Bulletin of Electrical Engineering and Informatics
Vol. 15, No. 2, April 2026, pp. 1509~1520
ISSN: 2302-9285, DOI: 10.11591/eei.v15i2.7918

Toward a business intelligence framework for e-government interoperability: data integration and decision support

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Article Info

Article history:

Received Nov 21, 2023
Revised Nov 5, 2025
Accepted Feb 22, 2026

Keywords:

Data integration
Data warehousing
E-government interoperability
E-justice
Service oriented architecture

ABSTRACT

In e-government systems, achieving smooth data interoperability is still a major challenge, especially in judicial systems where fragmented data management affects decision-making and service quality. In order to facilitate real-time data integration and interoperability, this paper suggests a novel service-oriented business intelligence (SOBI) framework coupled with a common central data warehouse (CCDW). Our approach, which uses the Moroccan legal system as a use case, makes use of materialized views and extract, transform, and load (ETL) procedures to guarantee scalable, secure, and efficient exchange of information between disparate systems. The framework provides a scalable model for e-governance while improving decision support, transparency, and service delivery. Findings highlight enhanced system performance and data sharing, with implications for broader e-government applications. The proposed approach provides a foundation for future extensions toward internet of thing-based urban planning and real-time data integration for smart and sustainable urban ecosystems.

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1. INTRODUCTION

The rapid advancement of digital technologies has transformed the way governments deliver public services, with many agencies increasingly adopting digital solutions to enhance efficiency, accessibility, and transparency. In this digital transformation, the value of data management and interoperability in information systems (IS) is widely recognized, with significant implications for service outcomes and system performance [1]. However, the justice sector's adoption of e-justice systems lags behind other government initiatives due to specific challenges such as process sensitivity, legal restrictions, and ensuring judiciary independence [2]. Addressing these challenges is critical for enhancing the connectedness, transparency, and efficiency of justice services.

One key aspect of this transformation is the need for effective data interoperability and better decision-making across various sources to improve public service quality and competitiveness in the modern world organizations must use accurate data, and right information at the right time. Business intelligence (BI) plays a crucial role in this by providing analytical tools that facilitate data-driven decision-making. BI solutions collect, integrate, and analyze data, enabling organizations to make informed decisions at all levels. The data warehousing pipeline is integral to this process, transforming raw data into valuable information assets by enforcing standards and consistency, and providing a reliable source of historical data [3].

Organizations are migrating to developing data warehouses that operate as a single version of truth as multiple data sources enter the picture. A data warehouse is optimized for reading operations by being designed in either a star schema or a snowflake schema. It also delivers a significant amount of data with pre-built aggregations, which improves performance. Despite the importance of data interoperability, achieving it is a complex task that requires innovative strategies.

Existing literature on e-government has highlighted the influence of legal, technical, and data considerations on the definition of successful quality of service outcomes and the potential for enhancing data interoperability, particularly in the judicial system [4]. Other frameworks, such as Morocco's 2012 e-gov interoperability framework, are restricted in their efficacy in judicial contexts by the absence of unified data warehousing and real-time integration [4].

In this context, the Moroccan government has launched the "Digital Morocco" program into action to get the country ready for a change from a knowledge-based society and economy to a technologically advanced one. Further to this, the Moroccan government states that making e-government data interoperable is an important step toward a successful digital transformation and the delivery of effective public and e-services. The research question that this study aims to resolve is: How can a unified data warehousing framework improve data interoperability and decision-making in e-justice systems?

This paper suggests a novel service-oriented business intelligence (SOBI) framework with a common central data warehouse (CCDW) in order to facilitate real-time data integration and interoperability in Morocco's judicial system. In contrast to previous methods, our framework ensures scalability, security, and efficiency by integrating materialized views, extract, transform, and load (ETL) processes, and WSO2 solutions. Our contributions include: i) a scalable SOBI architecture for e-justice; ii) a real-time ETL process with multi-agent systems; iii) a unified CCDW for centralized data storage; and iv) a workable implementation validated in Morocco's legal system. The remainder of this paper is structured as follows: the background section presents the related works and the basic architectures that are necessary to understand our research problem. The next section highlights the methodology and our proposed framework, and describes our justice use case study and the final section explains the conclusion.

2. BACKGROUND

2.1. Related works

Different researchers suggested a variety of approaches to improve the efficiency of e-government IS, including the citizen-centric approach [4], one-stop portal, social networks, cloud computing and big data analytics approach and integrated e-government. By offering a quick and easy way for users to obtain information and good services, these approaches enhance e-government services.

To meet the diverse needs of the end user, contemporary e-governance necessitates the integration of several public service organizations. Nonetheless, one of the most important requirements is the integration, coordination, and interaction of the diverse data produced by public sector organizations. In addition, IS have been progressively incorporated into court systems around the globe over the past three decades. This is an ongoing process, and each update has improved the usability and convenience of the services. The majority of e-justice studies, according to Contini [5], employ a functional paradigm in which technology is viewed as a tool or instrument for "greater justice." A recent review of the e-Justice literature stated several research areas, notably implementation success and risk factors (e.g., Maralbaeva, 2024 [6]), the assessment of the impact of digitization in courts [7], user experience and design principles, and criminal websites [8]. The vast majority of research on digital administrations concludes that the digital delivery of justice is relatively positive. Nonetheless, numerous e-Justice studies have highlighted the lack of data, data integrity, coordination, and data exchange between the diverse justice administration systems.

