Navigating "Wicked Problems" in Public Policy: The Power and Promise of Using SHAMROQ's Transdisciplinary Approach to Find Regulatory Text Patterns – A Mixed Method Study

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Abstract: *In an era marked by significant public policy challenges, including climate change, public health, and economic inequality, traditional bureaucratic or technocratic methods prove increasingly inadequate. These so-called "wicked problems," characterized by their complexity and resistance to simple solutions, require more dynamic, inclusive approaches, that transcend jurisdictional boundaries. Embracing these approaches, we extend SHAMROQ, a novel transdisciplinary approach that combines Software Engineering, Artificial Intelligence, Linguistics, and Logic to extract, classify, and model deontic expressions from regulatory texts. This mixed-method study examines three CFR titles: Title 16 Commercial Practices, Title 45 Public Welfare, and Title 48 Federal Acquisition Regulations Systems, with an emphasis on the distribution of deontic expressions and identifying challenges in regulatory text. The results, supported by a chi-square test of independence with a highly significant p-value < .001 , show a strong association between deontic expression types and CFR Titles. This research also provides deeper insights into regulatory language complexity by broadening the analysis across CFR Titles 16, 45, and 48. Title 16 features diverse permissions and obligations, reflecting commercial law's complexity. Title 45 uses strict directives like 'must' and 'shall' for public welfare compliance, while Title 48 focuses on obligatory terms for federal acquisition, aligning with procurement demands. Such insights can inform future research and practical applications in regulatory analytics, compliance, and public policy.*

Keywords: Transdisciplinary, SHAMROQ, complexity, public policy, regulatory compliance

1 Introduction

Today, public policy faces a range of unprecedented challenges, from climate change and public health to economic inequality and the online safety of children and youth[1]. These challenges, often referred to as "wicked problems," are not just complex and multifaceted, they are further complicated by interdependencies that make them resistant to resolution through traditional bureaucratic or technocratic means [1].

Furthermore, these problems often extend beyond jurisdictional boundaries, emphasizing the need for flexible, adaptive approaches over extended periods of time [2]. For example, in

[1] https://www.un.org/en/global-issues

environmental policy, emissions in one country can affect climate patterns in another, or in economic policy, a major economic decision in a powerful nation can influence global markets. Similarly, in the realm of public health, when a novel virus emerges in one region, as was the case with COVID-19, it can quickly spread and become a global pandemic.

Rittel & Webber noted that traditional practices are often inadequate. They argue that public policy concerns are inherently different from the problems that scientists and engineers deal with, as they are inherently complex, ill-defined, and rely on political judgment rather than clear solutions. In response to these challenges, Rittel & Webber argued for novel collaborative approaches that transcend disciplinary boundaries. While specific strategies for solutions are context-dependent, the main goal should always be to involve a wide range of perspectives [3].

A growing body of literature supports the notion that public policy issues demand a broader, more collaborative, and inclusive perspective. McGregor advocates using transdisciplinarity to bring together diverse knowledge, values and contexts when addressing complex public policy issues. McGregor shows how transdisciplinary approaches, such as Nicolescuian, Zurich, and Brazilian, can inform public policy for addressing complex societal problems [4]. Van der Waldt observed that public policy and administration, with its diverse knowledge spanning state theories, governance, law, ethics, and more, is well-suited for transdisciplinary research to address complex societal issues [5].

This sentiment is echoed by others, like Uwizeyimana and Basheka, who see transdisciplinarity as a pragmatic approach for public administrators to craft actionable and effective policy solutions [6]. Ndaguba and Ijeoma highlight the limitations of traditional and interdisciplinary methods in tackling today's complex societal issues [7]. Vargas and Restrepo contend that transdisciplinarity not only fortifies the core identity of disciplines like law, politics, and economics but also interconnects them, fostering a more holistic understanding of public issues and thereby paving the way for more equitable and effective policy recommendations [8].

At its core, transdisciplinarity merges different perspectives to offer an approach with a deeper understanding of multifaceted challenges [9, 10]. This holistic approach integrates insights from individuals, families, communities, educational entities, and a broad spectrum of non-governmental organizations. In the realm of technology, Mambo exemplifies how Software Engineering (SE) and Artificial Intelligence (AI) can merge different perspectives with transdisciplinarity to make knowledge and innovations more synergistic and complementary [11]. In this paper, we go one step further by exploring the synergy between SE, AI, Linguistics, and Logic with a novel transdisciplinary approach called SHAMROQ (Semantic Web Parameterization, Hohfeldian Legal Concepts, Artificial Intelligence, Metadata Enrichment, Reasoning System, Ontologies, and Query language).

SHAMROQ [12, 13] is designed to provide policy administrators, government agencies, software engineers, and legal practitioners with a means to extract deontic expressions from regulations and model them in LegalRuleML[2]. Consider the Children's Online Privacy Protection Act (COPPA)[3] where a digital service provider (DSP) aims to launch a new online platform targeted at children. Using SHAMROQ, the DSP can extract and comprehend the critical deontic

[2] https://docs.oasis-open.org/legalruleml/legalruleml-core-spec/v1.0/os/legalruleml-core-spec-v1.0-os.html
[3] https://www.ftc.gov/legal-library/browse/rules/childrens-online-privacy-protection-rule-coppa

expressions from COPPA, enrich the text with linguistic features, and convert them into conditional if/then rules. A statement like "operators must obtain verifiable parental consent before collecting personal information from children" gets evaluated to identify the obligation ("must"), the actor ("operators"), and the stipulated condition-action sequence.

SHAMROQ then systematically converts these enriched statements into conditional if/then rules: "IF an operator collects personal information from children, THEN they must obtain verifiable parental consent." This systematic conversion ensures that the mandates of regulations like COPPA are captured accurately and can be integrated into software systems, thus, supporting the prevention of inadvertent privacy breaches. Augmenting this automatic extraction capability is the incorporation of LegalRuleML.

In contexts like COPPA where multi-stakeholder understanding is crucial, the LegalRuleML formal modeling framework offers a unified, transdisciplinary lens, allowing for a consolidated comprehension across sectors from software developers to legal experts. By leveraging these features, stakeholders can navigate the intricacies of COPPA, facilitating the translation and compliance of its provisions in software solutions, and thereby supporting the online safety of children. With the capabilities of SHAMROQ in mind and understanding the complexities inherent in regulatory texts, a mixed method study is proposed and conducted.

The purpose of this mixed method study is to investigate the occurrence and usage of expressions, such as obligations, permissions, prohibitions, and dispensations, within three Codes of Federal Regulations (CFR): Title 16 Commercial Practices[4], Title 45 Public Welfare[5], and Title 48 the Federal Acquisition Regulations Systems[6]. Utilizing the SHAMROQ framework, this study aims to provide both quantitative and qualitative analyses: the former focusing on the frequency and distribution of these expressions; and the latter exploring the linguistic complexities that obstruct their automated extraction and classification.

