7-15-2024

# Enhancing Municipal Asset Management: Identifying Technical and Social Barriers to Advanced Data Integration in London, Ontario Using Socio-technical Theory

Gary Stronghill
*Western University*

# Enhancing Municipal Asset Management:

# Identifying Technical and Social Barriers to Advanced Data Integration in London, Ontario Using Socio-technical Theory

*Subject Keywords*: Asset Management, Data Model Management, Geospatial Data Governance, Municipal Management

*Geographic keywords*: Canada, Ontario, London

MPA Research Report

Submitted to:

The Local Government Program

Department of Political Science

The University of Western Ontario

Gary Stronghill

2024

## 1.0. Introduction

The Ontario Municipal Act of 2001 mandates that municipal councils represent the public and the municipality's well-being. To this end, and with growing populations, aging infrastructure, and spending constraints, a city needs a well-designed and executed asset management plan to ensure accountability and transparency in its operations.

"Sustainable urban infrastructure planning and maintenance require an integrated approach that considers various infrastructure assets and their inter-linkages as a holistic system" (Du et al., 2023). To state this differently, how a pipe, a valve, a service, a policy, or a strategic plan relate to one another and the entire municipal system.

Relational databases and file management techniques are most commonly used to create and manage the asset registry to support asset management programs throughout all municipalities today. "The current IT structures in many municipalities do not support seamless information sharing, highlighting the need for interoperable systems that facilitate communication and data exchange across departmental boundaries" (Hobson et al., 2011)

More innovative techniques, including ontologies and knowledge graphs, are being implemented across many sectors, including government. This study will mention case studies from Vancouver and Edmonton to illustrate these advancements. Municipalities will require continuous improvements to keep pace with technology, and this paper suggests that focusing on the asset registry is an excellent place to start.

This study will first examine the literature on advanced data integration and the theoretical means (socio-technical theory) to understand the challenges of implementing innovative projects and how maintaining momentum by balancing the socio-technical aspects of the entire asset management process will contribute to a more robust system.

Secondly, it will bring relevant case studies from the City of Vancouver and, to a lesser extent, Edmonton to the reader's attention, providing evidence of the viability of implementing innovative technology to solve municipal challenges.

Lastly, based on my experience in GIS, public administration, and asset management and supported by the knowledge gained in this study's research, the paper will conclude with recommendations for the City of London (or others) to enhance the asset registry (AR) using ontologies and knowledge graphs.

## 2.0. Background

### 2.1. Asset Registry

According to Ontario Regulation 588/17, municipalities must develop strategic asset management policies that integrate their asset management plans with their budgeting and long-term financial planning processes. This includes a commitment to continuous improvement and adopting appropriate asset management practices (Ontario Regulation 588/17, 2021). Additionally, municipalities must prepare asset management plans detailing lifecycle activities necessary to maintain current service levels. These activities encompass the entire lifecycle of assets, from construction to decommissioning, and involve a thorough assessment of costs, options, and associated risks (Ontario Regulation 588/17, 2021).

The asset management system’s purpose is to optimize the performance of all assets. To do this, information about real-world assets is required. This paper focuses on the built infrastructure and the asset registry (AR) needed for a robust asset management program. An AR is a repository for asset data containing detailed and essential information about physical assets within a municipality. It supports efficient and effective asset management practices as a central hub of geospatial infrastructure knowledge.

Complex decision-making in city infrastructure management is challenging. The asset registry integrates critical inputs and outputs from key systems such as CMMS (Computerized Maintenance Management System), GIS (Geographic Information System), financial systems, and SCADA (Supervisory Control and Data Acquisition) to support decision-makers. It includes attributes such as asset types (e.g., roads, pipes), condition ratings (e.g., poor, fair, good), performance, and maintenance history (e.g., work orders, inspections).

2.2. Data Management

The research question focuses on **identifying the technical and social barriers to adopting enhanced data integration techniques in municipal asset management, specifically knowledge graphs and ontologies**. The City of London's geomatics division is responsible for managing the city's geospatial infrastructure systems, including GIS, CMMS, geospatial data management, Planfile (as-built drawings), and surveying. This includes the asset registry (AR).

The division is evolving and continuously looking to improve to advance a centralized digital infrastructure asset management program for the city's approximate $28B worth of physical asset infrastructure. This paper focuses on two advanced data management strategies (knowledge graphs and ontologies) that, when understood and implemented, would make the program significantly more robust.

"Municipal asset data are characterized by their complexity and are often scattered across various systems and formats, leading to significant integration challenges" (Martin, 2021). This study refers to these barriers as a lack of interoperability and data fragmentation.

### 2.3. Data Integration Techniques

Interoperability is the ability of a system or component to function effectively with other systems and components. This concept is often understood and used in technology-related circles to refer to two applications exporting and importing data but can also represent a socio-barrier between two silos of expertise in a municipal organization (i.e., planning, engineering, operations, finance). "This interoperability enables data to be the centerpiece of an enterprise information policy" (Martin, 2021).

The interaction between technology and social aspects is crucial for effective information sharing in municipal governments. Departments must collaborate and share information to manage resources and provide services efficiently. The current IT structures in many municipalities do not support seamless information sharing, highlighting the need for interoperable systems that facilitate communication and data exchange across departmental boundaries (Hobson et al., 2011).