In addition, in 2012, a Moroccan e-gov interoperability framework was established to address interoperability [9]. This framework encompasses a set of principles and suggestions aimed at facilitating interoperability across three distinct layers: organisational, semantical, and technical. Nevertheless, after its initial implementation, the framework was subject to only one revision in 2022, which constituted very slight modifications to the technical layer of data interoperability. As opposed to the European Interoperability Framework (EIF), which has undergone constant revision [10]. Moreover, in the United Kingdom, the establishment of the Data Standards Authority (DSA) aims to facilitate the advancement of shared data standards, promote data interoperability, and foster ongoing evolution in governmental practices to fulfill the requirements of users [11].

Real-world e-governance implementations present valuable context for our research. The eIDAS framework of European Union’s supports cross-border digital identity and interoperability, but its complexity limits adoption in judicial systems [11]. In the US, the Federal Data Strategy prioritizes standardized data sharing, but has struggles with legacy system integration. In Africa, Kenya’s Huduma Centres consolidate

public services through a one-stop portal, although they lack unified data warehousing. Our research builds on these models by offering a scalable, real-time data integration solution designed for Morocco's judicial system.

Several other studies have been conducted with the aim of improving interoperability, data standards, and data infrastructure in Morocco [12]. Unfortunately, none of the aforementioned studies have particularly prioritized the construction of a unified centralized warehouse for justice system. Moreover, there has been a scarcity of study undertaken in this particular domain.

Due to the sensitive nature of legal work, we have identified the following significant issues as justification for the need for data interoperability among the numerous entities participating in the legal system, based on the literature and the current state of the judicial systems in Morocco [13]:

- Information is not always complete, accurate and reliable because of the fragmented data management architecture in which data is stored separately in unconnected systems, resulting in vulnerabilities
- Due to a heterogeneous environment of independently organized IS, end users may not always have quick, systematic access to all the information they require to complete their activities.

On the other hand, some studies states that the SOA-based architecture is more suitable for e-administration because it employs component-based applications that enable the composition of services from many service providers and ensures overall system security, confidentiality and scalability [14], [15]. However, there is still little work that provides a thorough architectural framework for genuine data interoperability for e-government. To facilitate interoperability between internal and external data services, this study presents a distributed e-government system based on BI and SOA using common data warehouse storage and a simple process like the ETL process. The proposed framework reduces data rejection from several agencies. Decision-making is supported by sharing and reuse of interdepartmental services, which can be improved. Table 1 provides a comparative analysis of existing e-governance interoperability approaches discussed in this section, outlining their limitations and demonstrating how our proposed framework addresses these shortcomings to enhance data integration and decision-making.

Table 1. Comparison of existing e-government interoperability approaches

Existing interoperability approaches	Key features	Limitations	Proposed framework's improvements
Citizen-centric [4]	Focuses on user-friendly portals	Limited data integration across systems	Integrates heterogeneous data via CCDW
Cloud computing [4]	Scalable storage and processing	Security and latency issues	Real-time ETL with multi-agent systems for efficiency
Morocco's 2012 framework [9]	Organizational and technical guidelines	No unified data warehouse; outdated revisions	Unified CCDW with real-time integration
European Interoperability Framework (EIF) [11]	Regular updates; multi-layer interoperability	Complex implementation for judicial systems	Simplified SOBI architecture tailored for e-justice
UK Data Standards Authority [12]	Shared data standards	Limited focus on real-time integration	Materialized views for query optimization

2.2. Service oriented business intelligence

SOBI architecture [16] is the synergy of the BI and service oriented paradigms. It attempts to solve real-world problems of integrating disparate "stove piped" enterprise systems. In addition, it aims to provide operational and MIS data, a road map for enhanced class integration, and a common data transformation mechanism, as well as principles and patterns for guidance.

The SOBI architecture objective is to:

a. Provide a framework for implementing best practices
b. Integrate at the most appropriate architectural level
c. Provide the data modelling of a BI project within the service orientation strategy of maintaining the source systems
d. Provide a common implementation for data transformations and data logic: i) data to data; ii) data to service; iii) service to data; iv) service to service; and v) data warehousing architecture

2.2.1. Definition of data warehouse

The data warehouse [17] is a specialized database designed to store all the information needed in the context of decision making and decision analysis. It is fed with data from heterogeneous sources through ETL tools. In essence, it serves as a central repository for gathering and organizing large volumes of an organization's data, helping to avoid the cost of storage systems and backup data at an enterprise level. The main functions of the data warehouse include:

- Data cleaning to ensure its quality
- Data integration form various sources

- Data mapping to correct structures or formats
- Data extraction
- Data transformation (into usable and readable format)
- Data loading (into the datawarehouse)
- Refreshing regularly the data to maintain it up to date

In his book "Building the Data Warehouse" [18], Bill Immon, father of the data warehouse concept, describes it as a “Subject oriented, integrated, non-volatile, time variant collection of data in support of management decisions”. According to the definition of a data warehouse, a data warehouse generally has following four characteristics.

- Subject-oriented means that the primary objective of a data warehouse is to facilitate an organization's decision-making process. Since data in any organization naturally focusses on subject areas, information gathered in a data warehouse is intended for a particular subject rather than the organization's operations or functions.
- Integrated: being integrated means that the data is collected in the data warehouse and may originate from various tables, databases, or even servers. However, it can be combined into a single unit that is efficient and logical for making strategic decisions easier.
- Non-volatile: since it is a snapshot of operational data at a particular moment in time, the data should remain stable and not disappear. The data in the data warehouse should typically be added, but it should rarely be deleted.
- Time-variant means that within a specific time frame, all of the data in the data warehouse can be located.

