Toronto Metropolitan University

PEMAC

Leveraging Municipal Asset Master Data and Information for Maintenance and Reliability Readiness

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White Paper

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This project has been conducted by Toronto Metropolitan University and PEMAC Asset Management Association of Canada through an initiative that is offered through the Municipal Asset Management Program, which is delivered by the Federation of Canadian Municipalities and funded by the Government of Canada.

Funding for the partner organizations' grants is provided by the Municipal Asset Management Program (MAMP), an eight-year, $110 million initiative funded by the Government of Canada and delivered by the Federation of Canadian Municipalities. The program provides asset management training, funding and information sharing to enable municipalities to access the data needed to plan effectively.

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EXECUTIVE SUMMARY

This white paper presents the activities and results of the project entitled *"Leveraging Municipal Asset Master Data and Information for Maintenance and Reliability Readiness."* The project was conducted jointly by Toronto Metropolitan University, the PEMAC Asset Management Association of Canada, and municipal representatives across Canada.

The project aims to influence the acquisition of timely and effective asset master data and information and provisioning of resources for Canadian municipalities to improve their maintenance management programs and operational readiness. The project involved five primary phases: (1) conducting a national current-state survey of Canadian municipalities, (2) data analysis and insights reporting, (3) curriculum development and delivery, (4) developing a white paper, business case, and guide, and (5) educate, collaborate and grow. The business case (Lawlor and Easa, 2024) and the guide (Lawlor et al., 2024) are presented separately.

The national survey of Canadian municipalities was conducted to determine how asset and maintenance management and reliability engineering data and information are collected, when, and how it is set up in various systems across the asset's lifecycle stages. Municipalities from very small to very large responded to the survey, and 71 responses were received. The survey results helped determine the current state conditions and future state opportunities. The success stories survey aimed to gather information regarding the municipality's exemplary work, including objectives for the exemplary work, pertinent lifecycle stage, areas of improvement, exemplary work description, implementation benefits, issues before implementation, and implementation challenges. The success stories covered small, medium, and large municipalities. The six-week live online training course (attended by 52 participants representing 21 municipalities) was delivered in two cohorts. The project has proposed four levers to advance asset maintenance and reliability throughout the four lifecycle stages: lifecycle planning, design & acquire/build/commission, operation & maintenance, and decommission & disposal. The levers are master data and resource readiness (MDRR) for maintenance and reliability, sustainability (climate change and circular economy), emerging technologies, and data standardization and guidelines. Finally, the white paper, business case, and guide are developed to help increase the profile, understanding, benefits, and requirements for asset master data and information readiness during an asset's acquisition stage before being handed over to the operations and maintenance stage.

Based on the course and survey findings, specific recommendations are made to advance MDRR throughout the asset lifecycle. The recommendations will help municipalities improve how and when they manage their systems to improve asset and maintenance management across municipalities. In addition, they will open the way for establishing an MDRR community and increase collaboration among professional organizations and Canadian municipalities to promote the maintenance levers proposed in this project.

ACKNOWLEDGMENTS

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Finally, the authors would like to recognize the efforts of the 71 municipality professionals who participated in the online survey, providing invaluable data and insights on their current asset management practices. We also extend our deepest gratitude to all the municipalities and their representatives who generously shared their time, experiences, and insights for the targeted success stories survey. Their stories and expertise have enriched this paper and benefited other organizations striving for excellence in maintenance and reliability readiness. Further, the authors recognize the 52 participants in the training course (representing 21 municipalities) who took the training course, participated in the lively discussion, and provided valuable input in the course's case studies and assignments.

The members of the PEMAC team, TMU team, and course instructors are listed below.

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GLOSSARY OF ABBREVIATIONS

AM	Asset Management
AST	Asset Systems Technology
API	Application Programming Interface
BIM	Building Information Modelling
CapEx	Capital Expenses
CMMS	Computerized Maintenance Management Systems
D & ABC	Design & Acquire/Build/Commission
D & D	Decommission & Disposal
DT	Digital Twins
EAMS	Enterprise Asset Management System
FCM	Federation of Canadian Municipalities
GFMAM	Global Forum on Maintenance and Asset Management
GIS	Geographic Information System
IoT	Internet of Things
ISO	International Organization for Standardization
KPI	Key Performance Indicators
MC%RAV	Maintenance Cost as a percentage of Replacement Asset Value
MM	Maintenance Management
MR	Maintenance and Reliability
MDRR	Master Data and Resource Readiness (data refers to both data and information)
O & M	Operation & Maintenance
OpEx	Operation Expenses
PAS55	Publicly Available Specification
PMI	Project Management Institute
PRC	Performance, Risk, and Cost
PM	Preventive Maintenance
PdM	Predictive Maintenance
PSAB	Public Sector Accounting Board
PSO	Public Sector Organization
RCM	Reliability-Centred Maintenance
SAP PM	Systems Applications and Products in data processing – Plant Maintenance

1.1 Background

Improving asset management (AM) for Canadian municipalities to realize better value from their assets has been recognized as a national need. Accurate and accessible data and information (or simply data) are essential for all asset lifecycle stages. Although data are necessary for all lifecycle stages, they are especially critical for the operation and maintenance stage to achieve master data and resource readiness (MDRR) for maintenance and reliability. Maintenance manages the assets to overcome failure and ensure operational continuity and involves four types: reactive, preventive, predictive, and breakdown (Rao, 2023). Reliability refers to the ability of the maintenance program to ensure continuity in operations with minimal downtime. The reliability measures include failure rate, time between failures, time to failure, and availability. MDRR provides all resources, data, and information to move assets toward a state of preparedness for maintenance and reliability (MR) work on the first operational day. For purposes of this project, the municipal asset lifecycle is designated into four stages: lifecycle planning, design & acquire/build/commission (D & ABC), operation & maintenance (O & M), and decommission & disposal (D & D), as shown in Fig. 1.1. This framework is a modified version of the framework of the Global Forum on Maintenance and Asset Management (GFMAM, 2014). The proposed framework highlights two essential aspects of municipal asset lifecycles.

First, lifecycle planning (Stage 1) has been designated as a distinct stage to stress the importance of proper long-range lifecycle planning of municipal assets. This is a critical stage for enabling MDRR as a combination of budget and process, where the AM office (financial) coordinates all lifecycle stages with the funding plans. Specifically, the long-range capital expenses (CapEx) identify maintenance cost as a percentage of replacement asset value (MC%RAV) at the outset and communicate that to the operation expenses (OpEx) budgeting planning team later when assets are selected. Following the lifecycle planning stage, Stage 2 (D & ABC) commences.

Second, the O & M stage was split to highlight their primary functions. The operation ensures the efficient and effective use of the assets to maintain suitable conditions. Maintenance optimizes the asset's performance, risk, and cost (PRC) by investing in significant maintenance and refurbishment strategies.

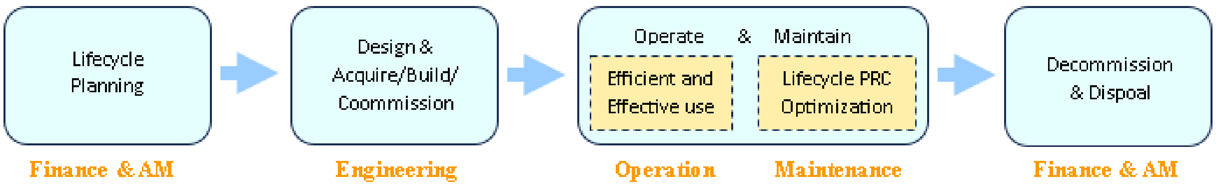

Fig. 1.1 Municipal asset lifecycle stages [modified from GFMAM (2014)

When the assets first become operational, they begin to deteriorate naturally and at an accelerated rate due to several factors. Then, the likelihood of partial and complete functional failure increases. When assets deteriorate at an accelerated rate, failures occur more frequently and earlier in the lifecycle. The consequences of asset failure can range from insignificant to catastrophic. Maintenance and reliability readiness is crucial as it ensures that resources, data, and information are available early in an asset's life to enable work execution and ensure that the underlying causes of deterioration are monitored and prevented at the most optimum cost/risk-benefit ratio of an asset's life.