### 2.4. Data Fragmentation

Data fragmentation refers to the issue of data being scattered across various systems and formats, leading to difficulties in consolidating and analyzing this information. Different departments within a municipality might use different software and databases, resulting in siloed data that is not easily accessible or integrable. This can impede the ability to gain a holistic view of municipal assets and make informed decisions.

These barriers, arising from multiple applications (systems) or domains (divisions or teams) operating somewhat autonomously, result in inefficiencies and suboptimal asset management strategies. The integration of geospatial knowledge graphs (KGs) and GIS-supported applications will expedite the evolution of municipal asset management programs by overcoming challenges related to interoperability and fragmented data handling. Knowledge graphs provide the underpinnings and architecture for effectively sharing data throughout an enterprise, contributing to developing a more data-driven and efficient urban asset management program in the City of London, Ontario.

Solving interoperability and data fragmentation are barriers all organizations face. Organizational change management, or the lack thereof, can significantly challenge the implementation of robust information systems necessary for managing infrastructure assets. This paper aims to identify and address these barriers, using Socio-technical Theory (STT) to highlight the importance of considering both social and technical aspects in the adoption of enhanced data integration techniques.

## 3.0. Literature Review

To support this paper, a review of data integration techniques was undertaken to better understand the innovative ideas of ontologies and knowledge graphs in the context of municipal government, specifically in infrastructure asset management. While it is important to provide a high-level introduction to the reader sufficient to see the benefits, avoiding delving into the advanced details of their design and functionality is equally important to maintain the scope of this study.

To better identify key barriers to implementation, socio-technical theory will provide a lens that emphasizes the human and technological factors that challenge the implementation of such initiatives. Lastly, a high-level review of current implementations (case studies) will round out the knowledge base compiled and used in support of the research question: What are the technical and social barriers to adopting knowledge graphs and ontologies in the municipal asset management system of the City of London?"

### 3.1. Asset Management

The Corporate Asset Management (CAM) Policy (By-law number CPOL.-389(a)-193) forms the foundation of the City of London's CAM Program, which helps identify and prioritize investments in municipal infrastructure to ensure it remains robust, safe, sustainable, efficient, and capable of supporting a high quality of life. The policy focuses on three fundamental goals:

1. Providing sustainable service to City customers.
2. Optimizing the value of municipal infrastructure assets while minimizing lifecycle costs.
3. Managing risks to service delivery.

The CAM Policy ensures alignment with the city's financial plans, budget, relevant Acts, accounting standards, policies, frameworks, and plans. It also emphasizes the importance of considering climate change mitigation, disaster planning, and informed decision-making regarding contingency funding (London, 2024).

### 3.2. Data Integration Techniques

Knowledge graphs and ontologies have emerged as pivotal data integration techniques, significantly impacting various sectors, including municipal asset management. Efforts from

Universities such as Toronto, along with private sector contributors, are leading the way in this direction of innovation using O&KG. Research also highlights the importance of interoperability in IT applications within municipal governments. The integration of diverse data sources and systems through ontologies can significantly reduce manual data handling, lower errors, and improve overall efficiency in municipal operations.

A knowledge graph represents a network of real-world entities and their interrelations, enabling a more intuitive and interconnected representation of data (Fig. 1). Du et al. (2022) highlight that knowledge graphs enhance the ability to retrieve, integrate, and interpret diverse data sources (GIS databases and text documents), fostering improved decision-making and operational efficiency in municipal contexts. This perspective is supported by the work of Hogan et al. (2021) and Ehrlinger & Wöß (2016).

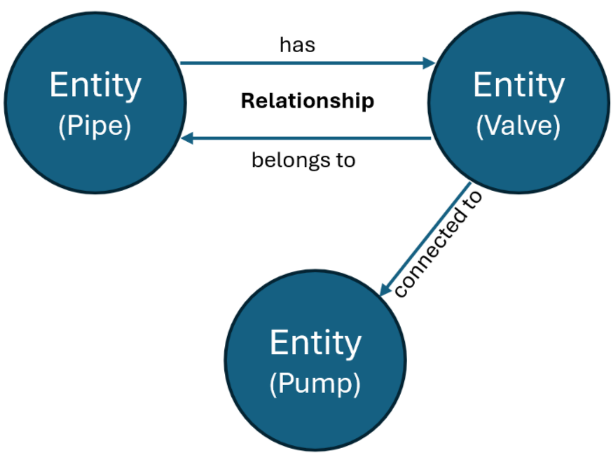

Fig. 1 – Simplistic Knowledge Graph

Knowledge graphs and ontologies have become essential tools in municipal asset management by enabling the integration of diverse data sources into a unified framework. Authors such as Halfawy and Figueroa (2006) emphasize the importance of these technologies in overcoming the traditional "islands of information," or "data silos," thus facilitating seamless data sharing and interoperability across municipal departments.

