A SYSTEM TO SUPPORT MONITORING AND SURVEILLANCE OPERATIONS WITHIN A WHOLESALE ELECTRICITY MARKET

A Dissertation Proposal

by

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ABSTRACT

This dissertation aims to investigate an intersection between several domains of expertise as they related to electric markets and electric market monitoring. These domains include: 1) data and information quality, 2) language engineering, 3) knowledge management, and 4) design science research. Electricity markets present unique research opportunities for deriving new value from data and information assets, due to the enormous volume of data generated, each day, by public utilities, transmission and market operators, and regulators.

These data assets are critically necessary to both ensure reliable operation of the North American Bulk Electric System (BES), as well as operate efficient markets for selling energy on a wholesale scale. The outcomes of these markets have tangible, long-term impacts on system reliability, prices set for residential and commercial energy consumers, and electricity infrastructure development.

Due to the lucrative nature of energy marketplaces, there are abundant opportunities for market participants to manipulate these markets. Market monitors are the group of professionals that work to ensure that the BES remains a fair, efficient, and open-access marketplace in the face of such manipulative action. They perform routine surveillance and forensic analysis to identify instances of fraud and market manipulation and refer such cases to regulatory authorities.

This research investigates the efficacy of designing and implementing a layer of abstraction between market monitors and the data that they use to perform their forensic analysis. Using domain-specific language engineering and information quality principles, the investigator expects to develop a system to ease data manipulation for market monitoring analysts and economists.

DEDICATION

For anyone that has struggled with their mental health, their identity, or finding their place in the world: I understand. I have been there. We are all in this together. This dissertation is dedicated to you.

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INDUSTRY ACRONYMS

APAC	Asian-Pacific region
AS	Ancillary Services
BES	Bulk Electric System
BSS	Bilateral Settlement Schedule
CRM	Capacity Reserve Margin
DA	Day-Ahead Market
DSL	Domain-Specific Language
DSRM	Design Science Research Methodology
DQ	Data Quality
EMEA	Europe, the Middle-East, and Africa region
FERC	Federal Energy Regulatory Commission
GPL	General-Purpose Language
HHI	Herfindahl-Hirschman Index
IQ	Information Quality
ISO	Independent System Operator
LMP	Locational Marginal Price
MP	Market Participant
MW	Megawatt
NERC	North-American Energy Reliability Corporation
RTO	Regional Transmission Organization
RT	Real-Time Market
SME	Subject Matter Expert
SOX	Sarbanes-Oxley Act of 2002
TCR / FTR	Transmission Congestion / Financial Transmission Rights
TO / TOP	Transmission Owner / Transmission Operator

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1. INTRODUCTION

This dissertation intends to introduce information quality research into the electricity market monitoring industry- a regulatory component of organized electric markets in the United States [1]. Organized electric markets are a critical component of the North American Bulk Electric System (BES) and its function to reliably and economically deliver power to consumers. Often touted as the "world's largest machine" [2] by electrical industry staff, the BES has become an important dependency in the lives of virtually every resident of the United States, Canada, and (a portion of) Mexico.

Given the high volume and value of transactions across multiple energy products, there are abundant opportunities for market participants to manipulate these markets. Market monitors are the group of professionals that work to ensure that the BES remains a fair, efficient, and open-access marketplace by identifying and referring behavior that violates established marketplace rules to the Federal Energy Regulatory Commission (FERC). Wholesale markets clear billions of dollars (USD) in revenue each year. Figure 1.1 displays overall energy consumption and cost for one of these markets, Southwest Power Pool's (SPP) marketplace, from 2020 to 2023. [1]

To illustrate the opportunity that superimposing information quality research onto the market monitoring domain poses, this chapter shall introduce the concepts of the BES, electric markets, and Market Monitoring, and provide detail as to how applying information quality concepts to Market Monitoring will help serve a previously unsolved problem within the industry.

[1] Across the time frame shown in Figure 1.1, the observed market generated an average revenue of over $9.5 billion, serving an average energy load of over 261 GWh. This figure was generated using data combined from multiple public reports [3], [4], [5], [6].

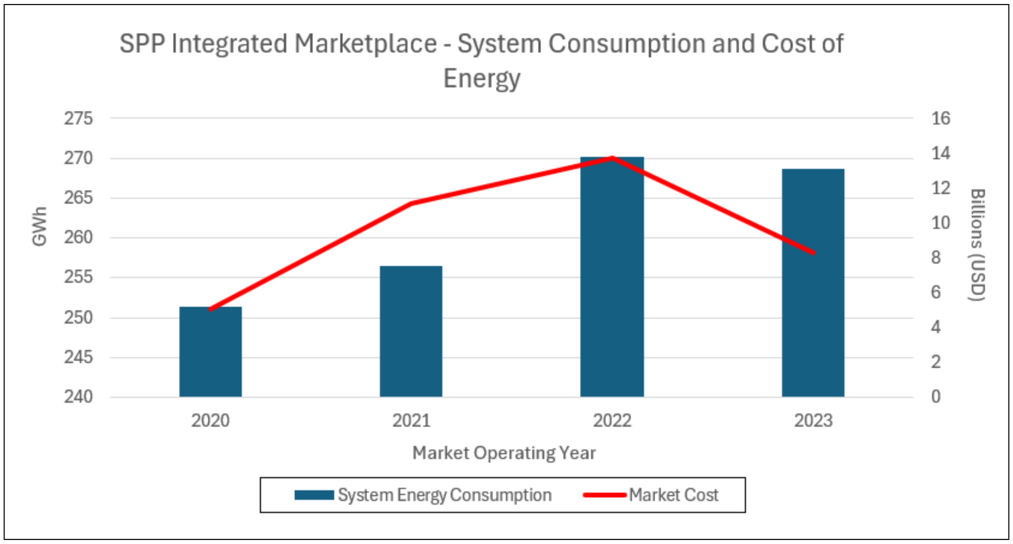

Figure 1.1: Four Year Overall Cost of Energy, SPP Integrated Marketplace

1.1 The North American Bulk Electric System

The BES [2] is a highly integrated system that facilitates the transmission of electric power (generalized as "energy") from generation to energy consumption (generalized as a "load") in a real-time and balanced [3] manner. Built with more than 500,000 miles [7] of physical transmission cabling and over 70,000 electrical substations [8], the BES constantly serves energy to North American consumers and industries alike. With few (relatively recent) exceptions [4] , energy is not stored in the system; it is generated (in response to a demand forecast) and then immediately transmitted and consumed by various loads. Figure 1.2 shows a conceptual configuration of some of the components [5] involved in the operation of the BES. [9]

[2] The North American Electric Reliability Corporation (NERC) serves as the Electric Reliability Operator (ERO) for the BES. In their Glossary of Terms (see References section), the BES refers to all high-voltage transmission lines and substations, generation resources, and all other equipment used in both inter/intra-state transmission of electric capacity.

[3] The term "balancing" refers to the need to only generate power as it is needed for consumption- subject to system capacity and economic constraints.

[4] Storage resources are a developing technology that can store energy for deployment during reliability emergencies or intervals of energy scarcity.

[5] An important distinction to note is between the *utility* and *retail* sectors shown in Figure 1.2. While referred to by several names (i.e. wholesale), utility generation and transmission refers to bulk energy (on the scale of MW) that is transmitted on the BES. The retails sector involves distribution of energy to residences and low consumption (on the scale of kW) commercial enterprises. This research focuses on wholesale energy markets, and thus is concerned with the bulk power generation and transmission domains.