According to Statistics Canada (2023), at the end of 2020, core public infrastructure in Canada, excluding social and affordable housing, had a total replacement value of $2.1 trillion. Roads, bridges, and tunnels accounted for over half (52.9%) of the total estimated replacement value, while water infrastructure accounted for 35.8%. The cost to replace all assets rated in poor or very poor condition was estimated at 10% of the total replacement value. The infrastructure in greatest need of rehabilitation or replacement (in poor or very poor) is road infrastructure (48.1%), followed by wastewater infrastructure (13.9%) and potable water infrastructure (11.1%). These statistics highlight the critical importance of MDRR and the need for innovative approaches to achieve it.

1.2 Project Scope

The project consists of four phases as follows (Fig. 1.2):

Phase 1: Conduct a national online survey. The purpose of this phase is to determine the current state conditions of asset master data at Canadian municipalities.

Phase 2: Identify success stories of municipalities. This phase involves developing a target online survey for municipalities that indicated their willingness to share their exemplary work.

Phase 3: Develop and deliver a training course for municipalities. This phase aims to (a) develop course material, including content, assignments, practical activities, and evaluation surveys, (b) design and create the course delivery system for professionals for online offering, and (c) evaluate and update the course materials after the first cohort. The training course consists of six lessons delivered twice in two cohorts.

Phase 4: Develop a white paper, business case, and practitioner's guide. These documents are based on the results of Phases 1-3. The following sections provide more details on these phases.

The primary phase of this project is the training course which aims to equip municipal leaders and practitioners with the essential knowledge to use MR as crucial drivers for AM success strategically. Participants gain an understanding of how each asset lifecycle stage contributes to MDRR. At its core, MDRR encompasses the strategic planning and commissioning of assets toward a state of preparedness for MR work. This course helps to advance MDRR throughout each lifecycle stage, especially the initial planning. In addition, how each lifecycle stage can support early MDRR delivery is highlighted.

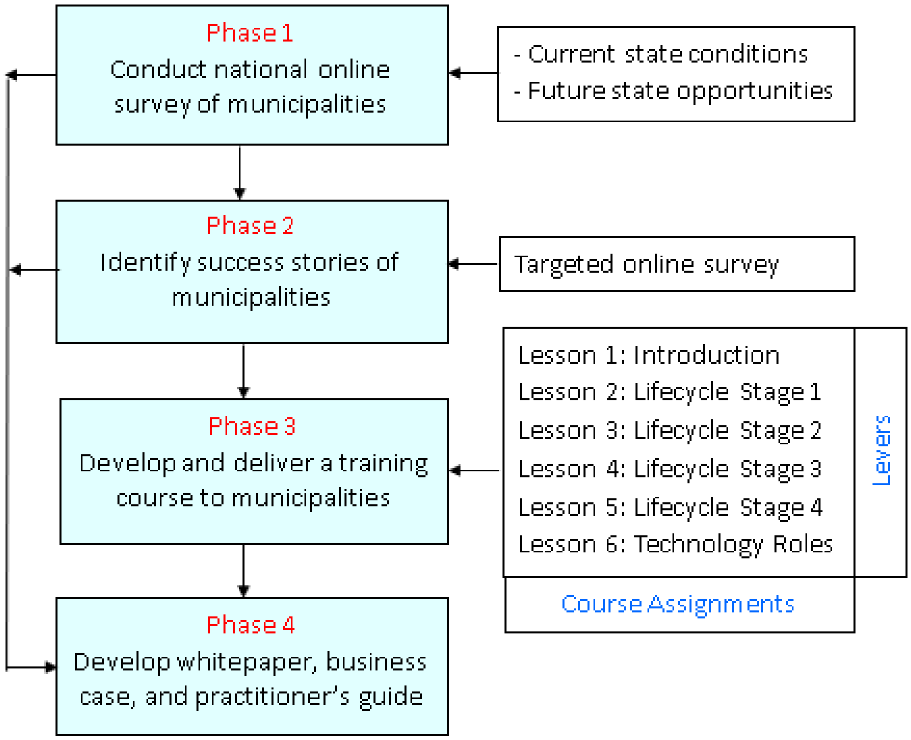

Fig. 1.2 Project phases

1.3 Project Objectives

The objectives of this project are twofold:

1. Enhance the standards for maintenance management and reliability engineering by raising awareness about the importance of planning and resourcing physical asset master data in support of 'Maintenance Readiness' during the acquisition and commissioning stage before handover to O & M to enable the realization of PRC deliverables (GFMAM, 2021).

2. Establish effective and efficient asset master data interoperability practices between lifecycle stages by incorporating four levers: MDRR, sustainability (climate change and circular economy), technology strategies, and data standardization and guidelines. This will increase municipalities' capacity to reduce traditionally high lifecycle costs due to premature asset disposal and replacement activities.

1.4 Report Organization

The report consists of six sections. Following this Introduction section, Sections 2-5 describe the Canadian municipal online survey, success stories based on a targeted online survey, the training course, and course participants’ feedback. Section 6 presents concluding remarks, including the pillars of good MDRR practices and the benefits of maintenance and reliability realization. Three appendices include the results of the Canadian municipality online survey, the exemplary work submissions by the targeted survey participants, and the descriptions of the training course assignments.

The *Canadian Municipal Survey on Leveraging Asset Master Data and Information* was distributed to public sector organizations (PSOs) across Canada, with respondents representing various provinces and territories. A total of 71 organizations participated in the survey. It targeted professionals involved in multiple aspects of asset management, including those in maintenance management, operations, finance, and engineering. The survey consisted of multiple-choice and open-ended questions, which captured quantitative data and qualitative insights. The survey responses were collected and analyzed to identify trends, patterns, and notable findings. The data were tabulated and interpreted to provide a comprehensive view of asset management practices across Canadian PSOs. This section presents the background and objectives, the survey questions, and highlights of the survey results. The detailed survey results and analysis are presented in Appendix A.

2.1 Background and Objectives

In increasingly complex urban environments and the growing demands on public infrastructure, effective asset management has become crucial for PSOs. The "*PSOs Survey on Leveraging Asset Master Data and Information*," conducted in December 2023, was designed to shed light on how PSOs across Canada manage their asset master data. This survey aimed to uncover the practices, challenges, and opportunities in the realm of asset management in the public sector, with a specific focus on the utilization and handling of asset master data.

The survey is driven by a need to understand how various PSOs approach asset management regardless of size or location. It explores the differences and similarities in asset management practices across different geographical areas and PSO sizes. The responses provide insights into the types of assets managed, the data collection and storage methods, and the lifecycle stages at which data is collected. The survey offers a comprehensive overview of various geographical, organizational, and asset class attributes within Canadian municipalities, shedding light on the diverse landscape of AM practices. This wide-ranging participation enriches the depth of insights gained from the survey results and provides a foundation for meaningful analysis and recommendations.

2.2 Survey Questions

The survey consisted of three sections. Section 1 includes questions about general municipality information (e.g. size, department, asset class, and respondent job title). Section 2 contains six questions for each of the 23 subcategories of asset master data, as shown in Table 2.1. The six questions are:

- Is data collected?
- What data is typically collected?
- What lifecycle stage is the data collected?
- How is the data collected?
- Where is the data/information stored? And
- Who are the primary data users?