By using semantic relationships to link data not easily linked, like a *pipe* and its *geographic location*, as well as its *maintenance records* and connected *water meters*, a knowledge graph provides a comprehensive and interconnected view of the city's water infrastructure. Additionally, it can link to other relevant documents such as *reports*, *strategic plans*, and *budgets*, thereby integrating operational data with planning and financial information for improved decision-making. "Katsumi, Huang, and Fox (2022) highlight that ontologies enhance decision-making by providing structured frameworks that support semantic interoperability, leading to more sophisticated analytics and better-informed strategic planning. This is echoed by Barramou et al. (2020), who argue that standardized, vendor-neutral data models inherent in knowledge graphs promote data reusability and maintain data consistency, which is essential for effective asset management. In municipal asset management, these technologies would be invaluable for integrating disparate data silos. They support the development of comprehensive asset inventories, improved maintenance scheduling, and better-informed strategic planning. They improve the efficiency and effectiveness of managing infrastructure assets.

The adoption of knowledge graphs and ontologies can lead to more resilient and adaptive municipal [asset] infrastructure systems, aligning with the goals of smart city initiatives, [or asset management initiatives] (Khan et al., 2019; Hitzler et al., 2020). By leveraging these advanced data integration techniques, municipalities can achieve a higher degree of operational efficiency and strategic foresight, ultimately benefiting urban infrastructure management and public administration.

### 3.3. Socio-technical theory

Socio-technical theory (STT) provides a framework for understanding the interplay between social and technical factors in organizational settings. Originating in the mid-20th century, it posits that optimal organizational performance is achieved when there is a harmonious alignment between social systems (people, culture, structure) and technical systems (tools, processes, technology) (Trist & Bamforth, 1951).

Organizations, including municipalities, often focus on technology while minimizing the social or human side. This imbalance can hinder program success and return on investment. A new system may be chosen and implemented based on satisfying certain goals, such as better reporting. Without educating and communicating with all users at all levels of the workflow to understand the impact on their workflow, there is a risk of jeopardizing 'buy-in' and difficulty regaining the trust and support needed to maximize the system. STT emphasizes the need for integrated design approaches that consider both human and technological dimensions. This means involving the users in the design of the system.

Providing a participatory environment when designing information systems and involving expert users at every stage ensures the system meets their needs and fosters a deeper understanding of the bigger picture: the other users in the workflow they don't see. This will lead to a well-informed team from top to bottom.

**4.0. Theoretical Framework**

“The rationale for adopting socio-technical approaches to systems design is that failure to do so can increase the risks that systems will not make their expected contribution to the goals of the organization” (Baxter, 2010). Socio-technical Theory (STT) emphasizes the interdependence of social and technical systems in organizational contexts. It advocates for the joint optimization of both to improve organizational performance and user satisfaction (Baxter, 2010). For example, the CMMS application and field staff’s ability to complete their function must be optimized for the best experience and return.

According to STT paradigm, people are considered a “resource to be developed,” encouraging collaboration, commitment, and a risk-taking environment, as opposed to competition, alienation, and minimal levels of risk-taking (Trist, 1981).

4.1. Multi-level Framework

Geels, a leading scholar in the field of sustainability transitions, developed and refined a multi-level perspective (MLP) framework over several years, integrating insights from various theoretical perspectives. The MLP on socio-technical transitions emphasizes the complex interplay between niche innovations (e.g., intelligent traffic signals), existing regimes (current technologies and related policy), and broader landscapes (organizational culture) (Geels, 2005).

The dynamic nature of implementing or changing a system (i.e., ontology and knowledge graph-supported AR) is characterized by phases of institutional complexity, where competing logics coexist and create friction (Hacker & Binz, 2021). Coordination efforts to prioritize technology projects are under pressure to make choices that will impact existing niches. There are times when an organization needs to undergo extensive technological change. A good example is London's implementation of CMMS to improve work order management, inspections, and reporting and, of course, improve data for use in the asset management system.

MLP uses the term ‘transition’ for moving from one system to another but accounting for all levels of the workflow. Implementation is more specific, more the action of applying the plan. One of the key takeaways from London’s *implementation* of Phase One CMMS was the lack of understanding of the complete process from both the technology and business side. In hindsight, had we understood MLP, we would have approached it as a transition (at every level) to CMMS and not just a new piece of technology we want stakeholders to use.

4.2. Socio (people)

These transitions involve not only technological substitutions but also changes in user practices, regulations, and cultural meanings (Geels, 2005). The MLP can be complemented by the concept of institutional work to focus on micro-level dynamics in niche projects (Vassilakopoulou & Marmaras, 2013). This combined approach offers valuable insights for policymakers, technology providers, and researchers in understanding the complex processes of socio-technical transitions and navigating institutional complexities (Hacker & Binz, 2021; Vassilakopoulou & Marmaras, 2013). The scope of this study doesn't pay attention to micro-level dynamics but recognizes they exist and should be understood and addressed in future projects.

Municipalities have complex organizational structures with varying interests and priorities. Workflows can be deeply ingrained within the culture, making change difficult. To adopt a knowledge graph-based system, significant work is needed to educate everyone about the bigger picture, requiring cooperation at every scale of the organization. Abbas (2023), paraphrasing Herbst (1974), wrote, "[s]ocio-technical design signifies [that] the [successful] design or redesign of (information) systems [must be] achieved through stakeholder participation and incorporating interaction between people and (new) technologies" (Herbst, 1974).

4.3. Socio-technical in the design

STT serves as a high-level framework to guide the design process. By addressing the potential socio-technical challenges early in the development phase, it allows time for evaluation, and re-education to occur leading to a better designed system. This approach mitigates the risks associated with transitioning systems, system usability, and stakeholder satisfaction. Adopting

STT ensures a holistic approach to system design, balancing technical capabilities with human factors to achieve an integrated and effective asset management solution.