The contributions of this paper are twofold. First, we provide a comparative analysis of Titles 16, 45, and 48 using the SHAMROQ framework. This analysis highlights the differences, similarities, and unique challenges each title presents when it comes to regulatory text complexity. The insights offer a deeper comprehension of the regulatory landscape, arming practitioners with precise methodologies to extract and navigate the requirements embedded within these titles. Second, we expand SHAMROQ's framework, where we initially validated CFR Title 48. Here, we show how the work can be adapted and applied to different titles. This adaptation will underscore the versatility of SHAMROQ and pave the way for its wider application across various regulatory domains.

2 Methodology

The research methodology is grounded in the pragmatist worldview [14]. We purposely selected this worldview to understand the transdisciplinary potential of SHAMROQ to extract deontic expressions from regulatory text – reflecting real-world complexities. Our commitment to a pragmatic approach informed our decision to use the mixed methods research design [15]. This research design choice facilitates a dual examination: a quantitative analysis of three titles of the

[4] https://www.ecfr.gov/current/title-16
[5] https://www.ecfr.gov/current/title-45
[6] https://www.ecfr.gov/current/title-48

code of federal regulations and a qualitative analysis into the regulatory complexity across different regulatory contexts. Furthermore, the design enables the collective impact of both types of data on the software implementation and refinement of SHAMROQ.

Commensurate with our research design, we formulated three research questions (RQ) to deepen the explanation of the occurrence and usage of deontic expressions within these three titles.

- RQ1: What is the distribution of obligations, permissions, prohibitions, and dispensations within titles 16, 45, and 48. How do they compare?
- RQ2: How do the syntactic structures and linguistic nuances of deontic expressions vary across the titles, and what challenges might these variations pose for automated extraction?
- RQ3: How does the integration of quantitative findings and qualitative insights holistically influence the software implementation and refinement of SHAMROQ to extract deontic expressions.

2.1 SHAMROQ: A Transdisciplinary Approach to Extracting Regulatory Requirements

In our methodology, SHAMROQ links SE, AI, Linguistics, and Logic to convert raw regulatory text into the structured format of LegalRuleML. Software Engineering [16] provides the foundational architecture and design principles to ensure that the pipeline is robust, scalable, and can handle vast amounts of regulatory data efficiently. Artificial Intelligence [17] powers the initial stages, where data is ingested, and extracted using Natural Language Processing (NLP) [18, 19].

Linguistics [20] comes into play by analyzing syntax, semantics, and context. Linguistics ensures the preservation of the nuances inherent in legal language, setting the stage for a representation in the ensuing format. The use of logic [21-25] translates the linguistically processed data into the well-defined constructs of LegalRuleML, formalizing the data in an organized and logically coherent manner to facilitate the integration into diverse legal systems or software solutions. To visualize the interaction of these disciplines within SHAMROQ, refer to Figure 1, which outlines the novel framework designed to address the "wicked problems" of regulatory language complexity.

As shown in Figure 1, there are several system documents that “Influences” the framework. These documents include the Statement of Work (SOW), Software Requirement Specification (SRS), and the Concept of Operations (CONOPS). Additionally, contracts, terms and conditions, laws, regulations, and policies are instrumental to the software engineering process. Collectively, these documents encapsulate the needs, goals, deliverables, constraints, limitations, security, and

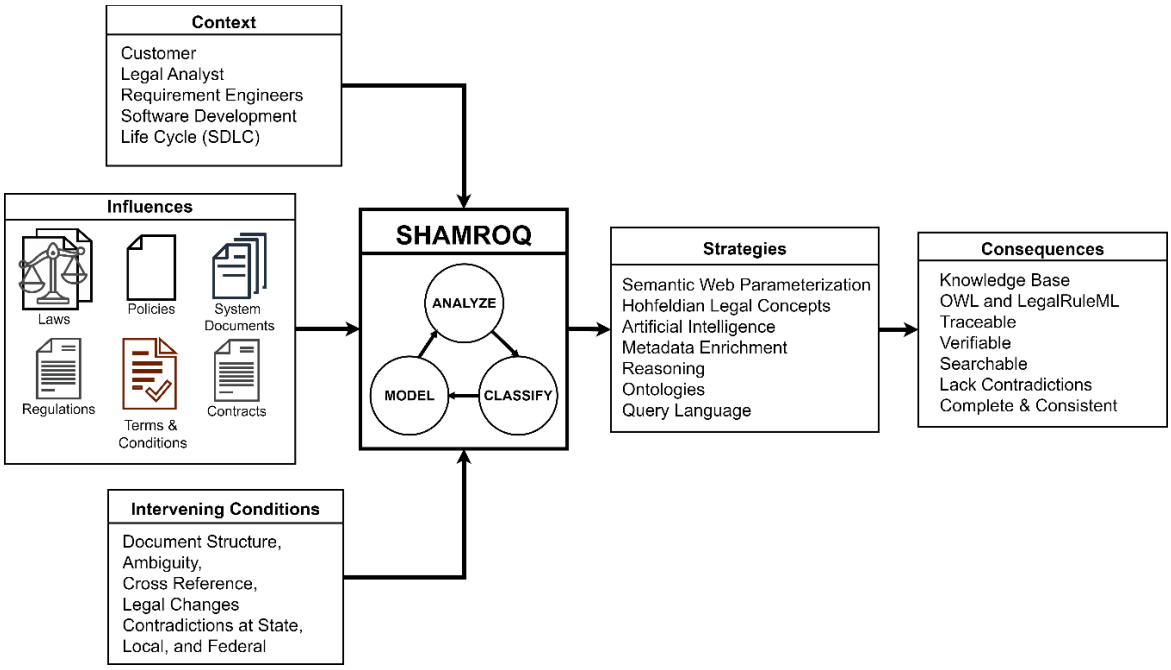

Figure 1: SHAMROQ Framework

performance criteria for a software system. By analyzing these documents, SHAMROQ can extract essential requirements and specifications that must be met. Understanding and addressing stakeholder needs is an important part of software engineering. As shown in the "Context" of Figure 1, SHAMROQ's framework considers the diverse needs and expectations of various stakeholders involved in regulatory compliance throughout the software development lifecycle (SDLC). These stakeholders include not just the legal practitioners and policymakers, but also requirement engineers, software developers and customers who interact with these regulations.

Another critical aspect of SHAMROQ is to handle the "Intervening Conditions" of the inherent ambiguities [26, 27], cross-references [28, 29], and varying structures of legal documents. The integration of the "Strategies" to include AI, linguistics, and logic enables it to navigate through the complexities of legal language, including changes and inconsistencies within and across different jurisdictional levels. By systematically analyzing and converting regulatory texts into structured formats like LegalRuleML, SHAMROQ helps to identify and reconcile potential contradictions and adapt to legal changes, whether at the state, local, or federal level. This identification, reconciliation, and adaptation ensures that the "Consequences" provide a more accurate and nuanced understanding of regulatory requirements, crucial for compliance, traceability, verifiability, consistency, and completeness across diverse legal landscapes.