Table 2.1 Asset master data

Question No.	Asset Master Data	Question No.	Asset Master Data
Q1	Asset number	Q13	Asset insurance
Q2	Asset description	Q14	Warranty and maintenance
Q3	Asset classification	Q15	Maintenance activities
Q4	Asset location	Q16	Maintenance strategy
Q5	Asset value	Q17	Maintenance notification
Q6	Asset lifecycle dates	Q18	Maintenance resource
Q7	Asset lifecycle costs	Q19	Asset failure
Q8	Installation date	Q20	Federal financial reporting
Q9	Estimated end-of-life date	Q21	Asset performance
Q10	Asset maintenance	Q22	O & M manuals
Q11	Functional location	Q23	Financial data
Q12	As-built drawings		

The 23 asset subcategories include asset number, description, classification, location, value, lifecycle dates and costs, maintenance, insurance, failure, and performance. They also include installation date, estimated end-of-life date, functional location, as-built drawings, warranty and maintenance, federal financial reporting, financial data, O & M manual, maintenance activities, strategy, notification, and resource.

Section 3 includes questions related to AM systems (a) analysis and (b) leadership, planning, and tactical execution. In addition, the participants were given a text box (optional) for each asset subcategory to provide any clarifying/additional comments. The survey was sent to nearly 700 Canadian municipalities, and the response was impressive.

2.3 Results: General Information

Geographical Distribution

- The survey saw the highest participation from Ontario (55.7%), followed by Alberta (17.1%) and British Columbia (12.9%). This distribution indicates a predominant representation from larger provinces, highlighting the need to understand asset management practices across diverse PSO sizes and geographical locations.

PSO Size and Population Served

- Most respondents (33.3%) come from PSOs serving populations over 400,000 people, suggesting a significant focus on asset management in larger urban centers.
- PSOs serving smaller populations (less than 5000 people) accounted for 14.5% of the responses, indicating the presence of asset management practices even in smaller communities.
- Based on the sizes of the communities represented by the participants, the total number of people that the participants represent ranges from a minimum of approximately 11,145,000 to an indeterminate maximum.

Sectional Representation

- A substantial portion of the respondents (51.4%) work in asset management, indicating its central role in PSO operations.
- Maintenance Management (17.7%) and Operations (7.1%) also show notable representation, underscoring the multi-disciplinary nature of asset management.

Asset Classes Managed

- Water and Wastewater Systems, both vertical (66.7%) and linear (56.5%), are the most commonly managed assets, reflecting the critical importance of water infrastructure in PSO services.
- Roads (58.0%) and Stormwater management (56.5%) also feature prominently, highlighting the importance of transportation and water management in urban planning.

Job Titles of Respondents

- Managers (41.2%) primarily answered the survey, indicating that middle management plays a crucial role in decision-making related to asset management.
- Other significant contributions came from Analysts/Specialists (14.7%) and Supervisors (11.8%), suggesting that the survey captures a broad spectrum of perspectives across organizational hierarchies.

The demographic analysis lays the groundwork for understanding the context in which the asset master data is managed. It highlights the varied scales at which PSOs operate and the different sectors that play a role in asset management. This diversity is critical in analyzing the survey's findings on asset classes managed, data collection methods, and the usage of asset master data.

The diversity in asset classes managed by PSOs poses unique challenges and opportunities. It necessitates tailored AM strategies that can accommodate each asset type's specific needs and characteristics. This diversity also calls for a multi-disciplinary approach, integrating expertise from various sectors to ensure effective management. Understanding the spread and focus of these asset classes is crucial for developing comprehensive asset management plans responsive to each asset type's specific requirements and the communities they serve. In addition, the insights into the asset classes provide a clear understanding of the scope and complexity of PSO asset management.

The distribution of job titles among the survey respondents highlights the layered and collaborative nature of asset management in PSOs. The presence of a range of professionals, from strategic decision-makers to technical experts and operational staff, underscores the need for comprehensive communication and coordination across different levels of the organizational hierarchy. This variety also reflects the diverse skill sets and perspectives required to manage the vast array of assets within PSO jurisdictions effectively. Further, understanding the roles and responsibilities of the professionals involved in asset management is crucial for appreciating the survey's findings. It provides context for the approaches, challenges, and priorities reflected in the responses.

2.4 Results: Asset Master Data

2.4.1 Data Collected or Not

The results show that 75% or more municipalities collect most types of asset master data at one or more lifecycle stages. However, specific data types are not collected by a sizable portion of municipalities, as shown in Table 2.2. As noted, three types of asset master data are not collected by 40% or more of municipalities: Asset failure analysis (62.0%), asset performance (62.0%), and maintenance strategy (44.9%). In addition, five types of asset master data are not collected by 25%-40% of municipalities: Maintenance resource (36.0%), asset insurance (28.8%), warranty and maintenance (28.0%), and asset lifecycle costs (26.8%). These results suggest the need to develop initiatives to help municipalities collect or obtain asset master data related to maintenance and performance. The training course has been designed to address this need.

2.4.2 Other Asset Master Data Categories

Other results related to lifecycle stages of equipment ID/Code data, data storage systems, primary users of the data, asset description data, storage systems and accessibility of asset data, lifecycle stages and collection methods, and asset data collected are presented in Appendix A. The following are the main implications of the results for asset management:

a. *Equipment ID/Code Data*: These data are critical for effective asset tracking and lifecycle management. The emphasis on the O & M stage reflects a focus on maintaining existing assets, which is crucial for prolonging asset life and ensuring service reliability. The variety in data collection methods indicates the need for standardized practices to enhance data accuracy and accessibility across different PSO departments. This analysis provides a glimpse into the operational AM aspects. It highlights the need for streamlined and effective data management systems to support the lifecycle management of PSO assets.

Table 2.2 Types of asset master data not collected by 25% or more municipalities.

Type of Asset Master Data	Municipalities (%)	
	Data Collected	Data Not Collected
Asset Failure Analysis: Asset failure cause, type, and root cause	38.0	62.0
Asset Performance: Functional Design Performance Standards	38.0	62.0
Maintenance Strategy	55.1	44.9
Maintenance Resource	64.0	36.0
Asset Insurance	71.2	28.8
Warranty and Maintenance	72.0	28.0
Asset Lifecycle Costs	73.2	26.8
Estimated End-of-Life Date	73.2	26.8

b. *Data Storage Systems*. The variety in data storage systems signifies different stages of technological adoption and data management maturity among PSOs. While advanced systems like CMMS and GIS offer robust asset tracking and spatial data management features, essential tools like Excel indicate a need for more sophisticated data management solutions in some PSOs. The diversity of tools also suggests data standardization and interoperability challenges, which are essential for efficient asset management, especially in larger or more complex PSO environments. Understanding the storage locations and systems for asset master data is crucial in assessing the effectiveness of asset management practices.

c. *Main Users of the Data*. The widespread use of asset master data across various PSO departments underscores the interconnected nature of asset management. It highlights the need for integrated systems and processes that facilitate seamless data sharing and collaboration among departments. Involving finance and capital planning departments in using this data also indicates the strategic importance of asset master data in long-term financial sustainability and infrastructure development. Understanding the primary users of asset master data within PSOs provides insights into asset management's collaborative and interdepartmental nature. This knowledge is crucial for developing comprehensive asset management strategies that cater to all stakeholders' needs.

d. *Asset Description Data*. Collecting and managing detailed Asset Description data are crucial for effective asset lifecycle management. The emphasis on serial numbers and functional data highlights the importance of tracking and categorizing assets for operational efficiency and maintenance planning. The varied methods of data collection point to opportunities for standardizing and streamlining data management processes, potentially leading to more effective asset management practices across PSOs.

e. *Data Storage and User Analysis*. The diversity in data storage systems points to varying levels of technological adoption and data management sophistication. This variety challenges data standardization and interoperability, which are vital for efficient asset management, especially in interdepartmental contexts. The varying degrees of accessibility to different departments highlight the need for integrated systems to facilitate comprehensive data sharing and usage across all relevant PSO sectors. Analyzing data storage systems and user accessibility provides an essential perspective on the infrastructure supporting asset management in PSOs. This insight is vital for understanding the operational dynamics and identifying areas where data management improvements can lead to more effective and efficient asset management.

f. *Lifecycle Stages and Collection Methods*. The lifecycle stage at which data is collected can significantly impact the effectiveness of asset management. Early-stage data collection can facilitate better planning and design, while ongoing O & M stage data updates are crucial for effective maintenance and management. The varied collection methods highlight potential areas for improvement, particularly in standardizing and integrating data collection processes. Streamlining these processes can enhance data accuracy, accessibility, and overall asset management efficiency. This analysis sheds light on the practical aspects of managing PSO assets. It highlights the need for robust, integrated data management systems to support effective asset management practices.

g. *Asset Data Collected*. The diversity of asset data collected by PSOs underlines the multifaceted nature of asset management. This data's strategic collection and use can significantly enhance decision-making, risk management, and financial planning. It also emphasizes the need for integrated data management systems that can handle complex and varied data types efficiently, ensuring that accurate and up-to-date information is available for all stages of asset lifecycle management. This analysis offers insights into the AM complexity and scope. It also underscores the importance of a strategic approach to data collection and management tailored to the needs of each stage of the asset lifecycle.