Integrating STT principles into the design phase of the AR would provide a framework to analyze the issues to adopting enhanced data integration techniques in municipal asset management systems. Perhaps I should have told you sooner, but to further the point; an asset management system is a socio-technical system according to its adherence to the five key characteristics seen below.

Below, I provide basic examples from an asset management system to satisfy Baxter's (2010) five key characteristics of open socio-technical systems.

**Interdependent Parts**: An asset management system integrates GIS data and maintenance schedules, where accurate location data is crucial for timely maintenance actions.

**Goal Adaptation**: The asset management system adjusts maintenance schedules and resource allocation based on near real-time data from inspection programs, as well as feedback from field workers.

**Internal Environment**: The asset management system includes a robust software platform (GIS, CMMS) and trained personnel who interpret data and make decisions (multiple divisions).

**Equifinality**: Achieving optimal asset management can be done through predictive analytics using machine learning, manual inspections by field staff, or a combination of both, providing flexibility in the system design.

**Joint Optimization**: The asset management system's effectiveness depends on both advanced software tools for data analysis (technology) and well-trained staff (socio) to interpret and act on the data, ensuring balanced optimization of both subsystems (socio-technical).

Incorporating socio-technical principles, specifically a multi-level perspective, is required to transition the multiple contributors to the Asset Register (AR), each producing data that is interdependent on one another. These operations produce critical data that the AMS needs, such as condition scores and maintenance details. The goal of a well-designed AR using ontologies and knowledge graphs would bring the data together in a smooth manner with minimal disruption to the *silos of expertise* that are required but can contribute to interoperability challenges as a result of *data silos*.

## 5.0. Methodology

### 5.1. Research Design

This study adopts a qualitative case study approach, focusing on the City of London's Geomatics Division to explore the technical and social barriers to adopting enhanced data integration techniques in support of infrastructure asset management, specifically the asset registry (AR). A qualitative case study is appropriate for this research as it allows for an in-depth understanding of complex phenomena within their real-life context.

### 5.2. Case Study

The City of London was chosen due to its ongoing efforts to advance its asset management system and the strategic role of its Geomatics Division. The Geomatics Division functions as the city's GIS/CMMS Centre of Excellence, making it an ideal case for studying the adoption of advanced data integration techniques. In my capacity as the manager of geospatial infrastructure systems and an MPA candidate (at the time of writing), I bring 25 years of experience in geospatial data management and a forward-looking perspective on the challenges of managing infrastructure assets. This selection allows for an examination of the unique challenges and opportunities encountered in this specific setting. Geomatics has always been the ‘keepers’ of spatial data, both legally defined and natural, as well as the built environment (asset infrastructure).

Given my dual role as a researcher and practitioner, there is a unique opportunity to provide insider insights.

5.2. Theoretical Framework

This study is guided by socio-technical theory (STT), which provides a lens through which to understand the interplay between technical and social factors in the adoption of new technologies. This framework helps categorize the identified barriers into technical and social challenges. It also serves to keep the connection between the two grounded in theory as this paper progresses.

Having an enhanced AR makes the system more successful in meeting the socio-technical criteria needed for project success. It's self-serving; STT helps build a system that, when implemented, will provide better service by successfully addressing STT priorities.

5.4. Data Collection

Relevant documents, including academic papers, literature reviews, white papers, policy and plans, and industry standards, were sought with a focus on the most recent discourse. A systematic search was conducted using databases such as Google Scholar and industry-specific repositories. Given the innovative subject matter and the pace at which it evolves, older documents help identify the need for better tools for asset data management but lack the currency of the technology itself, which is becoming more accessible to organizations.

### 5.5. Data Analysis

The collected data was analyzed using thematic analysis, a method well-suited for identifying patterns and themes within qualitative data. The analysis involved several steps:

1. Familiarization with the data through repeated reading and note-taking.
2. Identifying significant features related to barriers in data integration.
3. Categorizing the themes into technical and social challenges.

Implementing ontologies and knowledge graphs (O&KG) to define and interact with a complex system such as a municipal government presents several challenges. As with any attempts to implement technology solutions, we will face issues related to the interoperability between technologies (different systems, different file formats) and social elements (historic workflows, change management, perceived value).

### 5.6. Ethical Considerations

Ethical considerations were considered throughout the research process. Given my dual role as both a researcher and a manager within the case study context, it necessitates a conscious effort to mitigate any potential bias in the interpretation of findings. To this end, I limited my opinions, and what I do make of real-world examples, I keep within the scope of this paper. All data sources were publicly available, and no confidential information was used. The analysis was conducted with integrity, ensuring the accuracy and reliability of the findings.

## 6.0. Motivating Case Studies

### 6.1. Vancouver's Digital Strategy

The City of Vancouver released a digital strategy in 2013 identifying four pillars of focus: Engagement and Access, Infrastructure and assets, Economy, and Organizational Digital Maturity. The focus of this study relates to the pillars of **infrastructure and assets** and **Organizational Digital Maturity**, which are most relevant to enhancing municipal asset management. By conducting a 'current state assessment,' Vancouver identified three key themes: Design Strategically and deploy Tactically, Empower Employees to Support Empowered Citizens, and Digital Governance. Notably, they recognized a socio-technical barrier: "[s]trong resistance exists within the city to move services to a digital channel without addressing the end-to-end people, process, and technology concerns" (Vancouver, 2013).