2.2.2. Architecture of data warehouse

Data warehouses and their structures vary depending on the context of an organization's environment. Many architectures of data warehouse exist in the literature, according to several studies [19], five main data-warehouse architectures have been identified and are summarized in Table 2.

Table 2. Description of data warehouse architectures

Data warehouse architectures	Description
Independent data marts	This architecture consists of each organisational entity constructing its own data mart. These marts operate differently from one another. Typically, these marts frequently employ inconsistent data definitions and utilize diverse dimensions and measures, making it challenging to analyse the data across all marts [20].
Data mart bus architecture with linked dimensional data marts	This architecture is specifically dedicated to a business requirements analysis for a particular business process. The initial mart is designed for a specific business process and uses the same dimensions and units of measurement as future marts. Employing these dimensions and metrics, new marts are created, leading to logically integrated marts and an enterprise-wide perspective of the data. The marts retain atomic and summarized data in a star schema, enabling a dimensional view of the data [21].
Hub-and-spoke	This architecture is built upon a comprehensive analysis of data requirements at an enterprise-level. It aims to create an infrastructure that can be easily scaled and maintained. The architecture is developed iteratively through using the enterprise view of the data, subject area by subject area. Data at the atomic level is stored in its third normal form in the warehouse. Making dependent data marts using warehouse data as their source. Dependent data marts may be created for departmental, functional area, or special purposes and may have normalized, de-normalized, or summarized/atomic dimensional data structures depending on user needs [22].
Centralized data warehouse (no dependent data marts)	This architecture is similar to the hub and spoke architecture, with the distinction that there are no data marts dependent on this architecture. The warehouse stores atomic-level data, some summarised data, and logical views of data dimensions. Queries and applications can access relational data as well as dimensional views. This architecture represent typically a logical implementation of the hub and spoke architecture rather than a physical one [23].
Federated	This architecture is considered an appropriate solution for organisations with an existing, complex decision support environment that they do not wish to reconstruct. Business needs dictate the collection of data from existing data warehouses, data marts, and legacy systems. The integration of data can be reached through logical or physical means using shared keys, global metadata, distributed queries, or other technique [24].

2.3. Relevance of interoperability features to Electrical Engineering domains

The effectiveness of interoperability in the proposed e-governance framework is dependent on various architectural and technical feature that strongly correlate with principles found in Electrical Engineering disciplines. Table 3 compares these interoperability features to established EE fields such SCADA systems, internet of thing (IoT) integration, and real-time data collection. This comparison demonstrates the suggested framework's adaptability and cross-domain significance outside of the justice sector.

Table 3. Mapping interoperability features to electrical engineering domains

Interoperability feature	SCADA systems	IoT integration	Real-time data acquisition
ETL process	Standardizes and integrates sensor/actuator data from multiple control stations	Converts heterogeneous device data (e.g., JSON, XML, and MQTT) to unified formats	Enables real-time data flow normalization and pre-processing
Federated data warehouse (CCDW)	Allows decentralized control stations to share data with central monitoring	Supports integration across different device networks and vendors	Scales data acquisition from multiple locations without overload
Multi-agent system (monitoring+ETL agents)	Monitors field devices, detects faults, automates alerts	Handles distributed device communication and data cleaning	Improves responsiveness and fault-tolerance in data pipelines
Role-based access control (RBAC)	Limits access to control commands by operator level	Manages user/device permissions in large IoT ecosystems	Ensures secure access to real-time sensitive data
End-to-end encryption and anonymization	Secures SCADA data transmission from remote terminals	Protects personal data in smart city and health-related IoT applications	Secures data at source and during transfer, ensuring compliance
Materialized views for query optimization	Accelerates common queries (e.g., voltage trends and alarms)	Speeds up access to processed sensor data for applications like smart homes	Improves dashboard responsiveness for real-time monitoring
Standardized data exchange via service-oriented architecture (SOA)	Enables interoperation between old and new SCADA systems	Allows cloud platforms to consume sensor data from diverse sources	Promotes plug-and-play capability of new data sources
Real-time monitoring agents (WSO2+agent architecture)	Detects anomalies in SCADA field data and alerts operators	Continuously monitors device status and usage patterns	Enables on-the-fly issue detection and minimizes latency in data processing

3. METHOD

3.1. Overview

In our study, we focus on establishing a CCDW to facilitate data sharing and exchange among seven data providers in the justice sector. Each provider handles specific or shared data that needs to be stored in the CCDW. Our approach aims to address the challenge of sharing and exchanging data between internal and external departments, thereby improving interoperability within the e-government system.

3.2. Requirement analysis of common central data warehouse

Morocco has effectively programmed and developed a series of online administration projects, notably in the areas of financial decision-making, education, agriculture, national security through the large project of the National Electronic Identity Card V2, and justice sector. With many applications in each service, data exchange between services, data sharing between services and data integration application becomes an important requirement to significantly improve management efficiency and service quality. The relationship between the data provider and the user for our proposed CCDW and judicial entity data is described in Figure 1.

In our case, we have seven data providers, and each of these providers handles specific or shared data that needs to be stored in the proposed CCDW. Therefore, our data warehouse deals with various subjects that can be accessed by specific DATA USER (who can be whether it's a single data provider or multiple data providers).

To solve the problem of sharing and exchange of data between (internal and external) departments, the establishment of a CCDW is a primary strategy. The essential requirements for the CCDW we considered in our study are summarized below:

- Carry out data sharing and exchange across different departments
- provide data collection, processing and loading from data sources to the CCDW
- carry out centralized storage of government information resources to support the development of higher-level databases
- Provide integration application services for government and citizens while enhancing information management.