2.5 Results: Asset Management Systems

Appendix A presents the results of asset management systems. Based on the survey responses, opportunities for promoting MDRR related to leadership, planning, and technical execution have been identified (Table 2.3). By addressing these opportunities for improvement, Canadian municipalities can enhance asset performance, reduce costs, and mitigate risks, ultimately achieving long-term asset sustainability and maximizing the value of their infrastructure investments.

Table 2.3 Future leadership, planning, and technical execution opportunities

Aspect	Opportunity
Maintenance Work Capture	Promote adopting systems and processes that capture a higher percentage of maintenance work executed by maintenance trades in a single system. Increasing the percentage of captured work will facilitate proactive and reactive cost, time, and frequency analysis, leading to better data-driven decision-making and improved maintenance strategies.
Maintenance Management Structures and Teams	Advocate for establishing dedicated maintenance management structures and teams to enhance maintenance planning, scheduling, and execution. These dedicated resources will improve compliance, trade team efficiency, and asset reliability.
Maintenance Management in AM Policies	Emphasize the inclusion of maintenance management sections in AM policies. This integration ensures that maintenance practices align with the broader AM framework and facilitates comprehensive and effective asset management.
Maintenance Budgets in Capital Planning	Advocate for providing maintenance and repair budgets for installed assets as part of the new development capital planning process. Considering long-term maintenance costs during the lifecycle planning stage ensures sustainable asset management and proper funding for asset maintenance.
Maintenance Planning Functions	Support organizations in establishing full-time resourced maintenance planning functions with formal processes. This will ensure that maintenance work is ready for scheduling in advance, enabling regular measurement of compliance and trade team efficiency.
Municipal Regulations	Address the perceived lack of clarity in municipal regulations regarding support for maintenance management or reliability engineering. Clear regulatory guidance will promote and standardize maintenance management practices across municipalities.

2.6 Operational Challenges and Opportunities

The management of PSO assets involves navigating various operational challenges while also identifying opportunities for improvement and innovation. This section assesses the complexities of PSO asset management and explores potential avenues for enhancing asset management practices.

Data Management Challenges

- The diversity in data collection methods and storage systems presents significant challenges in standardization and interoperability. PSOs often grapple with integrating disparate systems and ensuring consistent data quality across different departments.
- The reliance on essential tools, like Excel, alongside sophisticated systems, like CMMS and GIS, points to varying maturity levels in asset data management. This can lead to inefficiencies in data retrieval, analysis, and decision-making.

Opportunities for Improvement

- There is a substantial opportunity for PSOs to adopt more integrated and standardized data management systems. Such systems can streamline operations, improve data accuracy, and facilitate better inter-departmental collaboration.
- The implementation of advanced technologies like AI and predictive analytics can enhance asset lifecycle management, enabling proactive maintenance and efficient resource allocation.

The survey findings suggest a potential for greater technological integration in asset management. Embracing modern technology solutions can significantly improve PSOs' management and maintenance of their assets.

Technology Solutions

- Adopting comprehensive asset management software that offers end-to-end functionality from data collection to analysis and reporting can significantly improve operational efficiency.
- Integrating GIS with CMMS and other management systems can provide a more holistic view of assets, combining spatial data with operational and maintenance information.

Strategic Use of Data

- Leveraging data for predictive maintenance and asset health monitoring can extend asset life and reduce unplanned downtime.
- Utilizing data analytics for strategic planning and budgeting can lead to more informed decision-making and optimized resource allocation.

Exploring operational challenges and opportunities underscores the need for PSOs to adopt a more strategic and integrated approach to asset management. Leveraging technological advancements and enhancing data management practices can drive significant improvements in asset management, ultimately leading to more sustainable and resilient public infrastructure. The final sections of this report will delve into the strategic implications of these findings and offer recommendations for advancing asset management practices in PSOs.

2.7 Strategic Recommendations

The insights gained from the survey highlight several strategic implications for PSOs' asset management. These implications indicate the need for a more cohesive and technologically advanced approach. The following recommendations aim to address these strategic needs and enhance overall AM practices.

Standardization and Integration of Data Management

- PSOs should work toward standardizing their data collection and storage processes. Unified data management systems can ensure consistency, accuracy, and ease of access to asset information across all departments.
- Integrating disparate systems like CMMS, GIS, ERP, and financial management tools can provide a comprehensive view of assets, facilitating better decision-making and operational efficiency.

Technological Advancements and Predictive Analytics

- Implementing advanced technologies such as AI, IoT sensors, and predictive analytics can transform asset management from a reactive to a proactive practice. These technologies can predict potential failures and optimize maintenance schedules, extending asset life and reducing costs.
- Developing digital twins of PSO assets can visually represent physical assets, enabling better planning, simulation, and asset health monitoring.

Capacity Building and Skills Development

- It is crucial to Invest in training and development programs for PSO staff is vital. As asset management becomes more technologically driven, equipping staff with the necessary skills to handle advanced software and analytics tools is essential.
- Encouraging cross-departmental training can foster a better understanding of the AM's interconnected nature and promote collaborative working practices.

Policy Development and Compliance

- PSOs should develop robust AM policies that align with regional and national standards. These policies should encompass all aspects of asset lifecycle management, including acquisition, operation, maintenance, and disposal.
- Ensuring compliance with regulatory requirements and keeping abreast of legislative changes can help PSOs avoid legal pitfalls and maintain high AM standards.

As previously mentioned, a targeted survey has been conducted with municipalities of diverse sizes, explicitly focusing on the MDRR of master data for public sector assets. The survey sought input from municipalities with real-world success stories with asset master data management and those with challenges. It aims to share compelling stories and effective AM practices, as reported by the participating organizations. This collection of experiences aims to provide valuable learnings and inspiration for enhancing AM strategies across various municipal contexts. The success stories submissions are presented in Appendix B, and highlights are presented in this section.

3.1 Targeted Online Survey

The targeted survey included the following questions:

1. Respondent’s questions: Respondent’s name and email.
2. Provide a brief title of the exemplary work.
3. Provide the organization’s objectives for your municipality's exemplary work. Briefly describe the effect the exemplary work had or will have on those organizational objectives.
4. Which lifecycle stage(s) is the exemplary work related to?
5. What is exemplary work related to? ((Please check relevant items: Asset Master Data, Asset Management Systems, Asset Management Decision Making, Asset Management Strategy & Planning, Maintenance and Reliability, Organization, Culture, and Leadership).
6. Describe in detail the exemplary work.
7. What benefits did implementing the exemplary work bring to your municipality?
8. Before starting your exemplary work, what were the issues (regarding value realization in AM) your municipality faced concerning performance, cost, and risk that caused you to move forward with the exemplary work?
9. What challenges did you face in implementing the exemplary work, and how did you address them?
10. Please provide any other comments or learning realized related to the exemplary work.
11. If you have any documentation related to your municipality's exemplary work that you would like to share with your response, you can upload it here.

3.2 Good AM Practices

(a) ***Data Quality Management.*** The Regional Municipality of Halton’s approach to data-driven lifecycle optimization emphasizes the need for high-quality, reliable data as the foundation of any reliability-centred maintenance and AM strategy.