One of the key barriers facing London, and arguably all municipalities, is resistance to change. Many processes within government organizations are ingrained in the culture, making integrating or changing to new systems difficult. In socio-technical theory, the imbalance between technology and people is a critical factor in a project's success. Vancouver's approach to addressing these barriers can provide valuable insights for London. For example, Vancouver understood that designing strategically and deploying tactically would help overcome resistance to change through careful planning that aligns with existing processes and addresses concerns users may have with the new direction.

Connecting back to the five characteristics of STT, Vancouver addressed the following: “System performance relies on the joint optimization of the technical and social subsystems. Focusing on one of these systems to the exclusion of the other is likely to lead to degraded system performance and utility.”

In 2013, they recognized that a lack of formal governance had resulted in a less cohesive experience and strategic impact. Governance lends to *joint optimization*, a unified system. London currently lacks unified governance across asset management systems. A good example is the role of AR and Geomatics in the asset management workflow of the City of London, which is still operating under historic governance models based on the collection of data through surveys, CAD, and GIS. This model needs to be updated to reflect the new roles and responsibilities around AR and CMMS, including enhanced data management like O&KG.

Vancouver defined its services and accountabilities, optimized technology use for productivity, and fostered a digital culture within the organization. The goal here is to drive strategic impact and reduce risk. The more they understand the relationships between their domains (services) and responsibilities, the better they can adapt to changes; *goal adaption* is another characteristic of a socio-technical system. For London to address key barriers to implementing enhanced data management like O&KG for its AR and to strengthen *goal adaption* and *joint optimization*, it will also need to implement robust governance.

### 6.2. Digital Infrastructure Mapping

Vancouver has digitally mapped its infrastructure with the objectives of implementing an agile infrastructure plan, optimizing digital infrastructure and physical assets, and continuously improving its digital infrastructure strategy. This digital representation of the city's infrastructure, including pipes, roads, and other assets, is incredibly valuable to asset management. Knowing and utilizing the location of assets in the real world to assist maintenance and inspection programs that ultimately feed the asset management system is critical. Ultimately, this represents an enhanced AR for the asset management system.

London can learn from Vancouver's approach to optimizing digital infrastructure, particularly when enhancing its Asset Registry (AR), building onto the existing structured geospatial knowledge with unstructured data sources, such as reports and other text documents.

### 6.3. City of Edmonton

To quickly share more innovative examples, Edmonton is noted for its integration of advanced technologies to enhance urban living. The city has implemented several applications and projects to improve the quality of life, including smart traffic management, which uses sensors to monitor traffic flow and adjust signals in real time to reduce congestion and improve road safety. Additionally, Edmonton is developing digital twin technology to create virtual replicas of physical assets and infrastructure for better scenario simulation and maintenance planning. Furthermore, the city applies predictive analytics using AI for various urban management tasks, such as infrastructure inspections and maintenance.

## 7.0. Case Study in Progress

Geomatics (at the City of London) plays a crucial role in modern municipal asset management by providing the tools and techniques necessary for effective data integration and analysis from the asset registry (AR). London's asset management plan is considered one of the leading examples among Ontario municipalities; however, in practice, the *interdependent parts* are not reaching *joint optimization*. This continuous improvement to the AR would be a strength of our asset management system. Next-generation Geomatics Divisions need education and tools to be the stewards of asset infrastructure data.

### 7.1. Background

The City's Geomatics Division has well-ingrained roles and responsibilities related to more traditional tasks like surveying, planfile, and drafting. In one form or another, spatial data management is as old as the city itself. It's fitting then that when designing the asset management plan, Geomatics was chosen to administer the asset registry. Over the past eight years, GIS and CMMS responsibilities have increased, and new roles have been developed to provide the expertise needed to not just keep up but improve upon current services.

Geomatics, along with Information Technology Services - GIS, is responsible for different sides of the city's geographic information system (GIS). With a virtual splitting of duties that ensures GIS technology infrastructure is well managed and aligns with corporate ITS policies, ITS provides expertise that will be critical to enhancing the AR. The data models and the geospatial data that are used in the asset management system (and other systems) are the domain of Geomatics in partnership with the respective divisions (i.e., water, sewer, roads, etc.) that are responsible for the core assets.

Ontario Regulation 588/17 (O. Reg. 588/17) relates to asset management planning for municipal infrastructure in Ontario, Canada, and identifies the core assets as being roads, water, sewer, and stormwater. In London, these assets account for approximately 80% of our replacement costs and therefore receive a higher degree of attention from our asset management plan and, therefore, the AR.

7.2. Data Management

Geomatics manages the CMMS, which our operations divisions use to inspect and manage work orders on city infrastructure (pipes, roads, etc.) in a GIS-centric application. The outputs (condition scores, installation dates, etc.) are used as inputs to the greater Corporate

Asset Management Team (CAM) as well as reports and decision-making efforts. Geomatics plays a critical role in municipal asset management as the steward of the asset registry. However, not all inputs to the asset management system (AMS) are available in GIS or CMMS.