2.1.1 SHAMROQ: Analyze, Classify, Model

The SHAMROQ framework consists of three phases: Analyze, Classify, and Model. In the Analyze phase, we systematically parse and interpret the XML files listed on the Code of Federal Regulation (Annual Edition)[7] website. The website compiles the general and permanent rules issued by various departments and agencies of the Federal Government. Each tile is provided

[7] https://www.govinfo.gov/app/collection/cfr/

electronically in PDF, TEXT, and XML formats. Our methodology uses the xml.etree.ElementTree Python module to parse and read the XML version of the title. This phase also involves resolving ambiguities and enriching the text with linguistic features through the spaCy[8] NLP pipeline. As illustrated in Figure 2, the pipeline takes as input the raw un-processed regulatory text. The text undergoes a sequence of operations that divide the text into tokens, such as words and punctuation, through a process known as tokenization. Next, each token is assigned a part-of-speech tag (e.g. nouns, verbs, adjectives) to denote its grammatical role. The text is then parsed to identify its grammatical structure, and entities such as persons, organizations, locations, and dates are labeled. These steps are executed using four key components: a tokenizer, a part-of-speech tagger, a dependency parser, and named entity recognition (NER). The resulting structure is a "Doc" object which encapsulates the outcome of the processing pipeline as a sequence of token objects with their associated linguistic annotations. The outcome of this phase is exported as a Comma-separated values (CSV) file, ready for the "Classify" phase.

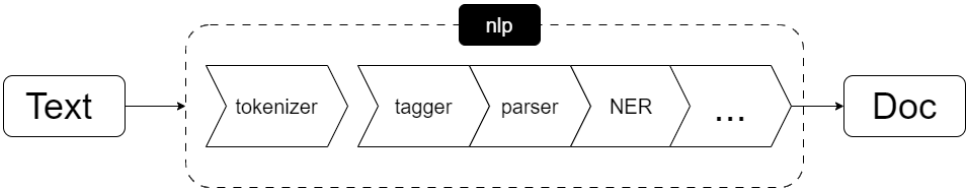

Figure 2: spaCy NLP Pipeline

In the Classify phase, the focus is on identifying statement-level and phrase-level concepts in each sentence and converting them into a conditional format. This identification includes extracting deontic expressions, such as obligations and permissions, using a rule-based NLP approach, which identifies specific keywords and syntactic structures. For instance, combinations of nouns and modal verbs like "should," "must," and "shall" indicate obligations.

Phrase-level concepts, detailing sentence structures, are also identified through part-of-speech and dependency parsing, leading to the formulation of if/then conditional statements. For example, the part of speech noun, proper noun, or pronoun followed by modal keywords like "should", "must", and "shall" , typically signify an obligation. On the other hand, phrase-level concepts incorporate the lexical structure of sentences, which include elements like subject, action, and object. These structures are extracted through a combination of part of speech and dependency parsing.

Once the sentences are classified according to their statement and phrase level concepts, they are converted into if/then conditional statements. These statements are then processed using OpenAI's GPT3.5 "text-davinci-003" model, accessed via the completion API[9]. The model, fine-tuned for deterministic outputs, uses specific prompts to ensure accuracy and efficiency, minimizing the need for post-processing. The Framing process follows, adapted from Marvin Minsky's [30] concept, where frames act as standardized templates to organize systematically each regulation. These include the Base Frame, which contains key data, for example, Prefix and Legal

[8] https://spacy.io/usage/spacy-101
[9] https://platform.openai.com/docs/guides/gpt/completions-api

Sources, and subsidiary frames including Regulatory, Conditional, Phrase Level, Statement Level, and Defeasibility frames, each capturing different aspects of the regulation.

Finally, in the Model phase, these frames are transformed into corresponding elements in LegalRuleML. Once mapped, the documents undergo validation against the LegalRuleML schema to ensure accuracy and adherence to legal rule modeling standards. Thus, SHAMROQ ensures a structured and precise conversion of regulatory texts into actionable legal formats.

2.1.2 SHAMROQ Limitations

SHAMROQ faces several challenges. For example, it must overcome technological limitations like processing large datasets or integrating with different legal databases, which can be demanding in terms of computational resources. In terms of legal language and cultural variations, SHAMROQ might struggle with the nuances of legal terms that differ significantly between jurisdictions, such as the varying interpretations of "privacy" in European versus American law.

User accessibility is another area of concern. For example, legal practitioners with limited technical background may find it challenging to adapt to SHAMROQ's complex functionalities. An example would be the need for specialized training to navigate its AI-driven analysis interface. Regarding accuracy, SHAMROQ's reliability in deciphering complex legal texts, such as those with multiple layers of nested conditions or ambiguous wording, is vital. A case in point is the hierarchical organizational structure, which typically contains chapters, sections, subsections, paragraphs, and sub-paragraphs.

Each layer of these documents can contain information that might be contextually dependent on higher or lower layers. For example, in structures that list mandatory conditions or actions, each sub-point (a, b, c, etc.) specifies a separate requirement and SHAMROQ is required to meet all these enumerated conditions to be in full compliance with the regulation. Moreover, regulations are notable for frequent references to other sections, also known as cross-references. Understanding and accurately interpreting these cross-references requires SHAMROQ to maintain referential integrity, a non-trivial task in complex hierarchical structures.

Despite these challenges, SHAMROQ excels in its ability to integrate across software platforms, providing a universal standard for policy overseers and developers. Its use of standardized rules promotes compatibility and interoperability, ensuring that it can function cohesively within a diverse range of legal and technical environments.

2.1.3 Related Work

Recent studies by Francesconi and Governatori [31] used Semantic Web technologies, particularly the Web Ontology Language, Second Edition[10] (OWL 2), for modeling deontic norms, such as obligations and permissions, enabling legal compliance checks. While they identified patterns for modeling these norms, their approach was limited by its use of basic examples and lack of automated extraction, reducing its practicality for large-scale use. SHAMROQ, in contrast, offers automated parsing and extraction of a wider range of deontic expressions from regulatory texts, thereby reducing manual effort.

Joshi and Saha [32, 33] applied deep learning to extract deontic expressions, effectively transforming the CFR into a graph data store. However, their method's reliance on text

[10] https://www.w3.org/TR/owl2-overview/

summarization might miss finer details in regulations. SHAMROQ detects these details by using spaCy's SpanRule object for precise extraction of full sentences and deontic expressions, overcoming the limitations of summarization.