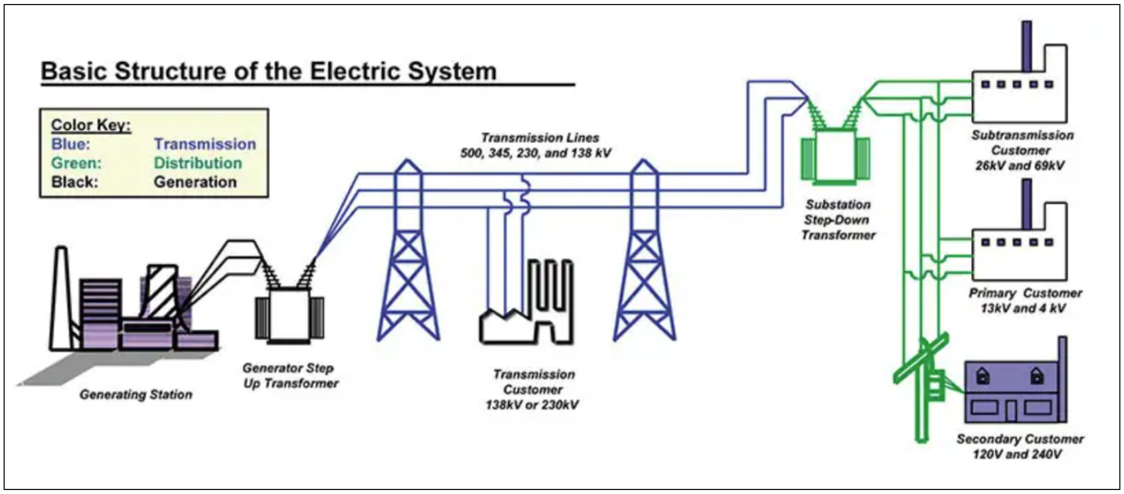

Figure 1.2: A conceptual illustration of the Bulk Electric System

The BES must be precisely managed, at all times, to balance power across the system and to exactly serve load. Deviations can create instances of voltage and frequency instability that have the potential to significantly damage BES infrastructure. Oftentimes, these deviations are caused by larger environmental events, such as periods of extreme hot or cold weather. Demand for electricity increases during these events [6], as do generator outages and fuel delivery problems [11]. No one entity manages the entire BES. Instead, this job is shared across different types of regional entities covering different geographic locales. This dissertation focuses, specifically, on organized markets, which pool resources managed by a Regional Transmission Organization (RTO) or an Independent System Operator (ISO). These entities serve multiple roles; their primary role is to function as a grid operator.

These organizations frequently act as Reliability Coordinators (RC) and Balancing Authorities (BA), monitoring power flows, balancing the grid, and acting to restore system reliability during and after an emergency. They also operate energy markets. Using a complex optimization, the RTO/ISO dispatches individual resources in economic order while respecting systems constraints; a concept termed security-constrained economic dispatch (SCED) [7]. They also serve as a revenue-

[6]Notable weather events that have materially impacted BES reliability include the 2020 Californian heat wave, as well as severe winter weather storms in 2021 and 2022 [10].

[7]Economic dispatch ("ED") is a concept that blends economics and the physical reality of the electric grid.

neutral clearing house for the bulk of energy and transmission-related transactions (as well as various financial products).

Serving these various functions to provide electricity generates enormous amounts of data on an hourly basis. This data is widely diverse in terms of sourcing, formatting, usage, sensitivity, and volume. It is the data assets generated by the operation of the BES that serve as the focus of this dissertation, specifically in the data generated by *electricity markets*.

1.2 An Introduction to Electricity Markets

As stated above, this research focuses on organized markets. A large portion of the BES includes centrally organized electricity markets. Electricity markets are of great importance to all stakeholders involved in the BES; they allow energy to be economically generated for consumers.

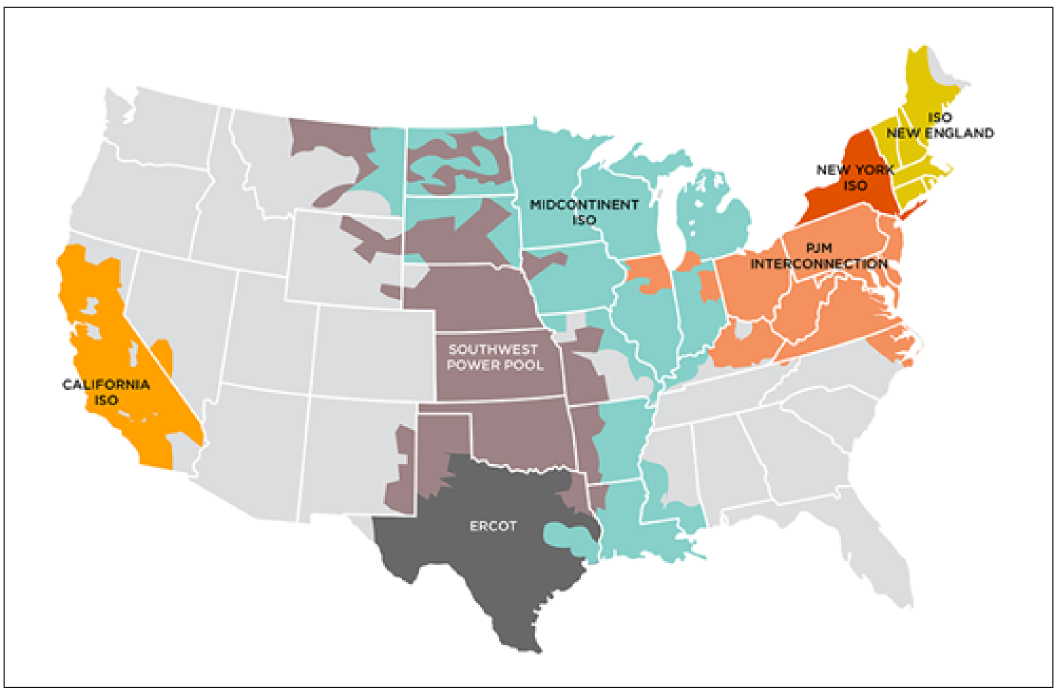

Figure 1.3: FERC Jurisdictional Market Territories

Figure 1.3 [1] displays, at a high level, how the US energy grid is divided into different territories and notes the name of the entity that runs the organized market. These territories are typically governed by FERC, with the exception of Texas [8].

1.2.1 Grid Operational Entities

Electricity markets are operated by a small number of operational entities [9] within North America. These entities fall under the jurisdiction of FERC, as indicated by Figure 1.3. The prominent entities that are impacted by market monitoring include Independent System Operators (ISO) and Regional Transmission Organizations (RTO). These entities are filed as non-profit businesses and typically perform similar functions. FERC Orders 888 and 889 initiated the formalized incorporation of an ISO, while FERC Order 2000 set forth the criteria that differentiate an ISO from an RTO.

1.2.1.1 Independent System Operator (ISO)

ISOs are organizations that manage power generation and transmission across the bulk electric system. They operate in an advisory capacity for generation owners (public and investor owned utilities, as well as independent power producers) and transmission owners and operators to effectively generate and trade power in an energy market. A common, helpful analogy that describes the function of an ISO is an air-traffic controller.

Air-traffic controllers merely monitor and route airplane traffic across the airspace over the United States. They own neither physical airplanes nor airlines, and function only as advisors to ensure safe passage of both private and commercial airplanes. ISOs work in a similar fashion. The ISO over the California energy market territory (CAISO) owns none of the transmission infrastructure across which electric power is shipped. However, CAISO manages the flow of energy across this system, and sends regular dispatch instructions to the generators that inject power into the BES.

[8]ERCOT, the electric system operator for Texas, is not within the jurisdiction of FERC. The Public Utility Commission of Texas, instead, has oversight of the ERCOT market territory. Alaska and Hawaii, additionally, maintain isolated electricity infrastructure.