(b) Asset Management Optimization. The City of Guelph's innovative corridor-level asset needs forecasting demonstrates how to break traditional silos in AM, using holistic approaches for better budget utilization and asset optimization.

(c) Effective Data Utilization. The City of Steinbach's use of GIS Dashboards for condition assessment data collection and visualization highlights the importance of making informed decisions based on accessible, visual data representations.

(d) Innovation in Asset Management. The City of Airdrie's State of the Infrastructure Report shows the value of building awareness and knowledge to address funding gaps and improve asset data quality through innovative reporting methods.

(e) Overcoming Common Challenges. RM of Torch River No.'88's introduction of software in their work order system for condition inspections addresses common challenges of centralizing asset data and reducing dependency on paper-based systems.

3.3 Successes and Challenges

(a) Technological Integration in Asset Management

Successes

- Enhanced decision-making and planning through advanced data visualization (e.g., GIS Dashboards).
- Improved accuracy and efficiency in asset condition assessments.
- Facilitation of predictive maintenance and long-term asset sustainability.

Challenges

- Navigating the initial complexity and cost of implementing new technologies.
- Ensuring staff are adequately trained and comfortable with new digital tools.
- Keeping up with rapidly evolving technological solutions.

(b) Holistic and Integrated Planning Approaches

Successes

- More effective resource allocation and budget utilization through comprehensive asset analysis (e.g., corridor-level forecasting).
- Better understanding of interdependencies among different asset types.
- Facilitating long-term strategic planning and asset longevity.

Challenges

- Overcoming traditional siloed approaches to asset management.
- Coordinating integrated planning across various municipal departments.

- Adapting to the broader implications of interconnected AM strategies.
- Replacing the existing engineering-based culture of maintaining municipal infrastructure with an M & R culture.

(c) Emphasis on Continuous Improvement and Adaptation

Successes

- Keeping AM strategies aligned with current needs and technologies.
- Encouraging a culture of innovation and proactive problem-solving.
- Ensuring long-term relevance and effectiveness of AM practices.

Challenges

- Balancing the need for continual improvement with resource constraints.
- Staying informed and updated in a field with constant technological and methodological advancements.
- Engaging stakeholders in ongoing adaptation and improvement processes.

3.4 Summary

This section, grounded in the diverse experiences and stories of municipalities across different sizes, is a testament to the ingenuity and resilience of the public sector's asset management. It showcases a range of good practices and the successes they have brought, alongside the challenges faced and overcome by these organizations. The learnings from these real-life examples highlight the potential for enhancing the MDRR of master data, a critical component in the efficient and effective management of public assets. As readers reflect on these stories, it is hoped that they find inspiration and practical insights that can be adapted to their organizational contexts, driving continuous improvement in the stewardship of public sector assets.

The training course will equip municipal leaders and practitioners with practical knowledge to improve their organization's MDRR. Through timely provision of asset data, information, and resources, participants learn how to use analytics, maintenance best practices, and reliability engineering to minimize asset lifecycle costs and service disruption risks. The elements of the training course include lessons focusing on lifecycle stages and assignments, along with four levers, as shown in Fig. 4.1. This section presents the course description, learning objectives, lessons' contents, and the levers introduced in the course to promote reliability readiness, sustainability, technology, data standards in maintenance management.

4.1 Course Description

The course focuses on MDRR across the primary lifecycle stages of an asset through a combination of instructed material by subject matter experienced instructions, open discussion and assignments; the overall intent is to learn, reflect and improve. The course consists of six 2-hour lessons. The course format is live online, delivered over 6 sessions, 2 hours each (including a 15-minute break), taught twice in two cohorts involving 52 participants. Participants were encouraged to engage with one another and the instructor throughout the course using various online tools to aid learning and collective knowledge. All PowerPoint lessons were available. With a focus on seamless and efficient data use across asset lifecycle stages, participants gather awareness of practices that position MR as critical enablers for municipal AM success.

The course includes presentations, group discussions, and five assignments related to the national online survey (Assignment 1), asset failure (Assignment 2), maintenance readiness optimization (Assignment 3), gap interoperability analysis (Assignment 4), and lesson discussion questions (Assignment 4). Assignments 2-4 are mini-case studies conducted by each municipality and graded by the instructor. Section 5 presents detailed descriptions of the case study's objectives and results.

4.2 Learning Objectives

By the end of this course, participants will be able to:

1. Explain foundational concepts of maintenance management and reliability engineering of MDRR within the AM context.
2. Identify common AM improvement opportunities and successes based on municipal survey findings.
3. Integrate master data requirements into all lifecycle stages.
4. Understand the implications of inadequate master data on asset lifecycle risk and costs.

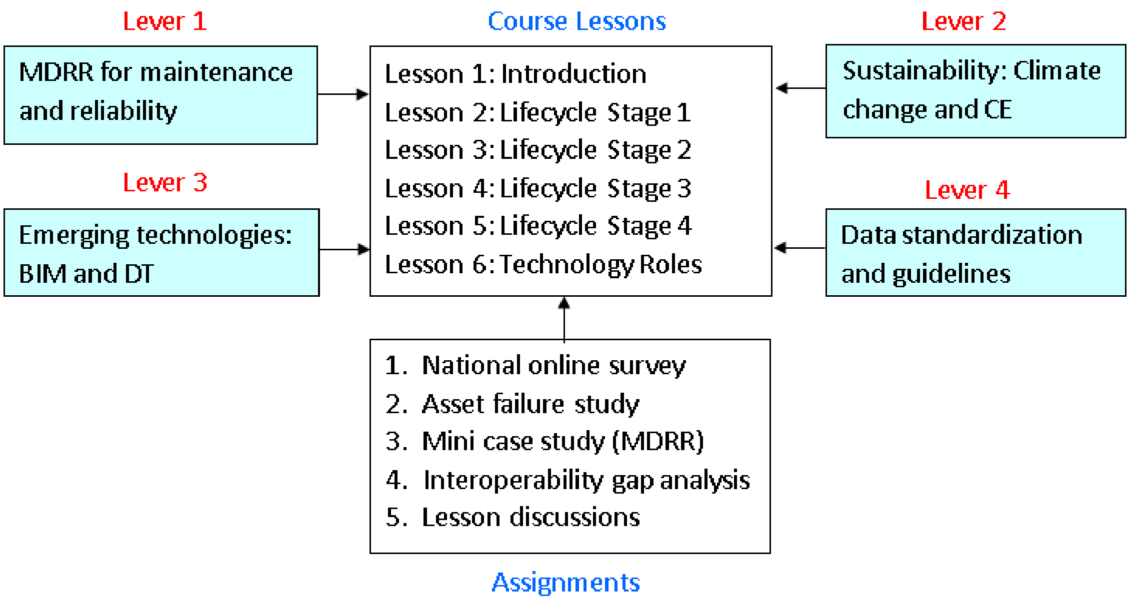

Fig. 4.1 Elements of the training course

5. Ensure the effective transfer of critical asset data between lifecycle stages and make critical decisions about the investment of resources.
6. Optimize maintenance strategies using asset performance data analysis.
7. Apply risk management to reduce asset failures and improve reliability.
8. Incorporate lessons learned into future asset lifecycle management.
9. Evaluate existing and emerging technologies to enhance data use across all asset lifecycle Stages.
10. Balance capital replacement versus asset repair/refurbishment trade-offs.
11. Learn how to optimize early lifecycle stages based on D & D decisions.
12. Understand linear and circular interdependencies between the asset lifecycle stages.
13. Explore technologies like EAMS, CMMS, condition monitoring, Internet of Things (IoT) and BIM to enhance data integrity across the asset lifecycle.