Breaux [34], in a process called Semantic Parameterization, uses Description Logic to represent domains structurally, effectively converting unstructured text into structured formats. Despite its effectiveness, the process is manual and subjective, leading to potential inconsistencies. SHAMROQ builds on this idea of structured representation by automating parsing and conceptual mapping and incorporates defeasible logic to handle exceptions and inconsistencies in legal text. It incorporates defeasible logic through the use of two concepts in LegalRuleML: the superiority relation and the strength of rules [35]. The superiority relation, critical for resolving conflicts between rules, is represented using the <Overrides> element within a 'hasQualification" block. This construct establishes a hierarchy such that one rule can supersede another based on a defined criteria.

The strength of rules has two options for representation in LegalRuleML. The first option is to include the rule strength within a <Context> block. The second option is to express the rule strength directly inside the rule using a "hasStrength" block. In either case, both options provide flexibility in defining the precedence and applicability of rules, ensuring that the most relevant and specific rules are applied in each legal context.

Table 1 provides a comparative overview, outlining differences in logical formalism, output formats, and preprocessing methods. SHAMROQ's integrated approach enhances regulatory analytics, offering a machine-readable rule analysis. In summary, earlier methods for extracting regulatory knowledge were limited by manual effort, text summarization, and limited rule languages. SHAMROQ addresses these issues by integrating natural language processing, knowledge representation, and AI reasoning for improved automated regulation analysis.

Table 1: Comparison of SHAMROQ and Semantic Parameterization

SN	Feature Set	Breaux Semantic Parameterization	Cook SHAMROQ Methodology
1	Logical Formalism	Description Logic (DL)	Defeasible Logic
2	Output Format	DL Knowledge Base	LegalRuleML
3	Step 1: Preprocess	Manual Disambiguation	Automated NLP and Coreference
4	Step 2: Grounding	Map Nouns, Verbs to DL Expr	Map Statements to If/Then
5	Step 3: Meta-model	Apply NL patterns to DL Expr	Translate rules to defeasible logic
6	Analysis	DL reasoning, Subsumption	Legal Reason, Conflict Detection
7	Techniques Used	Dictionary, NL Patterns	NLP, Generative AI, LegalRuleML

2.2 Mixed Method Design

We conduct an explanatory sequential mixed method research design in two phases. In the first phase, we collect and analyze the quantitative data. The findings from the first phase inform the second phase. The qualitative data, gathered in the second phase, is employed to clarify the quantitative findings obtained in the first phase. This design ensures that the qualitative phase is intricately tied to the quantitative results, enhancing the depth and breadth of understanding.

2.3 Data Collection

The data is sourced from the Code of Federal Regulations (Annual Edition) gov.info website[11]. The complete text of Titles 16 (two volumes, containing 1,108,086 words), Title 45 (five volumes, containing 2,496,592 words), and Title 48 (seven volumes, containing 3,399,939 words) are purposely chosen as they offer a large sample size and a diverse representation of regulatory domains, ranging from commerce and public welfare to federal acquisitions. Although our initial goal was to utilize the most recent versions of each title, the years 2023 and 2022 proved to be incomplete. Specifically, for 2023, titles 16, 45, and 48 were unavailable and the 2022 version was missing the third volume in Title 45 rendering the title incomplete. Given these constraints, we opted for the complete 2021 version for our processing.

To collect the data, we used a bespoke Python module, namely getCFRfromXML2-JSON.py, to extract relevant data from each Title. The core function, getCFRData, as seen in Figure 3, is responsible for parsing XML files. The PlantUML[12] diagram shows the use of the xml.etree.ElementTree Python module to search for the section number (SECTNO), subject (SUBJECT), and text (TEXT) elements within the SECTION element of the XML structure.

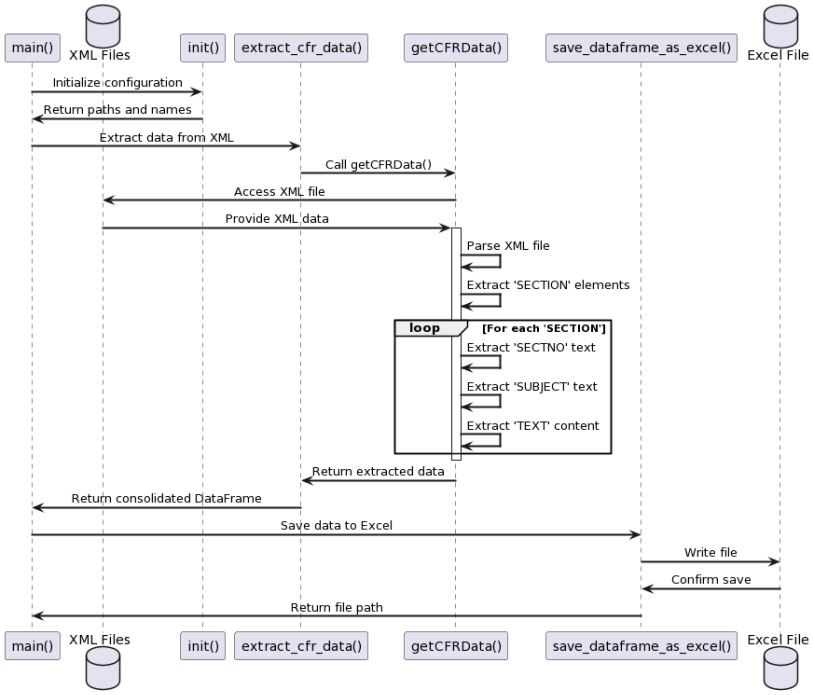

Figure 3. getCFRfromXML2-JSON.py Extraction

The extracted data is stored as dictionaries in a list, with each dictionary representing a section of the CFR. The "extract_cfr_data" function consolidates the extracted data from multiple XML files into a single Pandas DataFrame[13]. Once the data is aggregated and processed, the

[11] https://www.govinfo.gov/app/collection/cfr/
[12] https://plantuml.com/
[13] https://pandas.pydata.org/docs/reference/api/pandas.DataFrame.html

function saves it as an Excel file using the save_dataframe_as_excel functions. This function ensures the directory exists and the output file is available for processing.

2.4 Data Processing

To process the data, we used a custom Python module named analyze_CFR_from_CSV-JSON.py. This module uses SpaCy, an NLP library, to analyze text and extract linguistic features. It operates by reading a bespoke shamroq-patterns-rules.jsonl configuration file, which contains specific patterns for identifying permissions, obligations, prohibitions, and dispensations. These patterns are integrated into the SpaCy pipeline using a feature known as the "span_ruler" to allow the SpaCy model to identify and label text spans that match these patterns.

As depicted in Figure 4, the main function invokes the “read_excel_file()” function which reads input data from the Microsoft Excel file, which was produced by the getCFRfromXML2-JSON.py Python script. The core function, process_regulations, operates on each row of the DataFrame to identify the linguistic features and extract any matches associated with the text spans in the shamroq-patterns-rules.jsonl file. Upon identifying a matching text span, the function extracts these spans and labels them according to their identified category (i.e., ‘obligation’, ‘permission’, dispensation, or prohibition).