[9]"Grid Operational Entities", as referred to in this chapter, are not limited to the 2 categories listed. They also include Transmission Owners and Operators (TO / TOP), Regional Entities (RE), Balancing Authorities (BA), Reliability Coordinators (RC), and Federal Power Agencies. Oftentimes, an RTO or ISO will also support one or more of these functions (SPP, for example, hosts operational desks for performing reliability coordination).

1.2.1.2 Regional Transmission Organization (RTO)

According to the *Energy KnowledgeBase* product maintained by Enerdynamics (an educational entity in the energy space), RTOs are categorized by a group of four core characteristics (and an additional seven broad operational functions). The following lists identify these characteristics and functions that separate ISOs and RTOs. Although similar in nature; in fact, they are regulated by the same entities and have many of the same requirements under current law. It is important to note, however, that ISOs also operate energy markets and are subject to the same market monitoring requirements as RTOs.

Core characteristics of an RTO include:

1. Independent operation and authority from the market participants that join the RTO
2. Maintain a "regional configuration"
3. Maintain "operational authority for all transmission facilities under RTO control"
4. Maintain short-term reliability of their footprint

Operational functions of an RTO include:

1. Energy market design and “tariff administration”
2. Management of transmission capacity (FTR)
3. Management of flow on the transmission system
4. Support for ancillary services (AS)
5. Management of transmission capacity and capability, including imports and exports of power
6. Engineering support for planning the future state of the gid
7. Coordination between control boundaries
8. Market Monitoring

1.2.2 Types of Markets

Electricity markets are designed to serve one of several purposes. ISOs typically deploy and operate these different market designs, in concert, as a *marketplace* [12]. Southwest Power Pool's (SPP) Integrated Marketplace is such an example of this. To understand the scope of market monitoring activities, it is important to understand the main energy market designs that exist today. Arguably, there are five main types of electric energy market designs; each design may be deployed with possible variations on their theme (a marketplace that does not operate the function of a capacity market is one such example). Reference Table 1.1 for information on prevailing design types.

Market Type	**Purpose**
Capacity	Allows a load to purchase an agreement of firm capacity for service in the future- usually on the scale of months to years in the future.
Day-Ahead (DA)	Allows buyers and sellers to secure positions a day before the market sells energy to be consumed (operating day). This aids in realistic price formation.
Real-Time (RT)	Allows for adjustments between the DA market (what was expected on the day prior) and the system conditions that happen on the operating day.
Ancillary Services (AS)	Allows other providers to sell products that support grid reliability. For example, the ability of a generator to quickly "ramp up" to a certain production requirement is such a product sold in an AS market.
Transmission Congestion Rights (TCR)	Allows participants to hedge against congestion on the transmission system (adequate power can be produced in an area, but there may be difficulties in transmitting it to where it is consumed).

Table 1.1: Prevailing Electricity Market Designs

1.2.3 Market Complexity

The BES is a physical system upon which we superimpose a conceptual, economic market. This dichotomy is part of what makes the energy market so complex to both understand and govern with the data that it generates. Physical machines require continuous diagnostics to ensure that they are operating 1) effectively and 2) within adequate maintenance tolerances. The BES is no different.

Thermal generators that produce electricity are monitored for metrics including: wattage output, fuel consumption, greenhouse gas emissions. High-voltage transmission lines are monitored for temperature (heat is generated via electricity loss across conductors) and short-circuit events. Substations are monitored for transformer faults, tap configurations, and other mechanical system measurements. Each of these values is typically transmitted in a time-series format, resulting in constant streams of monitoring data. These time series data streams are typically parsed into *market intervals* that constitute "units of work" for market activity. Much of the analysis performed on wholesale electricity markets utilizes data secured from market intervals. Depending on the type of market that is under observation, an interval may range from a span of several seconds (dispatch instructions) to "between five and fifteen minutes" [1] (calculation of real-time market prices).

These diagnostic data are only a fraction of the data that are used in the operation of the BES, and much of it feeds into market systems [10] to calculate a realistic price of power at different locations throughout a market territory.

1.2.4 Market Settlements

Another subject area of the BES that generates complex and voluminous data includes a collection of processes that perform *market settlements*. In SPP's Integrated Marketplace, the Marketplace Protocols set forth an extensive settlement plan that determines how charges and credits are calculated and assigned to market participants. These settlement instructions also take into account events where the market must be "repriced", or re-settled due to external factors that occur during

[10] While market systems are composed of many different products, they are generally referred to as a *market clearing engine*.

the operation of a market- such as equipment outages, data communication errors [11], or extreme weather events.

Market settlements also generate enormous data volumes due to another necessary function: *shadow calculations*. Shadow calculations [12] are necessary in energy markets due to both the regulatory landscape and the fact that market participants leverage millions of dollars in capital during energy production and sale.

1.3 What is Market Monitoring?

Market monitoring is a discipline that sits at the intersection of two major knowledge domains: *forensics* and *economics*. As such, it takes a scientific approach to testing and analyzing transactions that occur within a marketplace. According to a report published by the United States Energy Association (USEA), Market Monitoring is a necessary component of markets "to ensure that market(s) participants cannot exercise market power, collude or engage in any other behavior that could give them a great market share, or higher profits" [15]. This appointment places the authority to request and analyze records generated by the operation of electricity markets into the hands of MMUs.

Market monitors will generally screen for MP behavior that matches the following criteria:

- Exercised (or attempted to exercise) positions of market power
- Market gaming through oversights in current market protocols or policy (usually outlined in a governing document, known as a Tariff
- Committed cases of market manipulation through acts of collusion, cross-product manipulation, malevolent influence on price formation, or untoward manipulation schemes (economic withholding, uneconomic production, wash trades, "pump and dump" schemes, etc.

[11] Data elements used to monitor and dispatch generation in the BES are collected and shared in the form of *SCADA* (Supervisory Control and Data Acquisition) [13].

[12] Shadow accounting involves the process of maintaining a separate system (in addition to a production accounting system) to track transactions and ensure that accounts are appropriately balanced. [14]

1.3.1 The Fall of Enron Corporation

The Enron Corporation, a former American-based commodities and energy broker, is a well-known case study in American corporate governance (or, rather, lack thereof). The fall of Enron (first signaled in late 2000) uncovered deep, systemic problems of fraud and deceptive business practices that directly influenced both the market monitoring and IQ disciplines. Outwardly, Enron appeared to be a stable and innovative company. At the turn of the century, Enron's books reflected an ownership of $60 billion in assets. This included an internet-based energy trading desk ("Enron Online") that cleared $2.5 billion in *daily* energy transactions [16]. In reality, Enron management operated under a culture of willful non-compliance, including (but not limited to):

- Energy withholding practices that caused enormous electricity prices in the California power market.
- Artificial energy shortages causing regular blackouts [13] within California service territory.
- Scheduling energy transactions to purely cause congestion on California's electric transmission system
- Accounting fraud (enabled by a creative use of "mark-to-market" based accounting) which allowed Enron to report expected revenues before they were realized.

These manipulative schemes had widespread impacts, including: 1) the bankruptcy of one of the largest utility companies in California, Pacific Gas and Electric (PG&E), 2) rolling blackouts, 3) increased transmission system congestion, and 4) higher than normal electricity bills for California ratepayers.

Enron's activities constitute both fraud and a behavior known as *market manipulation*; a form of conduct that attempts to willfully circumvent established market rules in pursuit of (usually) large profits. Their usage of market manipulation, especially in California, was a signal to federal

[13] A blackout (an event where power cannot be served) is a breakdown of a portion of grid infrastructure, caused by "an imbalance between power generation and power consumption" [17].

regulators that, at the time, there was not enough oversight in the operation of electricity markets. As a result, the United States Congress passed the Energy Policy Act of 2005 to introduce more stringent regulation over the energy industry.