The asset information system (AIS) also needs data from other sources such as reports, SCADA, engineering models, and various documents. Currently, the AR has no way to store or facilitate the extraction of data from various systems (manual efforts excluded), causing data fragmentation. Maintaining and sharing data across these ‘data silos’ is a challenge. O&KG will enhance the AR and provide access to this information, lessening the impact of data silos.

Information recorded in documents is recognized as being labor-intensive when assimilating into the AMS. Documents, for example, can be useful after scanned using OCR or entering key information from hardcopy paper forms manually. Fortunately, most of the 'paper' is gone, and most of the unstructured data we need for asset management is digital, like Word documents, spreadsheets, presentations, and reports. It’s still a challenge to incorporate their information (data) and turn it into knowledge, but being digital at least means they are ready for enhanced data integration.

A knowledge graph-powered asset registry, having the ability to draw relationships between a real-world asset, our water system as an example, and the documentation for the entirety of processes that go into its planning, procurement, maintenance, and replacement, would be the goal of an enhanced AR.

## 7.3. Current Data Integration Practices

Geospatial infrastructure asset data is captured from drawings, plans, and surveys that are converted from CAD to GIS, and the additional attributes to fill out the model are then collected.

This data is stored and managed in one of six geodatabases used to host the city's geospatial data. Not all of the data is directly related to asset management; however, the majority of it represents our built environment, the core assets of roads, water, sewer, and stormwater systems. The other data contributes to the larger scope of asset management, planning, and development, for example. Included are non-core assets such as parks and forestry, which still deserve attention in the asset management system.

Managing AR to the extent we are currently capable involves geospatial data models in relational databases that mirror real-world assets as closely as possible in a digital world. With the exception of model adjustments to aid in the interoperability of custom design tools, CRM, CMMS, and CAM, these data models have changed very little since our infrastructure was computer-aided drafting-based (CAD) and needed a review and redesign.

### 7.4. Evolution of Geomatics Role

There is an evolution required in geomatics roles and responsibilities to not just be the stewards of geospatial data but also knowledge engineers of the city's AR by leveraging innovative data management. Knowledge graphs and ontologies are two powerful tools that can provide a knowledge layer within the AR that draws its data from disparate systems, allowing for the searching and accessing of data.

If Geomatics 1.0 represents the evolution from paper to digital, hard copy designs being digitized to CAD and eventually received directly in a CAD format, and Geomatics 2.0 (current) represents the evolution from CAD to GIS, a period where data became more available, and attributes define the real-world assets as well as defining relationships to other data. Then, a Geomatics division that manages the enhanced AR and GIS data models for the majority of core and non-core assets as defined in O. Reg. 588/17, and the CMMS systems critical to asset management at the City of London must represent Geomatics 3.0.

### 7.5 Technical Challenges

#### Data Fragmentation

Integrating diverse data sources, including structured (database) and unstructured data (reports), presents significant challenges. Geomatics directly manages 2 of the four core assets' geospatial data as defined in o.reg 588/17, sewer and water. Integrating spatial and non-spatial information from as-built drawings. The other two core assets, stormwater, and transportation, are managed by other divisions that don't have the same technical abilities as Geomatics or focus on the data that the asset management registry needs.

#### Interoperability

Ensuring seamless interoperability between different GIS and asset management systems is a challenge. When fully implemented across all asset levels, CMMS will help alleviate interoperability challenges. Using enhanced data management techniques will also help with the effects of data silos, especially in the absence of CMMS. London has yet to implement CMMS in transportation, parks, and forestry, each representing a silo of expertise and associated data that require joint optimization and goal adaption to transition into a more robust asset management system.

### 7.6. Socio barriers

#### User Resistance

Resistance from users accustomed to traditional methods is always a concern. Lessons learned during the early phases of CMMS implementation have helped with the transition from older custom applications to a better-integrated system. Some domains have yet to evolve past hard copy and manual data entry; this poses a threat as the learning curve will be greater. However, the benefits will also be such that these new users will likely welcome the change.

Skill Gaps

Need for training programs to develop new skills among staff is critical to all innovative technology implementation. This need resides in many areas of our organization from ITS staff required to support more advanced systems to field workers trained in data collection. Given the integrated nature of enhanced data management specific to asset management, education at all levels of the organization will be critical to success.

## 8.0. Analysis and Discussion

### 8.1. Technical Barriers

Data Fragmentation

Municipal asset data are characterized by their complexity and are often scattered across various systems and formats, leading to significant integration challenges. For example, historical inspection records, which are crucial for asset management predictors, are often siloed and not easily accessible. This fragmentation impedes the ability to gain a holistic view of municipal assets and make informed decisions. As McComb (2019) emphasizes, "data is represented and managed specifically in service to the applications that use it, making the enterprise data architecture application-centric." This results in data being "trapped" within applications, requiring processes to "release" it for broader use.

Advanced techniques like knowledge graphs that can help alleviate data fragmentation necessitate sophisticated data modeling and integration capabilities. Much work has been done to address ontologies for urban environments that can serve well as starting points for implementing an enhanced AR. The City of Toronto has developed useful asset management ontologies that could serve as a starting point, but London would still face significant challenges in adapting these frameworks to its unique context.