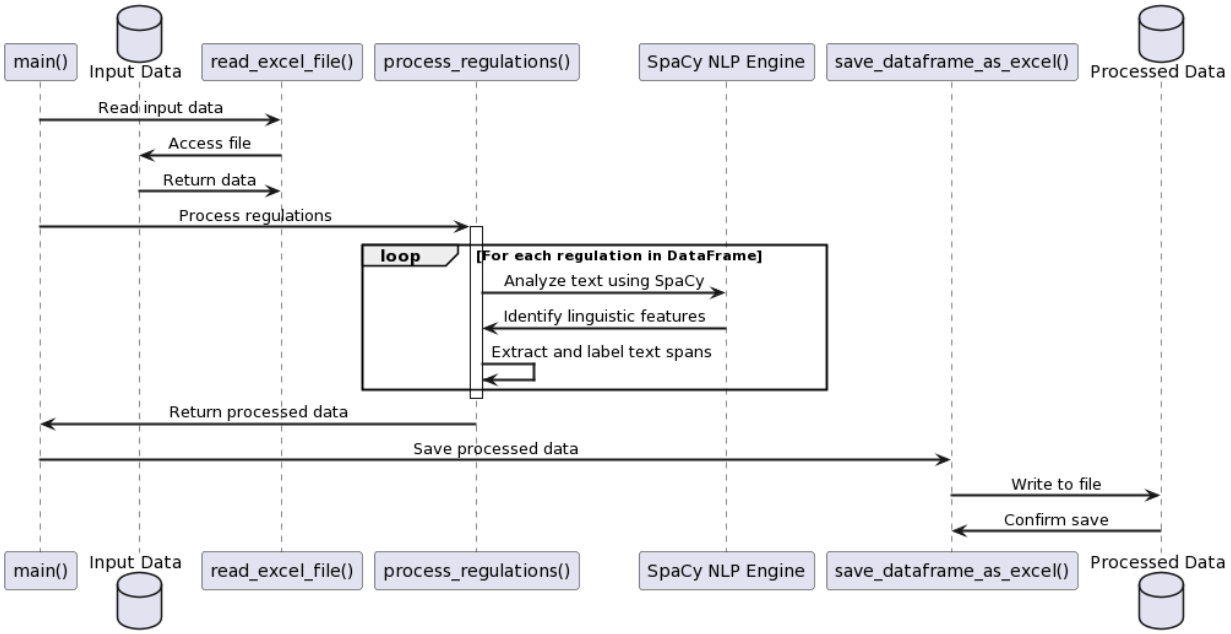

Figure 4: analyze_CFR_from_CSV-JSON.py Processing

The result of this analysis consists of the original text, the identified text spans, and their corresponding labels which are compiled into a new DataFrame. This DataFrame provides a comprehensive view of the analyzed text, highlighting the specific legal elements extracted from each section of the CFR.

2.5 Data Analysis

Our data analysis strategy combines both quantitative and qualitative techniques to address the research questions. For RQ1, we used the Statistical Package for the Social Sciences[14] (SPSS) software, Version 29.0, to understand how the expression types – namely obligations, permissions, prohibitions, and dispensations – are distributed across Titles 16, 45, and 48. We employed the chi-square test of independence [36] to determine whether there's a significant relationship between the type of expression and the specific CFR title where it appears.

In our exploration of the relationship between expression and title, we present a crosstabulation table of the counts (See Figure 5). This table offers an in-depth view of how each expression type is represented across the different titles. The rows represent different types of expressions, namely dispensations, obligations, permissions, and prohibitions. The columns are divided into three titles: Title16, Title45, and Title48. There is also a 'Total' column at the end, summing up the frequencies across all titles for each expression type. The rows and columns in the table of Figure 5 lays the foundation for our chi-square analysis. This chi-square statistical test is designed to determine if a significant association exists between the two categorical variables: Expression Types and Titles. The chi-square statistic was computed using Equation (1) where:

$$\chi^2 = \sum \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}} \quad (1)$$

- O_{ij} is the observed frequency for the cell at the i^{th} row and the j^{th} column.
- E_{ij} is the expected frequency for the same cell, calculated using Equation (2)

$$E_{ij} = \frac{Row\ Total_i * Column\ Total_j}{Grand\ Total} \quad (2)$$

For each cell in the contingency table, we computed the difference between the observed frequency and the expected frequency, squared this difference, and then divided it by the expected frequency. Finally, we sum up all these values to get the χ^2. Next, we calculate the degrees of freedom (df) for a chi-square test of independence using Equation (3).

$$df = (number\ of\ rows - 1) * (number\ of\ columns - 1) \quad (3)$$

Given χ^2 and df, we calculated the p-value using SPSS. The p-value measures how likely the results would be if our null hypothesis holds true – which in this instance means there is no association between expression type and title. If we get a significant p-value, i.e., less than .05, then the observed data is unlikely to have occurred by random chance alone, given that the null hypothesis is true. Accordingly, we can reject the null hypothesis in favor of the alternative hypothesis, affirming there is an association between expression type and title.

[14] https://www.ibm.com/products/spss-statistics

2.6 Data Verification

To verify that the assigned deontic expressions accurately matched the original text, we compared each Expression Type with the corresponding original sentences and modal verb phrases in the Analysis-CFR output file. Using Microsoft Excel's filtering feature, we cross-referenced these phrases, meticulously checking both content and context to ensure correct categorization.

Figure 5 presents the crosstabulation table that aggregates and displays each expression type by title, demonstrating the results of this verification process. We recognize that no verification method is perfect. Challenges include the inherent subjectivity in interpreting legal language and the potential to miss nuances in complex sentences. Despite these challenges, we are confident that our verification process has significantly enhanced the reliability of our analysis.

ExpresssionType * Title Crosstabulation

Count

		Title			
		Title16	Title45	Title48	Total
ExpresssionType	dispensations	230	306	216	752
	obligations	2581	4047	10584	17212
	permissions	1437	2038	3281	6756
	prohibitions	118	221	815	1154
Total		4366	6612	14896	25874

Figure 5: Distribution of Expression Types Across Titles

For RQ2, we conducted a qualitative analysis of linguistic patterns and challenges within each title. Using grounded theory [37, 38], we employed NVivo[15] 14, released 2023 for Windows to organize the coding and handling of the regulatory text. This analysis enabled us to discover and interpret distinct themes and patterns present in each title's text. As a result, we identified both shared and unique linguistic structures among the titles and observed different ways in which regulatory requirements are framed linguistically.

To address RQ3, we synthesized the quantitative and qualitative findings. This synthesis juxtaposed the distributions from RQ1 against insights from RQ2, providing a comprehensive framework to refine the SHAMROQ software. Our overarching goal is to offer holistic insights into the deontic expressions within the selected CFR titles and to inform SHAMROQ's future enhancements. Both SPSS and NVivo, chosen for their reliability, ensure a rigorous approach to our mixed-methods data analysis.