4.3 Lessons' Descriptions

As previously mentioned, the training course's lessons are aligned with the typical lifecycle stages. Lesson 1 (Introduction) aims to introduce MDRR. Lesson 2 (Lifecycle Stage 1 - Lifecycle Planning) aims to strengthen financial planning, data integration, and understanding master data impacts to inform how to make provisions for the entire lifecycle's success. Lesson 3 (Lifecycle Stage 2 - D & ABC) aims to deliver reliable, maintenance-ready assets. Lesson 4 (Lifecycle Stage 3 - O & M) aims to ensure effective and efficient asset utilization and PRC deliverables, optimize strategies, balance proactive and reactive costs, and nurture sustainable reliability practices to maintain desired condition grades. Lesson 5 (Lifecycle Stage 4 - D & D) aims to enable informed end-of-life decisions and continuous improvement. Lesson 6

(Technology Strategies) aims to incorporate technologies into asset lifecycles to enhance data and decision-making. The topics covered in each lesson are listed next.

Lesson 1: Introduction to Readiness

- What is MDRR?
- Importance of MDRR, standards and guidelines.
- Enabling and sustaining MDRR practices.
- Making assets 'maintenance ready' following commission.
- MDRR – value drivers.
- Climate change and circular economy considerations.
- Five organizational pillars of good practice to enable MDRR.
- Overview of Canadian municipal survey on asset master data.

Lesson 2: Lifecycle Planning Stage

- What are assets and AM planning?
- Maintenance and asset readiness planning.
- Asset life cycle management.
- Multi-stage financial planning considerations for MDRR.
- Financial planning.
- AM lifecycle decisions and expenditures.
- Asset maintenance planning.
- Asset value realization.
- Asset selection (technical specifications and standards).
- ISO 55000 suite of standards.
- Supplier performance management.
- Best practices/challenges for asset maintenance.

Lesson 3: Design & Acquire/Build/Commission Stage

- Enabling and sustaining practices to support strategies for MDRR.
- Establishing feedback loops to support MDRR.
- Pre-operational maintenance management that impacts overall asset lifecycle costs.
- Balancing performance, risk, and cost in maintenance management during the D & BAC stage of the asset life cycle.
- Evolving asset master data through the asset lifecycle during the D & ABC stage.
- Asset master data on 'informed decision-making.'

Lesson 4: Operation & Maintenance Stage

- Public sector condition grades and current state of public sector assets.
- GFMAM – Maintenance deliverables (risk, performance, and cost).
- Enabling and sustaining practices.
- Selecting the optimum maintenance mix.

- Non-tactical vs. tactical information types.
- Maintenance tactics - Four options.
- Asset data readiness and funnelling.
- Validating asset data and maintenance plans from the D & ABC Stage.
- Importance of asset master data.
- A foundational pillar of good practice.
- Leveraging technology for condition-based maintenance.
- Optimizing MR.
- Connecting maintenance to circular economy goals.
- Environmental lifecycle assessment for linear assets.
- Financial planning: Key input to maintenance.

Lesson 5: Decommission & Disposal Stage

- Factors to consider for 'end of life' decision-making for assets.
- Relevant data considerations for asset disposal decisions.
- Enabling and sustaining program practices for asset disposal.
- Consideration of the circular economy in asset disposal.
- Employing 'lessons learned' in future life cycle management.

Lesson 6: Technology Strategies

- Introduction to technology strategies and solutions.
- Technology strategy and solutions: Lifecycle Planning Stage.
- Technology strategy and solutions: D & ABC Stage.
- Technology strategy and solutions: O & M Stage.
- Technology strategy and solutions: D & D Stage.
- How do technology tools enable MDRR?
- What tools are used?
- Where in the lifecycle is it used?
- How do I best implement the tools?
- Technology needs for the entire lifecycle
- Digital twins.

4.4 Proposed Maintenance Management Levers

4.4.1 Lever 1: MDRR for Maintenance and Reliability

The MDRR lever involves specific suggested tasks for each lifecycle stage, as shown in Table 4.1. For lifecycle Stage 1, this lever is related to policy and procedures, strengthening financial interoperability, and seamless data integration: lessons learned. For lifecycle Stage 2, the lever involves effective transition practices for O & M. For lifecycle Stage 3, the lever involves effective transition practices from the D & D stage, data integrity and quality, maintenance optimization, data analysis and reporting, strategic asset management, fostering a sustainable improvement culture, and environmental synergy. For lifecycle Stage 4, the lever involves informed disposal decisions related to maintenance costs, asset condition, criticality, service levels, utilization, obsolescence, and sustainability.

Table 4.1 MDRR enabling practices for various lifecycle stages.

Lifecycle Stage	MDRR Enabling Practices
Lifecycle Planning	- Ensure AM policy and plans include whole-lifecycle considerations that support MR functions and align with long-range infrastructure plans. - Elevate financial planning and budgeting practices to provide the necessary resources for capital teams to deliver maintainable assets effectively. - Integrate long-range lifecycle budget estimates with OpEx budget planning processes to enable the 'right-sizing' of resources to execute MR functions effectively. - Integrate asset master data requirements across all lifecycle stages and systems to eliminate gaps contributing to increased costs. - Use the D & D data to inform the optimization of financial planning directly.
D & ABC	- Establish robust methodologies to provide feedback cycles between planning and design. - Use D & ABC's assets and systems to maximize reliability and maintainability outcomes for the O & M stage. - During the D & ABC stage, collate all asset data, information, and resource structures to enable optimum execution of work in the O & M stage - Establish robust methodologies for capturing and transferring asset master data from the D & ABC to O & M stages, preventing inaccuracies that could undermine maintenance efforts.
O & M	- Establish methodologies to validate, use and implement all data, information and resources provisioned. - Ensure that new asset data collected during the O & M stage is monitored and made ready for lifecycle optimization and reporting functions. - Harness asset data and insights to optimize maintenance practices, corrective strategies, and overall asset performance. - Develop key performance indicators (KPI) that support performance management and compliance. - Prepare asset data for end-of-life and new development planning. - Cultivate ongoing growth, empowering the team to evolve and enhance their capabilities. - Integrate circular economy principles into maintenance strategies, minimizing environmental impacts and promoting sustainability.

D & D	- Analyze the ongoing annual maintenance costs compared to asset replacement costs helps determine whether continued repair is economical. - Assess the physical condition, wear and tear, and defects to determine whether potential life remains or a major rebuild is needed. - Prioritize disposal based on asset criticality to operations and risk of failure. - Evaluate disposal options based on the ability to meet service level needs. - Assess usage profiles and demand requirements to right-size assets. - Consider replacement when parts, consumables, or expertise for legacy assets are difficult to procure. - Assess environment, social, and climate impacts to align the disposal plan with broader goals.

4.4.2 Lever 2: Sustainability (Climate Change and Circular Economy)

Sustainability can be achieved through efficient asset management, circular economy practices, optimized maintenance, green procurement, and emission and waste reduction to support Canada's climate goals. The training course has highlighted the sustainability aspects of each lifecycle stage, as shown in Table 4.2.

Table 4.2 Sustainability practices for various lifecycle stages

Lifecycle Stage	Sustainability Practices
Lifecycle Planning	- Promote sustainability. - Explore GHG reduction and circular economy. - Conduct infrastructure assessments. - Prioritize green procurement.
D & ABC	- Incorporate recycling for emission reduction. - Design and build efficient assets - Select assets that minimize fuel/energy consumption. - Execute green procurement.
O & M	- Identify assets requiring repair/rehab (value retention processes) - Prevent excess emissions through reliable assets. - Maintain sustainable procurement. - Select sustainable maintenance strategies.
D & D	- Reduce emissions through recycling. - Manage asset retirement for reuse/refurbishment/recycling. - Repurpose assets.

4.4.3 Lever 3: Emerging Technologies

Advanced technologies can bolster data accuracy, accessibility, and exchange across the asset lifecycle, enabling enhanced analytics and informed decision-making. The training course has highlighted the following current and potential technology implementations:

1. Integrated technology solutions spanning asset lifecycle stages break down data silos between planning, acquisition, operations, maintenance, and disposal.
2. Equipment and Process Sensors provide teams real-time asset monitoring data, fed into EAMS and trigger work based on changes or values before failures occur.
3. Field data seamlessly allows comprehensive views of asset status and geospatial relationships.
4. Cloud platforms, application programming interfaces (API), and data standards enable seamless cross-system information sharing.

