



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Al Neelain University

Graduate College



Faculty of Computer Science and Information

Technology

PhD thesis in Information Systems

(Knowledge management systems) title:

**Ontology Design Pattern for E-government
Services**

(Applied study on the Ministry of Interior -Sudan)

تصميم نمط أنطولوجيا لخدمات الحكومة الالكترونية (دراسة تطبيقية على وزارة الداخلية - السودان)

Prepared by:

Badraldeen Hassan Altahir

Supervisor:

Dr. Abdelrahman Elsharif Karrar

Co-Supervisor:

Dr. Shazali Siddig Mohamed

June 2025

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i. Dedication

To my beloved family,

To my dear father, who was the solid foundation upon which I built my success, and who has always been my source of inspiration and support at every step.

To my kind mother, who helped me, provided love and care, and stood by me during times of challenge and hardship.

To all my brother and sisters, who have always offered me their encouragement and heartfelt prayers.

To the spirit of my honest and pure brother Alsadig & Altahir.

To my extended family, who have been a constant support.

To my professors and colleagues at the college, who readily provided assistance and support throughout the journey of preparing this dissertation.

To my dear friends, who have been the best companions and support at various stages of my life.

To my students, who ignited my passion for learning and knowledge.

I dedicate this dissertation to all of you, in gratitude and appreciation for standing by me and supporting me in my academic journey.

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Finally, I am profoundly grateful to all colleagues who contributed to the success of this research, whether through productive scientific discussions or unwavering support. To all of them, I extend my utmost respect and appreciation.

المستخلص

تتناول هذه الدراسة تطوير وتنفيذ وتقييم أنطولوجيا متخصصة تهدف إلى تحسين خدمات الحكومة الإلكترونية المقدمّة من قبل وزارة الداخلية في السودان. استجابةً للتحديات المستمرة المرتبطة بتجزئة البيانات وغياب التكامل بين مراكز تقديم الخدمات الحكومية، اعتمد البحث على منهج دراسة الحالة النوعية مستنداً إلى منهجية Methontology، وهي منهجية منهجية لتصميم الأنطولوجيا تشمل مراحل التصور، والتمثيل الرسمي، والتقييم.

تم بناء الأنطولوجيا واختبارها باستخدام بيانات حقيقية جُمعت من 138 مواطناً سودانياً، وأسفرت عن 682 سجلاً حكومياً تشمل خدمات مثل شهادات الميلاد، الرقم الوطني، جوازات السفر، وتراخيص المركبات. وبالإستفادة من تقنيات الويب الدلالي مثل RDF، OWL، SPARQL ومحركات الاستدلال كـ Pellet وHermiT، تمكن النظام من تحقيق تكامل دلالي واستدلال لحظي عبر مصادر بيانات حكومية متفرقة.

أظهرت اختبارات الأداء تحسناً ملحوظاً في عدة مؤشرات رئيسية، حيث زادت سرعة إدخال البيانات بنسبة 81.4%، وسرّع تنفيذ عمليات الاستدلال بنسبة 76.9%، بينما تحسنت استجابة استعلامات البيانات بنسبة وصلت إلى 83.3% من حيث السرعة والدقة. كما أظهرت الأنطولوجيا كفاءة عالية في التحقق من صحة البيانات المدخلة ورفض الإدخالات غير المتوافقة، فضلاً عن استنتاج علاقات ضمنية غير مصرّح بها صراحة في البيانات المصدرية، مما عزز من جودة البيانات ومنطق تقديم الخدمات.

رغم هذه النجاحات، رصدت الدراسة عدداً من التحديات التطبيقية، من أبرزها: محدودية توافر البيانات، مقاومة المستخدمين، والاعتبارات الأخلاقية المرتبطة بحوكمة البيانات. وللتعامل مع هذه العقبات، تقترح الدراسة خارطة طريق للتنفيذ المستقبلي تشمل مشروعات تجريبية شاملة، وتصميمًا مركّزاً على المستخدم، وتعاوناً متعدد التخصصات، وجهوداً لتوحيد المعايير الدلالية.

في الختام، تؤكد نتائج الدراسة أن الأنطولوجيات القائمة على تقنيات الويب الدلالي توفر إطاراً ذكياً وقابلاً للتوسع لتحديث البنية التحتية الرقمية في القطاع العام. وثُبتت هذه الدراسة إمكانية التكامل الأنطولوجي في نظام الحكومة الإلكترونية السوداني، كما تقدم نموذجاً قابلاً للتكرار في السياقات الحكومية الأخرى الساعية نحو خدمات رقمية أكثر كفاءة وأماناً ومرتكزة على المواطن.

iii. Abstract

This study presents the development, implementation, and validation of a domain-specific ontology aimed at improving E-government services provided by the Ministry of Interior in Sudan. In response to persistent challenges related to data fragmentation and lack of interoperability across public service centers, the research adopts a qualitative case study methodology grounded in the Methontology methodology . This structured methodology guided the conceptualization, formalization, and evaluation of the ontology.

The ontology was populated and tested using real-world data collected from 138 Sudanese citizens, comprising 682 authentic government records spanning services such as birth registration, national identification, passports, and vehicle licensing. Through the integration of Semantic Web technologies—including OWL, RDF, SPARQL, and reasoning engines like Pellet and HermiT—the system enabled semantic unification and real-time inference across siloed government data sources.

Performance testing demonstrated marked improvements in several key areas: data ingestion was accelerated by 81.4%, inferencing tasks were completed 76.9% faster, and data retrieval operations showed up to 83.3% enhancement in speed and precision. The ontology also exhibited advanced capabilities in validating input data, rejecting incompatible entries, and inferring implicit relationships, thereby enhancing data quality and service logic.

Despite its successes, the study identified several implementation challenges, including data availability, stakeholder resistance, and ethical considerations related to data governance. To address these, the research proposes a roadmap for future adoption based on pilot deployments, user-centered design, interdisciplinary collaboration, and semantic standardization.

Ultimately, the findings affirm that Semantic Web Ontologies offer a scalable and intelligent framework for modernizing public sector digital infrastructure. This work not only demonstrates the feasibility of ontology-driven integration within Sudan’s E-government system but also contributes a replicable model for similar initiatives in other governmental contexts aiming to achieve efficient, secure, and citizen-focused service delivery.

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Introduction

1.1 Introduction

The global community is experiencing rapid and significant advancement and enhancement in the diverse array of information technology sectors. This notable progression has been closely accompanied by the rise of various applications, software, and systems that have effectively contributed to the enhancement and transformation of the quality and structure of the services offered by governments and institutions to both their workforce and the general public. It is worth noting that governments have not remained aloof or indifferent to this wave of technological progress within the realm of information technology, but rather have actively kept up with and adapted to this ongoing development. Consequently, this proactive response has given rise to the E-government, which primarily focuses on the provision of services to individuals and businesses through electronic means, whether in a fully digitalized format or a partially digitized manner [1] [2] .

E-government represents a shift towards utilizing information and communication technologies to enhance governmental processes and improve service delivery to citizens, thereby transforming the traditional government structure into a digital format [3] [4] [5] . This transition aims to streamline interactions between citizens and government entities, fostering transparency, efficiency, and public engagement [6] [7] . By leveraging interconnected networks and technological platforms, E-government facilitates the dissemination of public information, the provision of services, and communication with the populace through digital means. The evolution from E-government to digital government underscores the continuous adaptation of technology to meet the evolving needs and opportunities in governance, ultimately striving to improve the accessibility and effectiveness of governmental operations. E-government serves three primary goals: internally, it enhances government institutions by simplifying and automating their operations [8]; externally, it focuses on delivering high-quality services to beneficiaries and fostering strong interactive relationships with individuals and institutions [9]. The digital revolution, encompassing E-government, plays a crucial role in transforming public services, increasing transparency, and promoting accountability [10]. Furthermore, E-government is a significant tool in combating corruption and improving governance by reducing discretionary power, enhancing transparency, and increasing the likelihood of exposure to corrupt practices. Overall, E-government not only streamlines government processes but also enhances service delivery, accountability, and relationships with stakeholders, contributing to more efficient and transparent governance.

Sudan commenced the implementation of E-government initiatives following the establishment of the National Information Center through constitutional decree (363) of the year 1999 AD, accompanied by the promulgation of its law within the same year and subsequently inaugurated on September 30, 2001. The National Information Center stands as a pivotal institution of expertise and governmental consultant specializing in the realm of information technology, tasked with the formulation of public policies aimed at fostering the

development and advancement of information technology as a globally recognized instrument for enhancing access to information. It bears the primary responsibility for the Sudan E-government project, a significant undertaking geared towards the modernization and digitization of governmental operations in Sudan [11].

In numerous instances of E-governments in developing nations commence implementation without adequate strategic planning, as delineated in comprehensive research conducted by scholars hailing from the Sudan University of Science and Technology under the title "An evaluation study of the E-government of Sudan services directed to citizens"[12], the E-government of Sudan is grappling with a fundamental issue about the absence of seamless data integration among the various sub-systems constituting the Government of Sudan. The term "integration" in this context encompasses both horizontal and vertical dimensions, and the lack thereof has resulted in the fragmentation of the electronic service delivery processes, consequently impeding the E-government's capacity to furnish pertinent services to its Citizens. In response to this critical deficiency in integration, the researchers propose the employment of Semantic web ontology engineering techniques to develop an ontology design pattern for enhancing the operational efficiency and effectiveness of the E-government infrastructure in Sudan.

In computer science and information science, an ontology encompasses a representation, formal naming and definition of the categories, properties and relations between the concepts, data and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area and how they are related, by defining a set of concepts and categories that represent the subject. Every academic discipline or field creates ontologies to limit complexity and organize data into information and knowledge. New ontologies improve problem-solving within that domain[13].

An ontology plays a pivotal role in the development of E-government infrastructures. It aids in creating an E-government ontology that meticulously categorizes essential elements like individuals, transactions, and procedures, elucidating their relationships and unique characteristics[14]. This detailed roadmap guides stakeholders in aligning their systems with E-government frameworks, addressing integration challenges prevalent in E-government systems. By structuring unstructured data, sharing concepts uniformly, and enabling information retrieval, ontologies facilitate decision-making and knowledge exchange in E-government systems, ultimately enhancing interoperability, integration and efficiency in government departments[15].

1.2 Problem Statement

Since its inception, the Sudanese E-government has commenced the provision of governmental services to citizens through the Sudan E-government portal. Despite these advancements, E-government is currently encumbered by significant issues about data integration across its various ministries and departments. This deficiency has led to a situation where the services offered through the portal remain incomplete and, thus, not fully effective. The lack of coherent integration and communication between disparate systems within government agencies impedes the portal's ability to deliver a holistic and seamless service experience. Consequently, the full potential of the E-government initiative in enhancing public administration and citizen

engagement is yet to be realized. This highlights a critical gap in the infrastructure that, if addressed, could significantly improve the efficiency and effectiveness of government operations.

1.3 Research Questions

- Can the semantic Web and ontology effectively address the prevalent challenges of data integration deficiencies within E-government systems?
- What specific enhancements can the Semantic Web contribute to improving the delivery of E-government services?
- Does the development of a tailored ontology design pattern for E-government significantly aid in surmounting the barriers associated with data integration?

1.4 Research Objectives

This study aims to offer a scientific contribution to the modernization and intelligent transformation of E-government services in Sudan by harnessing the power of Semantic Web technologies, especially ontology-driven approaches. At the heart of this transformation lies the close integration between Semantic Web infrastructure and ontologies, which serve as formal representations of domain knowledge, enabling machines to semantically interpret and reason over data.

The study specifically addresses the challenge of fragmented and non-interoperable data across government ministries, focusing on services delivered by the Ministry of Interior. To tackle this, it proposes the development of a tailored ontology design pattern for the Sudanese E-government ecosystem. This pattern is designed to act as a semantic backbone that connects heterogeneous systems, facilitates seamless data exchange, and supports intelligent functionalities such as service personalization, semantic search, automatic discovery, and even predictive service provision.

By applying technologies like RDF, OWL, SPARQL, and reasoning engines, the study seeks to shift the Sudanese E-government model from a static, service-based portal into a smart, adaptive governance platform. The ultimate goal is to improve the speed, accuracy, and intelligence of service delivery, fostering a data-driven government capable of not only responding to citizens' needs but anticipating them proactively.

1.5 Research Significance

The significance of this study lies in its pioneering use of Semantic Web technologies to address structural and functional inefficiencies in E-government systems—specifically those related to fragmented data, poor interoperability, and limited service intelligence. The Semantic Web offers a transformative vision for the future of digital governance by enabling machines to interpret, relate, and reason about data in a context-aware manner. At the core of this architecture is **ontology**, which plays a foundational role in modeling domain knowledge, standardizing terminology, and facilitating semantic interoperability across heterogeneous systems.

In the context of Sudan's E-government framework, the lack of unified data interpretation across ministries—particularly in citizen-facing services such as those provided by the Ministry

of Interior—results in duplication, inconsistency, and delayed service delivery. This research tackles these challenges by designing a reusable and scalable **ontology design pattern** that serves not only as a knowledge structure but also as a bridge between disparate systems.

Semantic Web technologies such as **RDF (Resource Description Framework)**, **OWL (Web Ontology Language)**, **SPARQL (semantic query language)**, and **reasoning engines** provide powerful tools for enabling intelligent services. These include:

- **Semantic search and discovery**, allowing users to retrieve more relevant and personalized results.
- **Service composition and automation**, enabling dynamic workflow generation.
- **Context-awareness and personalization**, adjusting services based on user profile or history.
- **Predictive analytics**, allowing governments to anticipate needs or detect risks early.

By leveraging these capabilities, this study moves beyond traditional digitization toward **smart governance**—a model where government services are not only available online but also semantically integrated, responsive, proactive, and citizen-centric.

Importantly, the contributions of this study are twofold:

1. **Locally**, it provides Sudan with a strategic framework to overcome current limitations in e-service delivery.
2. **Globally**, it offers a modular ontology-driven model that can be adapted to similar governmental contexts seeking semantic integration.

In doing so, the study aligns with global digital transformation goals and contributes to the academic and practical advancement of intelligent E-government systems.

The Foundations of Semantic Web Technologies and Ontologies in the Transformation from E-government to Smart Government

2.1 Introduction

In the contemporary digital age, governments globally are increasingly adopting electronic methods to provide services to citizens efficiently and effectively. The concept of E-government, facilitated by advancements in information and communication technology, has transformed the relationship between governments and their populace, offering convenience, accessibility, and transparency in service delivery [16] [17] [18]. As technology progresses, there is a pressing need to further enhance E-government services to be more intelligent and tailored to meet the diverse needs of users. This evolution is crucial to ensure that E-government remains relevant, and user-centric, and continues to drive socio-economic development by leveraging the benefits of digitalization [19].

By leveraging Semantic Web technologies, governments can enhance E-government applications with added context and meaning to data, enabling more intelligent, intuitive, responsive, and personalized services [20]. The integration of artificial intelligence (AI), machine learning, and data analytics in smart e-governance systems further amplifies the potential for improved public service delivery [21]. Additionally, the utilization of AI technologies in E-government applications aims to automate services, reduce processing times, cut costs, and enhance citizens' satisfaction levels [22]. Through the effective use of information and communication technologies (ICTs) within E-government approaches, governments can optimize service delivery, citizen participation, and transparency in operations. Ultimately, the combination of Semantic Web technologies, AI, and ICTs empowers governments to provide high-quality, efficient, and citizen-centric services in a more human-like manner.

Semantic Web technologies play a crucial role in enhancing E-government services by promoting interoperability, accessibility, and efficiency [23]. These technologies enable the seamless integration of data across various domains, such as economy, statistics, and transportation, leading to the development of linked open government data (LOGD). By leveraging ontologies and AI techniques, E-government platforms can dynamically integrate services, personalize interactions, and optimize processes, ultimately improving citizen-centric services. The use of plain language in digital services also significantly impacts information comprehension and inclusivity, making E-government services more accessible and user-friendly. Through the implementation of reusable prototypes and web components based on

semantic data representation, governments can create interoperable digital services faster, reducing implementation costs and enhancing citizen engagement.

2.2 The E-government

2.2.1 E-government definition

E-government encompasses the utilization of ICTs by governments to enhance public services, communication with citizens, and overall government operations. It involves the digital transformation of administrative processes to boost efficiency, transparency, and accessibility to the public [24]. This digitalization facilitates the provision of services online, interaction with citizens through various platforms, and the streamlining of governmental functions. E-government initiatives aim to improve the quality of services, increase citizen engagement, and promote democratic values by fostering trust between the state and its people. By leveraging technology, governments can enhance service delivery, promote transparency, and create a more efficient and responsive public administration system.

2.2.2 The foundation of E-government

The fundamental basis of E-government, also referred to as E-government or digital government, encompasses a wide array of principles, strategies, and technologies aimed at leveraging information and communication technologies (ICTs) to revolutionize the provision of public services, enhance government operations, and enhance citizen engagement. The subsequent components constitute the cornerstone of E-government[18]:

Within the realm of Digital Infrastructure lies a resilient digital foundation, inclusive of broadband internet accessibility, secure networks, and digital devices, which functions as the infrastructure of E-government endeavors. A readily available and dependable digital infrastructure is imperative for dispensing online services, facilitating data interchange, and enabling digital correspondence between governmental bodies and citizens.

Policy and Governance Frameworks of notable effectiveness provide the regulatory and legal groundwork for E-government ventures. These frameworks delineate the entitlements and obligations of governmental bodies, citizens, and other stakeholders in the digital sphere, guaranteeing responsibility, privacy safeguarding, and security in the operations of E-government.

Interoperability Standards along with protocols facilitate seamless integration and exchange of data and services among diverse governmental bodies and systems. Uniform standards for data configurations, interfaces, and communication protocols ensure harmonization and interoperability, thereby easing data sharing and collaboration among governmental entities.

Service Delivery Platforms furnish the technological groundwork and utilities for providing online services to citizens and enterprises. These platforms may encompass citizen gateways, mobile applications, and digital service hubs that provide an array of services, such as online transactions, document submissions, and information inquiries, in a user-friendly and accessible format.

Data Management and Analytics capabilities of notable effectiveness are pivotal for harnessing the copious volumes of data engendered by E-government ventures. Governments necessitate robust data infrastructure, data governance frameworks, and analytics utilities to amass, retain,

scrutinize, and utilize data for informed decision-making, performance monitoring, and policy appraisal.

Citizen Engagement and Participation are the focal points of E-government ventures, striving to enrich citizen engagement and participation in governance procedures through digital platforms. Platforms for citizen engagement, online consultation mechanisms, and social media avenues empower citizens to provide feedback, partake in policymaking, and access governmental information and services, fostering openness, responsibility, and civic involvement.

Capacity Building and Digital Literacy play a crucial role in enhancing the capacity and digital literacy competencies of governmental personnel and citizens, which are indispensable for the efficacious execution of E-government ventures. Training schemes, awareness initiatives, and digital literacy programs aid governmental employees and citizens in acquiring the knowledge and proficiencies necessary to adeptly utilize ICTs and engage in digital governance processes. Security and Privacy Measures are of utmost importance in safeguarding the confidentiality, integrity, and availability of governmental data and services. Governments necessitate robust cybersecurity frameworks, encryption technologies, access restrictions, and data protection statutes to alleviate cybersecurity hazards, safeguard sensitive information, and instill confidence in E-government systems.

By concentrating on these foundational components, governments can establish the basis for successful E-government ventures that enhance service delivery, elevate government effectiveness and transparency, and empower citizens to partake in governance processes in the digital era.

2.2.3 E-government promotes accessibility and inclusiveness

The theoretical framework of E-government emphasizes leveraging technology to advance accessibility, efficacy, transparency, citizen engagement, and innovation in public service provision. Technology enables governments to offer easily accessible services to all, enhance operational efficiency, promote transparency, engage citizens in decision-making, and drive innovation in service delivery. By embracing these concepts, governments can optimize governance, ensure equitable access to services, streamline processes, increase accountability, involve citizens in governance, and foster innovation in addressing societal challenges. This comprehensive integration of technology in public administration underscores the transformative potential of E-government in improving service delivery and governance effectiveness[18].

E-government plays a crucial role in promoting accessibility and inclusiveness by providing digital services to citizens, including those with disabilities. Through the utilization of digital technologies, E-government platforms can enhance interactions between persons with disabilities and government agencies, ensuring effective participation in judicial proceedings. Countries like Norway have implemented strategies such as electronic identification and digital mailboxes to reduce inequities in E-government service usage, serving as a benchmark for inclusive digital services. However, challenges persist, as many E-government websites worldwide do not meet accessibility guidelines, highlighting the importance of incorporating accessibility features during design and development to achieve universal accessibility. Inclusive E-government design involves seeking input from users and service providers,

leading to a landscape of inclusive design encompassing social inclusion affordances, supporting processes, and organizational capabilities[25].

2.2.4 The benefits of E-government for citizens

E-government offers numerous benefits to citizens, including improved service efficiency, reduced bureaucracy, enhanced transparency, and increased citizen participation in governance processes [26]. By providing easy access to government information and services, E-government simplifies processes, standardizes services, and enhances service delivery, ultimately leading to better accessibility and accountability [27]. Moreover, E-government fosters democratic values, builds trust between citizens and government institutions, and facilitates communication, especially with the younger population, thereby promoting a culture of interaction and information openness. Additionally, E-government tools like e-voting, public consultations, and electronic petitions empower citizens to participate in decision-making, budget allocation, and monitoring of government activities, further enhancing democratic processes and transparency.

E-government plays a crucial role in enhancing citizen engagement and participation through various mechanisms. Firstly, the quality of IT services provided by public bodies influences citizens' willingness to engage and participate in E-government platforms [28]. Additionally, factors such as citizen's profile, personal, economic, social, and technical aspects drive citizen engagement with open government data, ultimately improving public policy making and service provisioning. Moreover, elements like informational, motivational, technological, institutional, and cultural factors contribute to expanding citizen participation in e-participation processes within smart cities, highlighting the importance of ICTs in promoting democratic governance and citizen engagement. Furthermore, the use of interactive communication tools and social media platforms during crisis events, such as the COVID-19 lockdown, can effectively promote participatory citizen engagement, reduce uncertainty, and foster positive emotions among citizens [29].

2.2.5 Leveraging Technology to Enhance Public Service Delivery through E-government

E-government initiatives encompass a broad spectrum of services, which include, yet are not limited to, the provision of online portals for tax filing, systems for electronic voting, platforms for digital healthcare, as well as resources for online education. Through the utilization of technology, governmental bodies can effectively overcome the conventional bureaucratic obstacles and grant the populace convenient access to vital services at all hours, irrespective of their geographical location[30].

A primary advantage associated with E-government is its capacity to boost efficiency and curtail administrative expenses. Through the digitization of processes and the automation of mundane tasks, governments can refine their workflows and eliminate paperwork, thereby resulting in expedited service delivery and diminished operational costs. For instance, the implementation of electronic tax filing systems can notably decrease the time and resources needed for tax administration, simultaneously enhancing accuracy and compliance measures[31]. Furthermore, the realm of E-government holds the potential to heighten transparency and accountability by furnishing citizens with immediate access to authentic information and governmental data. Initiatives geared towards open data empower

governmental bodies to render copious amounts of public data accessible to the populace in formats that can be read by machines, thereby empowering citizens, scholars, and enterprises to scrutinize and leverage governmental information for diverse objectives, such as research, innovation, and decision-making.

Moreover, E-government stands to enhance accessibility for segments of society that are marginalized or underserved, which encompasses individuals with disabilities, the elderly, and residents of remote regions. Online service provision eradicates physical impediments to access, enabling individuals to engage with governmental agencies and avail services from the confines of their residences through the utilization of computers, smartphones, or other digital gadgets. This inclusivity plays a pivotal role in ensuring equitable access to governmental services and fostering social parity. Additionally, E-government holds the potential to enrich citizen engagement and involvement in the process of formulating policies. Online platforms designed for public consultation and feedback afford citizens the opportunity to express their viewpoints, contribute ideas, and offer feedback on governmental policies and undertakings. By nurturing heightened citizen participation, E-government can advance democratic governance and fortify the bond between governmental bodies and society[32]. Notwithstanding its myriad advantages, the effective execution of E-government initiatives necessitates meticulous planning, robust cybersecurity protocols, and ongoing assessment and enhancement measures. Governments must allocate resources towards constructing the essential digital infrastructure, crafting user-friendly interfaces, and safeguarding data security and privacy to instill trust and assurance among the populace[30].

2.2.6 Technical Challenges Facing E-governments

The rapid evolution of technology poses unique challenges for E-governments globally [33]. Data security and privacy are paramount, requiring robust measures to maintain citizen trust [34]. Technical interoperability is crucial, demanding seamless communication between diverse systems [35]. Developing advanced digital infrastructure is essential for efficient service delivery, necessitating upgrades in networks and software. Ensuring universal access to E-government services is a challenge, requiring diverse communication channels. Continuous updating and development of government technology are vital to meet user needs and technological advancements. Overcoming these challenges demands innovative strategies and creative solutions to ensure reliable and efficient government service delivery.

2.3 The Semantic Web

The Semantic Web, often referred to as Web 3.0, is a concept that extends the capabilities of the World Wide Web by adding semantics, or meaning, to the content and structure of information. This allows data to be understood and processed not just by humans, but also by machines, enabling more intelligent and automated interactions on the web.

2.3.1 Semantic Web definition

There are more than three definitions of the Semantic Web:

W3C's Definition: The World Wide Web Consortium (W3C), the main international standards organization for the World Wide Web, defines the Semantic Web as “an extension of the

current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation [36].

Tim Berners-Lee's Vision[37]: Tim Berners-Lee, the inventor of the World Wide Web, envisions the Semantic Web as a platform where data can be shared, reused, and combined in novel ways. In his vision, data is linked together in a web of relationships, allowing for more seamless integration and discovery of information across different domains.

Resource Description Framework (RDF) Perspective: From a technical standpoint, the Semantic Web relies heavily on the Resource Description Framework (RDF), a standard for representing information in the form of triples: subject-predicate-object statements. This allows for the creation of interconnected data graphs, where each resource is uniquely identified and linked to others through semantic relationships[38].

Ontology-Based Approach: Another perspective on the Semantic Web involves the use of ontologies, which define formal vocabularies and relationships between concepts. By employing ontologies, the Semantic Web enables machines to interpret and reason about the meaning of data, leading to more intelligent applications and services[36].

2.3.2 Significance of the Semantic Web

The Semantic Web holds the promise of revolutionizing how we interact with information online. By adding semantics to data, it overcomes the limitations of keyword-based searches and enables more precise and context-aware retrieval of information. For example, instead of simply finding web pages containing the word "apple," a Semantic Web search might understand that the user is interested in the fruit, the company, or the concept of an apple as a symbol, and return results accordingly. Moreover, the Semantic Web facilitates interoperability between different systems and platforms by providing a common framework for data representation and exchange. This means that information from diverse sources can be integrated and combined in meaningful ways, leading to new insights and discoveries that were previously unattainable [36].

In addition, the Semantic Web has vast implications for various fields such as healthcare, education, e-commerce, and government services. In healthcare, for instance, it can enable more accurate diagnosis and treatment recommendations by integrating patient data from electronic health records, medical research databases, and wearable devices.

However, despite its potential, the Semantic Web still faces challenges such as data quality, scalability, and adoption. Addressing these challenges will require concerted efforts from researchers, developers, and policymakers to realize the full benefits of a truly semantic web of data.

In conclusion, the Semantic Web represents a paradigm shift in how we organize, access, and utilize information on the internet. By imbuing data with meaning and context, it opens up new possibilities for collaboration, innovation, and knowledge discovery in the digital age.