Enron's downfall resulted in a near-complete devaluation of their stock [14] , the dismantling of Arthur Andersen, (the auditor assigned to ensure that Enron was operating within the confines of financial reporting law), and a slew of legislation [15] serving as the impetus for energy market monitoring in the United States. Additionally, Enron's scandal was a significant contributor to the passing of the Sarbanes-Oxley (SOX) Act of 2002, imposing strict and detailed requirements on data that is used as input for financial reporting. As a result, SOX became another driving force in the implementation of Information Quality as both an academic discipline and as a business function.

In the years following the disbanding of Enron Corporation, FERC has pursued many more instances of deceptive behavior in organized energy markets. Through the employ of market monitors and FERC enforcement staff, manipulative cases can be pursued and penalized before they become even more critical threats. Table 1.2 lists several high profile cases of market manipulation that are distinct from the Enron case [20] [21] [22].

MP	**Damages/Penalty**	**Incident**
JP Morgan (2013)	$410 mm	Purchased and operated antiquated generation plants and offered them in the market as competitive generators
GreenHat Energy, LLC (2021)	>$229 mm	Participated in insider trading to purchase enormous positions in PJM's congestion market
Vitol Group (2024)	$2.3mm	Sold physical power at a loss in the DA market to favor their transmission congestion positions

Table 1.2: Prominent Cases of Market Manipulation

[14] As Enron entered into legal proceedings, their stock fell to under $1 per share (from a peak as high as $90 per share in mid-2000) [18].

[15] 18 CFR § 1c.2 (Prohibition of Electric Energy Market Manipulation) is an example of legislation that places monitoring authority in the hands of MMUs [19].

1.3.2 Skills of a Market Monitor

Market monitors are one of several groups that function as "unsung heroes" in electricity markets (and within the larger context of the North American bulk electric system). The work that they perform on a routine basis helps to ensure a reliable and economically sound marketplace for buying and selling energy and energy-adjacent ancillary services. Market monitoring units are typically staffed with analysts from a wide variety of both technical and non-technical backgrounds. These include: data analysts, statisticians, economists, accountants, technical writers, engineers, and other corporate staff dedicated to investigating events that occur in their jurisdictional markets.

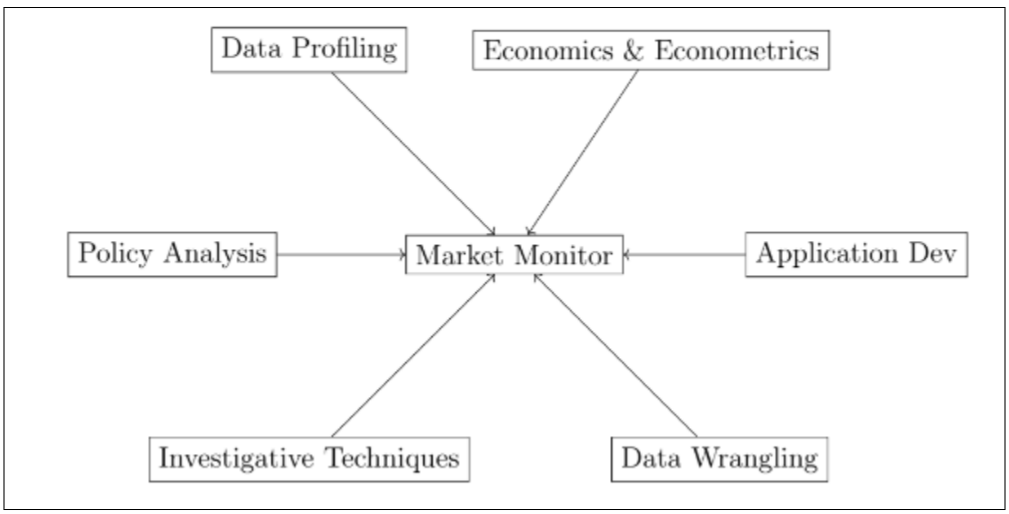

Figure 1.4: Diverse skill sets of a Market Monitor

Figure 1.4 illustrates a cross-section of several of the skill sets that market monitoring analysts might possess, based on the researcher's experience of working as a market monitor within Southwest Power Pool's (SPP) MMU. As one may imagine, it can be difficult to find an individual contributor that possesses an all-encompassing understanding of each of these knowledge areas.

Market monitors have a wide breadth of responsibilities that must be covered by their individual skill sets. Routine market surveillance is a continuous process that must evolve with the behaviors and trading patterns of market participants. As such, market monitors observe and investigate market bids and offers made each operating day, analyze generator behavior to identify erratic response to dispatch commands, ensure that participants are not covertly colluding or engaging in price fixing [16], review out-of-market transactions that take place through bilateral settlement schedules (BSS) [17] , and ensure that RTOs and ISOs are acting within the rules defined by their FERC-approved Tariff [18] documents (excluding ERCOT, which does not fall under FERC jurisdiction).

1.3.2.1 Market Monitoring Firms

The current groups involved with electricity market monitoring (both in North America and internationally[19]) include the following organizations compiled in Table 1.3. This list is not intended to be exhaustive, as other nations [20] in APAC and EMEA may not be reflected here.

1.4 Conducting Information Quality Research in Market Monitoring

The case study of Enron Corporation sets both a unique and compelling stage for the role that Information Quality and Information Science-based research can play in improving the business impact of an independent market monitor. Included amidst Enron Corporation's numerous failures of governance is a lack of access and understanding of the complex data generated by the energy industry. The operation of such a large system and marketplace can lead to many siloed data stores, undocumented schemas, and a slew of other IQ-based problems that can also be seen in market monitoring.

Furthermore, the cross-section of skills that market monitors must possess (to effectively perform their job functions) also underscores the importance that data literacy and data quality improvement hold in the market monitoring domain. An architecture solution, proposed as part of the deliverables of this dissertation, is paramount to designing a system to aid market monitoring

[16] Energy market prices are typically set on a marginal, spatial basis (representing the cost of injecting another MW of energy, at a location, in a market territory) [23].

[17] Bilateral settlement schedules are agreements between market participants that are used to trade energy outside of normal market operations [24], which help manage credit exposure in the marketplace.

[18] A Tariff is a governing document that outlines the rules for operating (and participating in) an energy market.

[19] The US Energy Association (USEA) published a report outlining international, independent market monitoring groups. Many of the international groups on this list come from that report (see References).

[20] See the list of Industry Acronyms for definitions of these regions

Name of Firm	Market Affiliation	Country
Federal Energy Regulatory Commission (FERC)	Jurisdictional oversight for all US-based energy markets	USA
SPP MMU	Southwest Power Pool (Internal)	USA
Potomac Economics	MISO, ERCOT, NYISO, ISO-NE (External)	USA
ISO-NE IMM	ISO-NE (Internal)	USA
CAISO MMU	California ISO (Internal)	USA
Monitoring Analytics	Pennsylvania, New Jersey, Maryland Interconnect (PJM)	USA
Market Surveillance Administrator	Alberta	Canada
Independent Electricity System Operator (IESO)	Ontario	Canada
Canada Energy Regulator	Jurisdictional oversight for all Canadian energy markets	Canada
Superintendencia de Electricidad y Combustibles	-	Chile
Agencia Nacional de Energia Electricia	-	Brazil
Ente Regulador de la Electricidad	-	Argentina
Superintendencia de Electricidad	-	Bolivia
Regulation on Wholesale Energy Market Integrity and Transparency (REMIT)	European Union Agency for the Cooperation of Energy Regulators	Europe
AER	Australian Energy Regulator	Australia
NZEA	New Zealand Electricity Authority	New Zealand

Table 1.3: A Roster of Groups with Market Monitoring Authority

staff in their work.

1.4.1 Subject Matter Expert (SME) Discussions

The potential use of this dissertation is driven, in part, by the opinions of subject matter experts in the field of electric energy. In support of this research, I have consulted multiple members in different sectors of the industry, including 2 professionals in enterprise asset management, and a separate discussion with a staff member in energy regulation. One such staff member, Dr. Kennedy Oyoo, performed information systems research in a different sector of the energy grid- "power and utilities"- focusing on the distribution of electricity to end users.