Digital Twins are virtual replicas of physical assets and processes that capture their design, behaviour, and other crucial parameters in real time. Technologies can also be used as predictive tools. With the right technology on day one, newly commissioned assets can immediately begin yielding asset performance data to inform optimal maintenance frequencies while providing visibility to help avert emerging failures through predictive maintenance. Lacking capable tools means perhaps blindly following ineffectual time-based schedules. Using analytics and digital technology is a force multiplier for infrastructure management capabilities. The upfront effort to properly implement maintenance management systems, predictive maintenance tools, and asset performance monitoring pays dividends in improved decisions and elevated asset reliability.

4.4.4 Lever 4: Data Standardization and Guidelines

The training course addresses AM standards which promote critical principles like risk-based decision-making. In addition, it actively bridges the gap between theory and practice, brought together by subject matter experienced practitioners whose work is related to the lifecycle stages.

When acquiring assets, organizations must comply with the legislation related to their technical standards and specifications. The technical standards are divided into three categories: (1) organization (internal), applicable to all projects for conformity (e.g. best practices of organizations, such as PMI and PSAB), (2) design guidelines, which provide high-level design principles and a set of recommendations, and (3) external standards, which are standardized best practices, primarily independent, non-governmental organizations, such as the International.

The ISO standards for asset management are ISO 55000 (Terms & Definition), ISO 55001 (Requirements), and ISO 55002 (Guidance). These standards are aligned with others, such as ISO 31000 (Risk Management), ISO 9001 (Quality Management), the SAE JA1011 Standard (Reliability-Centered Maintenance Process), and ISO 13374 (Condition Monitoring and Machine Diagrams).

The benefits of technical specifications and standards include efficiency in operations and maintenance, conformity with best practices and support for effective decision-making, and benchmarking against other organizations or industries. For example, adequate standardized documentation removes ambiguity, instills alignment, and builds institutional knowledge to sustain reliable infrastructure performance. Maintenance teams follow meticulous asset-specific technical drawings. Work instructions reinforce consistency. Without rigorous documentation entrenched during commissioning, maintenance quality and outcomes become subject to individual discretion and inconsistencies. Standardized documentation delivers far more than paperwork; it becomes the lifeblood of long-term asset care and collective team learning.

SECTION 5 - CASE STUDIES

As part of the training course, the participants were given five assignments, as follows: completing the national online survey (Assignment 1), studying an asset failure (Assignment 2), optimizing maintenance readiness (Assignment 3), gap interoperability analysis and improvement (Assignment 4), and lesson discussion questions (Assignment 4). Assignments 2-4 are mini case studies**.** Detailed descriptions of the assignments are presented in Appendix C. This section presents the case studies' objectives and results.

5.1 Objectives of Case Studies

Assignment 2 Objectives

- Apply Lesson 1 concepts to a real-world asset failure case. - Identify opportunities to improve maintenance data, tactics, and readiness.
- Strengthen foundational understanding of maintenance fundamentals.
- Practice scoping improvement initiatives based on conceptual learning.

Assignment 3 Objectives

- Demonstrate ability to analyze and optimize maintenance readiness for an asset.
- Apply risk-based analysis to inform maintenance priorities and strategies.
- Develop targeted data-driven improvements across the asset lifecycle stages.
- Protect confidential municipal information while conveying insights.

Assignment 4 Objectives

- Demonstrate understanding of asset data needs across lifecycle stages.
- Identify data-sharing opportunities between asset acquisition, operations and disposal.
- Recognize potential benefits of improving data flows between stages.
- Practice scoping a basic data integration improvement initiative.
- Apply concepts to a real-world asset-type example.
- Develop skills in analyzing and describing data requirements and integration opportunities.

5.2 Results of Case Study 1: Asset Failure

The asset failure case study assignment asked the nineteen participant organizations across cohorts one and two to examine real-world asset breakdown events at their organization. The exercise aimed to evaluate master data, maintenance practices, failure impacts, and potential data-driven improvements.

5.2.1 Analysis of Results

The submissions revealed premature failures across a diverse asset portfolio - from wastewater treatment digesters to road culverts and pumps. Despite unique contexts, common themes emerged.

A 53-year-old digester's roof catastrophically collapsed, with reactive maintenance implicated. Multi-year environmental violations compounded the $800,000 repair bill. Another vivid example was a rural culvert that unexpectedly failed, forcing 9-month road closures and a $700,000 emergency fix. Ten-year-old pumps also experienced early breakdowns, carrying failure costs up to $5 million.

These examples illustrated systemic gaps. Work orders lacked failure details to inform prevention, and asset data did not include risk rankings to prioritize tactics. Predictive maintenance was rare, as reactive work dominated. Failures inflicted widespread impacts, from injuries to service disruptions, environmental exceedances, and reputation damage.

To counter these trends, participants recommended enhancements to maintenance planning, integrated data systems, reliability principles, and condition monitoring. Though assets varied, the diagnoses aligned—robust master data and proactive tactics are vital to avoid run-to-failure outcomes.

By evaluating real-world cases, participants gained practical insights into driving asset resilience. While problems diagnosed were far-reaching, so was the potential. With a data-driven approach, they can transform asset management from reactive to predictive. But it takes the courage to examine failures before progress can take root critically. For communities relying on infrastructure performance, the stakes are too high to ignore the lessons breakdowns impart.

5.2.2 Summary of Asset Failures

Organization 1: Water Treatment Plant Digester

- 53 years old, expected life 50 years
- Catastrophic roof collapse causing spillage and plant shutdown
- $456,000 in repair costs
- $347,942 for mandated operational improvements
- Effluent non-compliance over 2 years following failure
- Increased risk of regulatory fines and reputation damage

Organization 2: Culvert on Rural Road

- Failed prematurely, leading to sinkhole formation
- Caused long-term road closure for 9 months
- Detours increased travel time for farmers and heavy equipment
- Unplanned project cost $700,000, moved up from the following year

Organization 3: Water Pump Station

- A 10-year-old pump unexpectedly failed; only halfway through the expected life
- High risk of full-service disruption with only 1 pump remaining
- Estimated cost of failure: $5,000,000
- Probability of 2nd pump failure: 12%
- Risk cost = Probability x Cost of failure = $600,000

5.3 Results of Case Study 2: Maintenance Readiness Optimization

In this section, we delve deeper into the transformative journey of various public sector organizations as they navigate the complexities of Maintenance Readiness Optimization (MRO). This exploration goes beyond the surface-level challenges of asset management, uncovering the nuanced intricacies of shifting from a traditionally reactive maintenance model to a more strategic, proactive approach. By examining diverse municipal contexts, this section sheds light on how these organizations harness data-driven insights, embrace technological advancements, and cultivate a culture of continuous improvement to redefine the landscape of municipal maintenance. The insights drawn from these diverse case studies not only illustrate the critical challenges faced but also highlight innovative strategies and best practices that pave the way for enhanced asset longevity, operational efficiency, and service reliability in the public sector.

5.3.1 Common Challenges Across Organizations

The case studies identify several critical challenges impeding effective maintenance strategies. Firstly, a deeply ingrained culture of reactive maintenance prevails, where actions are primarily taken post-failure, leading to inefficiencies and increased downtimes. Secondly, the inadequacy of data systems emerges as a significant concern; poor data quality and accessibility hamper informed decision-making and strategic planning. Lastly, there is a noticeable deficiency in implementing predictive maintenance practices. This lack of foresight and reliance on outdated methods contribute to unexpected asset failures and escalate direct and indirect costs. These systemic issues underscore the necessity for a shift in how organizations can approach improved maintenance readiness of core infrastructure.

5.3.2 Detailed Insights from Selected Participant Organizations

- *Organization 1*: Explored the challenges of managing a diverse asset portfolio. Identified a need for improved data-driven decision-making and integration of predictive analytics to anticipate and prevent asset failures.
- *Organization 2*: Demonstrated the impact of a reactive maintenance approach on public services, particularly in water infrastructure. Emphasized the cost savings and service improvements achievable through proactive, data-informed maintenance planning.
- *Organization 3*: Showcased the importance of staff training and development in successfully adopting advanced maintenance technologies and practices. Highlighted how strategic workforce development can enhance overall maintenance effectiveness.