3.3. Data classification

To uphold fairness and justice, we classify data into four types:

- Public data: poses little-to-no risk and is not considered sensitive.
- Internal data: not intended for public release but may be accessed under legislative regimes.
- Confidential data: must remain private and protected to avoid serious financial, legal, or regulatory consequences.
- Restricted data: could have serious consequences if revealed and is protected accordingly.

Our study found that more than 40% of data is considered confidential, and more than 30% is considered restricted in jurisdictions.

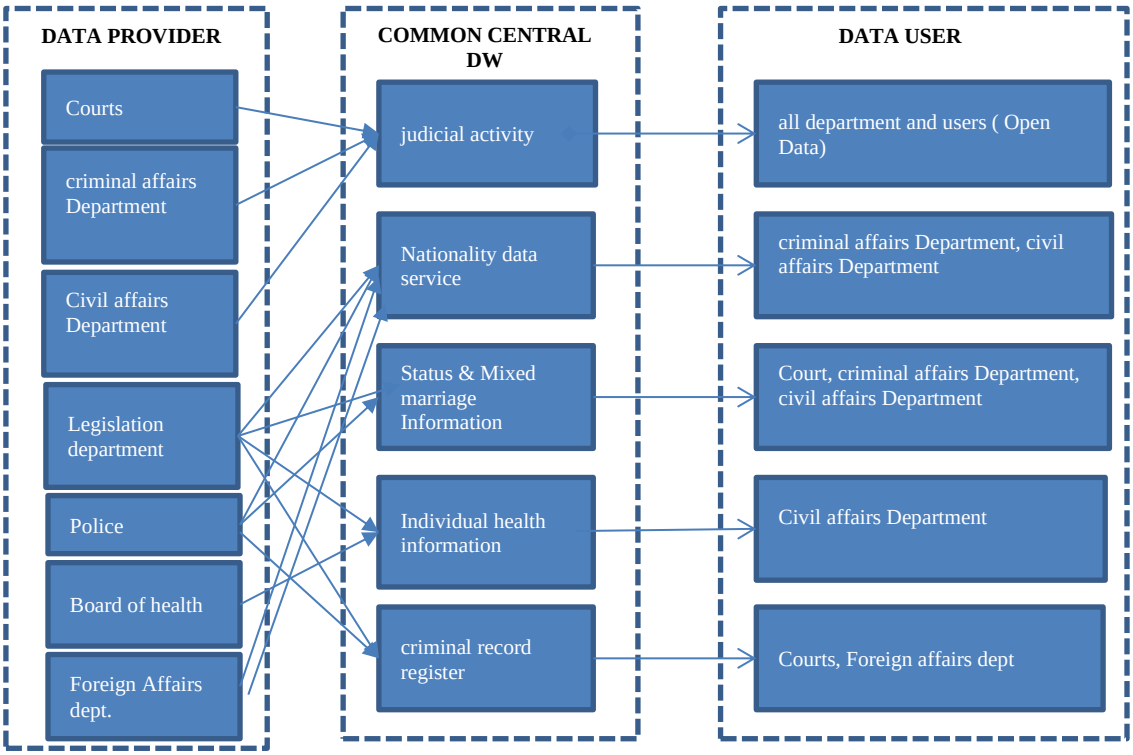

Figure 1. Relation of data provider and data user for judicial entity

3.4. The proposed formal interoperability framework for better e-governance

To address the challenges of interoperability inside the e-government system, we offer a BI architecture that enables greater collaboration and coordination among independent heterogeneous entities.

As illustrated in Figure 1, this collaborative framework allows the involvement of all entities in data interoperability. It describes the communications channels between the different administration to enhance the quality of the information exchange process and describes all exchangeable data types in order to reach the interoperability goals. It involves the interconnection of IS so that data registered in one system are automatically collected, processed in real time through an ETL process, loaded, and consulted by the concerned user via a CCDW. Due to the complex decision support of e-justice environment, the framework adopts a federated data warehousing architecture for data storage environment across the project entities, integrating and combining service oriented and BI techniques as web services.

Figure 2 depicts the formal, layered structure of the proposed CCDW for e-government data interoperability, which leverages service-oriented principles, BI tools, and real-time processing to enable semantic and technical integration among heterogeneous e-justice entities. It is composed of six main components: data provider management layer, data share and exchange layer, shared data marts, support application layer, data user layer, CCDW management layer, and CCDW security layer.

a. Data provider management layer

It manages data providers on producing and delivering their data. It concerns the multiple heterogenous data sources. Because of the disparate data of judicial administration, we differentiated 3 level of data provider (district level, the provincial and national level).

b. Data share and exchange layer

It is made up of a data sharing service and an ETL process, which is based on three main processes: data extraction, data transformation, and data loading. The ETL process constitutes the data provider for the shared data mart, which gathers data from the data source and loads it to the target data warehouse. Within the SOA framework, data share service deal with exposing specific share data stored in shared data mart into various departments that need data allowing them to access and retrieve that data in a standardized and interoperable manner.

c. Shared data marts

The shared DM of CCDW is composed of four parts: judicial activity, judicial ADM basic information database (including civil affairs register, criminal records, and legislation register), health basic information

database, and personal information database, which is organized according to user requirements and is maintained by administrators of the CCDW.