After refining SHAMROQ based on the integrated quantitative and qualitative findings, we plan to conduct an additional evaluation study. This study will involve applying the enhanced SHAMROQ framework to a new and expanded set of regulatory texts to assess its updated effectiveness in extracting and classifying deontic expressions. The results of this evaluation study are projected to further demonstrate the value of SHAMROQ and its ability to generalize across regulatory contexts.

[15] https://lumivero.com/products/nvivo/

3 Results and Discussions

In this section, we present the empirical evidence, encompassing both quantitative and qualitative insights, that emerged from our evaluation of deontic expressions within Titles 16, 45, and 48. This data illustrates the current capabilities of SHAMROQ and sets the stage for our subsequent evaluation, highlighting the importance of our findings in the broader context of extracting regulatory text.

Table 2: Deontic Expressions according to Title

Expression Type	Title 16	Title 45	Title 48
obligations	2581 (59%)	4047 (61%)	10584 (71%)
permissions	1437 (33%)	2038 (31%)	3281 (22%)
dispensations	230 (5%)	306 (5%)	216 (1%)
prohibitions	118 (3%)	221 (3%)	815 (6%)

3.1 Quantitative Findings

Quantitative RQ1: "What is the distribution of obligations, permissions, prohibitions, and dispensations within titles 16, 45, and 48. How do they compare?" In Table 2, three titles are examined for four distinct deontic expressions: obligations, permissions, dispensations, and prohibitions. For Title 16, 59% of the identified expressions are obligations, 33% are permissions, 5% are dispensations, and 3% are prohibitions. The distribution for Title 45 is somewhat similar, with obligations at 61%, permissions at 31%, dispensations at 5%, and prohibitions at 3%. However, for Title 48, a notable increase occurs in obligations, representing 71% of the expressions. Concurrently, permissions decrease to 22%, dispensations are at a mere 1%, and prohibitions constitute 6%. This initial overview suggests variations in the emphasis and focus across the titles.

To evaluate the relationship between the expression types (obligations, permissions, dispensations, and prohibitions) and the CFR titles (Title 16, Title 45, and Title 48), we conducted the chi-square test of independence. We formulated the following hypothesis:

- Null Hypothesis (H_0): There is no association between Expression Type and Title.
- Alternate Hypothesis (H_a): There is an association between Expression Type and Title.

As illustrated in Figure 6, our analysis revealed a chi-squared value of $\chi^2 = 681.637$ with six degrees of freedom (df). None of the cells had expected frequencies less than 5, with the minimum expected count being 126.89; thus, satisfying the assumptions of the test. This result is highly significant, with a p-value of $p < .001$. Given this outcome, we reject the null hypothesis in favor of the alternative, indicating a strong association between the expression type and CFR Title.

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	681.637[a]	6	<.001
Likelihood Ratio	681.609	6	<.001
N of Valid Cases	25874		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 126.89.

Figure 6: Association Between Deontic Expression Type and CFR Title

3.2 Qualitative Findings

Qualitative RQ2: "How do the syntactic structures and linguistic nuances of deontic expressions vary across the titles, and what challenges might these variations pose for automated extraction?" The deontic expressions within Titles 16, 45, and 48 each exhibit distinct semantic and syntactic characteristics reflective of their respective regulatory domains. The top modal verbs in each title reflect the specific regulatory needs and the degree of discretion or obligation intended in the language. "May" introduces flexibility, "must" indicates necessity, and "shall" imposes an obligation. The challenge for automated extraction and analysis is to understand and appropriately categorize the intent behind each modal verb within its specific context. Automated systems must be sophisticated enough to understand these subtleties to interpret accurately and apply the regulatory guidelines embedded within the language. Let's take a closer look at each title.

3.2.1 Insights into Title 16 Commercial Practices

Title 16 is characterized primarily by permissions and obligations (a combined 92%), with modal verbs "may," "must," and "shall", indicating varying degrees of discretion and compulsion. The modal verb "may," occurring notably in the expressions. "You may inspect," and "You may obtain," as illustrated in Figure 7, implies that the reader has the option to perform these actions, which suggests flexibility within the regulatory framework. This flexibility could be particularly useful for regulations where individual circumstances need to be considered. Moreover, we see a consistent syntactic pattern involving permissions. The sentence structure typically follows a Subject-Modal-Verb-Object (SMVO) pattern, which provides clarity and uniformity in regulatory language. Such patterns indicate conditional permission and specify who is allowed to perform an action under what circumstances and on what objects or in which locations. These patterns are critical for understanding the scope and limitations of permissions within the legal framework of Title 16.

On the other hand, as depicted in Figure 7, "must" and "shall," signify mandatory action required by law. This is evident in phrases, such as "you must certify" and "definitions shall apply". These verbs are definitive, creating a clear boundary of what is required for compliance and leaving no room for personal discretion. The choice of 'must' and 'shall' over more permissive language like 'should' or 'may' is significant. It indicates a deliberate effort to remove ambiguity, ensuring

that the requirements are understood as legal obligations rather than recommendations or options which is particularly important in regulatory texts where clarity and precision are essential to ensure proper compliance.

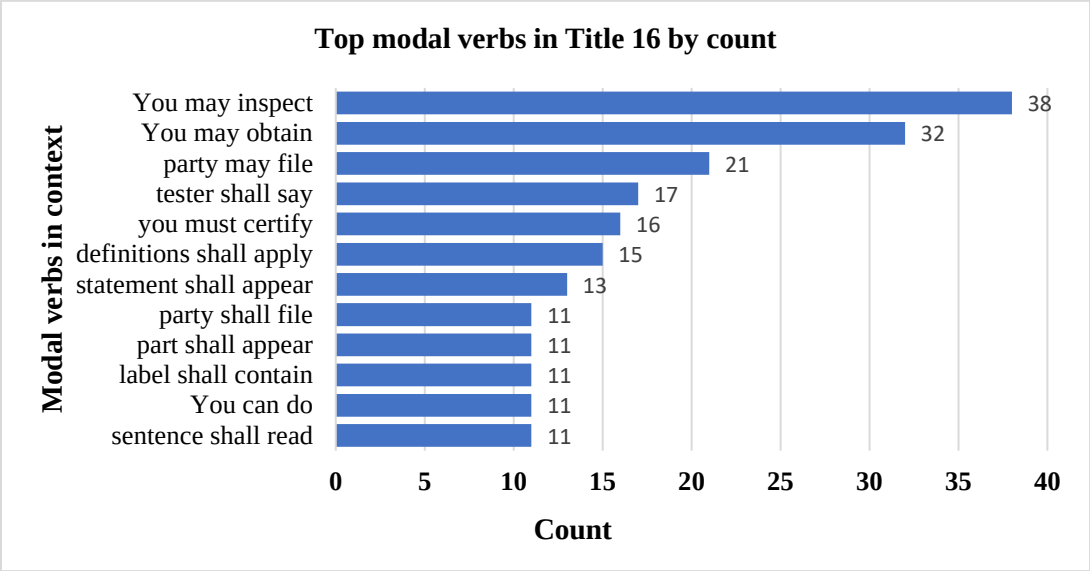

Figure 7: Title 16 Top Modal Verbs

Moreover, the use of 'must' and 'shall' signifies the non-negotiable aspect of compliance. In contrast to 'may,' which introduces the possibility or option, 'must' and 'shall' establish a clear boundary of what is legally binding leaving no room for personal discretion or interpretation, thereby simplifying the enforcement and adherence to these regulations.