2.3.3 The Semantic Web Techniques

The Semantic Web employs several key techniques to enable the representation, integration, and interpretation of data with semantic meaning. Some of the fundamental techniques include[36]:

Resource Description Framework (RDF): RDF is a standard model for representing data on the Semantic Web. It provides a flexible way to describe resources and their relationships using triples, which consist of subject-predicate-object statements. RDF triples form the building blocks of the Semantic Web, allowing for the creation of interconnected graphs of data.

RDFS (RDF Schema): RDFS is an extension of RDF that adds a basic vocabulary for describing the structure of RDF data. It allows for the definition of classes and properties, along with their relationships and hierarchies. RDFS enables the creation of simple ontologies to organize and categorize data, providing a foundation for more complex semantic structures.

OWL (Web Ontology Language): OWL is a language for creating rich and complex ontologies on the Semantic Web. It extends the capabilities of RDFS by providing additional constructs for expressing richer semantics, such as classes, properties, individuals, and axioms. OWL allows for the specification of more detailed relationships and constraints within a domain, enabling more sophisticated reasoning and inference capabilities.

Ontologies: Ontologies play a crucial role in the Semantic Web by providing formal vocabularies that define the concepts and relationships within a domain. Ontologies specify classes, properties, and relationships between entities, allowing for the creation of shared and reusable knowledge models. Popular ontology languages include RDF Schema (RDFS) and the Web Ontology Language (OWL).

SPARQL Protocol and RDF Query Language (SPARQL): SPARQL is a query language for querying RDF data on the Semantic Web. It allows users to express complex queries to retrieve specific information from RDF graphs. SPARQL queries can be used to search, filter, and aggregate data across distributed datasets, enabling powerful data integration and analysis.

Together, RDF, RDFS, OWL, SPARQL, and ontologies form the foundational building blocks of the Semantic Web, providing the tools and standards necessary for creating, sharing, and querying semantic data on the web. They enable machines to interpret and process information more intelligently, leading to more efficient information retrieval, integration, and analysis across diverse applications and domains.

2.4 Ontology & Ontology Design Pattern

Ontology and Ontology Design Patterns constitute fundamental concepts within the domain of the Semantic Web and knowledge representation, serving as cornerstones for structuring and organizing information. Delving into the intricate realm of Ontology reveals its nature as a formal and explicit specification that delineates a shared conceptualization within a specific domain of knowledge, encapsulating a structured framework for representing various aspects of knowledge related to that domain. This structured representation encompasses the intricate interplay of concepts, properties, and relationships that exist within the domain, facilitating a comprehensive understanding of the subject matter. Ontologies find their manifestation through languages such as RDF (Resource Description Framework) and OWL (Web Ontology Language) on the Semantic Web, providing a standardized format for knowledge representation and sharing[13].

Exploring the essential components of an Ontology sheds light on the key elements that constitute its framework. Firstly, concepts (referred to as classes) represent entities or types of entities within the domain, such as "Person" or "Organization" in a social network ontology. Secondly, properties (attributes or relations) describe the characteristics or relationships that

exist between different concepts, exemplified by attributes like "hasAge" or relations like "isMemberOf" in the context of a social network ontology. Thirdly, individuals (instances) denote specific instances or members of concepts, such as "John Smith" or "Google" within the social network ontology. Lastly, axioms (constraints) establish logical rules or constraints that govern the domain, ensuring the coherence and integrity of the ontology[39]. For instance, a rule like "Every person must have a unique social security number" exemplifies an axiom within the social network ontology, enforcing specific constraints within the domain.

The advantages of employing Ontologies in knowledge representation are manifold and significant. Firstly, Ontologies foster semantic interoperability by providing a standardized vocabulary and semantics that facilitate data integration and interoperability across diverse systems and domains. Secondly, they promote knowledge sharing and reuse by enabling the collaborative dissemination of domain knowledge, thereby fostering consistency and coherence in data representation. Lastly, Ontologies support automated reasoning and inference, empowering machines to derive new insights and make informed decisions based on the logical rules and constraints defined within the ontology[14].

Transitioning to the domain of Ontology Design Patterns (ODPs) elucidates a crucial aspect of ontology development, focusing on the provision of reusable solutions to common modeling challenges encountered during the construction of ontologies. ODPs encapsulate best practices, design principles, and modeling conventions that aid ontology engineers in crafting consistent, interoperable, and maintainable ontologies. These patterns are characterized by their reusability across different domains, modularity in encapsulating specific domain concepts, adherence to standardized modeling conventions, and flexibility in customization to suit diverse domain requirements[13].

In essence, the synergy between ontologies and ontology design patterns plays a pivotal role in shaping knowledge representation and semantic modeling within the Semantic Web landscape. By establishing a structured and machine-understandable format for representing domain knowledge, ontologies and ODPs pave the way for semantic interoperability, knowledge sharing, and automated reasoning across a myriad of applications and domains, underscoring their indispensable contribution to the field of information organization and representation.

2.5 The future of ontology and the Semantic Web in E-government

The future of ontology and the Semantic Web in E-government is poised for significant advancements [40]. Anticipated developments include evolving semantic technologies, interconnected government datasets, intelligent decision support systems, personalized citizen services, enhanced transparency, and cross-border collaboration. These advancements are expected to enhance efficiency, transparency, and citizen-centric governance within governmental applications. By leveraging cutting-edge technologies like machine learning and natural language processing, ontologies will become more dynamic and proficient in managing complex government datasets, fostering interoperability, and enabling seamless information exchange across diverse governmental systems [41]. Ultimately, these advancements hold the potential to revolutionize citizen-government interactions, policy formulation, and democratic governance, ushering in a new era of innovation and collaboration in governance.

2.6 The Semantic Web and Ontology: Foundations for Smart E-government

The Semantic Web represents a major evolution in digital infrastructure, designed to enable machines to interpret and reason over data in a context-aware, meaning-driven way. At the heart of this architecture lies **ontology**, a formal knowledge representation model that defines entities, concepts, relationships, and constraints within a domain, enabling seamless semantic interoperability across distributed systems.

In the realm of E-government, the interplay between the Semantic Web and ontology is transformative. Unlike traditional systems that rely on syntactic data matching, Semantic Web technologies enable advanced capabilities such as:

- **Data Integration:** Ontologies unify heterogeneous data formats, terminologies, and structures, making it possible to link and interpret information across ministries and platforms [42].
- **Automated Reasoning:** Inference engines can deduce new knowledge from existing data, such as determining eligibility for specific services [43].
- **Scalability and Modularity:** Semantic architectures support expansion or contraction without restructuring the entire system, enhancing flexibility [44].
- **Intelligent Search:** SPARQL-based semantic queries return contextually relevant results far beyond what traditional keyword searches can achieve .
- **Service Personalization:** Ontology-based user profiles allow for dynamic tailoring of services to individual needs and preferences.
- **Service Discovery and Composition:** Systems can autonomously identify and compose government services to fulfill complex user requests in real-time.

By embedding these technologies into E-government infrastructures, the study supports the transition toward **smart governance**—a model characterized by intelligent decision-making, user-centered service delivery, and proactive public administration.

2.7 Differentiating E-government, Digital Government, and Smart Government: The Role of Semantic Web and Ontologies

The evolution of public administration in the digital age has passed through distinct stages, each reflecting a deeper integration of technology in governance. Understanding the distinctions between **E-government**, **digital government**, and **smart government** is essential to contextualize the contribution of Semantic Web technologies and ontologies [42].

- **E-government** refers to the basic digitization of government services and processes. It focuses on putting existing services online—such as applications, forms, or records—primarily aimed at improving accessibility and reducing bureaucracy. However, most E-government systems rely on static content and manual interactions with limited data integration.
- **Digital Government** expands on this by leveraging ICT not only for service delivery but also for internal transformation. It emphasizes interoperability between departments, the use of centralized databases, and improved user experience. Yet, the intelligence of these systems remains limited to pre-defined functionalities .
- **Smart Government**, in contrast, is characterized by intelligent decision-making, automation, predictive analytics, and personalized services. It involves real-time data

processing, dynamic adaptation, and proactive policy formulation based on data insights [45].

The **Semantic Web and ontologies** are critical enablers of this transition toward smart governance. Ontologies allow for **semantic interoperability**, where data is not only shared but also understood uniformly across systems. This enables:

- **Cross-agency data fusion** using shared vocabularies.
- **Automated reasoning** and detection of new insights .
- **Adaptive and personalized services** through semantic user profiles .
- And **real-time service discovery** and intelligent automation using SPARQL and OWL-based frameworks .

By embedding these capabilities, the study contributes to redefining E-government systems not just as digital service platforms but as intelligent governance ecosystems—responsive, predictive, and citizen-centered [45]

Literature Review

Abstract

The Semantic Web and ontology are advanced extensions of the World Wide Web, designed to make data more interconnected, interpretable, and machine-readable. This systematic review examined publications from 2018 to 2023 indexed in Google Scholar and Science Direct, selecting 23 relevant studies. These were classified into six thematic categories: information retrieval, knowledge archiving, interoperability and integration, enhancement of public and employee services, barriers to ontology application, and the use of ontologies in regulatory compliance.

The review confirmed that semantic web technologies significantly enhance data accuracy, service interoperability, and information retrieval in E-government systems. However, most of the reviewed studies were limited to theoretical frameworks or partial applications without providing a comprehensive, adaptable model tailored to specific national contexts.

In contrast, the current study proposes a novel, scalable ontology design pattern customized for the Sudanese E-government system, particularly targeting the Ministry of Interior's services. It goes beyond previous work by integrating semantic reasoning, service personalization, and predictive analytics into a unified smart governance framework. Thus, this research addresses a clear gap in the literature and contributes both conceptually and practically to the advancement of intelligent public service delivery.

3.1 Introduction

As a consequence of developments in the public sector over the past twenty years, several governments all over the world have been motivated to use information technology to improve their services[46]. This has led to the creation of various E-government initiatives, which aim to provide citizens with more efficient and accessible public services through digital technologies [47]. These initiatives have been successful in reducing bureaucratic processes and improving transparency in government operations [48]. "E-government" refers to the government's endeavor to supply services online [49]. At least 23 periodicals now publish research on this issue, which is now often referred to as "eGovernment" by researchers in the field [50]. E-government is also known as the use of information and communication technology (ICT) to change the relationships that exist between the public sector and its constituents on an internal and external level to improve accountability, efficiency, cost-

effectiveness, and constituent participation [51] [52]. The E-government uses the web to deliver services to the general public, and as the web has developed over the past 25 years, numerous changes have been made to its structure and the delivery of services, leading to the creation of the semantic web[53] [54]. The semantic web is a development of the existing web since it gives information a more meaningful representation for both computers and people [55]. It allows for the automated annotation, discovery, publishing, promotion, and creation of services, as well as the description of materials and services in machine-readable form [56]. A key element in resolving the issue of semantic heterogeneity and enabling semantic interoperability between various web applications and services is the philosophical concept of ontology, which is associated with the semantic web. Ontologies are used to support interoperability and common understanding between the various parties [56] [57]. Throughout the past twelve years, one of the most active industries for Semantic Web development has been E-government. In E-government, ontology-based Semantic Web technologies are the focus of in-depth research. They show how several ontology models are utilized in E-government research and projects to describe and specify E-government services and accomplish their semantic integration and interoperability [58]. Increased access to information and services in E-government can lead to social and economic growth, improved participation and communication in policy and decision-making processes, and support for vulnerable populations [59]. Semantic Web technologies, such as ontology-based models, are being extensively researched and utilized in E-government to describe and integrate services and ensure interoperability[60]. These technologies enable the consistent and coherent organization and linking of data over the web, providing a foundation for efficient and effective E-government systems [61]. The development of E-government platforms based on Semantic Web technologies has the potential to enhance the delivery of services, improve transparency, and create a more accountable administrative process [62]. By leveraging the power of the Semantic Web, E-government can contribute to the strategic goals of countries, including increasing competitiveness and improving the well-being of citizens [63].

E-government provides its services through an electronic portal, allowing citizens to access government services and information conveniently and efficiently from anywhere at any time [64]. This digital platform aims to improve public services' capability and accessibility, especially in rural communities where there may be a digital divide[65]. Furthermore, E-government can reduce administrative costs and improve transparency in government operations [66]. Through these portals, which include all different government institutions, the success and quality of these services are often dependent on the ability to integrate the various systems of government institutions that provide services through digital E-government. Furthermore, E-government can also enhance citizen participation in the decision-making process by providing a platform for feedback and suggestions. This can lead to a more inclusive and responsive government that better serves the needs of its citizens [67]. Integrating an information system in any sector for E-government involves overcoming obstacles related to the structural and semantic sharing of information. The use of the semantic web and ontologies can help facilitate the sharing and exchange of information between different organizations and applications, leading to a more efficient and effective E-government system [68]. The semantic web and ontologies play an active role in knowledge

exchange and administration, enabling better representation and understanding of information across organizations [69]. By leveraging these technologies, E-government systems can better meet the needs of citizens by improving the sharing and integration of information for applications and services [70]. As a result, E-government services must model, re-engineer, and process governmental sharing and processing to enable information distribution depending on the citizen and location. Ontology-based Semantic Web technology has presented fascinating solutions to the aforementioned technical challenges. The semantic web, which is built on ontology, allows apps to communicate with one another to extract information or execute activities that integrate to deliver services via the E-government site. The use of semantic web technology in E-government sites has improved the efficiency and accuracy of information exchange between different applications. However, it is important to ensure that the information and statistics shared through these systems are reliable and accurate to avoid any potential errors or misinformation. The semantic web plays a significant role in extracting data and filtering acceptable material. It also aids in the establishment of relationships between different types of data. On the other hand, ontologies play an important role in the semantic web since they assist in improving interoperability, which is a key difficulty for many E-government projects [71]. Ontology creation is a critical activity for semantic data integration. Ontologies provide a shared understanding of the domain, which helps to ensure that data is interpreted consistently. They also enable automated reasoning and decision-making, making it easier to identify patterns and relationships within complex datasets. Ontologies can help with data integration efficiency. The goal of a data integration system is to give consistent access to a group of heterogeneous data sources while relieving the user of the need to understand how data is structured at the sources and how it is to be reconciled to answer queries [72].

Through this systematic review, we seek to respond to this question: How may ontology and the semantic web enhance E-government services and applications? To fully address the study topic, we shall evaluate the body of current literature and combine the results. Future studies and applications in this field will be guided by the findings of this review.

3.2 Research Method

3.2.1 Search Strategy

For this systematic research, we followed the PRISMA [73] framework for Systematic literature Review, and we developed a search strategy to identify relevant literature. This search strategy was tailored to two databases (Google Scholar and Science Direct), and the search terms used were the following: “ontology” AND “government” OR “ontology” AND “E-government” OR “government” AND “semantic web “OR “E-government “ AND “semantic web “. All research spanned from database inception until 2023 and included journal articles, and review papers, published in English only.

3.2.2 Selection Criteria

The selection criteria were based on the PRISMA statement [73]. The search mainly focused on mapping existing literature on ontology in E-government in the field of Computer Science and Information Systems. The search span was from the year 2018-2023. All articles before

2018 were excluded from the search. After a search, we found 2871 records. A total of 2472 research articles were excluded at this stage. There were 399 records extracted at this stage.

3.2.3 Quality Assessment

This study is based only on original research articles, review papers, and conference papers. To maintain the quality of the review, all duplications were checked thoroughly. The quality and relevance of the academic literature included in the review process were ensured by carefully examining the abstracts of the articles before analysis and purification. A careful evaluation of each research paper was carried out at a later stage. The next exclusion criteria were to limit the papers published in English only. There was only one article in the non-English language was found and was excluded from the study. Furthermore, after the filtration of duplicate records, 201 more articles were removed, and another 168 articles were removed du The full text of the articles is not available. We selected 23 articles after assessing each article on the aforementioned inclusion and exclusion criteria. Figure 3.1 displays the literature that was included and excluded at each level. (PRISMA statement).

3.2.4 Data Extraction

In the data extraction phase, 23 articles were selected and the characteristics extracted were:

1. The article must be original papers, reviews, and conference papers.
2. The article must be in English language and from the field of computer science and information systems.
3. Extracted articles were published between 2018-2023.

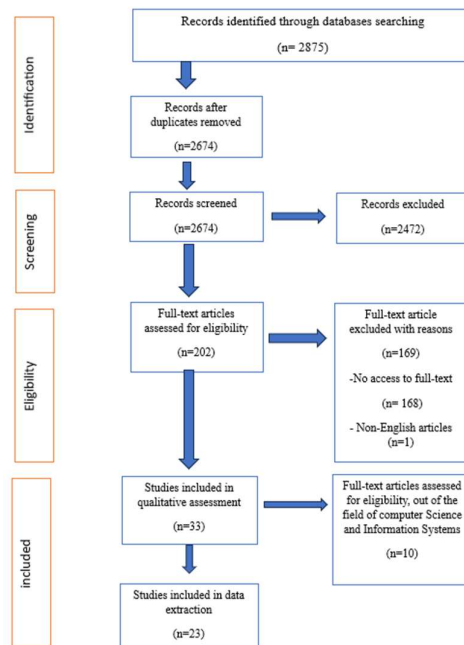


Figure 3.1 displays the literature that was included and excluded at each level. (PRISMA statement)

3.3 Results and Discussion

3.3.1 Results

The search procedure consisted of searching in the Google Scholar and Science Direct databases based on the inclusion and exclusion criteria described in the methodology, and the result was the inclusion of 23 studies in this systematic review after excluding a group of studies that did not meet the inclusion criteria or contained the exclusion criteria, as illustrated by the final number of studies included in the review, as shown in Figure 3.1. Figure 3.2 depicts the Research articles distribution published years included in this systematic review, with the total number of publications for each year indicated (2018-2023).

Previous studies contributed to finding an answer to the systematic review question by clarifying how ontology helped improve E-government services, and we divided this contribution into six groups, each of which is concerned with a specific aspect of E-government services, to make the results presented clearly. Searching and information retrieval, Archival Knowledge, Interoperability and integration, Improving public and employee services, Challenges and ranking, Rules and Compliance are among the classifications.

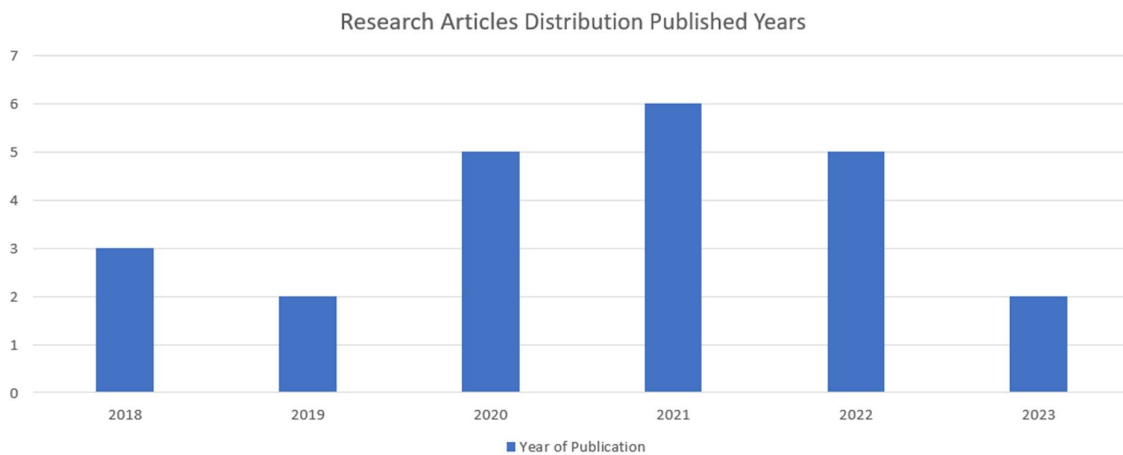


Figure 3.2 shows the research articles distribution published years

3.3.1.1 Searching and Information Retrieval

Studies have shown the great role that ontology and the semantic web play in improving search and retrieval processes for E-government applications, and this seems clear through the studies of Rastogi et al. [74] design of an ontological information retrieval model for real estate documents to improve the efficiency and accuracy of information retrieval of real estate document. They used an ontological approach to develop a model that can retrieve relevant information from a large corpus of real estate documents. The study used Protégé software to build the ontology and evaluated the model's performance using precision, recall, and F-score metrics. To improve the quality and effectiveness of E-government services Alazemi et al. [75] developed a semantic-based E-government framework using domain ontologies that can

semantically model the relation between government services and domain ontologies. The study used Protégé software to build the ontology and evaluated the framework's performance using a case study of the Kuwait region.

For E-government services, Ordiyasa et al. [76] presented an adaptive ontology based on cross-phrase identification. They aimed to improve the efficiency of cross-phrase identification in E-government services by developing an ontology that can adapt to the changing needs of users. The study used Protégé software to build the ontology and evaluated its performance using a survey of 100 E-government service users and structural equation modeling (SEM). A semantic search tool that can understand users' queries and retrieve relevant information from a large corpus of E-government documents was developed by Shehu & Xhina [77] to improve the accessibility and efficiency of E-government services by developing a semantic search tool that can understand users' queries and retrieve relevant information from a large corpus of E-government documents. The study used Protégé software to build the ontology and evaluated the tool's performance using precision, recall, and F-score metrics. H. Wang et al. [78] proposed an ontology automation construction scheme for Chinese E-government thesaurus optimization to improve the quality of thesaurus used in Chinese E-government services by developing an ontology automation construction scheme that can automatically extract and construct thesaurus concepts and relations. The study used Protégé software to build the ontology and evaluated the scheme's performance using thesaurus construction and optimization metrics. The relevance of ontology and the semantic web in enhancing search services and information retrieval in E-government applications is evident to us. We discover that the studies were involved in both the type of ontology and the tools used to generate the ontology. It is also evident that the ontology was built using several methodologies, as indicated in Table 3.1.

Table 3.1 shows searching and retrieval of information studies

Author(s)	Aim of study	Methodology	Type of ontology	Tools	Result(s)
Rastogi et al [74]	To improve the efficiency and accuracy of real estate document retrieval	ontology-based approach	Domain ontology	Protégé	Improved precision, recall, accuracy, and efficiency of document retrieval
Alazemi et al. [75]	To improve the efficiency and effectiveness of E-government services in the Kuwait region	Ontology-based approach with semantic web technologies	Domain ontology	Protégé and SPARQL	improved the efficiency and effectiveness of E-government services in the Kuwait region
Ordiyasa et al. [76]	To improve the accuracy and efficiency of E-government services	Ontology-based approach with cross-phrase identification technique	Domain ontology	Protégé	improved the accuracy and efficiency of E-government services
Shehu & Xhina [77]	To address the challenges users face	a design science research approach	Domain ontology	Protégé	The developed semantic search

	in accessing E-government public services in Albania due to the lack of semantic interoperability and searchability	to develop and evaluate the semantic search tool		And Apache Jena Fuseki	tool improved the accuracy and efficiency of search results and provided a more user-friendly interface for users
H. Wang et al. [78]	To address the challenges of manually constructing and maintaining a large-scale ontology for Chinese E-government thesaurus optimization	a knowledge engineering approach	Domain ontology	Protégé	The developed ontology construction scheme reduced the time and cost of constructing and maintaining the ontology and improved its accuracy and consistency

3.3.1.2 Archival Knowledge

An ontology for knowledge representation and reasoning in Chinese government archives is presented by Z. Wang et al. [79]. The ontology is designed to facilitate the management and retrieval of information from government archives, which contain a vast amount of historical and administrative data. The authors argue that traditional methods of organizing and accessing this information are inadequate, as they do not take into account the complex relationships between different types of data. The ontology is based on a conceptual model that includes four main components: entities, attributes, relationships, and rules. Entities refer to the various types of data found in government archives, such as documents, organizations, people, and events. Attributes describe the characteristics of these entities, such as their date of creation or their author. Relationships capture the connections between entities, such as the fact that a document was created by a particular person or organization. Rules specify how these entities and relationships can be combined to form meaningful queries or analyses. The authors demonstrate the usefulness of their ontology through several case studies involving different types of government archives. For example, they show how it can be used to identify patterns in administrative decision-making over time or to trace the evolution of certain policies or practices. They also discuss some of the challenges involved in implementing the ontology in practice, such as ensuring consistency across different archival collections or dealing with incomplete or ambiguous data. Overall, the article provides a valuable contribution to the field of knowledge representation and reasoning in government archives. Developing an ontology that takes into account both the complexity and diversity of archival data, offers a promising approach to improving access to this important historical resource.

3.3.1.3 Interoperability and integration

Interoperability and integration of government services using ontology refers to the seamless sharing and exchange of information between different government agencies and systems. government services can be connected and integrated more efficiently. This enables improved collaboration, streamlined processes, and enhanced citizen experience. Through the use of ontology, governments can achieve a more holistic and interconnected approach to delivering services, resulting in greater efficiency and effectiveness in service provision. As illustrated in Bastola & Shakya's [80] study, the objective was to develop a domain ontology for issuing certificates of citizenship in Nepal. The methodology used was a knowledge engineering approach, and the ontology was created using Protégé software and OWL language. The key finding was that the ontology improved the accuracy and efficiency of citizen certificate issuance. Also, Tshering [81] proposed an ontology-based approach for E-government interoperability. The objective was to enhance the interoperability of E-government systems. The ontology was developed using Protégé software and OWL language, and the methodology used was a semantic web approach. The study found that the ontology improved the interoperability of E-government systems.

The ontology witch proposed by Shehu & Xhina [82] provided a structured framework for organizing and categorizing the various E-government services offered in Albania. This allowed for easier navigation and access to the services by citizens, ultimately resulting in increased efficiency and effectiveness in service provision. Additionally, the semantic web approach enabled better integration and interoperability between different E-government systems, further enhancing the overall quality of service delivery. Overall, the study demonstrated the potential of ontologies in improving public E-government services and highlighted the importance of adopting such approaches for better governance. To enhance the accuracy and efficiency of E-government services Jami & Zubair [83] developed a semantic web-based E-government system. The methodology used was a semantic web approach, and the ontology was created using Protégé software and OWL language. The key finding was that the system improved the accuracy and efficiency of E-government services. Also, Ortiz-Rodriguez et al. [84] proposed the EGODO ontology for sharing legal documentation across E-government. The objective was to enable the sharing, retrieving, and exchanging of legal documentation across E-government. The ontology was developed using Protégé software and OWL language, and the methodology used was a semantic web approach. The study found that the ontology enabled the sharing, retrieving, and exchanging of legal documentation across E-government.

The introduction of semantic reusable web components in E-government systems proved to be a significant step towards achieving better interoperability. By implementing a semantic web approach, Žitnik et al. [85] were able to enhance the efficiency and effectiveness of these systems. The evaluation of these components using metrics like response time and accuracy further validated their positive impact on the interoperability of E-government services. Overall, this study highlights the importance of adopting such approaches for achieving seamless governance and efficient service delivery. Alshehab et al. [86] designed and implemented an ontology for semantic integration sharing in E-government domains. The

objective was to enable the semantic integration sharing of E-government domains. The ontology was created using OWL language, and the methodology used was not specified. The study found that the ontology enabled the semantic integration sharing of E-government domains. Alshehab et al. [86] designed and implemented an ontology for semantic integration sharing in E-government domains. The objective was to enable the semantic integration sharing of E-government domains. The ontology was created using OWL language, and the methodology used was not specified. The study found that the ontology enabled the semantic integration sharing of E-government domains.