Energy utilities struggle with a similar issue to those faced by market monitors- siloed data exists in different systems, and can exist with vastly different data quality scores (in terms of completeness, accuracy, etc.) Dr. Oyoo's research found that a key step- data validation- was missing from the ETL processes of an energy utility. Part of the research completed in his project resulted in an information template-based prototype system that cleansed and validated utility data according to automated assertion rules. Such a methodology has potential impacts for the market monitoring discipline, and can have an influence on the resulting system architecture of this dissertation (particularly in utilizing a system of templates to fetch market data).

2. LITERATURE REVIEW

A review of the literature surrounding information quality research within market monitoring units shows that there is a legitimate gap in how value is being derived from information assets. This gap is highlighted by several major issues (introduced in Chapter 1 and discussed in this literature review), including:

1. An aging workforce in the electric utilities industry that is reaching the tipping point for replacement
2. A disruption of traditional energy market design due to advances in technology and the regulatory landscape
3. A lack of focus on data and information quality research within the electric utilities industry

These issues represent a unique opportunity to yield important value from the data assets both generated and used by actors in the market monitoring sphere. The researcher will discuss each of these issues in the context of relevant literature, [1] and then introduce other relevant research that indicates how this design science project has the potential to improve these issues in the market monitoring landscape.

2.1 Business Landscape

2.1.1 An Aging Workforce

Many technical workforces are seeing a similar problem of an aging workforce; trained professionals are reaching retirement age at a rate faster than that of replacement. A 2006 study showed that the largest staff segment, of a surveyed group of energy professionals, is at (or beyond) retirement age. This same study cited "retirements, restructuring, and technology changes" as being

[1] Appendix B contains a listing of different search phrases used for finding relevant research included in this literature review.

the primary drivers of staff leaving the energy profession [25]. Such a problem impacts market monitoring as well.

MMUs (as previously discussed) were cemented into operation by the US federal government, not long before that same 2006 study. An energy research lab at UC Berkeley shows that staffing across market monitors is relatively low compared to other organizations in the industry. According to Goldman, Lesieutre, and Bartholomew, all operational market monitoring groups in the US had fewer than 20 FTEs (each) in employ by 2004 [26].

While these numbers appear low in comparison to other organizations with energy industry staff [2] , this study declares that budgets and headcount (at that time) increased significantly for market monitoring work. As such, this shows a trend of growing demand for market monitoring staff in a workforce that, holistically, employs many individuals on (or beyond) the horizon of retirement. One claim to helping combat this "brain drain" problem is a technology framework that "facilitates knowledge retention" [25], including systems (supported by an IT organization) that capture necessary processual knowledge.

2.1.2 Formation of Market Monitoring Units

Market monitoring units were formed in response to sweeping changes in how US corporations are now regulated. The fall of Enron Corporation gave way to the rise of the Sarbanes-Oxley Act of 2002, which issued stringent financial reporting and auditing requirements for all publicly traded companies. The Energy Policy Act of 2005, several years later, gave more authority for regulatory bodies to pursue cases of market manipulation and marketplace gaming. In addition, the act also elevated the definition of market manipulation for energy market participants.

To paraphrase the legislation, "it shall be unlawful for any entity... to use or employ, in connection with the purchase or sale of electric energy or the purchase or sale of transmission services subject to the jurisdiction of the Commission, any manipulative or deceptive device or contrivance..., in contravention of such rules and regulations as the Commission may prescribe as necessary or appropriate in the public interest or for the protection of electric ratepayers" [27]. In addition to

[2] As of Q1 2025, Southwest Power Pool employs over 800 FTEs (including their internal market monitoring staff).

electricity markets, natural gas markets also saw an increase in regulatory activity.

Coming into the current decade (2020's), we now see a slew of new external factors that affect the energy industry (and by extension, also affect the market monitoring domain) including:

- A global transition away from the use of fossil fuels in energy production
- Increased penalties for excess greenhouse gas emissions
- Developments in energy storage
- Enrollment of large energy consumers as demand response resources
- Renewable energy technology

Each of these factors have an effect on the energy market landscape [28]. In response, market monitors must develop strategies to observe these new market dynamics. These industry changes add to the data entropy in which market monitoring analysts operate. New standards for greenhouse gas emissions give way for new tactics that market participants can use as excuses for what is currently identified as manipulative behavior [3]. In a different market segment, energy storage technology has potential impact on the economic theory that governs electricity markets. Given that electric energy is an highly perishable commodity, then energy storage technology reduces that perishability factor. Each of these types of impacts change how market analysts must perceive, surveil, and report on energy markets.

2.1.3 The Data Domain for Market Monitoring

The data domain for market monitoring entities is a complex ecosystem. It is commonplace for monitoring analysts to seek and synthesize information for their roles from disparate sources both across the enterprise *and* from sources external to their company. This type of ecosystem can quickly become a data swamp without careful attention to business rules and the possession of institutional knowledge for how processes are carried out on market information.

[3]For example, a gas turbine generator that uneconomically produces power in a market interval can claim that they had to underproduce as part of curbing their greenhouse gas emissions.

FERC Order 760, a key piece of legislation that directly relates to this dissertation, dictates several key types of data that need to be provided by RTOs and ISOs to the Commission. Such data includes [29]:

1. Supply offers and demand bids for energy and ancillary services
2. Virtual offers and bids
3. Energy/ancillary service awards
4. Capacity market offers, designations, and prices
5. Resource output
6. Marginal cost estimates
7. Day-ahead market shift factors
8. Financial Transmission Right (FTR) data
9. Internal Bilateral Contracts
10. Pricing data for interchange transactions (otherwise known as scheduling and tagging)

The order identifies that such entities must provide this data to FERC on a regular basis. Understanding how to source and use this information also impacts the accuracy of market monitoring analysis. Defined by the industry terms "ex-ante" and "ex-post", assessments of market performance, market power, and market manipulation can be carried out prior to an event, or "after the fact"- when a market event has already occurred [30].

2.1.3.1 Public Market Data Systems

A major component of the market monitoring data landscape (and one that enables the development of this research) are the data systems that RTO/ISO organizations publish, allowing the general public a view into the operation and settlement of wholesale energy markets. Given that the data exists in the public domain, these public portals will be utilized to build the data fabric for this research.

One such example of a publicly-posted dataset comes from the California Independent System Operator. As part of their public postings, CAISO includes "curtailed and non-operational generator reports" on their site. A snippet of a more comprehensive report is shown in Figure 2.1 [31].

California ISO

Report Generated on : 03/23/2025 07:30:00 (PPT)
Trade Date: 03/23/2025

Curtailed and Non-Operational Generator AM Report

Resource ID	Resource Name	Outage Type	Capacity (MW)	Curtailed (MW)	Zone Name	BA
HELMPG_7_UNIT 2	HELMS PUMP-GEN UNIT 2	Planned/Forced	407.00	407.00	PGAE South	CISO
SYCAMR_2_UNIT 2	Sycamore Cogeneration Unit 2	Forced	76.00	76.00	SCE Gen	CISO
NORORC_2_NOSBX2	Northern Orchard Solar	Forced	150.00	150.00		CISO
POME_6_POMBT1	POME BESS	Forced	100.00	100.00		CISO
RATSKE_2_WAVBT1	Willy 9 Antelope Valley Complex	Forced	126.00	126.00		CISO
RDGPOWER_1_UNIT1	REDDING GT 1	Forced	18.00	2.00		BANC
RDGPOWER_1_UNIT2	REDDING GT 2	Forced	26.00	3.00		BANC
RDGPOWER_1_UNIT3	REDDING GT 3	Forced	26.00	3.00		BANC
RDGPOWER_1_UNIT4-6	REDDING CC 4-6	Planned/Forced	126.00	126.00		BANC
REP_6_UNITS	Roseville Energy Park	Forced	164.00	84.00		BANC

Figure 2.1: An example of a publicly-posted dataset from CAISO

Such a dataset enables this system to perform surveillance and analysis on generators in a market to screen for physical withholding, or other market gaming schemes. For further information on where to view live data from these systems, see Appendix D for a full reference of the systems that currently exist as public sources of market data.