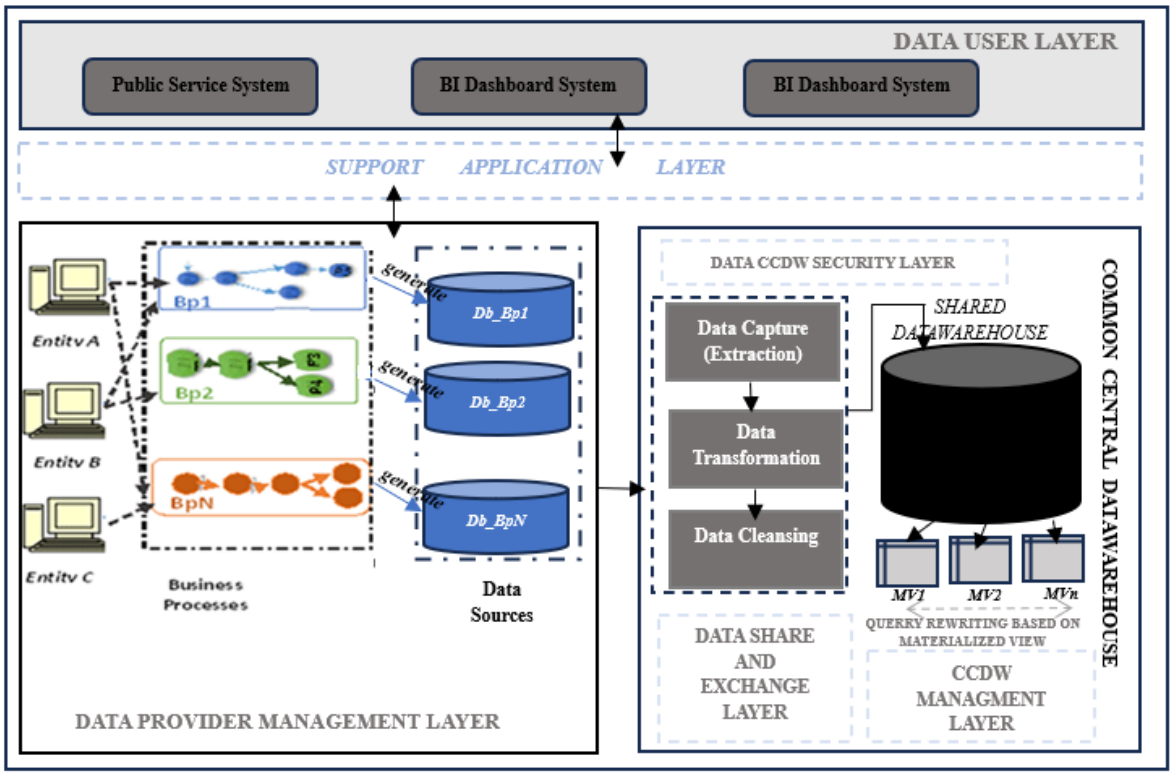

Figure 2. Layered architecture of the proposed SOBI formal interoperability framework for CCDW

d. Materialized view component

Query rewriting is based on Materialized view which are used within the CCDW to accelerate commonly executed queries and to enhance overall system performance.

e. Support application layer

It is the secondary development tool held by CCDW, with the major function is building personalized database by directly extracting data from shared data marts corresponding requirements of user.

f. Data user layer

It is composed of three parts: public service database, BI interactive dashboard system and application system. It provides centralized access of Application database to End User based on decision-making requirements, maintained by both administrators of CCDW and departments. It presents the results of comprehensively analyzed data related to the building's operational and maintenance management plan. The data analysis process aligns seamlessly with the extracted data from the various data sources of the judicial entities.

g. CCDW management layer

Its main function is to administer and control CCDW, involving share management, exchange management, run management, log management, authorization management, backup, and recovery management.

h. CCDW security layer

To deal with alarming and unpredictable security threats, CCDW must consider security. CCDW security layer is a base of other platform that monitors and protects CCDW. It deals with the security of operations and the prevention against inference problems that's why each entity depending on its level would have its own administrator in addition to a national or governorate-level "shared Data warehouse" administrator. The responsibilities of administrators therefore vary depending on the connection to the data warehouse they handle. For that, the layer implements:

- A role-based access control to limit data access by user level (district, provincial, national).
- An end-to-end encryption for data in transit and at rest.
- Audit logging to monitor data access and modifications and the anonymisation of confidential personal data to guarantee privacy.

These measures enhance trust in the system by ensuring compliance with legal standards and protecting against inference attacks.

3.4.1. Data collection, transformation, and integration process

Data collection start with seven data providers at different level (district, provincial, and national levels) submitting heterogeneous data (e.g., judicial records and legislation) to the CCDW using the data provider management layer.

The ETL process, is implemented by using WSO2 enterprise integrator, operates as follows: first of all, the extraction: multi-agent systems (monitoring and extracting agents) retrieve data in real-time from databases source, ensuring minimal impact on systems source. Secondly the transformation: transforming agents standardize data formats, resolve inconsistencies (like differing date formats), and anonymize sensitive data. and finally, the loading: loading agents store transformed data in shared data marts, which are organized in a star schema for efficient querying. By pre-computing frequent aggregations, materialized views optimize query performance. This process guarantees seamless integration across government systems, allowing the real-time data sharing and decision-making.

3.5. The prototype of our e-governance bi data interoperability framework

To enable the implementation of our approach within a real architectural context, it is necessary that some services combine the "request/ response" mode used in an SOA architecture with multi agent system in a data interoperability context as shown in Figure 3 (the use of 3 distinct groups of agents that allow the real time ETL process at 3 different level).