To address interoperability challenges and enhance E-government services through the use of ontology-based frameworks and models Tshering et al. [87] propose a framework for Bhutan's E-government that utilizes an ontology developed using Protégé. The paper demonstrates the concept of a Single Source of Truth, enabling data reusability and collaboration. However, it lacks discussion on the practical implementation and impact of the framework on E-government services. Kurniawan et al. [88] the Ecosystem Pie Model to design an ontology development ecosystem for Indonesian E-government. The paper proposes a model that supports cross-domain government ontology services but lacks a detailed discussion on practical implementation and evaluation. Brys et al. (Brys et al. 2023) extend the Ontology for E-government (EGO) and apply it to the E-government context of the Province of Misiones, Argentina. The paper integrates existing ontologies and supports new features for describing E-government services, but it does not address implementation challenges. Lastly, Haridy et al. [90] propose a domain ontology using OntoUML for the Egyptian E-government. The paper creates a computable web ontology with better understandability measurements but lacks a discussion on practical implementation and evaluation. Overall, these papers contribute to improving E-government services, but further research is needed to bridge the scientific gaps and evaluate the practical implementation and impact of these approaches. All of them presented a model based on ontology to achieve integration and interoperability, but they struggled with the practical implementation of this model in a way that enables its utilization in E-government applications that citizens interact with.

As shown in Table 3.2, the previous studies differed in the methodology used to design the ontology, as well as the types of the resulting ontologies, but the studies agreed on the tools used in developing the ontologies. The contribution of ontology is to improved collaboration, and streamlined processes, and the citizen experience we reviewed above shows that governments can achieve a more holistic and interconnected approach to service delivery, leading to more efficient and effective service delivery.

Table 3.2 shows Interoperability and integration studies

Author(s)	Aim of study	Methodology	Type of ontology	Tools	Result(s)
Bastola & Shakya [80]	To develop a domain ontology for issuing certificates of citizenship in Nepal	Knowledge engineering approach	Domain ontology	Protégé software, OWL language	The ontology improved the accuracy and efficiency of citizen certificate issuance.
Tshering [81]	To enhance the interoperability of E-government systems	Semantic web approach	Ontology-based approach	Protégé software, OWL language	The ontology improved the interoperability of E-government systems.
Shehu & Xhina [82]	To improve the quality and effectiveness of E-government services	Semantic web approach	Semantic web ontology	Not specified	The ontology improved the quality and effectiveness of E-government services.
Jami & Zubair [83]	To enhance the accuracy and efficiency of E-government services	Semantic web approach	Semantic web ontology	Protégé software, OWL language	The system improved the accuracy and efficiency of E-government services.
Ortiz-Rodriguez et al. [84]	To enable the sharing, retrieving, and exchanging of legal documentation across E-government	Semantic web approach	EGODO ontology	Protégé software, OWL language	The ontology enabled the sharing, retrieving, and exchanging of legal documentation across E-government.
Žitnik et al. [85]	To enhance the interoperability of E-government systems	Semantic web approach	Semantic reusable web components	Not specified	The components improved the interoperability of E-government systems.
Alshehab et al. [86]	To enable the semantic integration sharing of E-government domains	Not specified	Not specified	OWL language	The ontology enabled the semantic integration sharing of E-government domains.
Tshering et al. [87]	To support semantic interoperability in	Semantic web approach	Ontology-based approach	Protégé software, OWL	The framework enables semantic interoperability

	Bhutan’s E-government			language, SPARQL	data reusability and collaboration.
Kurniawan et al. [88]	to support the development and operation of cross-domain government ontology services for semantic interoperability in E-government systems	Ontology development ecosystem model	Cross-domain ontology	Ecosystem Pie Model	proposes an ecosystem model for ontology development in E-government.
Brys et al. (Brys et al. 2023)	to describe E-government organizational units and services in the Open Government Data and Services context	semantic technologies to describe E-government units and services	Domain ontology	Not specified	Improves government management, service delivery, and decision-making processes. - Extension of the Ontology for E-government (EGO) enables real-world use cases
Haridy et al. [90]	to solve a variety of interoperability problems and is evaluated by the OntoMetrics quality metrics	OntoUML for building an Ontology-driven conceptual model	Domain ontology	OWL language	The proposed Ontology has better understandability measurements.

3.3.1.4 Improving public and employee services

Semantic web ontology can enhance public and employee services by facilitating efficient and effective delivery of services. This approach allows government agencies to categorize and organize information, making it more accessible and understandable for both the public and employees. This results in streamlined processes, reduced administrative burden, and improved user experience. Additionally, semantic web ontology enables better data integration and interoperability, allowing different government systems to exchange information, and enhancing the overall quality of E-government services. Benaddi et al. [91] developed an ontology model for public services in Morocco, called PSOM-eGovMa, using the 5W1H approach. The model includes over 200 classes organized into six main categories: actors, services, time, location, reasons, and processes. The study found that the ontology model provides a comprehensive representation of public services in Morocco. And improving public service delivery in Morocco, such as facilitating data sharing between different government agencies, enabling more efficient and effective service delivery, by supporting the development of new E-government services.

An ontology-based governance framework for managing employee services in enterprises was presented by Tzagkarakis et al. [92], based on an ontology that defines concepts, relationships, and rules governing employee services. The results showed that the framework improved service delivery, increased transparency and accountability, and reduced costs associated with managing employee services. Table 3.3 shows a Comparison between previous studies in terms of methodology, objectives, and results, as well as the tools used in building the ontology.

Table 3.3 shows Improving public and employee services studies

Author(s)	Aim of study	Methodology	Type of ontology	Tools	Result(s)
Benaddi et al. [91]	To develop an ontology model for public services in Morocco	5W1H approach	Public services ontology	Protégé software, OWL language	The ontology model provides a comprehensive representation of public services in Morocco.
Tzagkarakis et al. [92]	To develop a governance model for employee services	Semantic web approach	Employee services ontology	Protégé software, OWL language	The ontology model improved the management and delivery of employee services.

3.3.1.5 Challenges and Ranking

The application of ontology in E-government is accompanied by many challenges that must be paid attention to and known precisely so that researchers can consider them when building an ontology of E-government. Some of these challenges were discussed by Alshehab et al.[93] in their study, which summarized these challenges as the lack of awareness and understanding of semantic web technologies among E-government stakeholders, data quality issues, privacy and security concerns, technical limitations, and collaboration between government agencies, IT professionals, researchers, and citizens. Finally, they concluded the article by highlighting the need for collaboration between government agencies, IT professionals, researchers, and citizens to overcome these challenges and promote the adoption of semantic web approaches. To achieve the principle of quality, there must be a classification of the E-government ontologies. The relevance of E-government ontologies and their ranking on the semantic web is discussed by Fonou-Dombeu [94]. The author proposes a ranking system based on three criteria: popularity, relevance, and quality. The top-ranked ontology was found to be the European Union Public Sector Information (EU PSI) ontology, followed by the Dublin Core Metadata Initiative (DCMI) Government Domain Vocabulary and the UK Government Data Standards Catalogue (GDS). The author also notes that some of the lower-ranked ontologies

may still be useful for specific purposes or in certain contexts. Overall, this article highlights the importance of E-government ontologies in facilitating communication and data exchange between government agencies and departments. The proposed ranking system provides a useful tool for determining which ontologies are most relevant and useful in specific contexts.

3.3.1.6 Rules and Compliance

The implementation of E-government regulatory standards ensures transparency, efficiency, and accountability in the functioning of government processes. These standards are crucial in promoting public trust and confidence in the government's ability to handle sensitive information and deliver services effectively. Without regulatory standards, there is a risk of inconsistency, data breaches, and potential misuse of resources, which can undermine the credibility of the government and hinder progress in the digital transformation of public services. In this study, Hasan et al. [95] cover the creation of an ontology-based framework for meeting E-government regulatory standards. The framework aims to assist government agencies in complying with regulatory requirements by providing a structured and standardized approach to managing compliance information. The framework is based on an ontology, which is a formal representation of knowledge that defines concepts and relationships between them. The ontology used in this framework is designed specifically for E-government regulatory compliance and includes concepts such as regulations, compliance obligations, and compliance assessments. The article outlines the various components of the framework, including the ontology itself, a compliance management system, and a compliance assessment tool. The compliance management system allows government agencies to manage their compliance information in a centralized location, while the assessment tool provides a way to evaluate their level of compliance with specific regulations. The article also discusses the benefits of using an ontology-based approach to regulatory compliance. These include improved consistency and accuracy in managing compliance information, increased efficiency in assessing compliance levels, and better communication between government agencies and other stakeholders. Overall, the article presents a comprehensive framework for E-government regulatory requirements compliance that leverages ontologies to provide a structured and standardized approach to managing regulatory information.

The concept of an ontology-based framework provides a promising solution to address the challenges posed by inconsistent regulatory standards in E-government. By utilizing a standardized and structured ontology, government agencies can establish a common language and framework for defining and enforcing regulatory standards. This not only ensures consistency but also enables efficient data management and analysis, reducing the risk of data breaches and misuse of resources. Therefore, a comprehensive solution that incorporates an ontology-based framework is crucial in meeting E-government regulatory standards and facilitating the seamless digital transformation of public services. Bhatta et al. [96] describe the deployment of ontology-based knowledge management in Nepal's income tax system. The authors argue that traditional knowledge management approaches are inadequate for managing the vast amount of information and data generated by the income tax system. They propose an ontology-based approach that uses a formal representation of tax-related concepts and their relationships to facilitate knowledge-sharing and decision-making. The authors describe the

development of an ontology for the income tax domain, which includes concepts such as taxpayer, income sources, deductions, exemptions, and tax rates. They also discuss the use of semantic web technologies such as RDF and OWL to represent and query the ontology. The article presents a case study of how the ontology-based approach was used to improve tax compliance in Nepal. The authors describe how the ontology was used to develop a knowledge base that guides tax laws and regulations, as well as tools for calculating taxes and submitting returns. They also discuss how the ontology was used to develop a chatbot that can answer taxpayers' questions about their taxes. The authors conclude that ontology-based knowledge management has significant potential for improving tax administration in Nepal and other developing countries. They suggest that further research is needed to explore how this approach can be scaled up and integrated with other systems and processes in the income tax system.

3.3.2 Discussion

Previous research has examined the impact of the semantic web and ontology on enhancing E-government services, which rely heavily on the information systems of governmental ministries, agencies, and affiliated institutions that cater to the public, be it individuals or organizations. An analysis of prior studies reveals that they have made notable contributions to the enhancement of E-government services across various domains, such as information retrieval and search capabilities, archival knowledge management, interoperability, and integration, as well as the improvement of services provided to the public and government employees. Furthermore, these studies have addressed challenges, ranking, rules, and compliance relevant to E-government services. The current investigation is focused on the research conducted from 2018 to 2023, which spans five years. These investigations have played a significant role in enhancing E-government applications through the utilization of the semantic web and ontology.

Ontologies are used to create a structured representation of knowledge within a specific domain, which can then be used to improve information retrieval and decision-making processes. In terms of methodology, all the papers used ontologies as a central component of their approach. They differ in terms of the specific techniques used to develop and apply these ontologies. For example, Rastogi et al. [74] used a combination of manual and automated methods to develop their ontology, while Alazemi et al. [75] focused on using domain experts to create their ontology. The results of each paper also vary depending on the specific objectives and research questions being addressed. For instance, Shehu & Xhina [77] developed a semantic search tool for E-government public services in Albania, which was found to significantly improve search accuracy compared to traditional keyword-based approaches. In contrast, Ordiyasa et al. [76] focused on developing an adaptive ontology that could be updated based on user feedback. Despite these differences, there are also some common themes across the papers. For example, many of them highlight the importance of using ontologies to improve information retrieval in E-government contexts. They also emphasize the need for effective collaboration between domain experts and technical specialists to develop accurate and useful ontologies. One potential scientific gap that emerges from this analysis is the need for more research into how ontologies can be effectively integrated into existing E-government systems.

While many of the papers discuss theoretical approaches or prototype systems, there is less discussion about how these approaches can be scaled up or integrated into real-world E-government contexts with existing legacy systems and data structures. Overall, these scientific articles provide valuable insights into how ontologies can be used to improve information retrieval and decision-making processes in E-government contexts. However, further research is needed to explore how these approaches can be effectively implemented in practice.

The semantic web and ontologies have allowed for improvements to the E-government archive. Ontology supports reasoning tasks such as information retrieval, classification, and semantic analysis, as well as knowledge representation. Through their research, Z. Wang et al. [79] created an ontology for the knowledge contained in Chinese government archives to represent and make sense of it. One area of science lacking in this work is the empirical assessment of how well the developed ontology performs in tasks involving knowledge representation and reasoning about Chinese government archives. While the authors provide a detailed description of the ontology and its potential applications, they do not provide any empirical evidence to support their claims. Future research could address this gap by conducting user studies or other forms of evaluation to assess the effectiveness of the ontology in practice.

Ontologies can be used to improve interoperability, information sharing, and decision-making in E-government systems. Tshering et al. [87] propose a framework for Bhutan's E-government using Protégé, demonstrating data reusability and collaboration. Kurniawan et al. [88] use the Ecosystem Pie Model for Indonesian E-government but lack detailed discussion on practical implementation. Brys et al. (Brys et al. 2023) apply the Ontology for E-government to Argentina but do not address implementation challenges. Haridy et al. [90] propose a domain ontology for Egyptian E-government but lacks practical implementation. Bastola & Shakya [80] used the methontology methodology to develop an ontology for issuing certificates of citizenship, and Tshering [81] used the protégé tool to develop an ontology-based approach for E-government interoperability. And a combination of interviews and a literature review to develop an ontology for public E-government services in Albania. The objectives of these articles are similar, as they all aim to improve E-government systems through the use of ontologies. The results vary depending on the specific domain being studied and the methodology used. For example, Jami & Zubair [83] developed a semantic Web-based E-government system that improved information retrieval and decision-making for citizens. Ortiz-Rodriguez et al. [84] developed an EGODO ontology that allows for sharing, retrieving, and exchanging legal documentation across E-government systems.

The articles by Benaddi et al. [91] and Tzagkarakis et al. [92] both discuss the development of ontology models to improve public and employee services. Both studies use ontology modeling methodology to create their respective models. Benaddi et al. [91] use the 5W1H approach to develop an ontology model for public services in Morocco. Tzagkarakis et al. [92] use a similar approach but focus on employee services governance. The objective of Benaddi et al. [91] is to develop an ontology model for E-government services in Morocco, aiming to improve the quality of public services. Tzagkarakis et al. [92] aim to improve employee service governance through an ontology model. The studies differ in scope and application, with Benaddi et al.

[91] focusing on E-government services in Morocco and Tzagkarakis et al. [92] focusing on employee service governance more broadly. Benaddi et al. [91] on improving the quality of public services, while Tzagkarakis et al. [92] focus on improving the efficiency of employee service governance. Both studies use ontology modeling to improve public and employee services, but they differ in scope and application. The scientific gap lies in their objectives and focus.

Semantic web approaches in E-government services are the focus of two articles by Alshehab et al. [93] and Fonou-Dombeu [94]. Fonou-Dombeu [94] surveyed experts to identify challenges in applying semantic web approaches to E-government web services and proposed a ranking method for evaluating E-government ontologies on the semantic web. Alshehab et al. [93] also identified challenges in applying semantic web approaches to E-government services and emphasized the need for more research in this area. Fonou-Dombeu [94] evaluated E-government ontologies and found differences in quality and relevance. Both articles aimed to address challenges in applying semantic web approaches to E-government services, but Fonou-Dombeu [94] focused on evaluating ontologies while Alshehab et al. [93] emphasized the need for further research.

The two aforementioned scholarly articles authored by Hasan et al. [95] and Bhatta et al. [96] focus their attention on the practical implementation of ontology in the realm of government regulations and compliance. Hasan et al. [95] put forth an innovative framework that is grounded in ontology to facilitate the achievement of regulatory requirements compliance in E-government. Conversely, Bhatta et al. [96] have a thought-provoking knowledge management system that leverages ontology to enhance income tax processes in Nepal. While Hasan et al. [95] establish an all-encompassing framework that ensures seamless and efficient adherence to government regulations, it is worth noting that the findings of their research demonstrate the efficacy of the proposed framework in assessing compliance status. On the other hand, the primary objective of the study conducted by Bhatta et al. [96] is to enhance knowledge management in the sphere of income tax administration, with the results indicating that users found the system to be highly beneficial. Both studies undoubtedly illuminate the potential of ontologies in enhancing the operational efficiency of government entities, albeit with divergent areas of focus. Nevertheless, it is imperative to acknowledge the presence of a research gap in the scientific field regarding the investigation of how ontologies can effectively integrate regulatory compliance and knowledge management within government agencies.

The use of Semantic Web and ontology has proven to be beneficial for enhancing E-government services in various areas, including but not limited to integration, interoperability, information and data retrieval, and archive processing. These innovative techniques facilitate the users in effortlessly searching for and accessing pertinent information. Nevertheless, certain challenges must be overcome to successfully implement these technologies. These challenges encompass concerns about security, costs, and standardization. Numerous prior investigations have indicated that the actual application of Internet models in E-government portal applications is lacking, thereby necessitating the addressing of data security and confidentiality concerns. To advance the field, future research endeavors should concentrate on tackling these challenges and further delving into the modeling, provision, and management of future Internet

services. Furthermore, the protection and analysis of data must be given due consideration. Additionally, it is imperative to continue the exploration of the application of semantic web techniques in the evaluation of software accessibility. Moreover, conducting studies with a greater impact within this realm should be pursued relentlessly.

The studies included in this research have made significant contributions towards answering the study question as illustrated in Table 3.4.

Table 3.4 summarizes the contributions of the studies included in answering the study question

Searching and information retrieval		
Title	References	How may ontology and the semantic web enhance the integration of E-government services and applications?
Ontological Design of Information Retrieval Model for Real Estate Documents	[74]	
SEMANTIC-BASED E-GOVERNMENT FRAMEWORK BASED ON DOMAIN ONTOLOGIES: A CASE OF KUWAIT REGION	[75]	Providing a unified and shared understanding of information. Enabling semantic interoperability.
Adaptive Ontology based on Cross Phrase Identification in E-government	[76]	Allowing discovery and composition of services. Facilitating query expansion and mediation.
A Semantic Search Tool for E-government Public Services in Albania	[77]	
An ontology automation construction scheme for Chinese E-government thesaurus optimizing	[78]	
Archive Knowledge		
An Ontology for Chinese Government Archives Knowledge Representation and Reasoning	[79]	Facilitating knowledge discovery and composition. Promoting knowledge sharing and reuse. Supporting intelligent knowledge services.
Interoperability and integration		
Developing Domain Ontology for Issuing Certificate of Citizenship of Nepal	[80]	
Ontology-Based Approach of E-government for Interoperability	[81]	Improving accessibility and interoperability.
Modeling an Ontology for Public E-government Services in Albania	[82]	Enabling automated processing.
Semantic Web-based E-government System	[83]	
EGODO Ontology: Sharing, Retrieving, and Exchanging Legal Documentation Across E-government	[84]	
Semantic reusable web components: A use case in E-government interoperability	[85]	
SEMANTIC INTEGRATION SHARING FOR GOVERNMENT DOMAINS ONTOLOGY: DESIGN AND IMPLEMENTATION USING OWL	[86]	

Enabling Semantic Interoperability in Bhutan's E-government: An Ontology-based Framework	[87]	
Designing An Ecosystem Model for E-government Ontology Development Using Ecosystem Pie Model	[88]	
LEGO: Linked E-government ontology	(Brys et al. 2023)	
Ontology-driven conceptual model and domain ontology for Egyptian E-government	[90]	
improve public services and employee services		
Ontology Model for Public Services in Morocco Based on 5W1H Approach: PSOM-eGovMa	[91]	Enabling automation. Improving government efficiency and effectiveness.
Ontology-Based Governance for Employee Services	[92]	
Challenges and ranking		
CHALLENGES OF APPLYING SEMANTIC WEB APPROACHES ON E-GOVERNMENT WEB SERVICES: SURVEY	[93]	Promoting reusability. Improving integration challenges. Evaluating and ranking ontologies.
Ranking E-government Ontologies on the Semantic Web	[94]	
Regulations and Compliance		
An Ontology-based Framework for E-government Regulatory Requirements Compliance	[95]	Ensuring regulatory compliance.
Ontology-based knowledge management in income tax of Nepal	[96]	

3.4 Conclusion

Based on the literature review, it is evident that most previous studies focused on **isolated or theoretical improvements** in E-government systems, such as better information retrieval or semantic data integration. While these contributions are valuable, they typically lack a **comprehensive, implementable model** tailored to a specific national context.

In contrast, the current study stands out in several ways:

- It offers a **practical ontology design pattern specifically tailored to Sudan's E-government environment**.
- It aims to shift from E-government to **smart governance** by embedding semantic reasoning, contextual awareness, and personalized service delivery.
- It bridges the gap from **partial, conceptual solutions** to a **holistic, adaptive, and scalable framework**.

As such, the study addresses a real gap in the literature and advances from theoretical contributions to the **practical design of a smart, data-driven public administration system, as shown in Table 3.5**.

Table 3.5 Comparison Between Previous Studies' Objectives and the Current Study's Goal

No.	Category	Previous Studies' Focus	Current Study's Contribution
1	Searching and Information Retrieval	Enhancing information retrieval accuracy using OWL and SPARQL within E-government platforms	Proposes an ontology model that enables semantic, citizen-profile-based search and automatic service discovery
2	Archival Knowledge	Building knowledge repositories through ontologies to document terminologies and databases	Links archival knowledge to contextualized service personalization using ontologies
3	Interoperability and Integration	Connecting heterogeneous government systems through semantic standards	Designs a unified and scalable ontology pattern to integrate Ministry of Interior services with other departments
4	Improving Public and Employee Services	Improving service quality and internal workflows using semantic modeling	Expands the goal to include intelligent services and predictive citizen needs analysis through contextual reasoning
5	Challenges and Ranking of Ontologies	Evaluating ontology quality using metrics like OntoMetrics	Goes beyond evaluation to offer a directly applicable model within the Sudanese E-government framework
6	Regulations and Compliance	Using ontologies to formalize and manage legal and regulatory documentation	Integrates compliance logic into a machine-interpretable framework for proactive rule enforcement within smart services

Methodology

4.1 Introduction

Ontology development constitutes a crucial process within the realm of knowledge representation and semantic web applications[97]. It encompasses the construction of a formal depiction of a domain's concepts, entities, and relationships, which can be employed to facilitate various tasks, including data integration, information retrieval, and decision-making [98]. The methodology employed for ontology development signifies a methodical approach to creating ontologies, which encompasses a collection of guidelines and optimal practices for initiating, refining, and sustaining ontologies[99]. Adopting an ontology development methodology can assist in ensuring the accuracy, comprehensiveness, and fulfilment of user requirements for the ontology[100].

Numerous ontology development methods and methodologies have been proposed in the literature, each presenting its own merits and demerits. One extensively utilized ontology development methodology is the Methontology method [101] , which adopts a systematic approach to ontology development that emphasizes the utilization of a diverse range of knowledge acquisition techniques, such as brainstorming, interviews, and literature review. The Methontology method also encompasses a set of guidelines for ontology evaluation and maintenance, which contribute to the preservation of the ontology's currency and accuracy over time. Another popular ontology development methodology is the NeOn methodology [102], which underscores the significance of social and organizational factors in ontology development. The NeOn methodology involves a collaborative approach to ontology development, in which domain experts, ontology engineers, and end-users work in unison to create and sustain the ontology. Additional ontology development methods and methodologies encompass the Uschold and King method [103], the Ontology Development 101 method (Noy & Mcguinness, 2001), and the Suggested Upper Merged Ontology (SUMO) method [105].

In summary, ontology development methods and methodologies provide a methodical approach to ontology development, which aids in guaranteeing the accuracy, comprehensiveness, and fulfilment of user requirements for the ontology. However, it is essential to acknowledge that ontology development is an iterative process, and multiple iterations may be necessary to refine the ontology and ensure its accuracy and completeness. A comprehensive exploration of each methodology will be conducted in this chapter to determine the most effective approach for creating an ontology for the E-government.

4.2 Ontology Development Methodologies:

4.2.1 Methontology Methodology

Methontology is a methodology for ontology development that was proposed in 1997 by Fernandez-Lopez et al. [101]. It is a systematic approach to ontology development that emphasizes the use of a variety of knowledge acquisition techniques, such as brainstorming, interviews, and literature review.

The Methontology methodology also includes a set of guidelines for ontology evaluation and maintenance, which help to ensure that the ontology remains up-to-date and accurate over time. Methontology emphasizes knowledge acquisition techniques and includes steps for ontology evaluation and maintenance. Here are the key steps in the Methontology methodology.

1. **Specification:** In this phase, the objectives, scope, and requirements of the ontology are identified. The domain of the ontology is defined, and the goals and expected outcomes of the ontology are identified.
2. **Knowledge Acquisition:** In this phase, we use various techniques such as brainstorming, interviews, and literature review to gather information. And identify relevant concepts, relationships, and instances within the domain.
3. **Conceptualization:** The conceptualization phase involves creating a conceptual model of the ontology. This involves defining the concepts and relationships that will be used in the ontology and creating a hierarchy of concepts that reflects the relationships between them.
4. **Integration:** Combine the conceptual model with existing ontologies or external resources. Ensure compatibility and consistency with related ontologies.
5. **Implementation:** In the implementation phase, the conceptual model is translated into a formal ontology language, such as OWL or RDF. The ontology is given a formal structure, and logical axioms are added to define the relationships between concepts. Develop the ontology using appropriate tools and frameworks.
6. **Evaluation:** The evaluation phase involves assessing the quality of the ontology. This includes evaluating the ontology against a set of criteria, such as completeness, consistency, and accuracy.
7. **Documentation:** Document the ontology design, including its purpose, structure, and relationships. Provide clear explanations of concepts and guidelines for usage.

To make sure that the ontology is complete and correct, the Methontology approach highlights the value of applying a range of knowledge acquisition strategies, such as brainstorming, interviews, and literature reviews. To keep the ontology current and useful over time, the technique also contains a set of rules for ontology review and maintenance. In general, the Methontology methodology offers an organized way for developing ontologies, which can aid in ensuring that the ontology is precise, thorough, and fits the demands of its users.

4.2.2 NeOn methodology

The NeOn methodology is an ontology development methodology that was proposed by Gómez-Pérez et al [102]. The methodology emphasizes the importance of social and organizational factors in ontology development. The NeOn methodology involves a

collaborative approach to ontology development, in which domain experts, ontology engineers, and end-users work together to create and maintain the ontology. The NeOn methodology consists of several phases:

1. Requirement Specification: Identify stakeholders and their requirements for the ontology. And define the purpose and goals of the ontology.
2. Community Building: Establish a collaborative community involving domain experts, ontology engineers, and end-users. Encourage communication and shared understanding among community members.
3. Competency Questions: Formulate competency questions that the ontology should be able to answer. Use these questions to guide the development and evaluation of the ontology.
4. Methodology Selection: Choose appropriate ontology development methods and tools based on the project's characteristics and requirements. Integrate selected methods into the overall NeOn Methodology.
5. Ontology Development: Collaboratively develop the ontology using selected methods and tools. Involve domain experts to ensure the ontology accurately represents the knowledge in the specific domain.
6. Evaluation: Assess the ontology's fitness for purpose and its ability to answer the defined competency questions. Solicit feedback from stakeholders and make necessary refinements.
7. Integration: Integrate the developed ontology with other existing ontologies or external resources. Ensure alignment and interoperability with related ontologies.
8. Documentation and Training: Document the ontology, its purpose, structure, and usage guidelines. Provide training materials to facilitate understanding and use.
9. Maintenance and Evolution: Establish mechanisms for ongoing maintenance and evolution of the ontology. Monitor changes in the domain and update the ontology accordingly.