2.2 Information Architecture and Domain-Specific Languages

2.2.1 The Importance of Institutional Knowledge

Another area that this research intends to address is maintaining institutional knowledge. As employees retire or make career changes into other industries, the institutional knowledge that they built often leaves with them. In market monitoring, this problem is amplified due to two, salient facts: 1) the number of individuals that work in market monitoring are small compared to the rest of the energy and utilities industries, and 2) market monitors often specialize in regards to analysis or policy work. Individuals who primarily work in market surveillance may never directly work in policy development for generator capacity accreditation.

In a personal anecdote, this "brain drain" has been seen within the SPP MMU. Several long-term employees have exited the MMU in pursuit of other roles, only to leave undocumented code behind them that others must support. This code exists in the form of SQL queries and/or SAS scripts that contain embedded business rules (as they were understood by these employees). Deciphering and supporting this code becomes a burden for others that inherit the work of these departed employees.

A 2016 publication *Knowledge Management in Esoteric Management* summarizes this issue well: "...knowledge sharing should be encouraged by placing employees working together closely to create pooled expertise..." [32]. When employees share knowledge, they can keep important information from being destroyed when key individuals leave a department. A system described this dissertation aims to foster knowledge sharing amongst employees.

2.2.2 Metadata Curation

To make sense of market monitoring data and develop an effective analytics prototype to aid market monitors in their work- understanding and mapping the metadata that governs the processes and workflows of market monitors is paramount. A recent study, *Research on Power Market Data Asset Management Framework*, identifies the use of a Data Management Capability Maturity Assessment Model (DCMM) that aids in data cataloging and metadata curation for the power systems industry. Their methodology takes a holistic view of analyzing how data and metadata are used in market contexts, and creates a topology system for cataloging such data [33].

2.2.3 Domain-Specific Languages

Domain-specific Languages (DSL) are powerful interfaces that enable subject-matter experts (SME) in any particular domain of expertise to perform tasks similar to a proper software developer that builds applications in general-purpose languages (GPL). A well-defined DSL can save many man-hours in development time for specific groups that have IT oriented needs, but lack the funding or access to talent for hiring a normal software engineer. DSLs also have the ability to lower the "barriers to entry" for SMEs that wish to write applications to handle work within their purview. With support from a DSL- a software engineer does not need to be deeply involved in business rules to understand how to develop an application (a common issue in the energy industry). Likewise, SMEs do not need to heavily codify their business rules into software requirements for an application to be developed.

The literature uncovered in this review supports both the claim that DSLs have high efficacy in financial contexts [34] and that they have been deployed in other areas of the energy sector, as identified by Sobernig, Strembeck, and Beck [35] in *Developing a Domain Specific Language for Scheduling in the European Energy Sector*. While this paper sets precedent for the use of DSLs in the energy industry, it presents an even larger gap that this dissertation intends to address. Beck's study only explores tagging and scheduling, which only encompasses a single component of market monitoring. Additionally, and far more importantly, the implementation of their DSL was constrained to a specific market interconnection in Europe, which is significantly less complex than the transmission and congestion issues that are seen throughout the North American Bulk Electric System.

Current issues in North America show large pockets of stranded load, which have significant economic (and, by extension, reliability) implications. Congestion on the BES constitutes a market (Financial Transmission Rights) that settles for billions of dollars. This is all due to the fact that monies have to be paid to rights holders for transmitting energy across a congested transmission infrastructure.

Similarly- the software industry has invested in making domain-specific languages more accessible to business users. Jetbrains (a prominent vendor in the developer tooling and integrated development environment space) has developed a workbench application- MPS (Meta-Programming System), a "projectional editor"- to allow non-developers to create DSL-like applications for business purposes. "Domain experts with inclination towards programming but without formal education in computer science will themselves build or customize DSLs to address the needs specific in their domains" [36]. The experience that Jetbrains developers have with educating others in the use of MPS support this idea.

Another area of DSLs that is essential to a successful implementation in market monitoring is modeling. Modeling, like in other areas of business and engineering, is how business rules are effectively mapped to artifacts in software engineering [37]. Modeling market monitoring concepts effectively is a critical step in ensuring that the system meets the needs of analysts and business users.

2.3 Research Design and Contributions

This project's design is based on the Design Science Research Methodology (DSRM), a process for developing new product artifacts. The researcher chose the DSRM for this project because the main research objective is to develop a domain-specific language for market monitors to use in their analysis.

Data and information quality problems exist today in the market monitoring body of knowledge. Domain-specific languages are powerful models for allowing users to systematically solve problems within a specific domain. As was determined in the literature review, DSLs have only had limited exposure in electricity markets (and even less exposure in market monitoring). This discovered gap in existing research serves as the inspiration for this project. Figure 2.2 provides more detail on the planned use of design science within this project. [4]

As established by the literature review, this project is a unique research endeavor in the following objective areas:

- It aims to develop a novel, interactive development environment for performing market surveillance and analysis
- It shall advance the field of information quality by providing a foundation (by way of a systematic literature review) for what information quality research has been conducted in

[4] See Appendix C for a schedule of the milestones and expected completion timeline for this project.

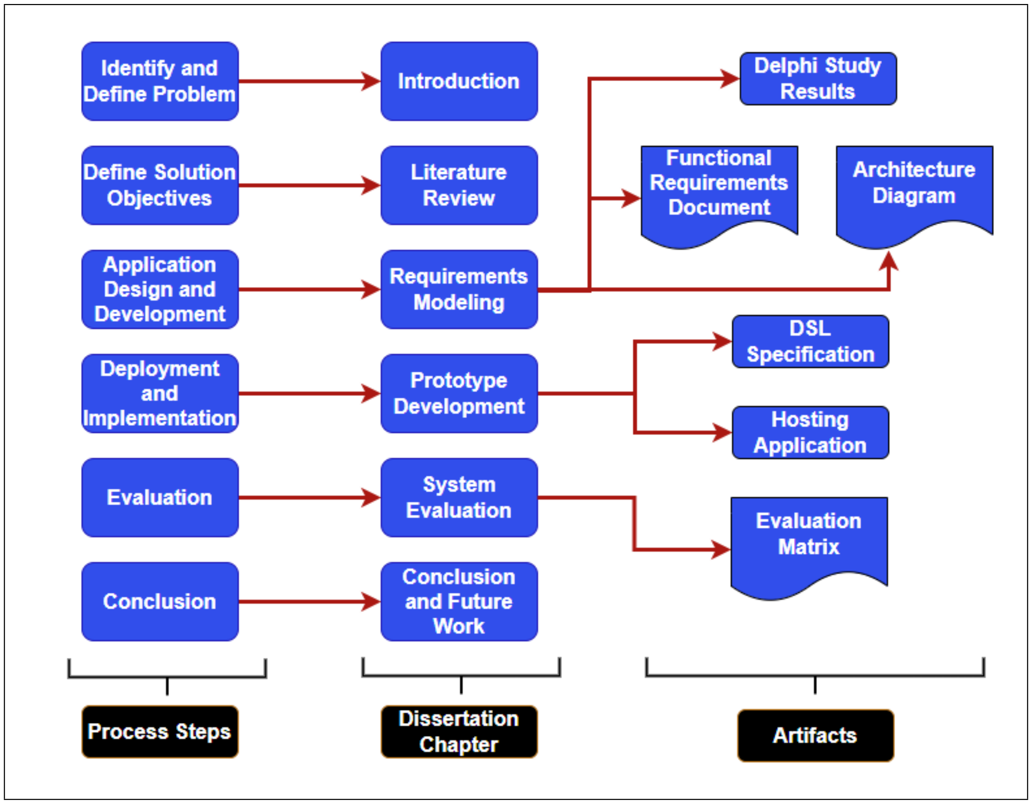

Figure 2.2: Design Science Research Methodology for this dissertation

the market monitoring domain, and what future opportunities exist

- It shall provide a flexible, metadata-driven architecture design that allows market monitors to fetch data from a variety of sources and formats that are used in market monitoring investigations. This design will be determined through use of the Delphi methodology