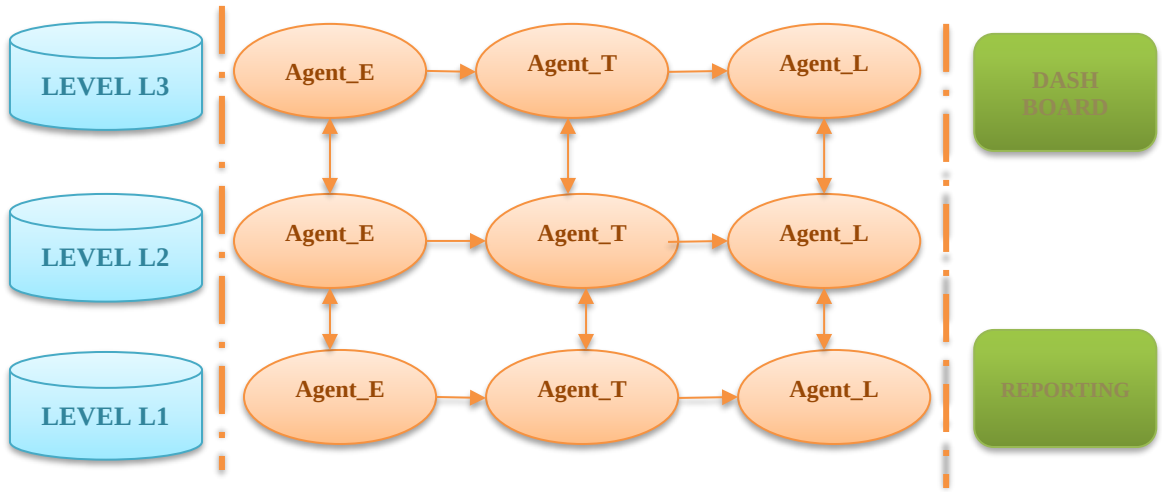

Figure 3. Integrated system of embedded agents for data interoperability detection (E: extraction, T: transformation, and L: loading)

Each agency level (district, regional, and national) constructs its own data warehouse using different protocols for access-management. In the ETL process, we employed a Multi Agent layer with the objective of integrating several agents that collaborate and perform various tasks according to their given roles in order to reduce the frequency of errors. The inclusion of agents at different phases of the ETL process, such as data extraction, data transformation, and data loading, serves to mitigate the potential for errors, enhance performance and reliability, and reduce execution time. When a problem occurs, Agents will trigger notifications. A warning is generated in the event that data is either lacking or insignificant.

Every agent is allocated a certain role by adhering to the established criteria for semantics and data formatting. The ETL-based agent method is employed in our scenario to enhance the effectiveness, efficiency, and security of the extraction, transformation, and loading process. In our prototype, agents are categorized into four distinct classes: the first group, referred to as the Monitoring Environment Agent, is responsible for monitoring the environment. The second group, known as the Extracting_Agent (Agent_E), is responsible for extracting information. The third group, referred to as the Transforming Agent (Agent_T), is responsible for transforming the extracted information. Lastly, the fourth group, known as the Loading Agent (Agent_L), is responsible for loading the transformed information.

4. RESULT AND DISCUSSION

The proposed framework for better e-governance aims to enhance data interoperability and decision-making processes in the justice sector. Through the establishment of a CCDW and the integration of BI tools, the framework enables efficient data sharing and exchange among different departments and entities. The framework was designed to meet the essential requirements for the CCDW, including data collection, processing, and storage, as well as providing integration application services for government and citizens. The framework was evaluated based on its ability to achieve the following objectives:

- Data sharing and exchange: the framework successfully facilitated data sharing and exchange across different departments, allowing for more efficient and transparent data governance processes.
- Centralized storage: the CCDW provided centralized storage of government information resources, enabling higher-level database construction and better integration management for information.
- Integration application services: the framework provided integration application services for government and citizens, allowing for better integration management and improved access to information.

4.1. Evaluation of the proposed prototype of the E-governance BI data interoperability framework using WSO2 solutions

The prototype of the E-governance BI data interoperability framework was developed using WSO2 solutions, including the WSO2 enterprise integrator and WSO2 data analytics server. These solutions were used to implement the ETL process, data sharing, and exchange layer, shared data marts, and support application layer.

- WSO2 enterprise integrator: this solution was used to implement the ETL process for data extraction, transformation, and loading. It facilitated the seamless integration of data from different sources into the CCDW.
- WSO2 data analytics server: this solution was used to analyse and visualize data collected in the CCDW. It provided insights into data trends and patterns, enabling better decision-making processes.

4.2. Performance of the prototype

The prototype demonstrated high performance in terms of data processing and integration. The use of WSO2 solutions allowed for efficient data extraction, transformation, and loading, resulting in a more streamlined data sharing and exchange process. Additionally, the prototype provided robust support for application development, enabling the creation of personalized databases and BI interactive dashboard systems.

4.3. Discussion

Implementing the proposed framework encountered several technical challenges, such as heterogeneous data formats, scalability issues and latency. For the heterogeneity of data formats: judicial data varies in structure (XML, CSV, and relational tables), which complicates the process of integration. The ETL process resolves this by using transformation agents to standardize different formats. Scalability issues: the growing volumes of data from seven providers are straining the storage and processing systems. The federated warehouse architecture and materialized views guarantee scalability by distributing data and optimizing queries. The latency: real-time ETL poses hazards of delays in large-scale exchanges. Multi-agent systems with WSO2 Enterprise Integrator reduce latency by parallelizing extraction and transformation processes. These solutions enabled the framework to handle complex judicial data efficiently.

Compared to existing approaches [25] and related works, the proposed framework and prototype offer several advantages. The use of WSO2 solutions provides a cost-effective and scalable solution for data interoperability in e-governance. Additionally, the framework's focus on data sharing and exchange across different departments and entities makes it a valuable tool for improving data governance processes.