3.2.2 Insights into Title 45 Public Welfare

Title 45 features a more prescriptive tone with a higher incidence of the modal verb "must." This is highlighted in Figure 8, with the use of phrases like "issuer must provide" and "entity must provide." These examples underscore the essential actions that entities must take, reflecting Title 45 focus on health and human services. Additionally, the verb 'shall' is also frequently used, as seen in phrases such as 'plan shall provide' further accentuating the obligatory nature of the stipulated actions, underscoring a strong imperative tone within the regulatory framework.

Despite the strong imperative tone, the modal verb 'may,' also presented in Figure 8, although less frequently, introduces an element of flexibility. Phrases like 'entity may use' offers a contrast to the otherwise rigid structure of the regulations. However, the frequent use of "must" and "shall" which highlight the need for entities to strictly follow the directives, is occasionally balanced with more flexible terms like "may," adding a layer of complexity to understanding the regulations. The challenge lies in interpreting when strict compliance is required and when room exists for discretion.

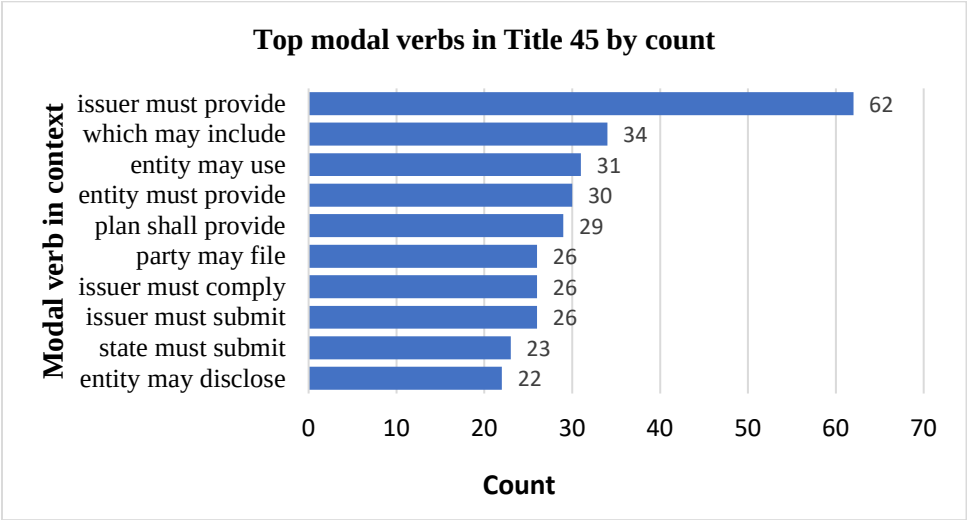

Figure 8: Title 45 Top Modal Verbs

To sum up briefly, the varying sentence structures in Title 45, ranging from simple to complex, can make it difficult to extract and understand the key points consistently. This consistency is especially challenging for automated systems, which must accurately interpret both the language and context of these regulations. Additionally, keeping up with changes in regulations is a constant challenge, as it requires frequent updates to ensure ongoing compliance. Overall, the main challenges in dealing with Title 45's regulatory text are its complexity, the need for accurate interpretation, and adaptability to changes.

3.2.3 Insights into Title 48 Federal Acquisition Regulations Systems

Title 48 is predominantly dominated by the modal verb "shall," which is a strong directive, often used to convey a sense of legal obligation. This is demonstrated in Figure 9 with expressions like "officer shall insert" and "contractor shall submit." These expression are prescriptive in nature, leaving little to no room for flexibility or discretion. The high frequency of "shall" aligns with the title's focus on federal acquisition regulations, where precise and unambiguous rules are critical to maintain consistency and fairness in the procurement process. The use of "shall" ensures that contractual obligations are clearly defined and understood by all parties involved.

Furthermore, this use of ‘shall’ underlines the serious legal implications in federal contracting. Compliance is not optional, as failing to adhere to these directives could lead to legal consequences. The clarity provided by "shall" in Title 48 is essential in a domain where misunderstandings or ambiguities can result in significant legal and financial repercussions. The prescriptive nature of the language also highlights the importance of thorough training and awareness for entities engaged in federal procurement, as a deep understanding of these obligations is critical for compliance.

For automated systems processing Title 48, the predominance of "shall" poses unique challenges. While it adds clarity to the regulations, these systems must be sophisticated enough to interpret the mandatory nature of these directives accurately within their specific contexts. Compared to other regulatory texts, Title 48’s use of "shall" may indicate a higher level of formality and rigidity, a factor that is crucial for developers of automated processing systems to

consider. Developers must ensure that these systems can appropriately adapt to and interpret the different tones and requirements across various regulatory texts.

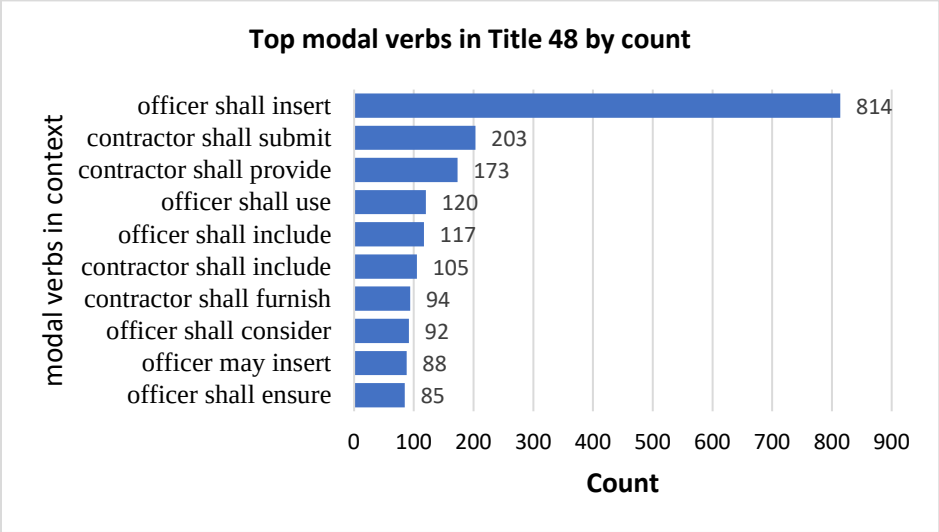

Figure 9: Title 48 Top Modal Verbs

As we look more closely at a comparative analysis of Titles 16, 45, and 48, with respect to RQ2, there are distinct variations in syntactic structures and linguistic nuances. Title 16, governing commercial practices, exhibits a diverse range of deontic expressions, reflecting the multifaceted nature of commerce regulation. These variations pose a challenge for automated systems, which must interpret a wide array of directive forms and contextual nuances.