- It shall perform an evaluation of the proof-of-concept prototype system for determining to what degree the system satisfies the requirements gathered in the Delphi study [5]

In addition to a domain-specific language for analyzing electricity market data, the system implementation portion of this project will also include a web application (with tooling) that show-

[5]This component of the research evaluates how well the current needs of market monitors are met. This has importance to the industry because, while market monitors are supplied with data from their jurisdictional markets, MMUs often must provide their own in-house support for programming and surveillance. The system described in this research gives way to a common, open-source, platform that market monitors can develop and extend for their own work.

cases the language's ability to aid in producing information products for MMUs.

2.3.1 Proposed Investigation

The investigation design for this dissertation is composed of 5 main components: a literature review, requirements gathering from subject matter experts, an architecture design (and accompanying documentation), development of a prototype that serves as an example implementation of the architecture design, and a period of evaluation to determine to what degree the prototype system satisfies the requirements document.

2.3.2 Limitations of This Research

The scope of work proposed in this dissertation is limited to the objectives outlined in the Research Contributions section. Specifically, it shall evaluate the artifact output of the DSRM process to ensure that the artifact functions as a "minimum viable product" for energy market analysis.

The proof-of-concept prototype discussed in this dissertation is not intended to be a production-ready system. It is not expected to be used in a live scenario for market monitors to immediately put into service. The data ingested into the prototype will be based on realistic data scraped from public data systems shown in Appendix D. The evaluation of this system will be based upon a requirements matrix developed from the results of the Delphi study that is also conducted in this research.

Further system optimization, bug-fixes, scalability, and use in live market monitoring scenarios are all considered "out of scope" for this dissertation, and are reserved for future work.

3. REQUIREMENTS MODELING AND ANALYSIS

This section to discuss the Delphi study conducted as part of this research, along with requirements modeling and analysis.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD CERTIFICATES

UA LITTLE ROCK

INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF ARKANSAS AT LITTLE ROCK
2801 S. University Ave., Little Rock, AR 72204-1099 | (O) 501.916-6209 | irb@ualr.edu

TO: Eric Charles Grasby / Dr. Daniel Berleant, Advisor

FROM: UA Little Rock Institutional Review Board

CC: Office of Research Compliance

DATE: October 4, 2024

PROTOCOL: #24-062 "Building an Information Quality-backed Analysis System to Support Monitoring and Surveillance Operations Within a Wholesale Electricity Market"

Thank you for your recent submission to the University of Arkansas at Little Rock Institutional Review Board (IRB). The IRB (FWA #00002205), has reviewed **Protocol # 24-062 "Building an Information Quality-backed Analysis System to Support Monitoring and Surveillance Operations Within a Wholesale Electricity Market".** The review was limited to activities described in the protocol narrative. On the basis of the review of this protocol, it has been determined that this research **does not meet the criteria of *human participant research*** based on 45 CFR 46.102.

You are reminded that:

1. The investigator assumes responsibility for notifying the University of Arkansas at Little Rock Institutional Review Board of any changes in the activities described in the protocol. Re-review might be required. Changes include the future use of the data even if that future use was mentioned in the protocol.
2. If absolutely no changes occur to the protocol, then the data does not need to be retained for the requisite three years.

Best of luck with your study.

Figure A.1: Interview Pilot Study

UA LITTLE ROCK
INSTITUTIONAL REVIEW BOARD (IRB)
UNIVERSITY OF ARKANSAS AT LITTLE ROCK
2801 S. University Ave., Little Rock, AR 72204-1099 | (O) 501.916-6207 | irb@ualr.edu

TO: Eric Charles Grasby / Dr. Daniel Berleant, Advisor

FROM: UA Little Rock Institutional Review Board

CC: Office of Research Compliance

DATE: March 25, 2025

PROTOCOL: #25-020-R1 "Building an Information Quality-Backed Analysis System to Support Monitoring and Surveillance Operations Within a Wholesale Electricity Market (Delphi Study Component)"

Thank you for your recent submission to the University of Arkansas at Little Rock Institutional Review Board (IRB). The IRB (FWA #00002205) has reviewed **Protocol #25-020-R1 "Building an Information Quality-Backed Analysis System to Support Monitoring and Surveillance Operations Within a Wholesale Electricity Market (Delphi Study Component)".** The review was limited to activities described in the protocol narrative. On the basis of the review of this protocol**,** we find that it meets the IRB's criteria for protection of human participants. Your protocol has been **approved** as <u>Human Participant Research</u>. You may now begin to collect data.

You are reminded that:

1. **Your IRB approval end date is March 24, 2026.** If you wish to continue to collect data past the IRB approval end date, you will need to submit a *Request for Continuing Review*. This request must be submitted and approved prior to the end date to allow for a seamless extension. If approval is not received by that date, all research involving human participants connected with this protocol must cease until such time as approval is received.
2. This permission to collect data is restricted to UA Little Rock Principal Investigators (PIs).
3. This approval is limited to **only** the activities described in the approved protocol narrative. Any changes to **Protocol #25-020-R1** (examples include, but are not limited to, a change in PIs, research staff, research design, recruitment, consent forms, or the data that are collected) require a *Request for Protocol Modification*. All requests must be approved by the IRB prior to the initiation of a change.
4. PIs and all research staff are required to follow all FERPA policies. For questions about FERPA policies, contact Malissa Mathis (mktrantham@ualr.edu).
5. All submissions, including modifications and extensions, are reviewed to ensure that the protocol meets current requirements for protection of human participants.
6. Unanticipated problems or new information about risk must be reported within 2 business days to the IRB. The Adverse Event reporting form is located at https://ualr.edu/irb/home/irb-forms/

Any future research using this data beyond what is described in the protocol requires IRB approval.

Best of luck with your study.

Figure A.2: Delphi Study

APPENDIX B

SEARCH QUERIES USED IN LITERATURE REVIEW

Google Scholar and IEEE Xplore were the primary academic databases that were queried for this dissertation.