Our study demonstrates the effectiveness of the proposed framework and prototype in enhancing e-governance through improved data interoperability. The use of WSO2 solutions has proven to be a successful approach, providing a scalable and cost-effective solution for data integration and analysis. Overall, the framework and prototype offer a practical and efficient way to improve data governance processes and decision-making in the justice sector.

4.4. Impact of interoperability on embedded systems in public justice e-services

Interoperability in public e-justice services [26] converts embedded systems from isolated components into intelligent, collaborative, and secure entities. By using federated data warehousing, agent-based ETL, and service-oriented architectures, the framework ensures that:

- Data flows easily between systems
- Security and access are tightly controlled
- Embedded systems can scale, adapt, and support advanced decision-making

This interoperability is more than just technical; it also supports the effectiveness, accountability, and accessibility of digital justice in modern governance. Table 4 shows how the proposed interoperability framework, which includes real-time ETL processes, a CCDW, and multi-agent systems, improves the functionality, security, and integration of embedded systems used in public justice e-services (such as court automation, identity verification, and law enforcement systems). Each row focusses on a crucial area of impact, relating it to embedded technologies and outcomes in the justice domain.

Table 4. Technical impact of interoperability features on embedded systems and e-justice service

Interoperability feature	Effect on embedded systems	Impact on public e-justice services
Real-time ETL	Enables devices to automatically standardize and sync data across platforms	Ensures timely data updates for courts, police, and legal systems
Federated data warehouse (CCDW) [27]	Connects distributed embedded systems across district, provincial, national levels	Facilitates seamless access to case files, records, and administrative data
Multi-agent system (monitoring and ETL agents)	Automates device-level monitoring, error detection, and task execution	Improves system reliability, reduces data inconsistencies, and alerts on anomalies
Role-based access control (RBAC)	Manages access permissions by user level and device type	Ensures that sensitive legal data is accessed only by authorized personnel.
End-to-end encryption and anonymization	Secures communication between embedded systems and CCDW	Protects privacy and complies with legal data protection standards
Materialized views and query optimization	Allows devices to retrieve pre-aggregated data efficiently	Speeds up report generation and decision support processes
SOA	Enables embedded devices to communicate using standard service protocols	Promotes interoperability among old and new justice technologies
BI dashboards and data visualization tools	Feeds embedded system data into centralized analytics platforms	Enhances transparency, performance tracking, and operational planning

5. CONCLUSION

In this paper we introduce a novel framework and prototype for enhancing e-governance through improved data interoperability. The framework demonstrates significant enhancements in data sharing, processing, and integration, leading to more efficient and effective data governance processes. We propose further research to refine the framework and evaluate its effectiveness in diverse e-governance contexts. Additionally, our paper presents the definition, architecture, and process of building a data warehouse. Using the Moroccan e-government data interoperability project, particularly in the e-justice context, as an example, we illustrate the design of a CCDW. We provide detailed information on the relationship between data providers and users in various government departments. Based on data analysis, we present the architecture of the CCDW technology. Our proposed method utilizes the SOBI framework for data sharing and exchange, which has been successfully applied in developing a shared data warehouse system for the Smart Government Moroccan project. Importantly, we implemented this framework using WSO2 solutions, which further validates its effectiveness and scalability in real-world applications. Our findings have broader implications for data e-governance, offering a scalable model for sectors like healthcare and education in Morocco and other countries facing similar data fragmentation challenges. Future work might investigate including artificial intelligence-driven analytics into the data warehouse to improve predictive insights, addressing scalability challenges for large-scale data volumes, and tackling issues of privacy and security, and implementation barriers such as cost, training, and regulatory compliance. This would broaden the SOBI/CCDW approach to smart cities for IoT-based urban planning, renewable energy via smart grids, and sustainable ecosystems, allowing real-time data flows for energy and civic optimisation.

ACKNOWLEDGMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or nonprofit sectors. Our sincere acknowledgment goes to Pr. Aris Ouksel, Professor of Information and Decision Sciences, from the University of Illinois at Chicago, USA for the support and assistance all along the project.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are not publicly available due to the sensitive nature of the judicial information involved, which is subject to privacy and legal restrictions under Moroccan data protection regulations. Data may be available from the corresponding author, [O.B.], upon reasonable request, subject to approval and compliance with applicable regulations.

REFERENCES

[1] M. C. Blanco, F. M. Gilmar, and T. Vesting, *The Rule of Law in Cyberspace*. Cham, Switzerland: Springer International Publishing, 2022, doi: 10.1007/978-3-031-07377-9.'

[2] D. Kwizera and S. Akkour, "Modernizing and digitalizing justice: Crossed perspectives on cyber justice in Morocco," *Journal of the Geopolitics and Geostrategic Intelligence*, pp. 139–158, 2022.

[3] F. Gurcan, A. Ayaz, G. G. M. Dalveren, and M. Derawi, "Business intelligence strategies, best practices, and latest trends: Analysis of scientometric data from 2003 to 2023 using machine learning," *Sustainability*, vol. 15, no. 13, p. 9854, Jun. 2023, doi: 10.3390/su15139854.

[4] H. Benaddi, N. Laaz, A. Bouhlal, and E. El Kettani, "Data storage architecture for e-government interoperability: Morocco case," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 29, no. 3, pp. 1678–1686, Mar. 2023, doi: 10.11591/ijeecs.v29.i3.pp1678-1686.

[5] F. Contini, "Artificial intelligence and the transformation of humans, law and technology interactions in judicial proceedings," *Law, Technology and Humans*, vol. 2, no. 1, pp. 4–18, May 2020, doi: 10.5204/lthj.v2i1.1478.