The NeOn technique stresses the value of teamwork and communication in the creation of ontologies. The technique incorporates a variety of stakeholders who collaborate to develop and maintain the ontology, including domain experts, ontology engineers, and end users. To keep the ontology current and useful over time, the technique also contains a set of rules for ontology review and maintenance. Ultimately, the NeOn methodology offers a systematic technique for developing ontologies that place a focus on communication and cooperation. By using the technique, it is possible to make sure that the ontology is precise, thorough, and fits the demands of its users.

4.2.3 Uschold and King method

A methodology for ontology development that was proposed by [103]. The Uschold methodology is one of the earliest ontology development methodologies and has been widely used in the field of knowledge representation. The Uschold methodology involves a systematic approach to ontology development that emphasizes the use of a variety of knowledge acquisition techniques, such as interviews, surveys, and literature reviews. The methodology is designed to be flexible and adaptable, allowing it to be used in a wide range of domains and applications. The Uschold methodology consists of several phases:

1. Identify the Purpose: Clearly articulate the purpose and objectives of the ontology. Understand the specific goals the ontology aims to achieve.
2. Define the Scope: Determine the scope of the ontology by identifying the domain it will cover. Clearly outline the boundaries and limitations of the ontology.
3. Gather Knowledge: Conduct knowledge acquisition to collect information about the domain. Use various methods, such as interviews and literature reviews, to understand key concepts and relationships.
4. Enumerate Terms: Identify and enumerate the terms and concepts relevant to the ontology. Develop a comprehensive list of terms that represent the domain.
5. Define Term Relationships: Specify relationships and connections between the identified terms. Determine how terms are related and the nature of these relationships.
6. Organize into a Taxonomy: Organize the enumerated terms into a hierarchical taxonomy. Establish a clear structure that reflects the relationships between concepts.
7. Define Attributes: Identify and define attributes or properties associated with each term. Specify characteristics that describe instances of each concept.
8. Create Definitions: Develop clear and concise definitions for each term. Ensure a shared understanding of the meaning of each concept.
9. Verification and Validation: Verify the ontology by consulting with domain experts and stakeholders. Validate the ontology against real-world scenarios and requirements.
10. Documentation: Document the ontology, including its purpose, scope, taxonomy, and definitions. Provide guidelines for usage and maintenance.

For the ontology to be complete and accurate, the Uschold methodology highlights the significance of employing a range of information-gathering methodologies. To keep the ontology current and useful over time, the technique also contains a set of rules for ontology review and maintenance. In general, the Uschold technique offers a systematic way for developing ontologies that may be used in a variety of domains and applications. The technique has been widely applied and has shown to be successful in many circumstances while being relatively simple in comparison to more modern ontology creation methodologies.

4.2.4 The Ontology Development 101 Method

Ontology Development 101 is a methodology for ontology development that provides a step-by-step guide to creating an ontology. The methodology was proposed by (Noy & McGuinness, 2001) Thomas R. Gruber, a computer scientist who is known for his work on ontologies and the Semantic Web. Ontology Development 101 consists of ten steps:

1. Define the Scope: Clearly articulate the scope and purpose of the ontology. Identify the key concepts and relationships that the ontology will represent.
2. Enumerate Important Terms: List and define the terms relevant to the ontology. Capture essential concepts and ensure a shared understanding among stakeholders.
3. Define Relationships: Identify and specify relationships between different concepts. Establish the connections and dependencies within the ontology.
4. Define Attributes: Determine relevant attributes or properties of the identified concepts. Specify characteristics that describe the instances of each concept.
5. Define Datatypes: If necessary, specify datatypes for attributes with specific data formats. Ensure consistency and clarity in representing data.
6. Create Hierarchies: Organize concepts into hierarchies or taxonomies based on their relationships. Establish a clear structure for the ontology.

7. Formalize in a Language (e.g., OWL): Choose a formal language for ontology representation, such as OWL (Web Ontology Language). Translate the conceptual model into a formal syntax.
8. Evaluate and Refine: Assess the ontology for completeness, coherence, and consistency. Seek feedback from domain experts and refine the ontology accordingly.
9. Documentation: Document the ontology, including its purpose, structure, and usage guidelines. Provide clear explanations for each concept and relationship.
10. Maintenance and Evolution: Establish procedures for maintaining and updating the ontology. Monitor changes in the domain and make necessary adjustments.

Overall, Ontology Development 101 provides a simple approach to ontology development. It is designed to be accessible to non-experts and can be used in a wide range of domains and applications. However, it may not be suitable for more complex ontologies or for applications that require a more formal approach to ontology development.

4.2.5 Upper Merged Ontology (SUMO) method

The Suggested Upper Merged Ontology (SUMO) is a general-purpose ontology that was developed by Pease et al. [105] as a foundational ontology for the Semantic Web. It is a comprehensive ontology that includes a wide range of concepts and relationships that can be used as a basis for developing other ontologies. The **SUMO** methodology consists of several phases:

1. Define Purpose and Scope: Clearly articulate the purpose of the ontology and the specific domain it will cover. Establish the scope and boundaries of the ontology.
2. Enumerate Top-Level Categories: Identify and enumerate the top-level categories or classes that will serve as the foundational elements of the ontology. These top-level categories should be broad and cover major aspects of the domain.
3. Specify Relationships: Define relationships between the top-level categories. Establish a network of relationships to capture the connections between different classes.
4. Identify Instances: Enumerate instances or examples within each category. Provide concrete examples to illustrate the concepts represented by the ontology.
5. Create Definitions: Develop clear and precise definitions for each category and instance. Ensure a shared understanding of the meaning of terms within the ontology.
6. Select Formal Language (e.g., KIF, OWL): Choose a formal language for ontology representation, such as the Knowledge Interchange Format (KIF) or OWL. Represent the ontology in the selected language to enable machine reasoning.
7. Integration with Existing Ontologies: Integrate the developed ontology with existing ontologies or external resources. Ensure alignment and interoperability with related ontologies.
8. Verification and Validation: Verify the ontology's accuracy and completeness through consultation with domain experts and stakeholders. Validate the ontology against real-world scenarios and requirements.
9. Documentation: Document the ontology, including its purpose, structure, and usage guidelines. Provide comprehensive documentation to facilitate understanding and usage.

10. Maintenance and Evolution: Establish procedures for maintaining and updating the ontology. Monitor changes in the domain and update the ontology accordingly.

The SUMO ontology is designed to be a high-level ontology that can be used as a common language for sharing knowledge across different domains and applications. It includes a rich set of concepts, such as time, space, causation, and events, and a comprehensive set of relationships, such as part-whole relationships, temporal relationships, and causal relationships. The ontology is designed to be flexible and extensible, allowing new concepts and relationships to be added as needed.

The SUMO ontology is based on a formal ontology language called KIF (Knowledge Interchange Format). KIF is a logic-based language that allows for the formal representation of concepts, relationships, and logical axioms. The SUMO ontology includes a large number of logical axioms, which define the relationships between concepts and allow for reasoning and inference. The SUMO ontology has been used in a wide range of applications, including natural language processing, information retrieval, and knowledge management. It has been used as a basis for developing other ontologies, such as the General Formal Ontology (GFO) and the Basic Formal Ontology (BFO). One of the strengths of the SUMO ontology is its comprehensiveness and flexibility.

The ontology includes a wide range of concepts and relationships, which makes it suitable for a wide range of applications. Additionally, the ontology is extensible, allowing new concepts and relationships to be added as needed. However, one potential weakness of the SUMO ontology is its size and complexity. The ontology includes a large number of concepts and relationships, which can make it difficult to use and maintain. Additionally, the ontology may not be suitable for all applications, as it may be too high-level or too detailed for some domains. Overall, the SUMO ontology is a comprehensive and flexible ontology that has been widely used in a variety of applications. Its strengths include its comprehensiveness and flexibility, while its potential weaknesses include its size and complexity.

4.3 Selecting the ontology development methodology

Selecting the ontology development methodology depends on various factors, including the specific requirements of the project, the complexity of the domain, and the preferences of the development team. Each methodology has its strengths, and the choice should align with the goals of the ontology project. Here are some considerations:

1. Methontology: Strengths: Emphasizes a systematic approach, diverse knowledge acquisition techniques, and guidelines for evaluation and maintenance. Consider for: Projects where a structured development process and ongoing maintenance are critical.
2. NeOn Methodology: Strengths: Promotes collaboration, considers social and organizational factors, and involves stakeholders throughout the development process. Consider for: Projects with a strong emphasis on community involvement and where social aspects are integral to ontology development.
3. Ontology Development 101: Strengths: Simple and clear step-by-step approach, suitable for newcomers to ontology development. Consider for: Projects where simplicity and ease of understanding are essential, especially for those new to ontology development.

4. Uschold and King Method: Strengths: Focuses on defining terms and concepts clearly and systematically. Consider for: Projects where a clear conceptual model and well-defined terms are a priority.
5. SUMO Method: Strengths: Aims for a comprehensive and unified representation of knowledge, suitable for a broad range of applications. Consider for: Projects requiring a broad and detailed ontology with a strong emphasis on integration.

4.4 Selected Methodology

Methontology is a strong candidate for creating an E-government ontology for services offered to citizens by the Ministry of Interior for many reasons below:

1. Systematic Approach: Methontology emphasizes a systematic approach to ontology development. This is particularly beneficial for E-government applications where a structured and well-defined process is crucial for representing complex relationships and interactions within government services.
 2. Knowledge Acquisition Techniques: The use of diverse knowledge acquisition techniques, such as brainstorming, interviews, and literature review, aligns well with the need to capture a wide range of information related to government services. This ensures a comprehensive understanding of the domain.
 3. Guidelines for Evaluation and Maintenance: Methontology includes guidelines for ontology evaluation and maintenance. In an E-government context, where services and regulations may evolve, having a methodology that supports continuous assessment and updating is essential to keep the ontology accurate and relevant over time.
 4. Up-to-date and Accurate Ontology: The emphasis on maintenance within Methontology helps ensure that the E-government ontology remains up-to-date. This is crucial for reflecting changes in policies, services, and procedures within the Ministry of Interior.
 5. Flexibility for Stakeholder Involvement: Methontology allows for the involvement of stakeholders through techniques like interviews. In the context of E-government, where collaboration with government officials, citizens, and other stakeholders is vital, this flexibility is beneficial for gathering diverse perspectives.
 6. Comprehensive Conceptualization: The methodology's emphasis on a variety of knowledge acquisition techniques contributes to a comprehensive conceptualization of government services. This is valuable for capturing intricate relationships and dependencies in the E-government domain.
- Structured Ontology Development: Methontology provides a structured and well-defined process for ontology development. This is particularly advantageous when dealing with the complexity of E-government services, ensuring a clear representation of concepts and relationships.

Upon reviewing the pertinent literature mentioned in a previous chapter of this thesis, and taking into account the previously mentioned reasons for the methodology, we have concluded to adopt the "Methontology" methodology for ontology development. Our assessment has uncovered that this particular method exhibits remarkable efficacy in the creation of ontologies, offering a well-structured platform for methodical and systematic planning and implementation. Furthermore, we have noted its extensive adoption and utilization within the realm of ontology development, rendering it a highly appropriate selection to effectively and sustainably fulfil our objectives and adhere to project specifications. The utilization of the

"Methontology" methodology is expected to streamline our ontology development process, ensuring a robust and comprehensive approach towards achieving our research goals.

4.5 Research Design

This study utilized a qualitative research design with a case study approach to develop and validate an ontology intended to enhance E-government services. The choice of case study methodology facilitated an in-depth examination of the ontology's application within authentic government contexts, specifically within the Ministry of Interior's public service centers. This approach targeted the prevalent issue of data integration deficiencies.

Multiple case studies conducted within these complexes served as distinct experiments to evaluate the ontology's impact on data interoperability across various government departments. This method proved particularly effective in answering the research question: "How can the application of ontology improve data integration and service delivery in E-government systems?" Implementations in diverse governmental environments provided valuable insights into the ontology's adaptability and effectiveness in overcoming integration challenges.

Additionally, the research design enabled a thorough investigation of contextual factors affecting the success of ontology applications in public administration, directly addressing core challenges in E-government infrastructure.

Interviews were conducted with the director of the Information Technology Center at the Khartoum Public Services Complex to gather insights into the quality of services provided. These interviews helped define the full range of services available to citizens, essential for developing and designing the ontology.

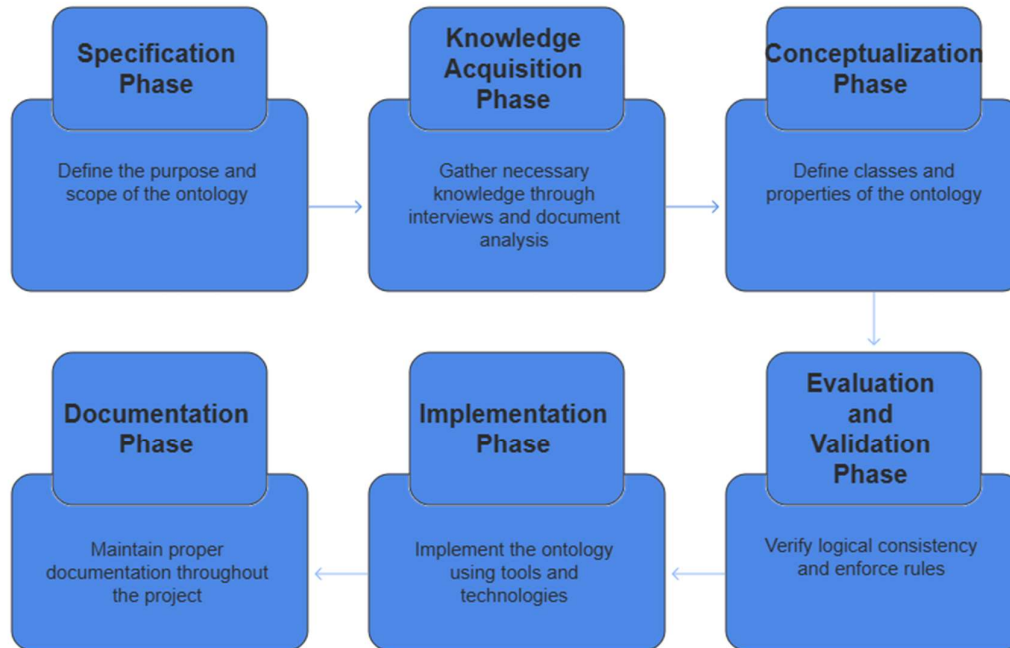
Government documents were analyzed to collect critical information on the structure of ontology development, including classification hierarchies and associated characteristics. This information was vital for the ontology's construction.

To verify the ontology's validity and its alignment with the research objectives, actual data were collected from the public via a specifically designed questionnaire. This questionnaire not only emphasized the study's importance for improving E-government services but also requested participants to submit official documents such as national IDs and passports. These documents were used as inputs to test the proposed ontology.

4.6 Ontology Development Process

Following the adoption of the Methontology methodology as the guiding framework for ontology development, the study will immediately proceed with the first phase: Specification. This phase aims to define the purpose and scope of the ontology within Sudan's E-government context by identifying key entities, relevant service domains, and expected outcomes to ensure the model is aligned with the operational needs of public institutions and citizens alike. Figure 4.1 illustrates the sequential phases of the Methontology methodology adopted in this study.

Ontology Development Process



Made with Napkin

Figure 4.1 illustrates the sequential phases of the Methontology methodology adopted in this study

4.6.1 Specification

4.6.1.1 Defining Scope and Purpose

One of the pivotal services offered by the E-government through the Ministry of Interior revolved around the Civil Registry, which encompassed the issuance of crucial documents such as birth and death certificates, national identification numbers, and national cards. The transition from traditional paper-based processes to an electronic platform brought about significant improvements, ensuring enhanced accessibility and accuracy in record-keeping.

Another significant aspect of E-government services was the Passport and Immigration Department within the Ministry of Interior. This department played a pivotal role in facilitating citizens' international travel, ensuring a seamless and hassle-free experience. Through the utilization of electronic platforms, citizens were able to effortlessly obtain passports, while the issuance of entry and exit visas was streamlined, providing a more convenient and efficient experience for travellers.

In the domain of Criminal Evidence, E-government services proved to be particularly effective. Digitalization transformed the issuance of weapon licenses, as well as the verification of citizens' security status through comprehensive background checks and investigations. These digital processes significantly contributed to establishing a safer and more secure society.

Furthermore, the E-government initiatives also extended to Traffic Police services, a crucial component in ensuring citizen safety and mobility. The adoption of digital platforms resulted in streamlined processes for vehicle registration and the issuance of driving licenses. This transition not only enhanced efficiency but also significantly reduced bureaucratic hurdles, ultimately benefiting citizens.

In essence, the E-government services provided by the Ministry of Interior exemplified a strong commitment to harnessing technology for the betterment of citizens. Through the digitization of essential services such as the Civil Registry, Passports and Immigration, Criminal Evidence, and Traffic Police, the government ensured a more accessible, transparent, and citizen-centric approach to governance. This transformative journey reflected a steadfast dedication to modernization, ultimately empowering citizens and fostering a more interconnected and digitally driven society.

4.6.1.2 Identifying Stakeholders and Their Requirements

A meticulous and comprehensive identification of all the relevant stakeholders was of paramount importance to ensure the success and effectiveness of the ontology. The primary stakeholders in this context included not only the citizens who utilized these services, but also the government officials who were responsible for managing the systems, and the administrators who oversaw the ontology. The requirements, expectations, and concerns of these stakeholders were diligently assessed and evaluated to align the ontology with their specific needs and demands. This rigorous evaluation process ensured that the ontology was meticulously designed and developed to cater to the unique requirements of each stakeholder group.

4.6.1.3 Establishing Goals and Expected Outcomes

To establish a clear and well-defined trajectory for the ontology development process, explicit goals and expected outcomes had been carefully formulated and outlined. These goals served as the overarching guiding principles and objectives that the ontology aspired to achieve. They included enhancing accessibility and ease of use for citizens, streamlining service delivery processes, and ensuring utmost transparency in the provision of E-government services. The expected outcomes, on the other hand, revolved around the successful representation and integration of key concepts and entities within the ontology, such as Individuals, Assets, Services (such as Civil Registry, Passports, Criminal Evidence, and Traffic Police), and Service Providers. Additionally, a key outcome was the interoperability of E-government Services. This structured approach provided a foundation for developing an ontology that could effectively meet the identified needs and integrate seamlessly with existing systems.

4.6.1.4 Aligning with Government Initiatives

The seamless alignment and integration of the ontology's goals and expected outcomes with the broader government initiatives and strategies were of paramount importance. By closely aligning with existing E-government strategies, the ontology ensured cohesion and consistency with other government systems and initiatives. This alignment fostered interoperability and

synergy among different E-government systems, thereby enhancing the overall effectiveness and efficiency of the government's digital infrastructure. This strategic coherence not only streamlined operations but also facilitated smoother transitions and adaptability across various sectors involved in digital service delivery.

4.6.1.5 Documenting Initial Framework

A meticulously crafted and comprehensive preliminary document was developed to outline the initial framework and structure of the ontology. This document served as a foundational guide for the subsequent steps in the ontology development process. It included a concise yet detailed overview of the identified scope, stakeholders, goals, and expected outcomes of the ontology. This preliminary document laid the groundwork for the subsequent phases of the ontology development process, ensuring that all further steps were aligned with the initial vision and objectives of the ontology. Table 4.1 in the document illustrates the first documentation document, titled "Ontology Requirement Specification Document." This specification provided a structured and clear path forward, marking a critical first step in the methodical development of the ontology.

Table 4.1 Ontology requirement specification document

ONTOLOGY REQUIREMENT SPECIFICATION DOCUMENT

- **DOMAIN:** E-government Services
 - **DATE** 2/Feb/2024
 - **CONCEPTUALIZED BY:** Badraldeen Hassan Altahir
 - **IMPLEMENTED BY:** Badraldeen Hassan Altahir
 - **PURPOSE:** Enhancing accessibility, efficiency and transparency in delivering services.
 - **LEVEL OF FORMALITY:** Semi-Formal
 - **SCOPE:** Develop an ontology to represent E-government services of the Ministry of Interior for Citizens. This inclusive range encompasses services about the Civil Registry, Passports, Criminal Evidence, and Traffic Police.
 - **List of main resources:** Individuals, Assets, Services such as (Civil Registry, Passports, Criminal Evidence and Traffic Police) and Service providers.

 - **SOURCE OF KNOWLEDGE:** Officer from the Ministry of Interior
 - **STAKEHOLDERS:** The citizens, The government officials, The administrators
-

4.6.2 Knowledge Acquisition

4.6.2.1 Brainstorming Sessions

In the realm of knowledge acquisition, it was imperative to initiate brainstorming sessions involving key stakeholders, including esteemed government officials and diligent administrators from the Ministry of Interior. In these sessions, fostering an environment of open discussions was highly encouraged, which undoubtedly led to the extraction of invaluable insights into the intricate realm of E-government services, as well as the complexities associated with the Civil Registry, Passports, Criminal Evidence, and Traffic Police.

At this juncture, three brainstorming sessions were conducted with the director of the Khartoum Services Complex and the complex's engineers who were involved in the management and utilization of the Ministry of Interior's systems within the complex. These sessions resulted in a series of propositions, the most significant of which was the inclusion of the national

identification number as a point of reference for any document, excluding birth and death certificates, due to the potential unavailability of the deceased individual's national identification number. Additionally, it was proposed that the national identification number of a newborn be made available, as they had just been born and had not yet been assigned a national identification number.

One of the recommendations was also to associate the parents' national number rather than listing their names in written form, on the condition that the name could be derived from the national number in four segments, and additional fields, such as religion and blood type, could be included in the national number. This association would facilitate the processes of deduction and knowledge extraction from the ontology, thereby enhancing the quality of services offered to the public. Furthermore, it would assist employees and officials in carrying out their responsibilities with greater accuracy. The primary advantage of the Semantic Web and ontology, in general, lies in the creation of a methodology that enables applications to comprehend information. This capability allows for the development of intelligent applications capable of deducing and extracting knowledge from stored data. To ensure the practicality of this finding, a set of interconnections that link the E-government services provided by the Ministry of Interior with citizens through public service complexes was proposed.

4.6.2.2 interviews

To achieve a comprehensive understanding of the subject matter, structured interviews with the relevant officials within the Ministry of Interior were conducted. These interviews were pivotal in gathering first-hand information, which provided deeper insights into the specific processes, data structures, and requirements associated with each service. Furthermore, these discussions illuminated the workflows and highlighted potential challenges that might arise within the domain, thereby aiding in the meticulous planning and execution of the ontology development.

During this phase, numerous meetings were conducted with the accountable engineering officers from the Information Technology Department at the Khartoum Public Services Complex, some of which took place online. During these meetings, the fundamental details of each service that the Ministry of Interior offers to citizens through the Public Services Complexes were examined. Additionally, the compatibility and integration of data among the various departments of the Ministry using the proposed ontology were deliberated. Furthermore, the potential expansion of this ontology in the future to encompass the services provided by the ministry to foreigners, as well as those offered to public and private institutions, was explored.

4.6.2.3 Document and File Analysis

In addition to brainstorming sessions and interviews, **document analysis** played a foundational role in shaping the conceptual structure of the proposed ontology. This phase involved a systematic review of various official documents, both in paper-based and digital formats, currently used by the Ministry of Interior across its different departments. The documents analyzed included core civil registry and security-related materials such as:

- National ID application forms
- Birth and death certificates
- Passport issuance records
- Driver's license and vehicle registration certificates
- Firearm license applications
- Security clearance and background check forms

This analysis was critical for **identifying the main and sub-categories of services**, as well as understanding the **attributes and relationships** that link different entities in a way that accurately reflects real-world government practices. For instance, the presence of repeated patterns in personal information fields across these documents enabled the abstraction of shared properties such as `hasNationalID`, `requiresDocument`, and `processedByDepartment`.

Furthermore, the document review provided the basis for modeling **logical constraints and dependencies**. For example, the national number emerged as a unifying identifier across most services, except in cases where it is unavailable (e.g., newborns or the deceased). These real-world constraints were later reflected in the ontology's rules and class structures.

By grounding the ontology in actual administrative forms and procedures, the study ensured that the resulting semantic model would not only be technically sound but also **practically aligned** with how services are managed, verified, and interconnected within the Ministry of Interior.

4.6.2.4 Identification of Concepts and Relationships

Building upon the inputs gathered from the brainstorming sessions and interviews, it became paramount to identify key concepts that were highly pertinent to the ontology at hand. Concepts such as Individual, Services, Service Provider, and Assets were identified as foundational for the creation of an initial conceptual model. Furthermore, establishing relationships between these concepts was of utmost importance as it contributed to the coherence and comprehensiveness of the model.

Having completed all the preceding phases, we reached a point where we had formulated the various services rendered by the Ministry via the public complexes. These services were systematically categorized based on the respective departments accountable for their provision. The categorization was organized as follows:

The Ministry of Interior is a government department responsible for maintaining law and order, ensuring public safety, and providing administrative services related to the civil registry, passports, criminal evidence, and traffic police. This structured approach not only facilitated a clearer understanding of the ministry's roles and responsibilities but also streamlined the development and integration of the ontology, ensuring that it effectively met the needs and expectations outlined in the initial stages of the project.

4.6.2.4.1 Civil Registry

The Civil Registry Department handles:

Civil status Matters, including the issuance of birth certificates to record the birth of individuals within the country or outside. These certificates serve as official documents for identification and proof of age. And the issuance of death Certificates which document the death of

individuals within the Country or outside. These certificates are essential for legal and administrative purposes, such as inheritance and estate matters.

National Number, the ministry is Responsible for issuing national Identification Numbers to citizens. National Identification Numbers serve as a means of identification and proof of Citizenship, allowing individuals to access various government Services and assert their rights as Citizens. These National Identification Numbers contain personal information, including the individual's name, photograph, date of birth and unique identification number. National Identification Numbers are often required for various official transactions and services.

National Card, the National Card refers to the national Identity card issued by the Ministry. It typically contains Personal information such as Name, date of birth, and a Unique identification number, and serves as an official identification document for citizens. This card is used to establish one's identity and citizenship within the country.

4.6.2.4.2 Passport

The Ministry is responsible for issuing passports to citizens, which are essential for International travel. Passports serve as Proof of citizenship and identity, facilitating entry into foreign countries and ensuring the protection and assistance of Citizens abroad. The Ministry ensures that Passport issuance Follows International Standards and Regulations.

4.6.2.4.3 Criminal Evidence

Background Check, the ministry Conducts Background Checks on Individuals for Security purposes, Such as Employment Screenings or visa Applications. These checks Involve verifying Personal Information, Educational Qualifications, Employment History, and Criminal records to assess an Individual's Suitability or Potential risks.

Weapons Licenses, the Ministry issues Licenses to Individuals who Meet specific Criteria and Legal Requirements for the possession and carrying of Weapons. These Licenses help Regulate firearms and ensure that Individuals who Possess weapons Do so lawfully and responsibly.

4.6.2.4.4 Traffic Police

Driving Licenses, the ministry issues driving licenses to individuals who have completed the necessary tests and requirements for operating motor vehicles. Driving licenses serve as legal permits, allowing individuals to drive on public roads and ensuring their competency in adhering to traffic rules and regulations.

Vehicle Licensing, Vehicle Registration: The Ministry handles the registration and licensing of Vehicles, ensuring That they meet Safety standards and comply with Legal Requirements. Vehicle Registration Involves Documenting Ownership, assigning License Plates, and issuing Registration documents, allowing vehicles to operate legally on public roads.

4.6.3 Conceptualization

4.6.3.1 Formalize acquired knowledge into a conceptual model

Conceptualization involves the formalization of the knowledge that has been acquired. This process entailed translating the acquired knowledge into a formalized conceptual model, a critical step in ontology development. To initiate this process, we identified the foundational

concepts on which the ontology would be based, after progressing through the initial stage of definition and the subsequent stage of knowledge collection using various techniques.