### Interoperability

Ensuring seamless interoperability between different GIS and asset management systems is another major technical barrier. The City of London's current enterprise approach exhibits data fragmentation and interoperability challenges, as different divisions use disparate systems managed independently. Standardizing data models is essential to enhance interoperability and enable better integration of management processes. An enhanced AR, underpinned by a comprehensive ontology for infrastructure assets, would support semantic and technical interoperability across systems.

Vancouver's digital strategy included a comprehensive digital mapping of its infrastructure, allowing for agile planning and optimized asset management. This approach significantly enhanced interoperability and provided valuable insights for maintenance and inspection programs.

## 8.2. Social Barriers

### User Resistance

Resistance from users accustomed to traditional methods poses a significant barrier. Implementing an enhanced AR requires a robust change management strategy that includes user involvement in the design process and education on the broader asset management goals. Stakeholder misalignment and lack of trust are significant obstacles that can hinder the successful adoption of new technologies. Applying STT can help address these issues by considering the human aspects of asset management systems, thereby facilitating smoother transitions.

Understanding the organizational context in which we are implementing asset management strategies is important to users of the system. Not understanding or appreciating the 'bigger picture' can cause resistance. Often the onus is put on users to change how they perform their work with little or no direct benefit to them, in some cases it can even slow down productivity in the field for productivity in the office (planning, designing, reporting).

Effective communication about the benefits and impacts of new technologies, coupled with adequate training, can mitigate resistance. Users are more likely to embrace changes when they understand the rationale behind them and feel competent in using new systems.

Training and Skills

Developing new skills among staff is crucial for leveraging advanced data integration techniques effectively. Municipalities often focus on technology implementation while overlooking the need for training programs to equip staff with the necessary skills. For instance, implementing knowledge graphs and ontologies requires new competencies in data management and analysis. Training programs should be designed to bridge these skill gaps and ensure that staff can fully utilize the new systems.

Training should not be a one-time event but rather an ongoing process. As technologies evolve, continuous learning opportunities should be provided to keep users updated and proficient in their roles. Training should also include non-technical elements to help build the collective knowledge of the organization. Exposure to other domains, for example, can teach teams how their work impacts others and promote a unified approach that goes beyond technology.

Lastly, developing training and skills shouldn't happen in a vacuum; soliciting input from users on training design and content is key to successfully addressing their needs. Accepting and actioning feedback can also be part of an educational program. This is being done with great success in the water and sewer operations divisions currently suing CMMS.

### Organizational Culture

Organizational culture plays a critical role in the adoption of technology. A culture that supports innovation and collaboration is vital for the successful implementation of enhanced data management systems. The case studies of Vancouver and Edmonton demonstrate how fostering a digital culture within the organization can lead to significant improvements in asset management practices. London can learn from these examples by promoting a culture that embraces technology and encourages cross-functional collaboration.

Implementing new technologies requires a shift in organizational culture. STT suggests that cultural change should be managed carefully and gradually, with efforts to build buy-in and support from all levels of the organization. Strong leadership is crucial for fostering a culture that supports technological change. Leaders should articulate a clear vision, demonstrate commitment to the change, and model behaviors that align with the desired cultural attributes.

### Application of STT

The findings align with the STT framework, highlighting the importance of addressing both social and technical factors in adopting enhanced data integration techniques. Meijer and Thaens (2018) propose a framework that emphasizes the need to link initial enthusiasm to long-term collaboration. Similarly, Jiang et al. (2020) highlight the necessity of aligning technological innovation with existing urban challenges. These insights underscore the importance of a balanced approach that considers the interplay between social systems (people, culture, structure) and technical systems (tools, processes, technology).

There can be a lot of 'hype' around a new initiative as stakeholders see the potential. As projects get implemented and the focus turns to administering, it's easy to forget about the continuous improvement that comes from collaboration. We turn our focus to 'keeping the lights on.'

**9.0 Conclusion**

This study investigated the technical and social barriers to adopting enhanced data integration techniques, such as knowledge graphs and ontologies. It did so by first summarizing the literature surrounding this topic, looking for information pertinent to the challenges to implementation. Secondly, I highlighted two examples that have implemented innovative systems with success, thus proving that they are within reach. Lastly, I will make recommendations based on knowledge gained from this study to focus on the City of London’s asset management system and its asset registry from the perspective of the Geomatics Division's current and future responsibilities.

This analysis was uniquely informed by the author's pursuit of an MPA and 25 years of experience as a GIS professional and manager within Geomatics. The analysis revealed technical and social barriers typical of most technology implementations, including data fragmentation, interoperability challenges, user resistance, and skill gaps. These barriers impede the effective integration of diverse data sources and the implementation of advanced asset management strategies.

The author's belief, supported by this report, is that the benefits of enhanced data integration techniques far exceed the challenges. Once implemented, silos of expertise remain, but the data they create becomes available, free from organizational structure, internal processes, and competing values. This makes the organization agile to change, allowing knowledge to be created and shared effectively. Looking to the future, digital twins enable us to run scenarios for our real-world systems, providing valuable insights and improving decision-making.

## 9.0. Recommendations

The case studies presented exciting innovations such as 'Digital Twins,' which one day will be commonplace. This study recognizes that at that scale, much work needs to be done, and covering the topic of digital twins is beyond the scope of this paper. However, ontologies are scalable, so London can implement, at a smaller scale, a single program, such as hydrant maintenance, or a larger initiative, such as water operations, to learn and develop familiarity amongst asset management teams.

