	An organized collection of facts or statistics for a thing.
Business	An entity or economic platform involving human where goods and/or services are exchanged for one another or for money.
Model	A phenomenon or action to replicate or analyze a thing.

Terms	Definitions
Public	A subset of human relating to or involving a set of people for common interest.
Technology	A subset of technical dealing with the actions, principles, and applications involving the domain of science.

APPENDIX

G. DISTANCE METHODS IN R

There are several distance methods supported by R such as “Euclidean”, “Maximum”, “Manhattan”, “Canberra”, “Binary”, and “Minkowski”. Euclidean distance method is the most widely used over all other methods for its robustness and completeness compared to other methods.

Available distance measures are (written for two vectors x and y):

Euclidean:

Usual distance between the two vectors (2 norm aka L_2), sqrt(sum((x_i - y_i)^2)).

Maximum:

Maximum distance between two components of x and y (supremum norm).

Manhattan:

Absolute distance between the two vectors (1 norm aka L_1).

Canberra:

Sum(|x_i - y_i| / (|x_i| + |y_i|)). Terms with zero numerator and denominator are omitted from the sum and treated as if the values were missing. This is intended for non-negative values (e.g., counts), in which case the denominator can be written in various equivalent ways; Originally, R used x_i + y_i, then from 1998 to 2017, |x_i + y_i|, and then the correct |x_i| + |y_i|.

Binary (aka asymmetric binary):

The vectors are regarded as binary bits, so non-zero elements are ‘on’ and zero elements are “off”. The distance is the proportion of bits in which only one is on amongst those in which at least one is on.

Minkowski:

The p norm, the p^{th} root of the sum of the p^{th} powers of the differences of the components.

VITA

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Mr. Mahmud has publications and presentations in the American Society for Engineering Management's International Annual Conferences since 2016. He has numerous other publications and presentations related to systems and technology design and integration for online teaching and learning, immersive media technology, and human-machine systems. His research interests are in Human-Computer Interactions (HCI), Modeling and Simulation, Systems and Data Analytics, and Human-Machine collaborative design and Management.