High-level searches used to find seminal articles in the areas of energy markets, market monitoring, and domain-specific languages:

- MARKET MONITORING
- MARKET MONITORING AND DOMAIN SPECIFIC LANGUAGE
- DOMAIN-SPECIFIC LANGUAGE AND BULK ELECTRIC SYSTEM
- DOMAIN SPECIFIC LANGUAGE AND FORENSICS
- DOMAIN-SPECIFIC LANGUAGE

Boolean and grouping operators were also employed to narrow the scope of the relevant articles returned for this literature review. Some of the queries included:

- "MARKET MONITORING" AND ("DOMAIN SPECIFIC LANGUAGE" OR "DOMAIN-SPECIFIC LANGUAGE")
- "MARKET MONITORING" AND ("DOMAIN SPECIFIC LANGUAGE" OR "DOMAIN-SPECIFIC LANGUAGE") AND ("ELECTRIC" OR "ELECTRICITY") -STOCK
- ("INFORMATION QUALITY" OR "DATA QUALITY") ("ELECTRICITY MARKET" OR "POWER MARKET" OR "ELECTRIC MARKET")
- ("INFORMATION QUALITY" OR "DATA QUALITY") (ELECTRICITY OR POWER OR ELECTRIC OR ENERGY) MARKET

- ("INFORMATION QUALITY" OR "DATA QUALITY") (ELECTRICITY OR POWER OR ELECTRIC OR ENERGY) "MARKET MONITORING"
- ("INFORMATION QUALITY" OR "DATA QUALITY") (ELECTRICITY OR POWER OR ELECTRIC OR ENERGY) WHOLESALE "MARKET MONITORING" -LABOR -LABOUR -"FINANCIAL MARKET"
- ALLINTITLE: WHOLESALE "INFORMATION QUALITY" OR "DATA QUALITY" OR ELECTRICITY OR POWER OR ELECTRIC OR ENERGY "MARKET MONITORING" -LABOR -LABOUR -"FINANCIAL MARKET"
- ALLINTITLE: ELECTRICITY "INFORMATION QUALITY" OR "DATA QUALITY" OR "MARKET MONITORING" -LABOR -LABOUR ("DOMAIN-SPECIFIC LANGUAGE" OR "DOMAIN SPECIFIC LANGUAGE") (ELECTRICITY OR ELECTRIC OR POWER OR ENERGY)

APPENDIX C

SCHEDULE OF RESEARCH MILESTONES

Note that these milestones are subject to change by the discretion of the principal investigator and research advisor. The timeline may become compressed or protracted as milestones are completed.

Semester	**Milestone Description**	**Associated Deliverables**
FALL 2024	Article Gathering for Literature Review	*Retrieved Existing Research*
	Literature Review Interviews	*Interview Results*
	Preparation for Qualifying Exam	*Slide Deck and Summary*
	Complete Qualifying Exam	-
	Complete Required CITI Modules	*CITI Completion Certificate(s)*
SPRING 2025	Complete Writing Literature Review	*Dissertation Chapter (2)*
	Complete Writing Proposal	*Dissertation Proposal*
	Schedule Proposal Defense	-
	Complete Proposal Defense	-
	Develop Initial Set of Delphi Study Questions	*Delphi Study Questions*
	Seek IRB Approval	*IRB Approval Letter*
	Begin Seating Delphi Panel	*Coordination with Experts*
SUMMER 2025	Complete Dephi Study	*Paper Publication*
	Create Requirements Document	*FRD, BPMN Flows, etc.*
FALL 2025	Finish Requirements Chapter	*Dissertation Chapter (3)*
	Begin Prototype Development	*Prototype Artifacts*
	Begin DSL specification	*DSL Spec*
	Begin Implementation Dissertation Chapter	*Dissertation Chapter (4)*
SPRING 2026	Iterative Development	*Prototype Artifacts (cont)*
	Track evaluation metrics for prototype	*Evaluation results*
SUMMER 2026	Prototype Setup/Deployment	*PoC environment*
	Iterative Development & Bugfixes	*Bug-fixes / version enhancements*
	Implementation and Evaluation Chapters	*Dissertation Chapters (4, 5)*
FALL 2026	Finish Conclusion Chapter	*Dissertation Chapter (6)*
	Complete Dissertation Formatting	*Dissertation Ready for Defense*
	Dissertation Defense	-

Table C.1: Schedule of Milestones for this Dissertation

APPENDIX D

PUBLIC MARKET DATA SOURCES

- Data Miner 2, PJM Corporation - `https://dataminer2.pjm.com/list`
- Member Information Reporting Application (MIRA), Monitoring Analytics - `https://www.monitoringanalytics.com/tools/tools.shtml`
- Market Data Transparency Service, ERCOT - `https://www.ercot.com/services/mdt`
- Open Access Same-Time Information System, California ISO - `http://oasis.caiso.com/mrioasis/logon.do`
- CAISO Data Library, California ISO - `https://www.caiso.com/library/market-data`
- MISO Data Exchange, MISO - `https://data-exchange.misoenergy.org/`
- Marketplace Portal, Southwest Power Pool - `https://portal.spp.org/`
- Wholesale Energy Market Reports, US Energy Information Administration (EIA) - `https://www.eia.gov/electricity/`
- Operational Data Portal, New York ISO - `https://www.nyiso.com/energy-market-operational-data`
- ISO Express, ISO New England - `https://www.iso-ne.com/markets-operations/iso-express`

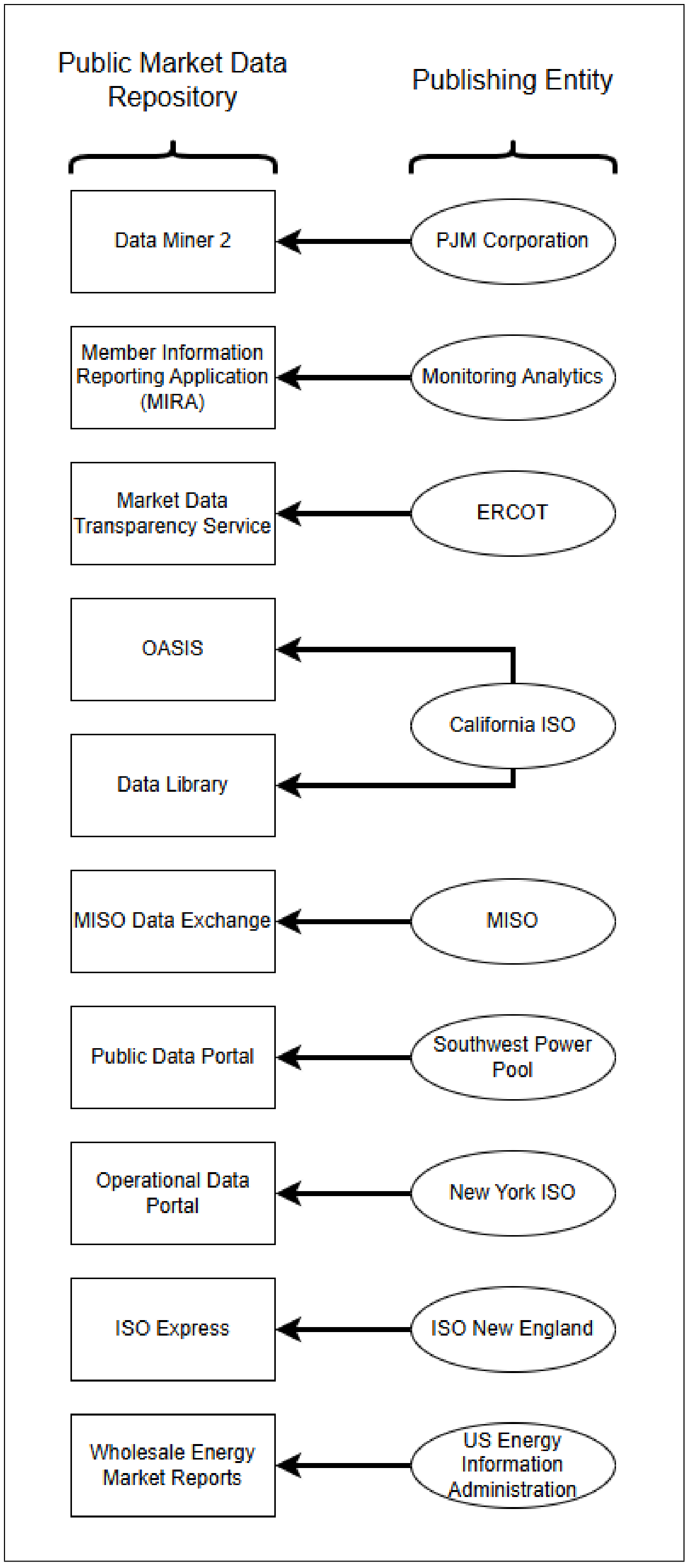

Figure D.1: Public Market Data Sources