Based on the findings, the following recommendations are proposed for the City of London to enhance its asset management practices by incorporating socio-technical principles into its design.

Conduct a Current State Assessment

There needs to be tighter integration in the knowledge created and managed for an asset's entire lifecycle. Using inputs like o.reg 588/17 to create an ontology that defines that digitally (semantically) could serve as a framework to assess the current state asset management systems level of compliance. Recall a visual of circles connected by lines, with each circle representing a rule; if we can't satisfy the rule, we have connections to be made and data to be found.

Develop a Strategic Plan

London is well-positioned to implement an ontology and knowledge graph-designed asset registry. The limiting factor is the scale of implementation, but that is beyond the scope of this paper. (City of London, 2023, p. 68) of the City's Strategic Plan lists the following in support of such projects:

- Provide high-quality enterprise-wide staff training informed by industry best practices.
- Implement continuous improvement approaches enterprise-wide.
- Implement technology, business processes, data, and analytics through the Technology Investment Strategy.
- Conduct targeted service reviews to ensure the efficient and effective allocation of resources.

The Corporate Asset Management Policy is a Council policy that sets out the city's approach to planning, designing, constructing, acquiring, operating, maintaining, renewing, replacing, and disposing of its municipal infrastructure assets in a way that ensures sound stewardship of public resources, while delivering effective and efficient customer service. The CAM Policy provides a foundation for the City's CAM Program, which assists in identifying and prioritizing investments in existing and future municipal infrastructure assets. The policy also identifies the roles and responsibilities of staff who make infrastructure-related decisions to provide a clear governance structure to ensure that other elements of the CAM Program (CAM Strategy, CAM Plan, CAM Processes) align with the CAM Policy (City of London, 2024).

The connection between London's Asset Management division (AM) and the Geospatial Infrastructure Systems Group (GISG) needs to be further developed to strengthen the asset management system. This would require Geomatics (which includes GISG) roles and responsibilities to be better defined and aligned with AM.

Implement Governance Structures

It's been recognized that London needs to establish a GIS governance structure to oversee data management and interoperability efforts, ensuring consistent application of standards and practices across divisions. Governance plans going forward should be considering more advanced data management, to prepare for upcoming needs. A distinction between governance on the hardware and software, vs the data model and data it contains, will be important to make.

## 10.0. References

Abbas, R., & Papagiannidis, S. (2023). Socio-Technical Theory: A review. In S. Papagiannidis (Ed.), *Theory Hub Book*. Available at https://open.ncl.ac.uk

Aurel von Richthofen, P. H. (2022). Semantic City Planning Systems (SCPS). *Journal of Planning Literature, 37*(3), 415–432.

Baxter, S. (2010). Socio-technical systems: From design methods to systems engineering. *Elsevier*, p. 14.

City of London. (2024, July 10). Corporate Asset Management. Retrieved from https://london.ca

City of Vancouver. (2024, July 5). In-Depth Strategy. Retrieved from https://vancouver.ca

Du, H., Wang, L., Alechina, N., & Jackson, M. (2023). City infrastructure ontologies. *Computers, Environment and Urban Systems, p. 104*, 101991.

Du, J., Wang, S., Ye, X., Sinton, D. S., & Kemp, K. (2022). GIS-KG: Building a large-scale hierarchical knowledge graph for geographic information science. *International Journal of Geographical Information Science, 36*(5), 873-897. https://doi.org/10.1080/13658816.2021.2005795

Ehrlinger, L., & Wöß, W. (2016). Towards a definition of knowledge graphs. In *SEMANTiCS (Posters, Demos, SuCCESS)*.

Fatimazahra Barramou, K. M. (2020). Toward a Multi-Dimensional Ontology Model. *Journal of Geographic Information System, 12*, 697-715.

Gracias, J., Parnell, G., Specking, E., Pohl, E., & Buchanan, R. (2023). Smart Cities—A Structured. *Smart Cities, p. 6*, 1719-1743.

Halfawy, M., Newton, L., & Figueroa, R. (2005). Municipal Infrastructure Asset Management Systems: State-of-the-Art. *Institute for Research in Construction, National Research Council, Canada*.

Hogan, A., Blomqvist, E., Cochez, M., D'Amato, C., de Melo, G., Gutiérrez, C., ... & Zimmermann, A. (2021). Knowledge graphs. *ACM Computing Surveys (CSUR), 54*(4), 1-37. https://doi.org/10.1145/3447772

Katsumi, M., Huang, T., & Fox, M. (2022). Towards Requirements for an Ontology of Asset Management. In *12th International Workshop on Formal Ontologies meet industry* (p. 12). Tarbes, France.

Martin, S. S. (2021). The rise of the knowledge graph: Toward modern data integration and the data fabric architecture. *O'Reilly Media, Inc.* Retrieved from https://www.cambridgesemantics.com/oreilly

Richthofen, A. v., & Halfawy, M. (2022). Developing Enterprise GIS-Based Data Repositories For Municipal Infrastructure Asset Management. *Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, 10.

Richthofen, A. v., & Papagiannidis, S. (2023). Socio-Technical Theory: A review. *Theory Hub Book*. Available at https://open.ncl.ac.uk