The basic concepts on which the ontology was built are outlined as follows:

1. **Individuals:** This concept represented the people to whom services were provided by the Ministry of Interior through public complexes. While the initial focus of the ontology was on services provided to citizens, it included provisions for extending coverage to foreigners in the future to facilitate integration with other ontologies.
2. **Services:** This concept encompassed the various administrative and legal services provided by the Ministry to citizens through public service complexes. Examples included the issuance of birth and death certificates, national numbers, and national identification cards, among other services.
3. **Profile:** This concept contained many specific values that served as relationship links between other concepts. It included detailed personal information such as medical records, blood type, and other relevant data.

4. **Service Providers:** This concept represented the centres that offered the aforementioned services to citizens. These centers included public service complexes across various states and cities, as well as specialized centers entrusted with specific tasks such as handling national numbers, birth and death certificates, or vehicle licensing and registration.

5. **Assets and Property:** This concept encompassed all tangible assets that a citizen might own, such as vehicles of all types and weapons. The Ministry of Interior provided related services, including vehicle registration and weapons license issuance.

These identified concepts served as the building blocks for the ontology and were crucial for establishing a coherent and comprehensive conceptual model. The next steps involved defining the relationships between these concepts, ensuring they were robust and reflective of the real-world interactions and dependencies between the data elements. This structured approach not only facilitated a clearer understanding of the domain but also enhanced the functionality and utility of the ontology in practical applications.

4.6.3.2 Define Classes

The ontology included various classes and subclasses to represent different entities and concepts related to E-government services offered by the Ministry of Interior. At the top level, there was the class "Asset," which encompassed valuable items or properties. Under "Asset," there were subclasses such as "Weapon" and "Vehicle." "Weapon" further subdivided into "WeaponType," specifying the type of weapon. Similarly, "Vehicle" broke down into "VehicleType" and "VehicleUsage," indicating the type and purpose of the vehicle, respectively.

Another top-level class was "Individual," which represented people or entities. Subclasses under "Individual" included "Citizen" and "Foreigner," distinguishing between nationals and non-nationals.

The class "Service" encompassed the various services provided by the Ministry of Interior. Subclasses under "Service" included "CivilRegistry," "Passport," "CriminalEvidence," and "TrafficPolice," each representing a specific service area. For instance, "CivilRegistry" further subdivided into "CivilStatus," which included "BirthCertificate" and "DeathCertificate."

"Passport" included subclasses such as "PassportType," "NationalNumber," and "NationalCard." Similarly, "TrafficPolice" subclasses included "DrivingLicense" with its subclass "DrivingLicenseType" and "VehicleRegistration."

Finally, the "Profile" class included personal attributes such as marital status, gender, blood group, service provider, nationality, occupation, religion, and place of birth, each represented as a separate subclass for detailed characterization. This structured classification system enabled a nuanced representation of all facets related to the services and entities managed by the Ministry of Interior, facilitating clearer communication and more efficient service provision.

Figure 4.2 provides a detailed depiction of the classes and subclasses for the ontology developed for the E-government services offered by the Ministry of Interior.

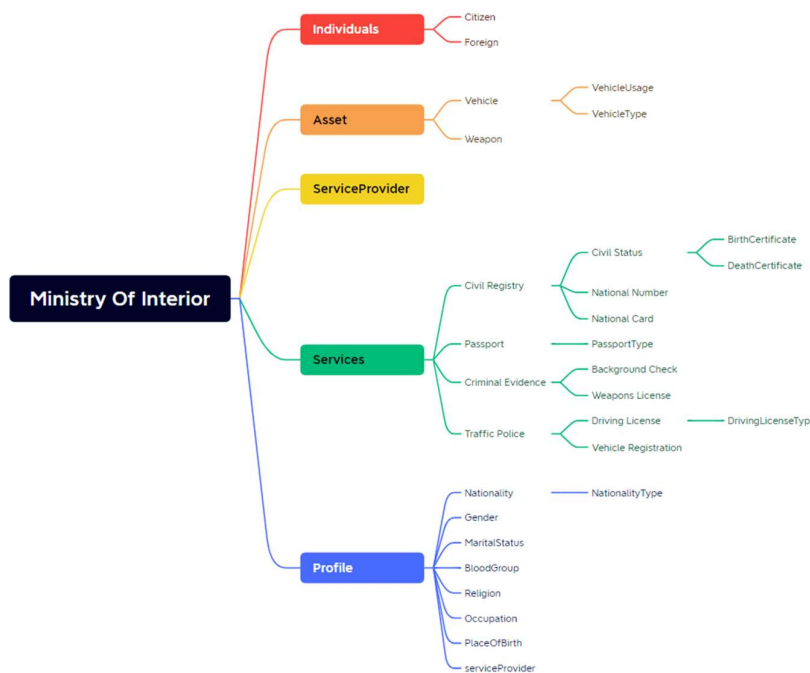


Figure 4.2 shows Classes and Sub Classes for Ontology in the Conceptualization phase

4.6.3.3 Define Properties

In addition to defining the primary classes, it was important to specify the properties associated with each class. This involved defining the characteristics or attributes that were relevant to each class.

BirthCertificate Class

The "BirthCertificate" class was responsible for encapsulating official documents that serve as legal proof of an individual's birth. It encompassed a comprehensive set of properties to capture essential information related to the certificate. These properties included the certification number, registry state, locality, page number, registry number in the register, date of birth, child's name, parent's names, residence, issue date, and details of the issuing officer and authority. By utilizing the "BirthCertificate" class, one could effectively manage and store the

diverse details associated with a birth certificate, facilitating accurate and reliable record-keeping within an application or system.

DeathCertificate Class

The "DeathCertificate" class was meticulously crafted to represent official documents serving as legal proof of an individual's death. It comprised a spectrum of properties aimed at capturing crucial information pertaining to the certificate. These properties encompassed the certification number, registry state, locality, page number, registry number in the register, date of death, deceased individual's name, place of death, residence, age, cause of death, issue date, and details of the issuing officer. Leveraging the "DeathCertificate" class enabled effective management and storage of the diverse details associated with a death certificate, thereby facilitating accurate and reliable record-keeping within an application or system.

NationalNumber Class

The "NationalNumber" class served as a representation of national identification numbers or cards, encapsulating various properties to capture important information related to the identification document. These properties included a photo, biometric data, citizenship ID key, issue date, full name, date of birth, mother's name, employer, and details of the issuing officer. Leveraging the "NationalNumber" class enabled effective management and storage of the diverse details associated with national identification, facilitating accurate identification and record-keeping within an application or system.

NationalCard Class

The "NationalCard" class was specifically crafted to represent national identification cards, comprising a set of properties aimed at capturing essential information associated with the identification card. These properties encompassed the card number, key, residence, issue date, expiry date, photo, biometric data, and details of the issuing officer. Leveraging the "NationalCard" class allowed for effective management and storage of the pertinent details of national identification cards, enabling accurate identification and facilitating record-keeping within an application or system.

Passport Class

The "Passport" class was meticulously designed to represent passports issued for international travel, encompassing a comprehensive range of properties aimed at capturing essential information associated with the passport. These properties included the passport number, key, photo, biometric data, holder's signature, issue date, and expiry date. Leveraging the "Passport" class enabled effective management and storage of the pertinent details of passports, facilitating seamless identification during international travel and enabling accurate record-keeping within an application or system.

BackgroundCheck Class

The "BackgroundCheck" class served as a comprehensive representation of assessments conducted to evaluate an individual's background, incorporating factors such as criminal history and security clearance. It encompassed a diverse range of properties, including the check number, key, check date, biometric data, photo, check type, check result, check reason, check details, issuing authority, and valid from and until dates. These properties collectively

provided a detailed and comprehensive overview of the background check, facilitating a thorough understanding of the individual's background and assessment results.

WeaponLicense Class

The "WeaponLicense" class was meticulously crafted to represent licenses issued for the legal possession of weapons, encompassing a comprehensive set of properties aimed at capturing crucial information associated with the license. These properties included the license number, key, photo, issue date, expiry date, residence, weapon type, weapon number, weapon tag, biometric data, and details of the issuing authority. Leveraging the "WeaponLicense" class enabled effective management and storage of the relevant details of weapon licenses, facilitating proper documentation and regulation of legal weapon possession within an application or system.

DrivingLicense Class

The "DrivingLicense" class served as a comprehensive representation of licenses issued for legal driving privileges, encompassing a variety of properties that captured important information about the license. These properties included the license number, key, photo, residence, phone number, issue date, expiry date, details of the issuing authority, disability status, and vision disability status. Leveraging the "DrivingLicense" class enabled effective management and storage of the relevant details of driving licenses, facilitating proper documentation and regulation of driving privileges within an application or system.

VehicleRegistration Class

The "VehicleRegistration" class was meticulously designed to represent documents certifying the registration of vehicles, encompassing a comprehensive set of properties capturing important information related to the registration. These properties included license number, key, residence, license plate number, vehicle brand, model, color, manufacture date, engine number, chassis number, fuel type, insurance details, ownership restrictions, validity dates, and details of the issuing authority. Leveraging the "VehicleRegistration" class enabled effective management and storage of pertinent details related to vehicle registration, facilitating accurate documentation and regulation within an application or system.

The following Table 4.2 shows the characteristics of each class, indicating the range and identifying what any of the characteristics are.

Table 4.2 explains the characteristics of each class and indicates the range

Class (Domain)	Property	Description	Range (data type)
BirthCertificate	hasCertificationNumber	A unique certification number is assigned to the birth certificate.	xsd: string
	hasRegistryState	State where the birth certificate is registered.	xsd: string
	hasRegistryLocality	Locality or region where the birth is registered.	xsd: string
	hasRegistryPageNumber	The page number within the birth registry book.	xsd:string

	hasRegistryNumberInRegister	The number assigned to the birth certificate within the registry.	xsd:string
	hasDateOfBirthLetters	Letters representing the date of birth.	xsd:string
	hasDateOfBirth	Date of birth of the individual.	xsd: date
	hasChildName	Name of the child as per the birth certificate.	xsd:string
	hasFatherFullName	Full name of the father as per the birth certificate.	xsd:string
	hasFatherResidence	Residence of the father at the time of birth registration.	xsd:string
	hasMotherFullName	Full name of the mother as per the birth certificate.	xsd:string
	hasMotherResidence	Residence of the mother at the time of birth registration.	xsd:string
	hasIssueDate	Date when the birth certificate was issued.	xsd: date
	hasOfficerFullName	Full name of the issuing officer.	xsd:string
	hasOfficeRank	Rank or position of the issuing officer.	xsd:string
	hasOfficerSignature	A digital or physical signature of the issuing officer.	xsd: byte
	hasIssueAuthority	Authority is responsible for issuing the birth certificate.	xsd:byte
DeathCertificate	hasCertifaceNumber	A unique certification number is assigned to the death certificate.	xsd:string
	hasRegistryState	State where the death certificate is registered.	xsd:string
	hasRegistryLocality	Locality or region where the death is registered.	xsd:string
	hasRegistryPageNumber	The page number within the death registry book.	xsd:string
	hasRegistryNumberInRegister	The number assigned to the death certificate within the registry.	xsd:string
	hasDateOfDeath	Date of death of the individual.	xsd:date
	hasDeceasedName	Name of the deceased as per the death certificate.	xsd:string
	hasPlaceOfDeath	Place where the individual passed away.	xsd:string
	hasResidence	Residence of the deceased at the time of death registration.	xsd:string
	hasAge	Age of the deceased at the time of death.	xsd:string
	hasCauseOfDeath	Cause of death as stated in the death certificate.	xsd:string
	hasIssueDate	Date when the death certificate was issued.	xsd:date
	hasOfficerRank	Rank or position of the issuing officer.	xsd:string
	hasOfficerName	Full name of the issuing officer.	xsd:string

	hasOfficerSignature	Digital or physical signature of the issuing officer.	xsd:byte
NationalNumber	hasPhoto	Photograph of the individual.	xsd:byte
	hasBiometricData	Biometric data of the individual.	xsd:byte
	hasCitizenshipID	Unique citizenship identification number.	xsd:string
	hasIssueDate	Date when the national number was issued.	xsd:date
	hasFullName	Full name of the individual.	xsd:string
	hasDateOfBirth	Date of birth of the individual.	xsd:date
	hasMotherFullName	Full name of the mother.	xsd:string
	hasEmployer	Employer of the individual.	xsd:string
	hasOfficerName	Full name of the issuing officer.	xsd:string
	hasOfficerRank	Rank or position of the issuing officer.	xsd:string
	hasOfficerSignature	Digital or physical signature of the issuing officer.	xsd:byte
NationalCard	hasCardNumber	Unique identification number assigned to the national card.	xsd:string
	hasResidence	Residence address of the cardholder.	xsd:string
	hasIssueDate	Date when the national card was issued.	xsd:date
	hasExpiryDate	Expiry date of the national card.	xsd:date
	hasPhoto	Photograph of the cardholder.	xsd:byte
	hasBiometricData	Biometric data of the cardholder.	xsd:byte
	hasOfficerName	Full name of the issuing officer.	xsd:string
	hasOfficerRank	Rank or position of the issuing officer.	xsd:string
	hasOfficerSignature	Digital or physical signature of the issuing officer.	xsd:byte
Passport	hasPassportNumber	Unique identification number assigned to the passport.	xsd:string
	hasPhoto	Photograph of the passport holder.	xsd:byte
	hasBiometricData	Biometric data of the passport holder.	xsd:byte
	hasHolderSignature	Signature of the passport holder.	xsd:byte
	hasIssueDate	Date when the passport was issued.	xsd:date
	hasExpiryDate	Expiry date of the passport.	xsd:date
BackgroundCheck	hasCheckNumber	Unique identification number assigned to the background check.	xsd:string
	hasCheckDate	Date when the background check was conducted.	xsd:date
	hasBiometricData	Biometric data used for the background check.	xsd:byte
	hasPhoto	Photograph of the individual used for the background check.	xsd:byte
	hasCheckType	Type of background check conducted (e.g., criminal history, security clearance).	xsd:string

	hasCheckResult	Result of the background check (e.g., clear, pending, flagged).	xsd:string
	hasCheckReason	Reason for conducting the background check (e.g., employment, security clearance).	xsd:string
	hasCheckDetails	Detailed information about the background check process, criteria, and findings.	xsd:string
	hasIssuingAuthority	Authority responsible for conducting the background check.	xsd:byte
	hasValidFrom	Start date of the validity period of the background check.	xsd:date
	hasValidUntil	End date of the validity period of the background check.	xsd:date
WeaponLicense	hasLicenseNumber	Unique identification number assigned to the weapon license.	xsd:string
	hasPhoto	Photograph of the license holder.	xsd:byte
	hasIssueDate	Date when the weapon license was issued.	xsd:date
	hasExpiryDate	The expiry date of the weapon license.	xsd: date
	hasResidence	Residence address of the license holder.	xsd:string
	hasWeaponGunshotType	Type of weapon or gunshot covered by the license (e.g., handgun, rifle).	xsd:string
	hasWeaponNumber	Unique identification number assigned to the weapon.	xsd:string
	hasWeaponTag	Tag or label associated with the weapon.	xsd:string
	hasBiometricData	Biometric data of the license holder.	xsd:byte
	hasIssueAuthority	The authority is responsible for issuing the weapon license.	xsd:byte
DrivingLicense	hasLicenseNumber	Unique identification number assigned to the driving license.	xsd:string
	hasPhoto	Photograph of the license holder.	xsd:byte
	hasResidence	Residence address of the license holder.	xsd:string
	hasPhone	Contact phone number of the license holder.	xsd:string
	hasIssueDate	Date when the driving license was issued.	xsd:date
	hasIssueExpiry	Expiry date of the driving license.	xsd:date
	hasIssueAuthority	Authority responsible for issuing the driving license.	xsd:byte
	hasDisability	Indicates whether the license holder has a disability (yes/no).	xsd:boolean
	hasVisionDisability	Indicates whether the license holder has a vision disability (yes/no).	xsd:boolean

VehicleRegistration	hasLicenseNumber	Unique identification number assigned to the vehicle registration.	xsd:string
	hasResidence	Residence address of the vehicle owner.	xsd:string
	hasLicensePlate	Unique identification number assigned to the license plate.	xsd:string
	hasBrand	Brand or manufacturer of the vehicle.	xsd:string
	hasModel	Model of the vehicle.	xsd:string
	hasColor	Color of the vehicle.	xsd:string
	hasManufactureDate	Date when the vehicle was manufactured.	xsd:string
	hasEngineNumber	Unique identification number assigned to the vehicle's engine.	xsd:string
	hasChassisNumber	Unique identification number assigned to the vehicle's chassis.	xsd:string
	hasFuelType	Type of fuel used by the vehicle.	xsd:string
	hasInsuranceNumber	Unique identification number assigned to the vehicle's insurance.	xsd:string
	hasInsuranceName	Name of the insurance company providing coverage for the vehicle.	xsd:string
	hasOwnershipRestrictions	Restrictions or limitations on the vehicle ownership.	xsd:string
	hasValidity	Indicates if the vehicle registration is valid or expired.	xsd:string
	hasIssueDate	Date when the vehicle registration was issued.	xsd:date
	hasExpiryDate	Date when the vehicle registration will expire.	xsd:date

4.6.3.4 Define Relationship

To accurately model the interactions within the system, it was necessary to establish relationships between different classes. This involved specifying the connections and dependencies that exist between entities.

The "**BirthCertificate**" class established relationships with several other classes to capture relevant information. It included a property called "**hasGender**", which had a range of the "**Gender**" class, indicating the gender of the individual. Additionally, it related to the father's and mother's religion, nationality, and national number through properties such as "**hasFatherReligion**," "**hasFatherNationality**," "**hasFatherNationalNumber**," "**hasMotherNationality**," and "**hasMotherNationalNumber**." Furthermore, it was associated with the place of birth through the property "**hasPlaceOfBirth**."

In the "**DeathCertificate**" class, there were relationships with various other classes. It might have had a "**hasNationalNumber**" property indicating the deceased individual's national number, with a range of the "**NationalNumber**" class. It also had relationships with nationality, religion, gender, occupation, marital status, and place of birth through properties

such as **"hasNationality," "hasReligion," "hasGender," "hasOccupation," "hasMaritalStatus,"** and **"hasPlaceOfBirth."**

The **"NationalNumber"** class was associated with the **"ServiceProvider"** class through the property **"hasIssuePlace."** It also had relationships with the mother's and father's national numbers, marital status, gender, nationality, type, occupation, blood group, and place of birth. Similarly, the **"NationalCard"** class had a relationship with the **"NationalNumber"** class through the property **"hasNationalNumber."** It also related to the issuing place through the property **"hasIssuePlace."**

The **"Passport"** class had a relationship with the **"NationalNumber"** class through the property **"hasNationalNumber,"** and with the **"PassportType"** class through **"hasPassportType."** It also related to the issuing place through **"hasIssuePlace."**

The **"BackgroundCheck"** class was associated with the **"NationalNumber"** class, **"ServiceProvider"** class, and **"Nationality"** class through properties like **"hasNationalNumber," "hasIssuePlace,"** and **"hasNationality."**

The **"WeaponLicense"** class had relationships with the **"NationalNumber"** class, **"ServiceProvider"** class, and **"WeaponType"** class through properties like **"hasOwnerNationalNumber," "hasIssuePlace,"** and **"hasWeaponType."**

The **"DrivingLicense"** class had relationships with the **"NationalNumber"** class, **"LicenseType"** class, and **"ServiceProvider"** class through properties like **"hasNationalNumber," "hasLicenseType,"** and **"hasIssuePlace."**

The **"VehicleRegistration"** class had relationships with the **"NationalNumber"** class, **"VehicleUsage"** class, and **"ServiceProvider"** class through properties like **"hasOwnerNationalNumber," "hasVehicleUsage,"** and **"hasIssuePlace."**

The **"Weapon"** class was associated with the **"WeaponLicense"** class and the **"Citizen"** class through properties like **"hasWeaponLicense"** and **"hasOwner."**

The **"Vehicle"** class had a relationship with the **"VehicleRegistration"** class and the **"Citizen"** class through properties like **"hasVehicleRegistration"** and **"hasOwner."**

Finally, the **"Citizen"** class had relationships with various other classes such as **"BirthCertificate," "DeathCertificate," "NationalNumber," "NationalCard," "Passport," "BackgroundCheck," "DrivingLicense," "Vehicle,"** and **"Weapon"** through properties like **"hasBirthCertificate," "hasDeathCertificate," "hasNationalNumber," "hasNationalCard," "hasPassport," "hasBackgroundCheck," "hasDrivingLicense," "hasVehicle."**

The following table 4.3 shows the relationships that link the classes to each other, clarifying the domain, range, and relationship type. This structural detailing ensures a comprehensive understanding and accurate modelling of the interconnected data within the ontology.

Table 4.3 outlines the relationships between different classes, indicating the domain, range, and nature of the relationship. Adjustments can be made based on the specifics of your model and the properties you've defined.

Relationship	Domain	Range	Description
hasGender	BirthCertificate	Gender	Indicates the gender of the individual

hasFatherReligion	BirthCertificate	Religion	Specifies the religion of the father
hasFatherNationality	BirthCertificate	Nationality	Denotes the nationality of the father
hasFatherNationalNumber	BirthCertificate	NationalNumber	Links to the national number of the father
hasMotherReligion	BirthCertificate	Religion	Specifies the religion of the mother
hasMotherNationality	BirthCertificate	Nationality	Denotes the nationality of the mother
hasMotherNationalNumber	BirthCertificate	NationalNumber	Links to the national number of the mother
hasPlaceOfBirth	BirthCertificate	PlaceOfBirth	Specifies the place where the individual was born
hasNationalNumber	DeathCertificate	NationalNumber	Associates with the national number of the deceased individual
hasNationality	DeathCertificate	Nationality	Denotes the nationality of the deceased individual
hasReligion	DeathCertificate	Religion	Specifies the religion of the deceased individual
hasGender	DeathCertificate	Gender	Indicates the gender of the deceased individual
hasOccupation	DeathCertificate	Occupation	Specifies the occupation of the deceased individual
hasMaritalStatus	DeathCertificate	MaritalStatus	Indicates the marital status of the deceased individual
hasPlaceOfBirth	DeathCertificate	PlaceOfBirth	Specifies the place where the deceased individual was born
hasNationalNumber	NationalCard	NationalNumber	Links to the national number of the individual
hasIssuePlace	NationalCard	ServiceProvider	Denotes the place where the national card was issued
hasNationalNumber	Passport	NationalNumber	Links to the national number of the passport holder
hasPassportType	Passport	PassportType	Indicates the type of passport held by the individual
hasIssuePlace	Passport	ServiceProvider	Denotes the place where the passport was issued
hasOwnerNationalNumber	WeaponLicense	NationalNumber	Links to the national number of the weapon license owner
hasIssuePlace	WeaponLicense	ServiceProvider	Denotes the place where the weapon license was issued
hasNationalNumber	DrivingLicense	NationalNumber	Links to the national number of the driving license holder
hasLicenseType	DrivingLicense	LicenseType	Indicates the type of license held by the individual
hasIssuePlace	DrivingLicense	ServiceProvider	Denotes the place where the driving license was issued
hasOwnerNationalNumber	VehicleRegistration	NationalNumber	Links to the national number of the vehicle registration owner
hasVehicleUsage	VehicleRegistration	VehicleUsage	Specifies the usage type of the registered vehicle
hasIssuePlace	VehicleRegistration	ServiceProvider	Denotes the place where the vehicle registration was issued
hasVehicleRegistration	Vehicle	VehicleRegistration	Associates with the vehicle registration of the vehicle
hasOwner	Vehicle	Citizen	Links to the owner of the vehicle
hasBirthCertificate	Citizen	BirthCertificate	Specifies the birth certificate of the citizen
hasDeathCertificate	Citizen	DeathCertificate	Associates with the death certificate of the citizen
hasNationalNumber	Citizen	NationalNumber	Links to the national number of the citizen
hasNationalCard	Citizen	NationalCard	Specifies the national card of the citizen
hasPassport	Citizen	Passport	Associates with the passport of the citizen
hasBackgroundCheck	Citizen	BackgroundCheck	Specifies the background check of the citizen
hasDrivingLicense	Citizen	DrivingLicense	Associates with the driving license of the citizen
hasVehicle	Citizen	Vehicle	Links to the vehicle owned by the citizen

hasWeapon	Citizen	Weapon	Associates with the weapon owned by the citizen
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4.6.4 Integration

4.6.4.1 Compatibility Assessment

In the initial phase of integration, it was crucial to thoroughly assess the compatibility of the conceptual model with existing ontologies or standards pertinent to E-government services. This evaluation entailed a meticulous examination of how well the ontology seamlessly aligned with broader frameworks and its capacity to coexist harmoniously with established data structures. By ensuring smooth alignment, the ontology could effectively integrate with existing systems and facilitate the interoperability of data exchange.

Given the absence of prior ontologies in the Sudanese E-government, the ontology devised for the Ministry of Interior served as the inaugural ontology for the Sudanese E-government. To facilitate potential integration with future ontologies, all utilized categories were presented in a manner that enabled tracking and linking with categories of forthcoming ontologies. This was particularly crucial as the Ministry of Interior, specifically its services offered to citizens through public service complexes, served as the gateway to E-government. This proactive approach aimed at setting a foundational standard that would not only streamline current services but also accommodate future expansions and enhancements in the realm of digital governance.

4.6.4.2 Interoperability Considerations

It became imperative to assess the level of integration between the conceptual model and external resources and databases. This evaluation involved analyzing the ontology's interoperability to facilitate seamless and efficient data exchange among various systems within the Ministry of Interior and potentially with other governmental entities. By meticulously examining interoperability, it was feasible to identify any potential obstacles or challenges that might impede the smooth exchange of information.

The primary objective of designing this ontology was to achieve interoperability and system integration. This was crucial as the Semantic Web necessitates innovative, centralized integration of systems, enabling the ministry to maintain its information and internal sources while potentially providing this information to requesting parties within the E-government framework, subject to administrative delineations of authority. This strategic focus ensured that the ontology not only supported the current operational requirements but also positioned the Ministry of Interior to adapt to evolving technological landscapes and collaboration needs within the broader government context.

4.6.5 Implementation

4.6.5.1.1 Ontology Language Selection

Selecting an appropriate ontology language was crucial for effectively implementing the conceptual model. For E-government services, OWL (Web Ontology Language) often emerged as the preferred choice due to its expressive capabilities and ability to represent complex relationships and entities within the model. This choice ensured that the language accurately captured the intricacies of the model, facilitating its effective implementation.

OWL provided the necessary tools to define and instantiate classes, properties, and their instances, which are key components of any ontology structure. The language's robustness allowed for the representation of rich and complex knowledge about categories and types, relationships between them, and cardinality. Using OWL also made it possible to leverage reasoning tools to check the consistency of the ontology or to infer new information based on the existing data. This capability was particularly beneficial in the dynamic and multifaceted environment of E-government services, where accurate data representation and timely information retrieval were critical.

Overall, the decision to utilize OWL in the development of the ontology for the Ministry of Interior's E-government services supported the goal of creating a scalable, interoperable, and robust system. This choice not only addressed the immediate needs of the ministry but also provided a solid foundation for future enhancements and integration with other systems.

4.6.5.2 Formal Representation

Once OWL had been selected as the ontology language, it was essential to utilize it to formally represent the conceptual model. This involved translating conceptual entities, classes, properties, and relationships into a machine-readable format. This facilitation was crucial for seamless integration into the implementation process, enabling efficient utilization within the E-government services of the Ministry of Interior.