[6] A. Maralbaeva, "Evolution of e-justice platforms: From ICT in courts towards 'digital justice' portal in Kyrgyzstan," *International Journal for Court Administration*, vol. 15, no. 1, 2024, doi: 10.36745/ijca.582.

[7] R. K. Ahmed, K. H. Muhammed, I. Pappel, and D. Draheim, "Impact of e-court systems implementation: A case study," *Transforming Government: People, Process and Policy*, vol. 15, no. 1, pp. 108–128, Jan. 2021, doi: 10.1108/TG-01-2020-0008.

[8] N. Yavuz, N. Karkin, and M. Yildiz, "E-justice: A review and agenda for future research," in *Electronic Government*, 2022, pp. 385–414, doi: 10.1007/978-3-030-92945-9_15.

[9] OECD, *Digital Government Review of Morocco: Laying the Foundations for the Digital Transformation of the Public Sector in Morocco*. Paris, France: OECD Publishing, 2018, doi: 10.1787/9789264298729-en.

[10] European Commission, Directorate-General for Informatics, *New European Interoperability Framework: Promoting Seamless Services and Data Flows for European Public Administrations*. Luxembourg: Publications Office of the European Union, 2017, doi: 10.2799/78681.

[11] Government Digital Service and Central Digital and Data Office, "Data Standards Authority Strategy 2020 to 2023," GOV.UK, 2020. [Online]. Available: https://www.gov.uk/guidance/data-standards-authority-strategy-2020-to-2023. (Accessed: Mar. 30, 2026).

[12] H. Benaddi, N. Laaz, E. El Kettani, and Y. Hannad, "Ontology model for public services in Morocco based on 5W1H approach: PSOM-eGovMa," *Procedia Computer Science*, vol. 198, pp. 429–434, 2022, doi: 10.1016/j.procs.2021.12.265.

[13] G. Taffoni, "Morocco: Judicial changes between European and domestic models," in *The Politics of EU Judicial Support after the Arab Spring*, 2020, pp. 91–109, doi: 10.1007/978-3-030-50773-2_3.

[14] E. B. M. Mahmoud, E. B. Omar, and A. M. Ouksel, "Big data interoperability for e-governance," *Journal of Computer Science*, vol. 15, no. 10, pp. 1430–1438, Oct. 2019, doi: 10.3844/jcssp.2019.1430.1438.

[15] A. Shukla, B. Katt, L. O. Nweke, P. K. Yeng, and G. K. Weldehawaryat, "System security assurance: A systematic literature review," *Computer Science Review*, vol. 45, p. 100496, Aug. 2022, doi: 10.1016/j.cosrev.2022.100496.

[16] S. Gordon, R. Grigg, M. Horne, and S. Thurman, "Service-oriented business intelligence," *The Architecture Journal*, vol. 6, no. 1, pp. 23-32, 2006.

[17] A. Nambiar and D. Mundra, "An overview of data warehouse and data lake in modern enterprise data management," *Big Data and Cognitive Computing*, vol. 6, no. 4, 2022, doi: 10.3390/bdcc6040132.

[18] W. H. Inmon, *Building the Data Warehouse*, 3rd ed. New York, NY, USA: John Wiley & Sons, 2002.

[19] R. D. Thantilage, N.-A. Le-Khac, and M.-T. Kechadi, "Healthcare data security and privacy in data warehouse architectures," *Informatics in Medicine Unlocked*, vol. 39, p. 101270, 2023, doi: 10.1016/j.imu.2023.101270.
[20] G. Blazic, P. Poscic, and D. Jaksic, "Data warehouse architecture classification," in *Proceedings of the 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2017, pp. 1491–1495, doi: 10.23919/MIPRO.2017.7973657.
[21] P. Patel, "Cross-functional data modeling and data mart design for sales intelligence," *International Journal of Science and Research Archive*, vol. 16, no. 03, pp. 1383–1392, Jan. 2026, doi: 10.30574/ijsra.2025.16.3.2518.
[22] K. J. Merceedi *et al*., "Analyses the performance of data warehouse architecture types," *Journal of Soft Computing and Data Mining*, vol. 3, no. 1, 2022, doi: 10.30880/jscdm.2022.03.01.005.
[23] B. Guntupalli, "ETL architecture patterns: Hub-and-spoke, lambda, and more," *International Journal of AI Big Data and Computational Management Studies*, vol. 4, 2023, doi: 10.63282/3050-9416.ijaibdcms-v4i3p107.
[24] A. Venditti and F. Fasano, "A systematic approach to choose the data warehouse architecture," in *Proceedings of the 5th International Conference on Information Systems Security and Privacy*, 2019, pp. 711–718, doi: 10.5220/0007700307110718.
[25] O. Ogunwole *et al*., "Modernizing legacy systems: A scalable approach to next-generation data architectures and seamless integration," *International Journal of Multidisciplinary Research and Growth Evaluation*, vol. 4, no. 1, pp. 901–909, 2023, doi: 10.54660/.ijmrge.2023.4.1.901-909.
[26] A. Campmas, N. Iacob, and F. Simonelli, "How can interoperability stimulate the use of digital public services? An analysis of national interoperability frameworks and e-government in the European Union," *Data Policy*, vol. 4, 2022, doi: 10.1017/dap.2022.11.
[27] R. Kern, A. Kozierkiewicz, and M. Pietranik, "The data richness estimation framework for federated data warehouse integration," *Information Sciences*, vol. 513, pp. 397–411, Mar. 2020, doi: 10.1016/j.ins.2019.10.046.

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