Title 45, in contrast, heavily utilizes 'must' and 'shall,' indicative of its focus on health and human services where clear, unambiguous directives are essential for public safety and program integrity. The predominance of these terms simplifies automated extraction but requires high accuracy in identifying obligatory actions. Title 48, dealing with federal acquisition, presents a different set of challenges, often blending technical jargon with regulatory directives, which can complicate the extraction process due to the complexity and specificity of language used.

The variation in syntactic complexity and linguistic style across these titles underscores the challenge for automated extraction. Systems must be equipped with advanced natural language processing capabilities to accurately differentiate and interpret these nuances. Particularly, the ability to discern context and intent becomes crucial, as the same modal verb can imply different levels of obligation or discretion in different regulatory environments. Moreover, the presence of complex sentence structures, especially in Title 48, demands sophisticated algorithms that can navigate through intricate linguistic constructs without losing the essence of the directive.

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comparative analysis highlights the need for contextually aware and adaptable extraction mechanisms in software, capable of handling the diverse landscape of regulatory texts.

3.3 Mixed Method Synthesis

Mixed Method Transdisciplinary RQ3: "How does the integration of quantitative findings and qualitative insights holistically influence the software implementation and refinement of SHAMROQ to extract deontic expressions?" The quantitative insights from SHAMROQ's initial data examinations highlight its capability to identify and extract deontic expressions with varying degrees of success. Statistically, modal verbs such as "shall" and "must" are captured with high accuracy, suggesting an effective algorithmic recognition of these strong deontic indicators.

The qualitative analysis provides depth to these findings by revealing that SHAMROQ's algorithm may not fully grasp the linguistic context within which these expressions are used. For instance, the same modal verb might convey different degrees of obligation depending on its syntactical position or the presence of negations and conditionals. Furthermore, expressions of possibility or permissibility, such as "may" or "can," present additional challenges due to their subtlety and varied use in legal language.

Integrating these insights informs software implementation in several ways. First, it suggests the need for an enriched linguistic model that can account for the complexity and variability of deontic expressions. Fostering an enriched linguistic model may involve training SHAMROQ with a broader dataset that includes a variety of regulatory texts to improve its understanding of context and usage patterns. Secondly, the refinement of SHAMROQ should incorporate rule-based algorithms for more straightforward cases of deontic expressions, while employing machine learning techniques for those requiring contextual interpretation. The nuanced use of language, as unearthed by qualitative analysis, demands an adaptable approach that can learn from new examples and continuously improve.

The iterative application of these insights leads to a holistic enhancement of SHAMROQ. By cyclically updating the tool's algorithms with quantitative and qualitative feedback, SHAMROQ becomes more adept at navigating the intricacies of regulatory texts resulting in higher precision and recall rates, reducing false positives and false negatives, and increasing the reliability of automated extraction processes. Ultimately, the integration of quantitative findings and qualitative insights leads to a more sophisticated and contextually aware SHAMROQ. This iterative process not only improves the tool’s current performance but also sets a precedent for continuous learning and adaptation, ensuring that SHAMROQ remains effective as legal language evolves. Through this integrated approach, we can better understand and capture the multifaceted nature of deontic expressions in regulatory texts, thereby enhancing both the tool’s utility and the field of automated legal text analysis.

3.4 Conclusion and Future Work

The current study sought to deepen the understanding of deontic expressions within Titles 16, 45, and 48 of the CFR using the SHAMROQ framework. The findings shed light on several significant aspects. Our exploration of Titles 16, 45, and 48 has revealed distinct patterns in the syntactic structures of deontic expressions. The frequency analysis of modal verbs, such as "shall," "must," and "may" points to a nuanced use of language that serves different legislative purposes across

titles. Title 16 frequently employs "may" to suggest permissibility, indicating a degree of discretion left to the reader. Conversely, Title 48 predominantly uses "shall," denoting obligation and a more directive tone, which reflects its contractual nature.

The variations observed pose significant challenges for automated extraction by SHAMROQ. The software's current iteration demonstrates a robust capacity to identify and categorize these expressions; however, the subtleties in linguistic contexts suggest a need for refinement. For instance, while "may" typically indicates permission, its use in a regulatory context could imply a conditional requirement, a nuance that automated systems often struggle to discern. The qualitative insights from the data further emphasize the complexity of legislative language. These insights suggest that while quantitative data provides a foundation, the qualitative context shapes the interpretation and subsequent application of deontic expressions. The integration of these findings underscores the importance of a multi-faceted approach to the development of legal text analysis tools.

In conclusion, our analysis across Titles 16, 45, and 48 has provided a comprehensive understanding of the syntactic structures of deontic expressions within legislative texts. The quantitative findings indicate a marked difference in the frequency of modal verbs across titles, which, alongside qualitative insights, highlights the complexity and variability of legal language. This complexity presents both a challenge and an opportunity for the advancement of tools like SHAMROQ. The implications of this research extend beyond software implementation. They touch upon the broader context of legal interpretation and the need for nuanced understanding in the automation of legal text analysis. It is evident that the integration of quantitative and qualitative methodologies enriches the refinement process of SHAMROQ, paving the way for more sophisticated and context-aware legal analytics software.

Future iterations of SHAMROQ must incorporate advanced linguistic models that account for the subtleties of language usage in legislative texts and the conflicts or inconsistencies that may arise in the SOW, SRS, and CONOPS. Considering the inconsistencies among these documents, including conflict resolution statements like “In the event of a conflict between XXX and YYY, XXX prevails,” SHAMROQ’s ability to interpret and prioritize conflicting directives could be a significant area for future development. This consideration is particularly pertinent given the frequent changes in government regulations and system documents over time or even within a project lifecycle. Furthermore, the evolving nature of legal frameworks poses a question for SHAMROQ: how can it adapt to changes or authoritative decisions over time? Addressing this question could substantially enhance the framework's utility, ensuring it remains relevant and accurate in a shifting legal and regulatory environment.

Another area of refinement lies in adding features that would differentiate the strength of modal verbs. As an example, some customers may view “should” as weaker than “shall” or “must”, and could be tagged in a way. Can SHAMROQ's classifier be tailored to discern and categorize these varying degrees of obligation or recommendation? Exploring this could potentially improve the precision of automated legal text analysis. In short, this study has shown, the integration of such models is critical to the development of effective legal informatics tools. We call upon further transdisciplinary research to expand upon these findings, integrating linguistic, computational, and legal expertise to enhance the precision and utility of automated legal text analysis.

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