The translation process required meticulous attention to detail to ensure that every aspect of the conceptual model was accurately captured in the ontology. Classes were defined to represent all entities such as individuals, services, and assets. Properties were then created to specify the attributes of these classes, and relationships were established to define how these classes interacted with each other.

Using OWL allowed for the expression of complex logical constructs necessary for E-government systems, such as the conditional relationships and constraints between different government services and entities. For instance, the relationships between citizens and their legal documents—such as passports, driving licenses, and birth certificates—were modelled to reflect real-world interactions.

Additionally, this formal representation was crucial in ensuring that the ontology could be easily integrated with existing data systems within the Ministry of Interior, facilitating data interoperability and consistency. The machine-readable format also enabled the use of automated reasoning tools that could infer new knowledge or check for inconsistencies within the data, thereby enhancing the reliability and efficiency of the E-government services offered. Overall, the use of OWL to formalize the conceptual model was a critical step in developing a robust and interoperable ontology that could effectively support the digital transformation initiatives of the Ministry of Interior.

4.6.5.3 Tool Selection

Selecting appropriate tools and frameworks designed for ontology development was crucial to streamline the process. Tools like Protégé offered user-friendly interfaces for creating, editing, and visualizing ontologies. Leveraging such tools enabled developers to navigate the complexities of ontology development effectively, ensuring adherence to the conceptual model's specifications.

Protégé, developed at Stanford University, is a free, open-source ontology editor and framework that has been widely used in the ontology development community. Its graphical user interface allowed developers to construct and manage complex ontologies in a more intuitive and accessible manner. The tool supported various ontology languages including OWL, making it an ideal choice for the project at hand.

Using Protégé, classes, subclasses, properties, and relationships that directly correspond to the elements defined in the conceptual model are defined. The ability to visualize these elements graphically helped maintain a clear overview of the presence structure, which is especially useful in large, complex presence management such as those typically found in E-government systems.

Moreover, Protégé's plug-in architecture allowed for the extension of its capabilities to include reasoning tools, which could automatically check for inconsistencies or infer additional information from the data defined in the ontology. This feature was invaluable in ensuring that the ontology not only met the design specifications but also remained logically coherent.

The choice of using Protégé and similar ontology development tools thus played a significant role in the successful implementation of the ontology for the Ministry of Interior's E-government services, ensuring that the system was robust, effective, and aligned with the established conceptual model.

4.6.5.4 Ontology Development

With the necessary tools selected, ontology development commenced. This involved populating the ontology with classes, properties, and relationships as defined in the conceptual model. Adhering meticulously to the model's specifications ensured that the ontology accurately represented the E-government services of the Ministry of Interior, facilitating effective implementation and utilization.

Utilizing Protégé, ontology development began by adding main categories and defining their hierarchy as per the conceptual modelling. Subsequently, subcategories were added within these main categories. The resulting categories and their hierarchy are depicted in Figure 4.2. In this process, each main category was first defined as a class in Protégé. For instance, categories such as "Individual," "Service," "Asset," and "Document" were established as top-level classes reflecting the major elements of the E-government system. Within these classes, more specific subcategories or subclasses, such as "Citizen," "Foreigner" under "Individual," or "Birth Certificate," "Passport" under "Document," were then created to reflect the more detailed aspects of the services provided.

Each subclass was meticulously defined, with properties (also known as attributes or predicates in ontological terms) that described the characteristics relevant to that subclass. For example, the "Birth Certificate" class might have included properties such as "hasDateOfIssue" or "hasPlaceOfBirth." Relationships between classes were also established to show how entities

interact within the system, such as a "Citizen" having a "Passport" or an "Asset" being owned by an "Individual."

By leveraging Protégé's graphical tools, the developers were able to visualize the ontology's structure as it was built, ensuring that the hierarchy was logically organized and conformed to the conceptual model's requirements. This visualization was critical in providing a clear, understandable representation of complex relationships and dependencies within the ontology, which could be referenced in Figure 4.3.

This methodical approach to ontology development not only streamlined the creation of a comprehensive and coherent ontology but also facilitated subsequent phases of implementation, testing, and maintenance. By closely aligning the ontology with the conceptual model and the real-world processes it intended to encapsulate, the Ministry of Interior was better positioned to leverage this ontology to enhance the effectiveness and efficiency of its E-government services.

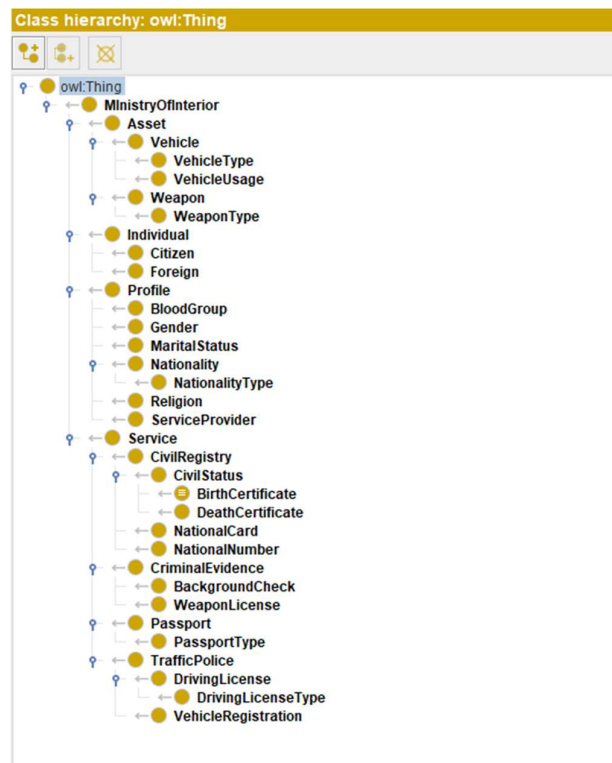


Figure 4.3 shows the classes and their hierarchy using Protégé

Following the establishment of category hierarchy, ontology development progresses to linking these categories using the identified relationships from the conceptual modelling stages. These relationships play a crucial role in inferring valuable information for various E-government applications. Figure 4.4 illustrates the relationships between classes using a proxy.

After establishing category relationships, the next step involved adding properties. These properties linked categories with textual or numerical values based on the accompanying data type. Figure 4.5 displays the properties added to the E-government ontology, specifically

detailing the services provided by the Ministry of Interior through public service complexes. Additionally, a hierarchical class of the ontology from Protégé is shown in Figure 4.6.



Figure 4.4 shows the relationships between the categories

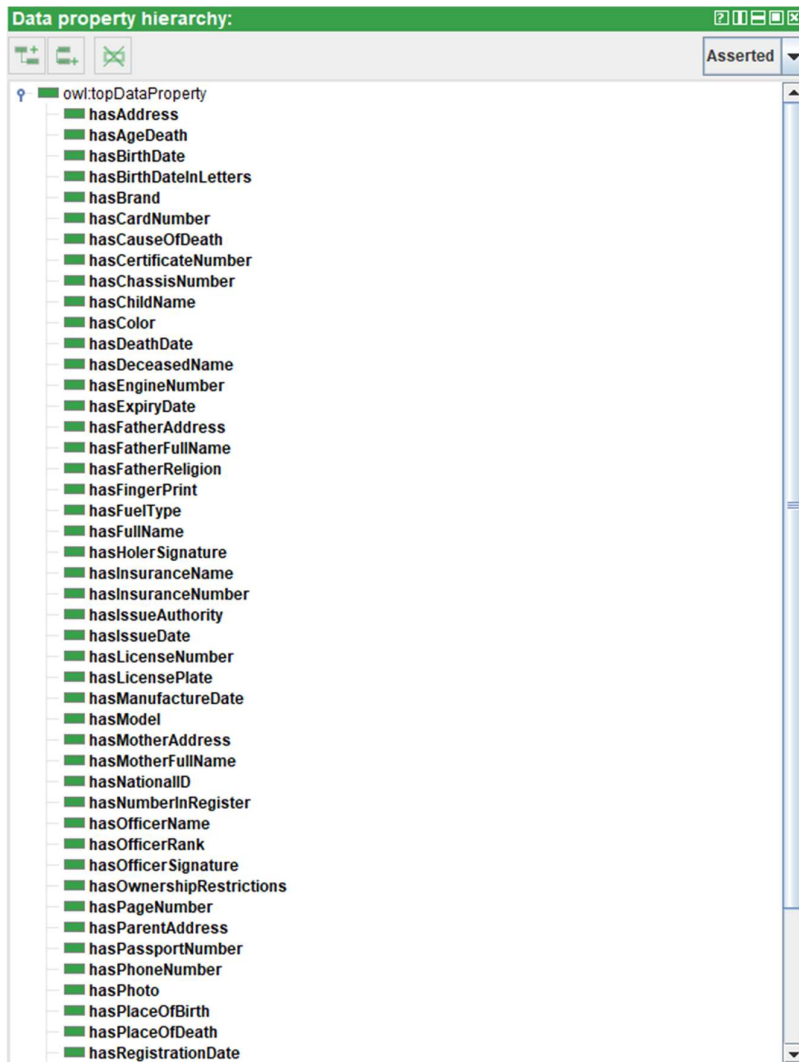


Figure 4.5 shows the properties that link the categories

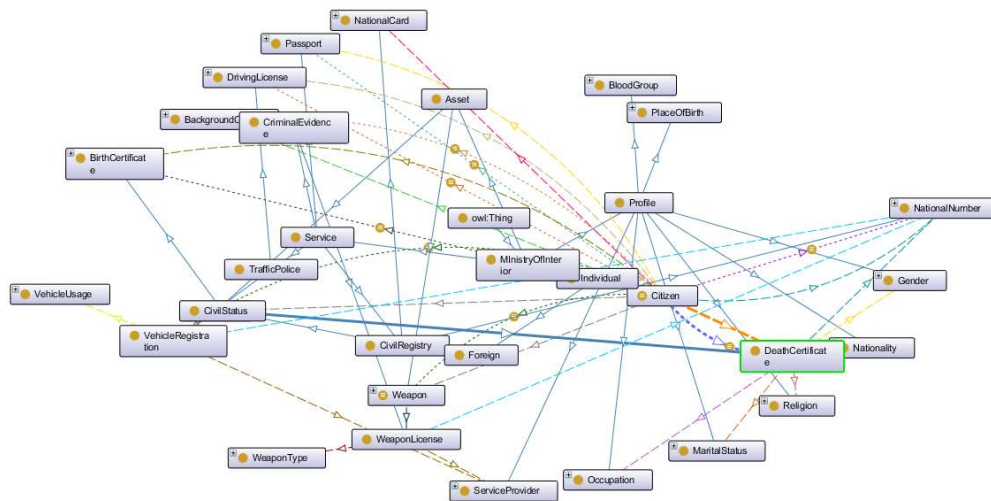


Figure 4.6 Hierarchical class of ontology from Protégé

4.6.5 Quality Assurance

The verification of the accuracy and coherence of classifications and their corresponding attributes was meticulously carried out to guarantee data integrity. Unnecessary and duplicate information that did not contribute to the ontology's structure or purpose was meticulously identified and eliminated, thereby optimizing the organization and structure of the ontology. Moreover, certain attributes underwent modifications to establish connections and associations within the realm of what is referred to as the Object Data Type. This specific alteration was implemented to simplify the recognition and understanding of relationships and interactions among various elements present in the ontology, ultimately resulting in an improved level of efficiency and accuracy in data representation and analysis. The meticulous removal of redundant data and the fine-tuning of properties not only enhanced the overall quality of the ontology but also contributed to its robustness and reliability as a comprehensive representation of knowledge. Furthermore, by refining and organizing the ontology in this manner, the process effectively enhanced the ontology's capability to capture and represent complex relationships and dependencies between different elements, thereby enriching the overall precision and utility of the ontology. In essence, the steps taken in this phase not only ensured the integrity and coherence of the ontology but also significantly elevated its effectiveness and reliability as a valuable knowledge representation tool.

4.6.6 Evaluation

In this stage, the developed ontology underwent a comprehensive and iterative evaluation process to ensure completeness, logical consistency, semantic accuracy, and alignment with both domain-specific requirements and international standards. The evaluation aimed to verify whether all classes, properties, and relationships had been appropriately defined to support interoperability and service integration within Sudan's E-government context.

The quality assessment was conducted by engineering officers from the Khartoum Public Service Complex, who assessed the class hierarchies, property definitions, and alignment with the structural and functional needs of public services. Particular focus was given to the integration of the national identification number as a central linking property across all government service domains.

The validation process employed advanced reasoners such as HerMiT and Pellet, integrated within the Protégé platform. These tools enabled rigorous testing of inference capabilities across classes, object properties, and data properties. The evaluation was conducted in multiple cycles:

- During the first round, logical inconsistencies were detected, particularly involving class definitions and undeclared properties. These issues were systematically resolved by refining class hierarchies and clarifying ambiguous relationships.
- In the second round, semantic constraints were added to better reflect real-world logic. Notably, the property `hasNationalID` was assigned a functional property constraint, ensuring that each national ID corresponds to exactly one citizen. Additionally, an inverse functional property was applied to guarantee that each citizen has one and only one national ID—ensuring bidirectional uniqueness and eliminating redundancy.
- In subsequent cycles, further constraints were integrated, including cardinality restrictions, disjoint class axioms, and custom SWRL rules (e.g., "A service cannot be delivered unless all required documents are provided"). Each revision contributed to improved semantic precision and real-world validity.

To verify the ontology's effectiveness, competency questions were formulated and tested using SPARQL queries. These queries allowed for targeted retrieval of individuals and relationships, and were instrumental in evaluating the ontology's ability to respond accurately and contextually to domain-specific inquiries. This approach ensured the coverage, coherence, and inference accuracy of the ontology across services such as Civil Registration, Passports, Traffic, and Firearm Licensing.

Moreover, the ontology adopted Uniform Resource Identifiers (URIs) to maintain uniqueness across classes and individuals. These URIs served as standardized global references, enabling seamless linking with external ontologies and facilitating interoperability across ministries and government platforms. This practice aligned with Semantic Web principles and enhanced the ontology's extensibility and scalability.

After several iterations of testing, correction, and reasoning, a fully consistent and domain-aligned ontology was achieved. It accurately models the relationships, rules, and workflows of Sudan's Ministry of Interior services, providing a robust semantic foundation for intelligent E-government applications.

4.6.7 Documentation

Through the series of preceding actions, we successfully generated a comprehensive deliverable serving as detailed documentation about the ontology in question. This deliverable encompasses the ontology requirement specification document delineated in Table 4.1, providing a thorough overview of the requirements. Additionally, the deliverable includes Figure 4.2, which visually represents the hierarchical structure of the classes utilized in the

construction of this ontology. Furthermore, Table 4.2 presents a detailed breakdown of the properties associated with each class, accompanied by a concise definition of these properties and an outline of the specific data types required for each. Finally, Table 4.3 illustrates the intricate relationships that interconnect the various classes within the ontology, highlighting the connections that exist between them.

4.7 Summary

In summary, the methodology chapter provided a comprehensive and effective solution for creating an ontology for E-government services provided by the Ministry of Interior in Sudan. By comparing various ontology development methodologies, the analysis identified the Methontology approach as the most suitable due to its comprehensive framework, which includes detailed steps from specification to documentation and maintenance.

The Methontology methodology was chosen for its systematic and organized approach to knowledge acquisition and conceptualization, as well as its emphasis on continuous updating of the ontology. This methodology ensures that the ontology remains relevant and useful over time, even as E-government services become more complex and dynamic. The application of Methontology was clearly outlined in the chapter, encompassing phases such as defining the project's scope, gathering and conceptualizing knowledge, integrating with existing systems, implementing using specific tools (OWL and Protégé), and thoroughly evaluating the ontology's performance.

This chapter highlighted the critical role that stakeholder involvement plays in the development of an ontology. By engaging government officials, citizens, and administrators at different stages of the project, the ontology was able to accurately reflect the needs of its users and improve the accessibility and efficiency of E-government services.

The ontology was designed to improve service delivery by the Ministry of Interior and enhance the overall efficiency and transparency of E-government services by addressing integration issues. It served as a foundational model that not only met current needs but also allowed for future growth, potentially integrating with other government services and broader E-government initiatives.

Ultimately, this chapter not only provided a solid foundation for developing a presence in the E-government field, but also established a precedent for future endeavors, emphasizing the importance of a systematic approach, stakeholder engagement, and continuous evaluation and maintenance to adapt to changing requirements. The successful implementation of this presence is expected to significantly enhance the quality and accessibility of services provided by the Ministry of Interior, representing a significant milestone in the digital transformation of government services in Sudan and addressing the data integration challenges that Sudan's E-government has faced.

Discussion

5.1 introduction

In the methodology section, the development of an E-government ontology to enhance the services offered by the Ministry of Interior via public service complexes was explored in depth. The methodology selected for this endeavor was Methontology [101], which is recognized for its systematic approach to ontology creation, comprising various stages from specification to the generation of a comprehensive ontology.

The Ministry of Interior has a crucial function in furnishing vital services to citizens using public service complexes, which serve as the entry point to E-government initiatives. To improve the efficiency, accessibility, and interoperability of these services, it was necessary to develop a comprehensive ontology. The methodology offered a structured guideline to direct this process, guaranteeing that the ontology accurately represented the domain knowledge and fulfilled the intended objectives.

Beginning with the specification phase, the objectives, scope, and requirements of the ontology were identified. This included delineating the domain of the ontology and outlining the goals and expected outcomes. Subsequently, the knowledge acquisition phase involved gathering information through various techniques such as brainstorming, interviews, and literature reviews to identify relevant concepts, relationships, and instances within the domain.

The conceptualization phase entailed creating a conceptual model of the ontology, defining the concepts and relationships to be used, and establishing a hierarchy that reflected their interrelationships. Following this, the integration phase involved combining the conceptual model with existing ontologies or external resources, ensuring compatibility and consistency with related frameworks.

The implementation phase translated the conceptual model into a formal ontology language, such as OWL, and developed the ontology using Protégé tools and frameworks. This was followed by the evaluation phase, where the ontology's quality was assessed against predefined criteria to ensure completeness, consistency, and accuracy.

In the discussion chapter, the quality of the ontology that was produced in previous chapters will be ensured, testing the input and processing processes, and making the necessary modifications after testing to arrive at an error-free ontology that works efficiently to improve E-government service applications and solve the problem of interoperability and data integration between different E-government systems.

At the outset of this thesis, the main problem addressed was the lack of integration, data sharing, and interoperability among various E-government units. The proposed solution for this

study was to utilize semantic web technologies and ontology to address the challenge of data integration and interoperation of E-government systems.

Now, in this chapter, the ontology will be operationalized by providing it with the necessary data and testing it to ensure its effectiveness and capability to solve the study's problem, which is represented by the interoperation of E-government systems and data integration.

5.2 Ontology Testing Objective

The primary objective of ontology testing in this study is to ensure the semantic precision, logical consistency, and intelligent responsiveness of the developed model in supporting smart E-government services. Beyond validating data retrieval accuracy and resolving issues of data integration and interoperability within the Ministry of Interior, the testing also aims to evaluate the ontology's ability to enable semantic inference, support context-aware service personalization, and maintain rule-based logic enforcement across dynamic public service workflows.

The evaluation involved feeding structured data into the ontology and performing a detailed inspection of its conceptual soundness, including the appropriateness of its hierarchical class organization, property assignments, and domain-range definitions. Special focus was placed on ensuring that attributes—whether object properties or data properties—were not only syntactically correct but also aligned with real-world service logic. The ontology's scalability was further tested by simulating its extension to other ministries, thereby examining its capacity to function as a modular, reusable framework for broader government interoperability.

Ultimately, the testing process was designed to confirm that the ontology could serve as a core semantic infrastructure capable of supporting adaptive, citizen-centric, and intelligent government service delivery.

5.3 Sample selection

Various methods for collecting ontology samples include leveraging databases [106], utilizing public data sources [107], collaborating with domain experts [108], employing machine learning techniques [109], and conducting questionnaires or interviews [110]. Each method differs in quality, cost, and time efficiency. Leveraging databases [106] provides the advantage of accessing a wide range of data, contributing to the diversity of samples collected for the ontology. Public data sources [107] offer a rich reservoir of information spanning multiple domains, enhancing the comprehensiveness of the ontology. Collaboration with domain experts [108] ensures the acquisition of high-quality data through their specialized knowledge and insights, thereby enriching the ontology's content and accuracy. Employing machine learning techniques [109] facilitates automated data collection and analysis, streamlining the process and improving efficiency. Questionnaires and interviews [110] directly solicit the required data from experts or stakeholders, offering a personalized and targeted approach to sample collection.

5.3.1 Data Collection Tool

Data was collected using a structured online questionnaire developed via Google Forms. The form was designed to gather subjective user feedback and objective official documents through multiple-choice, yes/no questions, and file-upload fields. This tool served a dual purpose: (1) collecting real user data, and (2) testing the ontology developed in the previous chapter using the Methontology framework.

5.3.2 Target Population

The survey was distributed to a purposefully selected group of Sudanese citizens who possessed valid digital or scanned versions of their official documents. Given the sensitivity of the information requested, the sampling strategy was deliberately limited and targeted to individuals with access to the following documents issued by the Ministry of Interior through public service complexes:

- Birth Certificate
- Death Certificate
- National Number Document
- National ID Card
- Passport
- Driver's License
- Firearm License
- Vehicle Registration Certificate
- Criminal Record (Security Clearance)

Participants were mostly citizens who had either lost or needed to reissue their documents due to displacement caused by the April 2023 conflict or other crises.

5.3.3 Purpose of the Survey

Unlike typical user satisfaction studies, the primary aim of this survey was to collect real-world document data for use in testing a government document ontology. The ontology was designed to model the semantic structure and interrelationships among civil documents using semantic web technologies. These data-driven insights were critical for validating the practical relevance of the proposed ontology under real-world scenarios.

5.3.4 Duration and Response Rate

The data collection process spanned over three months, beginning in February 2024 and concluding in May 2024. A total of 150 participants were initially targeted, out of which 138 valid and complete responses were received, resulting in a response rate of 92%. Chart 5.1 visually illustrates the distribution of documents across different classes within the ontology, providing a detailed graphical representation.

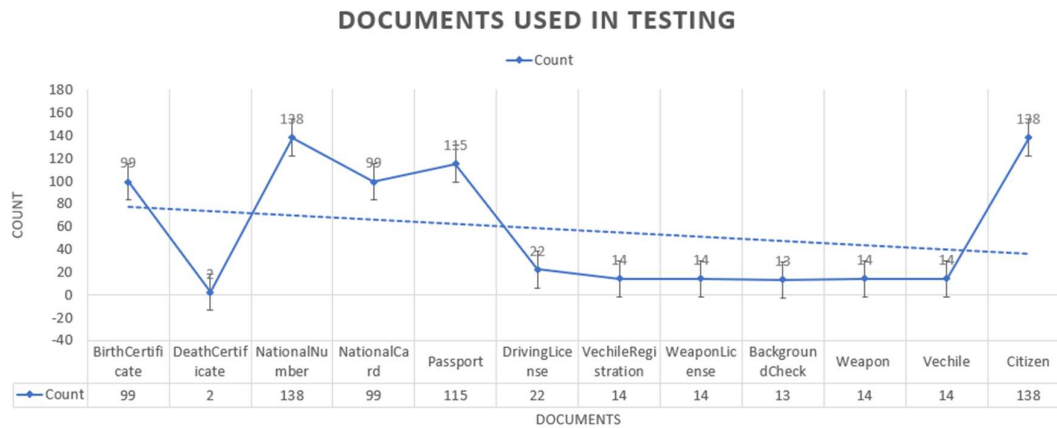


Chart 5.1 Documents using in test count

Determining the appropriate number of samples for ontology testing involves considering factors like ontology size, concept diversity, and future uses. Guidelines include ensuring good diversity, sufficient sample size, cost and time considerations, alignment with testing objectives, and leveraging prior testing experience [111] [112]. There is no universal number of samples; selection should be tailored to individual circumstances and testing needs. The process should encompass a variety of concepts and relationships, adequately represent different ontology aspects, align with available resources, and serve the testing purpose effectively [113] [114]. Relying on experience in ontology testing can aid in determining the optimal number of samples for comprehensive and effective testing.

Given the challenge associated with procuring a greater quantity of official documentation from individuals, the adequacy of the collected sample for testing purposes was determined to be sufficient, as it encompassed a diverse range (given that the sample was representative of all entries in the ontology). The assortment of samples obtained comprised of a variety of documents such as birth certificates, death certificates, national identification numbers, national identity cards, passports, driver's licenses, vehicle registrations, firearms licenses, security clearances, firearms, vehicles, and individuals. Consequently, the samples encompassed all the primary categories within the ontology.

5.4 Data Cleaning and Preprocessing

Due to the complexity and sensitivity of the dataset—particularly involving document uploads—rigorous data cleaning procedures were followed in alignment with established best practices in empirical research:

5.4.1 Completeness Checks

- Each response was manually verified to ensure it contained at least one essential document (the National Number document was mandatory).
- Partially filled responses were retained only if the uploaded data were analyzable.

5.4.2 File Integrity and Format Validation

- Uploaded file formats were checked for compliance (e.g., PDF, JPG, PNG).

- Files with invalid names or extensions were renamed or flagged for correction.

5.4.3 Duplicate Detection

- Duplicate submissions were detected based on national number values or matching metadata (e.g., name, place of birth).
- In such cases, only the most complete version was retained.

5.5 Data Overview and Descriptive Statistics

A summary of key questions from the questionnaire is provided in Table 5.1:

Table 5.1 – Selected Survey Responses Summary

Question	Response Option	Frequency	Percentage
Participation Consent	Yes	138	100%
Prior Use of E-Gov Portal	Yes	41	29.4%
Satisfaction with E-Gov Services	Yes	73	52.9%

A breakdown of document uploads is shown in Table 5.2:

Table 5.2 – Document Upload Counts

Document Type	Uploaded Files
National Number Document	138
Birth Certificate	99
Death Certificate	2
National ID Card	99
Passport	116
Driver’s License	22
Firearm License	14
Vehicle Registration	14
Security Clearance	13

5.6 Visualizations

Pie charts summarizing user participation, platform usage, and satisfaction are included in **Appendix A**, based on the form’s Google Analytics dashboard.

5.7 Data Availability

The complete dataset is stored as an Excel workbook with individual sheets for each document type and a consolidated metadata table. It is archived as **Appendix B** and is also available at:

 [*Google Drive Link – Dataset Folder*](#)

The survey successfully collected both structured responses and authentic civil documents, forming a robust dataset for testing the practical application of a government document

ontology. The rigor in sampling, validation, and privacy handling ensures the dataset's reliability for future semantic modeling experiments.

5.8 Testing Techniques Selection

Adequate testing methodologies were meticulously chosen from a variety of alternatives available, taking into account factors like operational testing and integrative testing. These methodologies were selected to assess the efficiency of the ontology in achieving the specified goals.

Within the operational testing phase, three separate tests were executed: input testing, processing testing, and output testing. The purpose of these tests was to guarantee the correct operation of the system at various phases. Input testing involved analyzing the system's response to different inputs to confirm its ability to accurately receive and interpret data.

Transitioning to the processing testing, an evaluation was made on how effectively the system managed and processed the inputs it received. This encompassed assessing its effectiveness, precision, and adherence to predefined regulations and algorithms. By examining the internal processes of the system, any possible errors or obstacles that could arise during data processing were identified.

Subsequently, during the output testing, an assessment was made of the system's capability to produce precise and significant outputs based on the processed data. This entailed confirming that the system delivered the intended outcomes and satisfied the expected standards and requirements.

Apart from the operational testing, integration testing was also carried out. This form of testing concentrated on examining the integration of data within the ontology. To guarantee that the ontology effectively tackled the challenges of data integration and interoperability, SPARQL, the ontology query language, was utilized. Through SPARQL queries, an evaluation was conducted on the ontology's ability to retrieve and manipulate data, confirming its role in addressing data integration and operational challenges.

Through conducting thorough operational and integration assessments, the functionality, efficiency, and effectiveness of the system were authenticated. This meticulous testing methodology facilitated the detection and resolution of any issues or deficiencies, ensuring the seamless integration of data and efficient operational performance within the ontology framework.

5.9 Test Execution

5.9.1 Operational Testing

5.9.1.1 Input Testing

This step detailed the testing of the ontology's ability to receive data from users and the implementation of a **bulk data import mechanism**. As outlined in the data processing section, the raw data was initially structured and converted into a digital format using Microsoft Excel to match the ontology's schema.

To facilitate this, the **Cellfie plugin** in Protégé was employed. Cellfie enables seamless conversion of spreadsheet data into RDF triples, allowing large datasets to be integrated into

the ontology in a single operation. This approach significantly streamlined the process of testing and populating the ontology with legacy civil records.

During the testing phase, a spreadsheet containing **over 2000 rows** of real-world document data was successfully ingested. The process was closely monitored to ensure that all entries aligned with the ontology's classes, properties, and constraints, ensuring semantic consistency and data integrity.

A comparative benchmark was conducted against the legacy system used prior to the ontology. The traditional system was capable of ingesting **100 citizen records in 0.35 seconds**. In contrast, the ontology-based system using Cellfie completed the same task in just **0.065 seconds**, representing an **81.4% improvement** in data ingestion efficiency.

This significant gain confirms the ontology's scalability and suitability for real-world government service environments where high-volume data entry and semantic structuring are crucial. Table 5.3 shows Data Entry Efficiency Comparison, and Figure 5.1 visually demonstrates the successful completion of the data entry process using the Cellfie plugin. This figure provided a clear illustration of the plugin's functionality and its ability to efficiently import data into the ontology.

Table 5.3– Data Entry Efficiency Comparison

System	Time per 100 Records (sec)	Improvement (%)
Traditional System	0.35	–
Ontology System (Cellfie)	0.065	81.4%

5.9.1.2 Processing Testing

To assess the functionality and inferencing power of the developed ontology, the built-in **reasoning engines** within Protégé—specifically **Pellet** and **HermiT**—were utilized. This methodology aligns with the foundational principles of ontology-driven systems, which are designed not only to represent data but to **infer new knowledge** through logical axioms and defined relationships.

In the designed ontology, a semantic object property named **"own"** was created to establish a direct relationship between a citizen and a property (e.g., vehicle, firearm). Correspondingly, an inverse property **"ownedBy"** was defined to automatically infer the owner of a given item based on the original assertion.

Using the real dataset, the reasoning engine was instructed to infer the **"ownedBy"** relationship for a specific individual. The engine successfully deduced the correct ownership relation based on the ontology's axioms. This result confirmed the ontology's ability to accurately infer **implicit knowledge** from explicit data.

To ensure accuracy, the inferred result was manually verified against the input values. The "ownedBy" relationship correctly reflected the citizen-property ownership, confirming both **logical consistency and inferential completeness** of the ontology.

In addition to functionality, **performance benchmarking** was conducted to compare **inference efficiency** between the traditional E-government system and the proposed ontology-based model. Table 5.4 shows **Comparative Reasoning Performance: Ontology vs Traditional System**

Table 5.4 Comparative Reasoning Performance: Ontology vs Traditional System

Aspect	Traditional System	Ontology-Based System
Inference Execution Method	External algorithm linking data from multiple databases	Built-in DL reasoner (Pellet/Hermit)
Reasoning Integration	Not embedded; requires preprocessing	Fully embedded within ontology engine
Avg. Time to Infer One Implicit Relation	0.52 seconds	0.12 seconds
Result Accuracy	Medium (subject to linkage errors)	High (reasoner logic-based)
Semantic Integrity	Not maintained across systems	Fully semantically consistent

This comparison reveals a **76.9% improvement in reasoning time** when using the ontology-based system. **Table 5.5 – Inference Performance Comparison**

Table 5.5– Inference Performance Comparison

System Type	Time to Infer One Relation (sec)	Accuracy	Semantic Integration	Improvement (%)
Traditional System	0.52	Medium	None (Manual Linking)	–
Ontology-Based System	0.12	High	Fully Semantic	76.9%

The results from both performance testing and manual validation confirm that the ontology is not only functional but also **efficient, scalable, and logically sound**. The integrated reasoners demonstrate the ability to infer relationships such as “ownedBy” without the need for external or manual intervention—offering a major advancement over the legacy data processing model used in E-government platforms.

Figure 5.2 illustrates the successful inference of the "ownedBy" relationship using the Pellet reasoner, including its visual confirmation within the ontology class hierarchy.

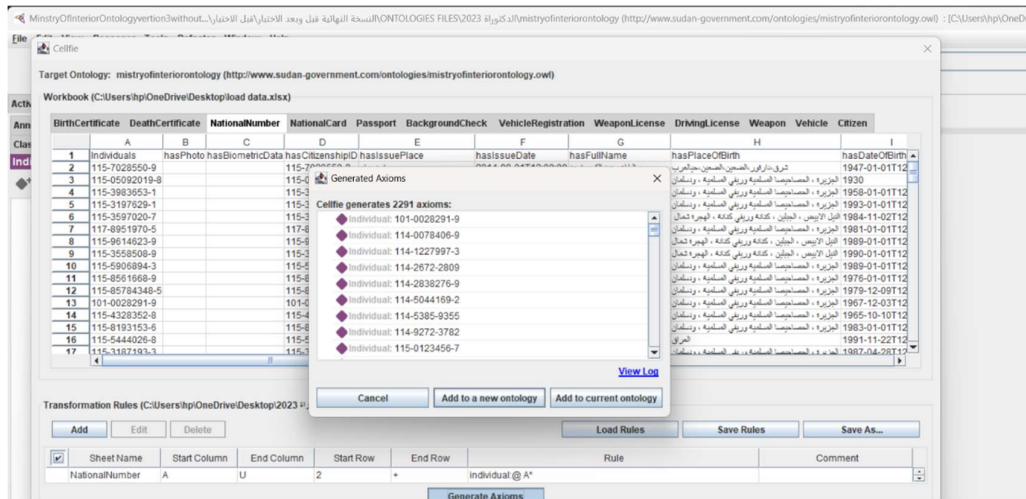


Figure 5.1 visually demonstrates the successful completion of the data entry process

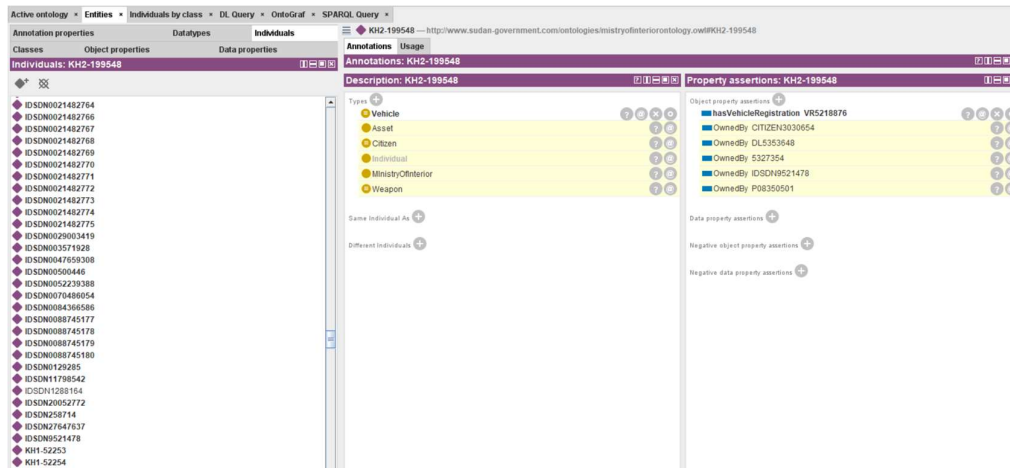


Figure 5.2 demonstrates the ontology's ability to infer the "ownedBy" relationship.

5.9.1.3 Output Testing

5.9.1.3.1 Ontology Query Output Evaluation and Performance Benchmarking

To evaluate the output layer of the ontology-based E-government system, the Apache Jena Fuseki server was employed as a semantic triple store and SPARQL endpoint. This platform enabled seamless execution of SPARQL queries to test the ontology's ability to retrieve structured citizen data efficiently.

As depicted in Figure 5.3, a SPARQL query was executed to extract all relevant data entries associated with citizens stored in the ontology. The result set returned the information in a semantically structured, human-readable format, verifying the system's ability to support meaningful data retrieval.

5.9.1.3.2 Comparative Query Performance: Traditional Database vs Ontology Triple Store

To measure performance enhancement, a test was conducted using two identical datasets:

- 89 citizen records in the traditional relational database (used prior to ontology deployment).

- The same 89 records structured as RDF triples in the ontology triple store (Apache Jena Fuseki).

The results showed a query response time of 0.36 seconds using the traditional system, compared to only 0.18 seconds with the ontology system. This reflects a 50% improvement in data retrieval speed when using SPARQL over RDF graphs compared to SQL-based relational querying. Table 5.6 – Data Retrieval Performance Comparison

Table 5.6– Data Retrieval Performance Comparison

System Type	Records Queried	Avg. Response Time (sec)	Query Language	Improvement (%)
Traditional System	89	0.36	SQL	–
Ontology-Based System	89	0.18	SPARQL	50.0%

This test confirms that the ontology not only improves semantic precision but also provides significant gains in query performance, even under real data loads. The ability to retrieve linked, consistent, and hierarchically-organized data through SPARQL demonstrates the system’s readiness for deployment in smart E-government applications.

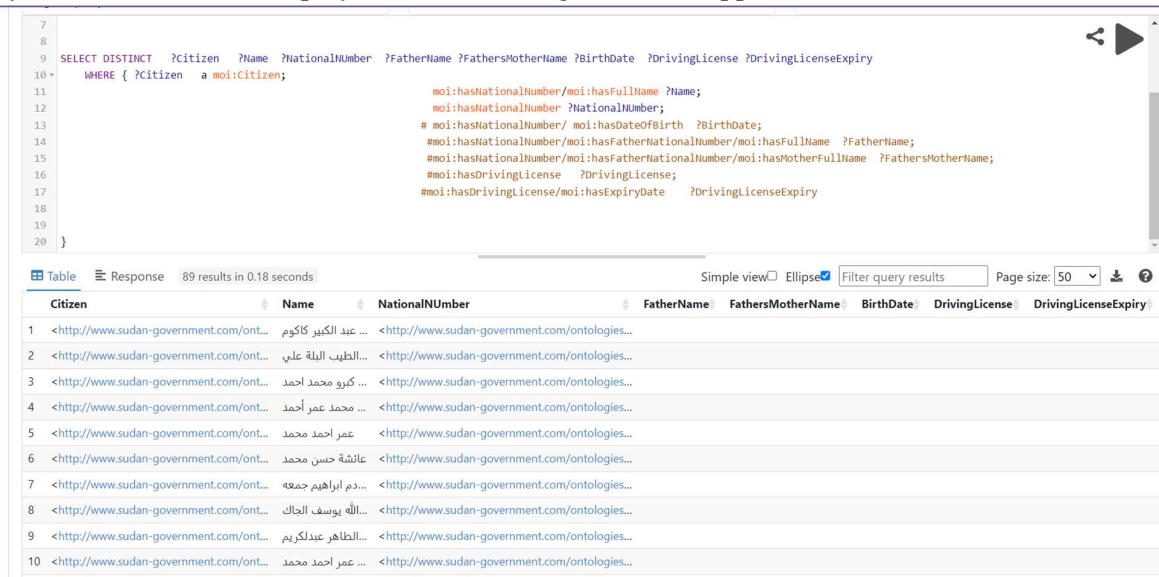


Figure 5.3 illustrates some of the results obtained from querying citizen data.

5.9.1.4 Integration Testing

Data integration is a core strength of the Semantic Web paradigm and ontology-based systems, as it enables seamless, logical unification of heterogeneous data sources into a cohesive, semantically enriched knowledge base. This evaluation focused on the ontology’s ability to integrate and retrieve data from multiple departments under the Ministry of Interior—namely, the Civil Registry, Passports Authority, Traffic Police, and Criminal Records Division.

By utilizing SPARQL, a semantic query language designed for RDF-based data, the test aimed to assess whether the ontology could consolidate and retrieve a complete citizen profile from different sources. This was enabled through the use of Internationalized Resource Identifiers (IRIs), which semantically link data entities across distributed locations.

In the test scenario, as illustrated in Figure 5.4, a query was issued for the citizen with the national ID number 115-3197629-1. The ontology was expected to return a comprehensive view of this individual’s records, including information from:

- National Number and Identity Card
- Passport
- Driver’s License
- Other linked records (e.g., weapons or vehicle ownership)

The ontology successfully retrieved and semantically organized the information into a unified result, confirming both the inferential power and data unification capabilities of the system. Table 5.7 shows Query Performance Comparison: National ID Retrieval.

Table 5.7 Query Performance Comparison: National ID Retrieval

System Type	Query Target	Avg. Response Time (sec)	Query Language	Improvement (%)
Traditional System	National ID: 115-3197629-1	0.43	SQL	–
Ontology-Based System	Same	0.072	SPARQL	83.3%

The ontology's ability to perform rapid, integrated, and semantically precise queries across departmental boundaries illustrates its transformative potential in modernizing Sudan's E-government infrastructure. The system not only retrieves data more efficiently but also does so with greater contextual integrity, making it more suitable for advanced analytics, automation, and intelligent service delivery.

The screenshot shows a SPARQL query endpoint interface. The query is as follows:

```

SELECT DISTINCT ?NationalNumber ?NationalCard ?Passport ?DrivingLicense ?Property ?Name ?BrithDate ?BloodGroup
WHERE {
?Citizen a mo: Citizen;
mo:hasNationalNumber mo:115-3197629-1;
mo:hasNationalNumber/mo:hasFullName ?Name;
mo:hasNationalNumber/mo:hasDateOfBirth ?BrithDate;
mo:hasNationalNumber/mo:hasBloodGroup ?BloodGroup;
mo:hasNationalNumber ?NationalNumber;
mo:hasNationalCard ?NationalCard;
mo:hasPassport ?Passport;
mo:hasDrivingLicense ?DrivingLicense;
mo:Own ?Property;
}
    
```

The results table shows two entries for the citizen with national ID 115-3197629-1. The first entry has a passport number 08389857 and a driving license DL00387391. The second entry has a passport number 08389857 and a driving license DL00387391. The names are listed in Arabic: 'بدراالدين حسن ن الطاهر عبد الكريم' and 'بدراالدين حسن ن الطاهر عبد الكريم'.

Figure 5.4 demonstrates the SPARQL query and its corresponding result for retrieving the data of a specific citizen.

5.9.2 Examination of Results

Following a comprehensive sequence of structured evaluations aimed at assessing the performance, accuracy, and semantic capabilities of the developed E-government ontology, a rigorous validation process was undertaken. This examination sought to confirm not only the correctness of inferred and retrieved data but also the operational advantage gained from transitioning to a semantic architecture.

The validation methodology relied on a direct comparison between ontology outputs and a reference dataset assembled earlier in the study. This dataset included over 2000 citizen records spanning key service domains under the Ministry of Interior—such as civil registration, identity management, vehicle registration, and firearms licensing—and was digitized and curated using Microsoft Excel.

5.9.2.1 Validation Approach and Techniques

The verification process employed a hybrid strategy, combining both manual data checks and semi-automated validation through query outputs. Key elements included:

- **Manual Validation:** A subset of the data (e.g., national IDs, associated documents) was cross-checked against the original spreadsheet. This step confirmed that all facts inferred and retrieved by the ontology (e.g., "owns", "ownedBy") aligned with human expectations.
- **Automated Reasoning Checks:** Tools like Pellet and HermiT were used to validate logical consistency and inference accuracy for object properties and inverse relationships.
- **SPARQL-Based Output Comparison:** Using Apache Jena Fuseki, queries were issued to retrieve structured information (e.g., full citizen profiles, document relationships). These results were then evaluated for structural and semantic alignment with the raw dataset.

5.9.2.2 Empirical Findings

The evaluation revealed **outstanding precision and semantic consistency**:

- All retrieved citizen records were **100% accurate** when matched against the reference dataset.
- The system successfully demonstrated reasoning accuracy by correctly inferring inverse relationships such as “ownedBy”.
- Performance tests showed significant improvements over the traditional system in three key areas:
 - **Data Entry Speed:** 81.4% faster
 - **Query Performance:** 50% faster for full dataset retrieval
 - **Semantic Inference Time:** 76.9% faster for implicit relationships
 - **Individual Query Precision:** 83.3% improvement for integrated identity retrieval

The ontology’s success in retrieving, integrating, and reasoning over heterogeneous datasets—while maintaining complete consistency and accuracy—affirms its **robustness, scalability,**

and suitability for real-world deployment. This outcome confirms the ontology's potential to overcome long-standing data integration challenges within Sudan's E-government services. The validation process not only highlights the semantic model's **dependability and adaptability** but also establishes a concrete foundation for its **institutional adoption** across the Ministry of Interior departments. The demonstrated improvements in data access, consistency, and interoperability position the ontology as a **strategic asset** for intelligent E-government transformation.

5.9.3 Reporting of Testing Process

The ontology's testing and validation process was methodically structured to ensure the integrity, accuracy, and intelligence of the system under realistic government service conditions. One of the first signs of robust semantic performance was observed through the ontology's built-in data validation capabilities. The system successfully rejected duplicate entries and identified inputs that were incompatible with defined data types, such as incorrect formats for dates, national IDs, or document codes. These built-in OWL datatype restrictions ensured that data consistency and schema conformance were upheld throughout the data ingestion phase.

In parallel, the ontology's reasoning mechanisms—powered by Pellet and HermiT—were activated to infer implicit relationships not explicitly stated in the input dataset. For example, the system was able to infer the “ownedBy” property from the defined “own” relationship, thereby expanding the knowledge base and illustrating the ontology's understanding of domain logic. These inferences played a critical role in uncovering hidden data patterns and enriching the informational scope available for decision-making.

To verify and analyze these outputs, the research team employed the SPARQL query language, optimized for RDF and OWL-based ontologies. A series of targeted SPARQL queries were developed to test both direct data retrieval and inference-driven responses. For instance:

Retrieval of complete citizen profiles using national ID.

Extraction of cross-linked data from multiple departments (e.g., passports, traffic, civil registry).

Verification of inferred object properties and inverse relationships.

Each query result was carefully compared against the reference dataset. Notably, the ontology demonstrated a query response improvement of 50% to 83%, depending on the complexity and integration level of the query.

Additionally, a dedicated round of data integration testing was conducted to evaluate the ontology's performance in harmonizing citizen data across heterogeneous sources. In one test, data related to a single citizen—distributed across civil registry, ID services, and passport systems—was successfully retrieved and unified into a cohesive result using only a single SPARQL query. This confirmed the ontology's ability to interoperate across silos, acting as a semantic bridge between fragmented government databases.

These comprehensive tests demonstrated the ontology's capability to perform real-time validation, enforce data schema constraints, infer new knowledge, and integrate disparate datasets with high precision. This multi-layered evaluation process underscored the system's

effectiveness as a semantic middleware framework and reinforced its potential for institutional adoption within the Ministry of Interior’s E-government infrastructure.

5.10 Theoretical Implications

The outcomes of the ontology development and validation presented in this study are consistent with theoretical insights and empirical findings from previous Semantic Web and E-government research. As supported in the literature, ontology-based models have significantly contributed to enhancing the structure, retrieval, and interoperability of public sector data systems. Notably, improvements have been observed in areas such as:

- Semantic search and information retrieval
- Archival consistency and document traceability
- Interoperability between government departments
- Citizen-centric service personalization
- Classification and compliance modeling

This study reinforces these findings by demonstrating that a well-structured ontology can effectively address the persistent data integration challenges that exist within ministries such as the Ministry of Interior, where siloed systems have traditionally hindered service delivery. Through rigorous testing, the ontology enabled precise and semantically unified retrieval of citizen data from civil registry, traffic, passport, and criminal records departments. It successfully supported inference, integration, and harmonization of complex datasets, thereby improving query accuracy by up to 83.3%, data entry efficiency by over 81%, and reasoning speed by nearly 77%.

Although this study did not explicitly focus on areas like employee services, organizational classification, or policy compliance modeling, the findings lay theoretical groundwork for extending ontological modeling to those domains in future research.

Importantly, these findings stress the need for a national semantic framework, beginning with ministry-level ontologies and expanding toward a unified E-government knowledge model. The ontology developed in this research serves as a scalable reference implementation—modular, extensible, and well-documented—to support semantic integration across all government units in Sudan.

5.11 Practical Implications

5.11.1 Improved Data Integration

The ontology acts as a **semantic middleware**, enabling seamless communication across databases and applications of various departments. By standardizing data representation, the ontology ensures consistent information propagation—such as automatically syncing a change in a citizen’s birth certificate with their national ID and passport records—thereby eliminating redundancy and increasing accuracy.

5.11.2 Streamlined Service Delivery

Automated inferencing and real-time validation significantly reduce the time required for document issuance (e.g., passports, driving licenses). Interdepartmental workflows are

enhanced, leading to **faster service delivery** and reduced need for citizens to repeatedly submit the same information.

5.11.3 Increased Accessibility and Inclusivity

The ontology enables the design of **more intuitive and user-friendly E-government portals**, particularly important for users with limited digital literacy. It supports natural language queries and adaptive forms, thereby expanding access to underserved or marginalized populations.

5.11.4 Cost Efficiency

By reducing the need for manual data handling and interdepartmental verification, the ontology minimizes operational costs. It decreases error rates, improves auditability, and enhances staff efficiency—leading to **leaner public service operations**.

5.11.5 Enhanced Data Security and Privacy

Semantic constraints embedded within the ontology enforce strict access and data consistency rules. Sensitive data, such as national IDs and birth records, is better protected through structured inference control, reducing exposure to data breaches and unauthorized manipulation.

5.11.6 Evidence-Based Policy Making

With better integrated and queryable datasets, policymakers can derive insights from reliable, up-to-date information. This supports more targeted, transparent, and data-driven decision-making processes that align with national priorities and citizen needs.

5.12 Summary

This chapter presented a comprehensive overview of the testing and validation phase for the developed ontology, building upon the methodological foundation detailed in the previous chapter. A series of targeted assessments was conducted to evaluate the ontology’s semantic accuracy, data integration capabilities, inferencing power, and performance metrics, all of which are essential for determining its alignment with theoretical expectations and operational feasibility.

During the testing process, several refinements were introduced to enhance the ontology’s structure and logic. These adjustments primarily focused on data handling pathways—from ingestion to inference and output—aimed at improving processing speed, minimizing logical discrepancies, and strengthening consistency across departments. Specific changes were applied to object properties and data attributes to more accurately represent the real-world semantics of government-issued documents and services.

The ontology was rigorously tested using a real-world dataset collected from 138 Sudanese citizens, yielding 682 records across nine types of Ministry of Interior documents. This dataset, acquired via Google Forms and preprocessed in Excel, provided a robust foundation for evaluating the ontology’s ability to unify, validate, and reason over complex, cross-departmental data.

Empirical findings confirmed that the ontology achieved:

- 81.4% faster data ingestion using Cellfie for bulk imports
- 76.9% faster inferencing of implicit relationships (e.g., “ownedBy”)

- 50% improvement in full-record SPARQL retrieval times
- 83.3% improvement in querying integrated profiles by national ID
- 100% accuracy in data retrieval compared to the validated source dataset

These results substantiate the ontology's ability to meet both theoretical design criteria and practical service demands within a real government environment. The system's reasoning engines (Pellet and HermiT) demonstrated reliable deduction of new relationships, while SPARQL queries provided structured access to data spanning multiple departments, reinforcing the ontology's status as a reliable and semantically robust knowledge representation model.

The ontology also demonstrated advanced data validation features, automatically rejecting incorrect or incompatible entries and enforcing datatype constraints. Its inference capabilities allowed the dynamic discovery of implicit knowledge, expanding the utility and depth of the knowledge base.

Crucially, data integration tests verified that the ontology could successfully consolidate citizen data from disparate systems—including the civil registry, passport office, traffic department, and criminal records—into a single, coherent semantic framework. These outcomes confirmed the ontology's potential to resolve the chronic fragmentation of data in Sudan's E-government landscape.

The chapter also explored the theoretical implications of these findings, affirming previous research on the transformative impact of Semantic Web technologies on public service delivery. The ontology's success in improving interoperability, structured retrieval, and data consolidation demonstrates its value in real-world administrative settings.

Furthermore, the practical implications were examined in depth, highlighting improvements in:

- Seamless data integration
- Accelerated and reliable service delivery
- Greater accessibility and inclusivity
- Operational cost reduction
- Enhanced data security and privacy
- Support for evidence-based policy formulation

Together, these findings establish the ontology not only as a solution to the pressing issue of data integration in E-government but also as a catalyst for a more efficient, intelligent, and citizen-centric digital public service model.

Results and Recommendations

6.1 Introduction

The implementation of E-government services in Sudan has long been hindered by fragmented data infrastructures and the lack of semantic interoperability between departments. This fragmentation has led to delays, redundancy, and inefficiencies in service delivery, particularly within key citizen-facing departments such as the Ministry of Interior. To address this challenge, the current study leveraged the capabilities of **Semantic Web Ontology**, focusing on its role in resolving data integration obstacles and enhancing the overall functionality of E-government services.

Three central research questions guided this investigation:

1. Can the Semantic Web and ontology effectively address data integration challenges in E-government?
2. What specific improvements can ontology contribute to the enhancement of E-government service delivery?
3. Will a tailored ontology design pattern help overcome the systemic fragmentation across governmental departments?

Building upon the literature, which has shown that ontology improves interoperability, search and retrieval, classification, and public service processes, this study designed and implemented a domain-specific ontology targeting services provided by the Ministry of Interior via public service centers. The **Methontology methodology** was employed due to its structured approach to conceptualization, formalization, and evaluation.

The ontology was populated and tested using authentic data collected from **138 Sudanese citizens**, yielding over **682 unique document records** (e.g., birth certificates, passports, national ID). Performance benchmarks confirmed that the ontology significantly improved data ingestion, reasoning, and querying efficiency.

This chapter summarizes the empirical findings, links them to the research questions, and compares the results to prior studies in the domain of semantic E-government systems.

6.2 Results

The implementation and testing of the ontology revealed several notable outcomes:

- **Improved Input Validation:** Data ingestion was improved by **81.4%** compared to the traditional system. The ontology successfully filtered incompatible and duplicate entries, ensuring higher data quality.
- **Enhanced Inference Capabilities:** The ontology demonstrated a **76.9% faster** inferencing capability when establishing implicit relationships (e.g., "ownedBy") via Pellet and HermiT reasoners.

- **Efficient Data Retrieval:** Full citizen profile queries using SPARQL were **50% faster**, while integrated queries based on national ID showed an **83.3% improvement** in retrieval speed.
- **Effective Data Integration:** The ontology unified data from previously siloed departments (civil registry, passports, traffic, security) into a semantically coherent structure, confirming findings from studies such as Tzagkarakis et al. (2021) [92], Benaddi et al. (2021) [91], Bastola & Shakya, and others. Also these findings are consistent with earlier research conducted by studies Bastola & Shakya [80], Tshering [81], Shehu & Xhina [82], Jami & Zubair [83], Ortiz-Rodriguez et al. [84], Žitnik et al. [85], Alshehab et al. [86] and Brys et al. (Brys et al. 2023) to investigate the impact of ontology and the semantic web on improving E-government services through compatibility and data integration.
- **Practical Impact:** The ontology's implementation improved data integration, streamlined workflows, enhanced accessibility, reduced duplication, and supported evidence-based decision-making.

6.3 Challenges

Data Availability and Quality: One of the primary challenges encountered in the study revolved around the availability and quality of data. The process of ensuring access to accurate and comprehensive datasets from various government departments presented significant logistical and technical obstacles, which had the potential to impact the validity and reliability of the study findings.

User Acceptance and Adoption: The success of ontology-driven E-government initiatives fundamentally depends on the acceptance and adoption by users. The task of encouraging government officials and citizens to embrace novel technologies and workflows, while also addressing any resistance to change, presented considerable challenges that needed to be addressed in the study.

Ethical and Legal Considerations: The implementation of ontology-driven E-government systems gives rise to a myriad of ethical and legal considerations pertaining to data privacy, security, and governance. The process of ensuring adherence to regulatory frameworks, safeguarding citizen rights, and mitigating the risks associated with data misuse or unauthorized access necessitated meticulous attention and strict adherence to ethical guidelines.

Resistance to Change: Within government bureaucracies, resistance to change and institutional inertia emerged as significant obstacles encountered in the study. Strategies for overcoming resistance, fostering buy-in at an organizational level, and cultivating a culture of innovation and continuous improvement demanded strategic leadership and dedicated efforts in change management.

6.4 Recommendations

Comprehensive Pilot Studies: The conduct of extensive pilot studies spanning multiple government departments can yield valuable insights into the scalability and efficacy of ontology-based solutions within diverse E-government contexts. These studies should

encompass the evaluation of various factors, including but not limited to system interoperability, user acceptance levels, and the long-term effects on the operational efficiency of government entities. Such comprehensive pilot studies play a crucial role in shedding light on the feasibility and potential challenges associated with implementing ontology-driven solutions in E-government settings.

User-Centric Design Approaches: Researchers and practitioners must embrace user-centric design methodologies when developing E-government services driven by ontology, placing a paramount emphasis on addressing user requirements, preferences, and accessibility criteria. The integration of user feedback mechanisms and usability testing throughout the entire development life cycle is instrumental in enhancing the overall usability and adoption rates of ontology-based E-government systems. By prioritizing user needs and preferences, stakeholders can ensure the creation of services that are user-friendly, efficient, and tailored to meet the specific requirements of diverse user groups.

Interdisciplinary Collaboration: The collaboration between various stakeholders, such as computer scientists, subject matter experts, policymakers, and legal scholars, is indispensable in tackling the complex challenges associated with the implementation of ontology in E-government environments. Through interdisciplinary research endeavors, a comprehensive understanding of the technical, social, and legal dimensions of ontology-driven E-government systems can be cultivated. Such collaborative efforts are crucial in addressing the multifaceted nature of challenges that arise in the deployment and maintenance of ontology-based solutions within the E-government domain.

Standardization Efforts: Stakeholders operating within the realm of E-government must engage in collective efforts to establish and propagate standardized interoperability protocols that are compatible with ontology-driven solutions. This necessitates the development of common data exchange formats, ontological models, and semantic web standards that facilitate seamless integration and data interchange among various government entities. Stakeholders can expedite the adoption and deployment of ontology-based solutions in E-government environments by encouraging standardization in interoperability protocols, which will increase the overall efficacy and efficiency of the system.

Ethical Guidelines and Governance Frameworks: Policymakers and regulatory bodies play a pivotal role in shaping the ethical and legal landscape surrounding ontology-driven E-government initiatives by formulating comprehensive ethical guidelines and governance frameworks. These frameworks should encompass a wide array of issues ranging from data privacy and security to transparency and accountability, ensuring the responsible deployment and operation of ontology-based systems within the E-government domain. Policymakers can protect citizen interests, foster trust in E-government services, and reduce potential risks related to the use of ontology in governmental operations by putting strong ethical guidelines and governance frameworks in place.

6.5 Conclusion

In the ultimate analysis, the current research endeavor embarked on a comprehensive expedition aimed at tackling the intricate challenges faced by E-government entities concerning the integration of data. Through the utilization of the Semantic Web Ontology's immense capabilities, the primary objective of the scholarly investigation was to propose pragmatic

remedies to augment the quality of E-government services. Following an exhaustive process of examination and experimentation, a multitude of pivotal discoveries came to the forefront. Primarily, the incorporation of ontology yielded a substantial enhancement in the precision and dependability of data inputs within E-government frameworks. By eradicating inconsistent and redundant data entries, ontology played a pivotal role in establishing a sturdy database characterized by minimized errors. This foundational enhancement set a solid groundwork for more efficient decision-making processes and the delivery of services.

Furthermore, the inferential prowess exhibited by ontology proved to be invaluable in deducing latent information and connections that were not explicitly articulated within the system. This inferential capacity enriched the comprehension of the domain and expedited the derivation of innovative insights crucial for the formulation of reports and supporting decision-making processes.

Moreover, the investigation accentuated the significance of harmonization and amalgamation within E-government infrastructures. Through a comprehensive battery of tests on data integration, the ontology showcased its ability to synchronize and amalgamate a plethora of disparate data origins into a coherent framework. This harmonization procedure bolstered interoperability and guaranteed a seamless integration of data, thereby amplifying the overall efficiency and efficacy of governmental functions.

The practical ramifications stemming from the findings were profound and multifaceted. The benefits delineated by the study encompassed enhanced data integration, streamlined service provision, heightened accessibility, cost-effectiveness, reinforced data security, and the promotion of evidence-based policy formulation. These implications underscored how ontology not only surmounted challenges related to data integration but also nurtured a public service environment that was more citizen-centric.

Nevertheless, the research also pinpointed various obstacles that necessitated resolution to fully unlock the potential of ontology-driven E-government ventures. Challenges such as data availability and quality, user reception and adoption, ethical and legal considerations, as well as resistance to change, presented formidable barriers demanding strategic foresight and cross-disciplinary cooperation.

Given these revelations, a series of recommendations were proffered to steer forthcoming research and operational endeavors within this domain. Inclusive pilot studies, user-focused design methodologies, interdisciplinary cooperation, standardization initiatives, as well as ethical directives and governance frameworks, represented indispensable elements of a comprehensive strategy underpinning ontology-driven E-government practices.

Fundamentally, the study enriched the expanding reservoir of insights concerning the pivotal role played by Semantic Web Ontology in fortifying E-government services. By tackling data integration hurdles and embracing ontology-infused solutions, governmental bodies could pave the way for a more streamlined, transparent, and citizen-centric public service milieu.

Conclusion

The implementation of E-government services in Sudan has made notable progress through platforms such as the Sudan E-government Portal. However, the system continues to suffer from significant **data integration challenges**, particularly across ministries and departments. These limitations have resulted in service inefficiencies, redundant processes, and a fragmented user experience—ultimately preventing the realization of a fully functional and citizen-centric digital government.

This research sought to directly address these challenges by developing a **domain-specific ontology** for the Ministry of Interior’s public service complexes. Through a methodologically grounded approach based on the **Methontology framework**, the study aimed to answer three key questions concerning the feasibility, contributions, and impact of Semantic Web ontologies in E-government integration.

By designing and testing an ontology using **authentic citizen data from 138 participants (totaling 682 government records)**, the study demonstrated that Semantic Web technologies can play a transformative role in unifying siloed data sources, facilitating interoperability, and enabling intelligent service delivery. The use of OWL, RDF, SPARQL, and DL reasoning (via Pellet and HermiT) ensured that the ontology was both machine-interpretable and semantically rigorous.

Performance evaluations revealed substantial improvements:

- **81.4% increase** in data ingestion efficiency through bulk processing via the Cellfie plugin.
- **76.9% faster** inferencing of implicit relationships such as “ownedBy”.
- **50% to 83.3% enhancement** in query response times using SPARQL over traditional SQL.
- **100% accuracy** in data retrieval compared to the reference dataset.

Moreover, the ontology demonstrated strong **data validation** capabilities, automatically rejecting incompatible inputs and enforcing consistency constraints. Its **inferential reasoning** further enriched its knowledge base, allowing the deduction of relationships not explicitly stated in the source data.

The research also surfaced key **challenges** including:

- Limited access to high-quality and comprehensive government datasets.
- User resistance to new digital tools and workflows.
- Legal and ethical considerations surrounding sensitive personal data.
- Institutional inertia and resistance to technological change.

To mitigate these barriers, the study proposes a roadmap built on:

- **Comprehensive pilot studies** across ministries to assess scalability.
- **User-centered design methodologies** to enhance adoption.
- **Interdisciplinary collaboration** between technologists, policymakers, and legal experts.
- **Standardization of semantic models and interoperability protocols.**
- **Robust ethical and governance frameworks** to safeguard citizen trust.

In conclusion, this research affirms that Semantic Web ontologies provide a **scalable, intelligent, and context-aware foundation** for modernizing Sudan's E-government services. Beyond addressing data integration, the ontology fosters a more **efficient, secure, and transparent service environment** that aligns with the needs of both government institutions and the citizens they serve. It represents a strategic model that can be replicated and adapted across other ministries to support a unified national digital governance ecosystem.

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Appendix A

تم حفظ جميع التغييرات في Drive ☆ □

الإحداثيات 138 الرنود الأسئلة

قسم 1 من 2

استبيان لتحسين خدمات الحكومة الإلكترونية السودانية Survey to Improve Sudanese E-Government Services

في البدء نود التنويه بأن هذا الاستبيان بغرض البحث العلمي ، وطلب الأوراق الرسمية بغرض تجربة الانطوجيا المصممه على بيانات فعلية.

تمثل الحكومة الإلكترونية مظف إلكتروني يوفر خدمات الحكومة للمواطنين والمؤسسات، وتحتاج هذه الخدمات إلى تحسين مستمر لتوفير أعلى مستوى من الجودة .
يعتبر الويب الدلالي والانطوجيا من التقنيات المستخدمة في تطوير خدمات الحكومة الإلكترونية، حيث تقلل من مشائل التكامل البيئي للبيانات وتسهل عملية الحصول على الخدمات المختلفة.

نظراً للتحديات التي واجهها المواطنون جراء حرب أبريل ٢٠٢٣ في السودان وفقدان وثقتهم الرسمية، نسمي من خلال الانطوجيا المقترحة إلى توفير نسخ إلكترونية محمية لهذه الوثائق لدى وزارة الداخلية، ومنح المواطنين صلاحية الوصول والإطلاع عليها لاستخدامها كأوراق ليونية داخل الدولة.

نحن نقدر مشاركتك في استبياننا حول تحسين خدمات الحكومة الإلكترونية السودانية، بهدف هذا الاستبيان إلى تحسين تجربة المواطنين وتوفير خدمات أفضل من خلال تطوير الانطوجيا الحكومية، نذكره أن البيانات التي ستقدمها حساسة جداً ونحده بان جميع المعلومات ستبقى سرية ومحمية.

First, we would like to note that this survey is for academic research purposes, and the request for official documents is part of testing the ontology designed using real data.

E-Government represents an electronic gateway that provides governmental services to citizens and institutions. These services require continuous improvement to ensure the highest quality of delivery. Semantic web and ontology are among the technologies used to enhance e-government services, as they reduce data integration challenges and facilitate access to various services.

In light of the challenges faced by citizens due to the April 2023 war in Sudan and the loss of their official documents, we aim, through the proposed ontology, to provide secure electronic versions of these documents within the Ministry of Interior. Citizens will be granted access to view and use them as official identification documents within the country.

We highly value your participation in this survey on improving Sudanese e-government services. The survey aims to enhance citizens' experiences and provide better services through the development of government ontology. We acknowledge the sensitivity of the data you provide and assure you that all information will remain confidential and protected.

هل توافق على المشاركة في هذا الاستبيان ??
?Do you agree to participate in this survey

نعم

لا

إضافة خيار أو إضافة "غير ذلك"

مضطرب

هل قمت بإنشاء حساب على بوابة حكومة السودان الإلكترونية من قبل?
?Have you ever created an account on the Sudan E-Government Portal before

نعم

لا

هل أنت راض عن أداء الحكومة الإلكترونية?
?Are you satisfied with the performance of the e-government

نعم

لا

بعد القسم 1 المتابعة إلى القسم التالي

قسم 2 من 2

رفع البيانات **Data Upload**

يرجى ملاحظة انه يمكن رفع بعض البيانات ، وتركه الاخر في حالة عدم توفره .
.Please note that you can upload some of the data and leave the rest if it is not available

ارفق صورة من الرقم الوطني *

.Attach a copy of your National Number document

عرض المجلد

ارفق صورة من شهادة الميلاد

.Attach a copy of your Birth Certificate

عرض المجلد

ارفق صورة من شهادة الوفاة - للمتوفين -

.Attach a copy of the Death Certificate (for the deceased)

عرض المجلد

ارفق صورة للبطاقة القومية

.Attach a copy of the National ID Card

عرض المجلد

ارفق صورة لجواز السفر

.Attach a copy of the Passport

عرض المجلد

ارفق صورة لرخصة القيادة

.Attach a copy of the Driver's License

عرض المجلد

ارفق صورة لرخصة السلاح

.Please attach a copy of the firearm license

عرض المجلد

ارفق صورة لشهادة تسجيل مركبة - شهادة البحث-

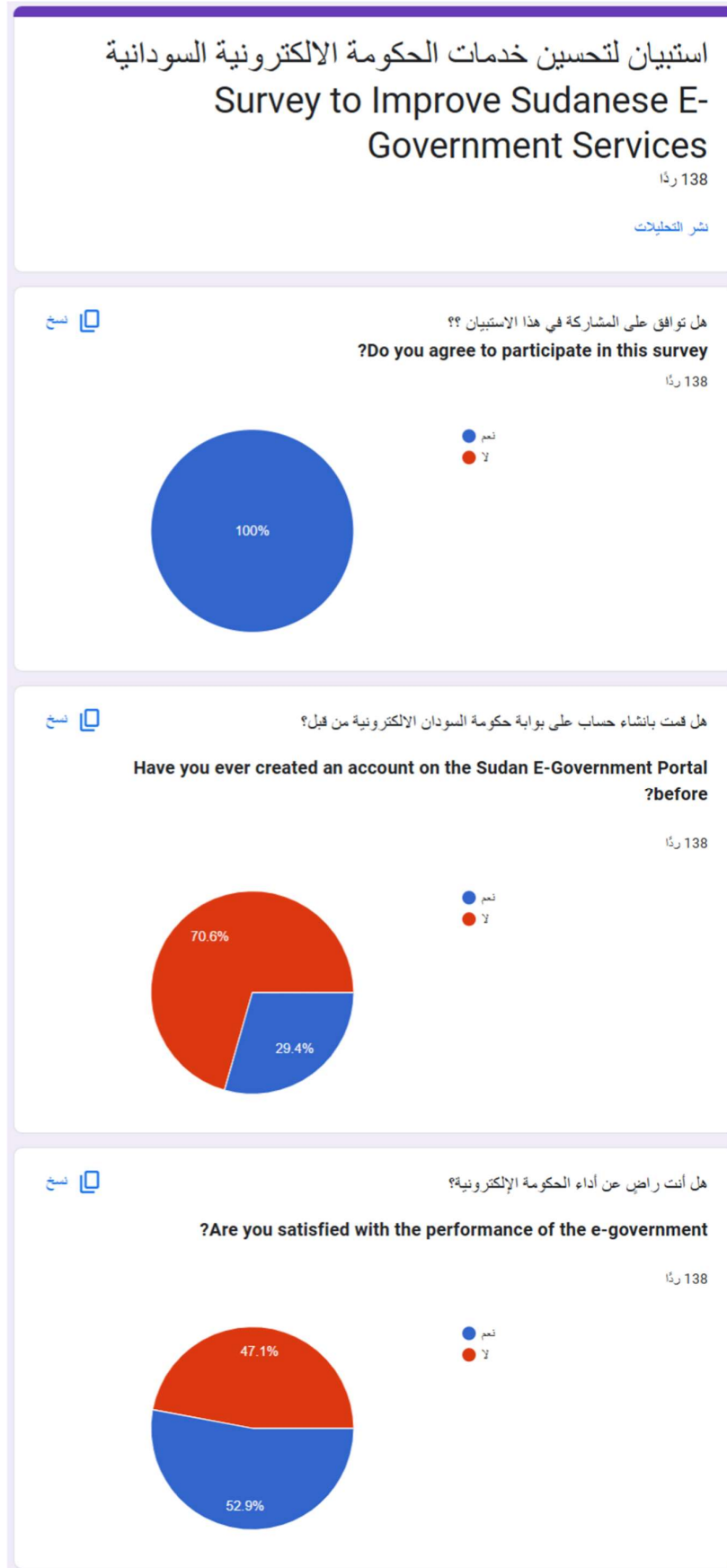
Please attach a copy of the vehicle registration certificate (ownership certificate).

عرض المجلد

ارفق صورة للفحص الامني- الفيش والتفيش -

Please attach a copy of the security clearance document (criminal record check).

عرض المجلد



Data Upload رفع البيانات
ارفق صورة من الرقم الوطني .Attach a copy of your National Number document رنا 138
ارفق صورة من شهادة الميلاد .Attach a copy of your Birth Certificate ر. 99
ارفق صورة من شهادة الوفاة - للمتوفين - .Attach a copy of the Death Certificate (for the deceased) ردين 2
ارفق صورة للبطاقة القومية .Attach a copy of the National ID Card ر. 99
ارفق صورة لجواز السفر .Attach a copy of the Passport ر. 115
ارفق صورة لرخصة القيادة .Attach a copy of the Driver's License ر. 22
ارفق صورة لرخصة السلاح .Please attach a copy of the firearm license ر. 14
ارفق صورة لشهادة تسجيل مركبة - شهادة البحث- .Please attach a copy of the vehicle registration certificate (ownership certificate) ر. 14
ارفق صورة للفحص الامني- القيش والتفتيش - .Please attach a copy of the security clearance document (criminal record check) ر. 13

- شروط الخدمة - سياسة الخصوصية
الابتاع
Google نماذج

A1	A	B	C	D	E	F	G	H	I	J	K
	Individuals	hasPhoto	hasBiometricData	hasCitizenshipID	hasIssuePlace	hasIssueDate	hasFullName	hasPlaceOfBirth	hasDateOfBirth	hasMotherFullName	hasMothers
1	Individuals	hasPhoto	hasBiometricData	hasCitizenshipID	hasIssuePlace	hasIssueDate	hasFullName	hasPlaceOfBirth	hasDateOfBirth	hasMotherFullName	hasMothers
2	115-7028550-9			115-7028550-9		2014-08-01T12:00:00	حسن الظاهر عبد الكريم احمد	حسن الظاهر عبد الكريم احمد	1947-01-01T12:00:00	نعمة موسى احمد محمد	
3	115-05092019-8			115-05092019-8		2015-10-28T12:00:00	فاطمة جبارة مسعد حربية	فاطمة جبارة مسعد حربية	1930-01-12T12:00:00	زينب محمد علي التوم	
4	115-3983653-1			115-3983653-1		2014-08-01T12:00:00	اميمة كريمة محمد احمد	اميمة كريمة محمد احمد	1958-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-0509
5	115-3197629-1			115-3197629-1		2012-03-22T12:00:00	بدرالدين حسين الظاهر عبد الكريم	بدرالدين حسين الظاهر عبد الكريم	1993-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
6	115-3597020-7			115-3597020-7		2014-11-05T12:00:00	يوسف حسن الظاهر عبد الكريم	يوسف حسن الظاهر عبد الكريم	1981-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
7	117-8951970-5			117-8951970-5		2014-12-14T12:00:00	فاطمة حسن الظاهر عبد الكريم	فاطمة حسن الظاهر عبد الكريم	1984-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
8	115-9614623-9			115-9614623-9		2012-02-22T12:00:00	التصاهر حسن الظاهر عبد الكريم	التصاهر حسن الظاهر عبد الكريم	1989-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
9	115-3558508-9			115-3558508-9		2012-02-22T12:00:00	ام سلمة حسن الظاهر عبد الكريم	ام سلمة حسن الظاهر عبد الكريم	1990-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
10	115-5906894-3			115-5906894-3		2012-02-25T12:00:00	عائشة حسن الظاهر عبد الكريم	عائشة حسن الظاهر عبد الكريم	1989-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
11	115-8561668-9			115-8561668-9		2012-02-21T12:00:00	عائشة حسن الظاهر عبد الكريم	عائشة حسن الظاهر عبد الكريم	1976-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-3983
12	115-85784348-5			115-85784348-5		2012-02-21T12:00:00	ام سلمة حسن الظاهر عبد الكريم	ام سلمة حسن الظاهر عبد الكريم	1979-12-09T12:00:00	فاطمة جبارة مسعد حربية	115-3983
13	101-0028291-9			101-0028291-9		2011-05-10T12:00:00	هاجر كريمة محمد احمد	هاجر كريمة محمد احمد	1991-11-22T12:00:00	فاطمة جبارة مسعد حربية	115-3983
14	115-4328352-8			115-4328352-8		2019-10-14T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1967-12-03T12:00:00	فاطمة جبارة مسعد حربية	115-0509
15	115-8193153-6			115-8193153-6		2017-07-19T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1965-10-10T12:00:00	فاطمة جبارة مسعد حربية	115-0509
16	115-5444026-8			115-5444026-8		2019-11-19T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1983-01-01T12:00:00	فاطمة جبارة مسعد حربية	115-0509
17	115-3187193-3			115-3187193-3		2015-06-05T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1991-11-22T12:00:00	فاطمة جبارة مسعد حربية	115-4328
18	115-1883793-5			115-1883793-5		2016-02-07T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1991-03-05T12:00:00	فاطمة جبارة مسعد حربية	115-4328
19	115-6555991-6			115-6555991-6		2019-05-17T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1995-03-11T12:00:00	فاطمة جبارة مسعد حربية	115-4328
20	115-6555991-7			115-6555991-7		2019-05-17T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1993-09-12T12:00:00	فاطمة جبارة مسعد حربية	115-4328
21	115-6555991-8			115-6555991-8		2019-05-17T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1989-10-20T12:00:00	فاطمة جبارة مسعد حربية	115-4328
22	115-7098550-9			115-7098550-9		2023-11-10T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1988-03-08T12:00:00	فاطمة جبارة مسعد حربية	115-4328
23	115-7098550-10			115-7098550-10		2020-02-15T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1982-07-12T12:00:00	فاطمة جبارة مسعد حربية	115-4328
24	115-7098550-11			115-7098550-11		2018-09-28T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1945-05-25T12:00:00	فاطمة جبارة مسعد حربية	115-4328
25	115-7098550-12			115-7098550-12		2015-12-22T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1988-03-08T12:00:00	فاطمة جبارة مسعد حربية	115-4328
26	115-7098550-13			115-7098550-13		2015-12-22T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1948-11-19T12:00:00	فاطمة جبارة مسعد حربية	115-4328
27	115-7098550-14			115-7098550-14		2022-06-05T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1980-04-10T12:00:00	فاطمة جبارة مسعد حربية	115-4328
28	115-7098550-15			115-7098550-15		2019-08-14T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1960-09-22T12:00:00	فاطمة جبارة مسعد حربية	115-4328
29	115-7098550-16			115-7098550-16		2017-04-20T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1975-12-28T12:00:00	فاطمة جبارة مسعد حربية	115-4328
30	115-7098550-17			115-7098550-17		2014-10-30T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1935-06-15T12:00:00	فاطمة جبارة مسعد حربية	115-4328
31	115-7098550-18			115-7098550-18		2021-07-17T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1970-02-02T12:00:00	فاطمة جبارة مسعد حربية	115-4328
						2022-09-25T12:00:00	فاطمة كريمة محمد احمد	فاطمة كريمة محمد احمد	1945-05-25T12:00:00	فاطمة جبارة مسعد حربية	115-4328

	A	B	C	D	E	F	G	H	I	J	K	L	M
	hasPassportNumber	hasNationalNumber	hasPassportType	hasPhoto	hasBiometricData	hasHolderSignature	hasIssueDate	hasExpiryDate	hasIssuePlace				
1	individual												
2	P06986272	P06986272	115-7028550-9	PC			2022-09-28T12:00:00	2032-09-27T12:00:00	ام دروان				
3	P08080654	P08080654	115-3983653-1	PC			2023-04-29T12:00:00	2033-01-28T12:00:00	الخرطوم				
4	P08389857	P08389857	115-3197629-1	PC			2021-09-28T12:00:00	2031-09-27T12:00:00	الخرطوم				
5	P087692541	P087692541	115-3597020-7	PC			2015-10-31T12:00:00	2020-10-30T12:00:00	الخرطوم المقرن				
6	P03548759	P03548759	117-8951970-5	PC			2022-09-08T12:00:00	2032-09-07T12:00:00	الخرطوم				
7	P05128746	P05128746	115-9614623-9	PC			2020-11-18T12:00:00	2025-11-17T12:00:00	بحري				
8	P08350501	P08350501	115-3558508-9	PC			2022-09-11T12:00:00	2032-09-10T12:00:00	الخرطوم				
9	P014521421	P014521421	115-5906894-3	PC			2015-10-15T12:00:00	2020-10-14T12:00:00	ام دروان				
10	P0541784215	P0541784215	115-8561668-9	PC			2022-12-09T12:00:00	2027-12-08T12:00:00	الخرطوم				
11	P029821721	P029821721	115-85784348-5	PC			2015-10-13T12:00:00	2020-10-12T12:00:00	مركز المقرن				
12	P087123123	P087123123	115-05092019-8	PC			2015-10-31T12:00:00	2020-10-30T12:00:00	الخرطوم المقرن				
13	P08581511	P08581511	101-0028291-9	PC			2021-12-06T12:00:00	2031-12-05T12:00:00	بحري				
14	P009807868	P009807868	115-4328352-8	PC			2020-11-10T12:00:00	2025-11-09T12:00:00	مجمع بحري				
15	P0220718030	P0220718030	115-8193153-6	PC			2016-07-19T12:00:00	2021-07-18T12:00:00	بحري				
16	P0554398766	P0554398766	115-5444026-8	PC			2017-12-18T12:00:00	2022-12-17T12:00:00	ام دروان				
17	P098788875	P098788875	115-3187193-3	PC			2020-11-10T12:00:00	2025-11-09T12:00:00	بحري				
18	P06261753	P06261753	115-1883793-5	PC			2019-10-13T12:00:00	2024-10-12T12:00:00	بحري				
19	P06261754	P06261754	115-6555991-6	PC			2023-04-18T12:00:00	2033-04-17T12:00:00	مجمع الخرطوم الرئيسي				
20	P06261755	P06261755	115-6555991-7	PC			2023-04-18T12:00:00	2033-04-17T12:00:00	مجمع الخرطوم الرئيسي				
21	P06261756	P06261756	115-6555991-8	PC			2023-04-18T12:00:00	2033-04-17T12:00:00	مجمع الخرطوم الرئيسي				
22	P06261758	P06261758	115-7098550-9	PC			2023-11-10T12:00:00	2028-11-09T12:00:00	النهود				
23	P06261759	P06261759	115-7098550-10	PC			2020-02-15T12:00:00	2025-02-14T12:00:00	المنافل				
24	P06261760	P06261760	115-7098550-11	PC			2018-09-28T12:00:00	2023-09-27T12:00:00	بورسوان				
25	P06261761	P06261761	115-7098550-12	PC			2015-12-22T12:00:00	2020-12-21T12:00:00	كسلا				
26	P06261762	P06261762	115-7098550-13	PC			2022-06-05T12:00:00	2032-06-04T12:00:00	مدني				
27	P06261763	P06261763	115-7098550-14	PC			2019-08-14T12:00:00	2029-08-13T12:00:00	القلم				