- *Organization 4:* Focused on integrating new technological solutions, such as IoT and AI, into their existing maintenance systems. Discussed challenges in technology adoption and the importance of aligning these innovations with the organization's specific maintenance needs and capabilities.

5.3.3 Strategies for Improvement

- Adoption of predictive maintenance techniques to foresee and mitigate potential failures.
- Enhancement of data quality and system accessibility to inform and streamline maintenance decisions.
- Comprehensive training programs for maintenance staff to ensure proficiency in advanced maintenance practices.
- Seamless integration of new technological solutions into existing maintenance systems.

5.3.4 Impact and Potential of Optimization

These case studies collectively demonstrate the transformative potential of a proactive, data-driven approach to maintenance. Implementing these strategies early in an asset's life promises significant improvements in maintenance efficiency, reduced downtime, and extended life.

5.4 Results of Case Study 3: Interoperability Gap Analysis

This Case study overview weaves together the real-life experiences of 19 participant organizations, each contributing to a collective story of overcoming challenges in municipal asset management. These organizations shared their insights, painting a vivid picture of the hurdles and opportunities faced in optimizing and transforming data management practices.

5.4.1 Common Themes Across Organizations

Each organization faced unique challenges, reflecting the diverse landscape of public sector asset management. The participants' stories highlight common themes, from a city's urban sprawl to rural roads and complex industrial water and wastewater processing plants.

Data Integration and Sharing

- Identified Challenge: Multiple organizations reported fragmented data systems leading to inefficient operations and decision-making delays.
- Specific Insight: One municipality highlighted how its maintenance data was disconnected from operational data, resulting in reactive rather than preventive maintenance strategies.
- Recommended Solution: Implementing a unified data platform to streamline data flow across departments.

Real-Time Data and Emergency Response

- Identified Challenge: A particular case showed that a lack of real-time data severely impacted the municipality's ability to respond promptly to infrastructure emergencies.
- Specific Insight: The delay in road repair due to data unavailability was cited, significantly affecting local transportation and the economy.
- Recommended Solution: Establishing real-time data-sharing systems for immediate response and decision-making in emergency scenarios.

Predictive Maintenance through Advanced Technologies

- Identified Challenge: Organizations expressed the need for predictive maintenance but lacked the necessary technological infrastructure.
- Specific Insight: An example was provided where predictive analytics could have anticipated a major asset failure, saving significant repair costs and downtime.
- Recommended Solution: Gradual integration of IoT and AI for predictive analytics and maintenance planning.

Balancing Innovation and Existing Systems

- Identified Challenge: Several participants noted the difficulty in integrating new technologies with legacy systems.
- Specific Insight: One municipality had challenges adopting IoT solutions due to compatibility issues with their older systems.
- Recommended Solution: Develop a phased approach for technology integration, ensuring compatibility and staff training.

5.4.2 Projected Outcomes and Benefits

- *Operational Efficiency:* Unified data systems are expected to streamline operations, reducing time and resources spent on data management.
- *Cost Reduction:* Predictive maintenance, enabled by IoT and AI, could significantly lower unexpected repair costs and extend asset life.
- *Strategic Asset Management:* Enhanced data accessibility will empower municipalities to make informed, strategic decisions regarding asset management.

5.5 Summary

Section 5 has presented three case studies that captured the main ideas from the course participants' submissions. The first study analyzes asset failures, revealing the need for robust data and proactive maintenance strategies. The second study, Maintenance Readiness Optimization, highlights the shift from reactive to predictive maintenance, emphasizing the importance of data-driven decision-making. The final study explores interoperability gaps, advocating for integrated data systems and advanced technologies like IoT and AI. Collectively, these studies provide actionable insights, underscoring the necessity for a holistic, data-centric approach in municipal asset management.

The case studies have (1) highlighted a move toward strategic, data-driven, and sustainable asset management practices in different asset classes, (2) identified primary areas for improvement related to data management, resource allocation, technological adaptation, and environmental compliance, and (3) focused on three themes: Transition to proactive maintenance, technological integration and data management, and sustainability and environmental compliance.

In addition, the case studies covered various asset classes, including heavy machinery, infrastructure, community facilities, and marine facilities. This diversity underscores the broad applicability of maintenance management principles across different sectors. The challenges encountered/solved in the case studies relate to data management, resource allocation and training, adapting to new technologies, and environmental risks and compliance. The Business Case (Lawlor and Easa 2024) provides more details on various case studies demonstrating best practices.

SECTION 6 - CONCLUDING REMARKS

6.1 Project Summary

This white paper culminates from a national project to enhance maintenance and reliability readiness in the Canadian public sector. Central to this initiative was developing a comprehensive national survey, a specialized training curriculum, detailed data analysis, and the active participation of various entities in case studies. The project's core intent was to frame the current state of maintenance and reliability readiness, emphasizing infrastructure maintenance as a pivotal tool in ensuring asset value and supporting communities. Key findings illustrate that effective infrastructure maintenance is not only crucial for asset longevity but also plays a vital role in sustaining the services and quality of life in communities. This project's success highlights the indispensable role of maintenance and reliability readiness in shaping a resilient and efficient public sector in Canada.

6.2 Canadian Municipality Online Survey: Key Takeaways

The Canadian online survey has provided valuable data and perspectives, highlighting the current state, challenges, and future opportunities in PSO asset management. The survey underscores the critical importance of effective asset management practices in the public sector. The following are the key takeaways from the survey:

(a) *Diverse Asset Management Practices*: The survey revealed a diverse range of asset management practices across Canadian PSOs. The variability in data management, storage systems, and technological adoption reflects the different stages of asset management maturity.

(b) *Technological Integration and Standardization*: A significant opportunity exists for PSOs to advance their asset management practices through technological integration and standardization. Modern technologies and standardized data practices can lead to more efficient, effective, and sustainable asset management.

(c) *Collaborative and Strategic Approach*: Effective asset management requires collaboration, integrating various departments and leveraging their collective expertise. A strategic approach, underpinned by robust policies and compliance with regulatory standards, is essential for long-term success.

6.3 Pillars for Good MDRR Practices

Based on this project, the following pillars of organizational good practices that enable MDRR have been identified:

1. *Asset Management Policy and Plans.* Asset management policy and plans that support effective MR objectives. Municipal AM policies should outline the criticality of MR to public services, infrastructure performance, and fiscal responsibility. Asset management plans then detail risk, criticality, and other frameworks to prioritize assets for service levels. This enables maintenance resources and activities to be aligned to the most mission-critical infrastructure, especially for the state-of-good repair and refurbishment Planning.

2. *Sufficient CapEx Financial Resources for Initial Maintenance Deliverables.* Adequate capital expenditure funding enables the initial provisioning of maintenance requirements during the asset design, build, and commissioning lifecycle stage. This includes investment in reliability-focused designs, spare parts, specialized tools, maintenance software, warranties, and training. Underfunded CapEx hampers building maintenance readiness for new/upgraded assets, which may result in higher than anticipated maintenance costs and increased D & D frequencies within the asset portfolio.

3. *Procurement Plans that Embed Maintenance Requirements into the D & ABC Lifecycle Stage.* Municipal procurement contracts should mandate maintainability, reliability, and operability requirements based on asset criticality and expected failure modes. Requirements may include standards compliance, condition monitoring capabilities, vendor training, manuals, defined warranties, and spare parts. This embeds maintenance considerations into the delivered assets and the ability to define asset care plans.

4. *Sufficient OpEx Financial Resources to Enable Future Maintenance Work.* Allocating adequate operating expenditure funding ensures municipalities can deliver preventive, predictive, and reactive maintenance aligned to asset criticality and asset demands regarding risk, performance, and costs. Optimization of labour, parts, supplies, and services prevenance-maintaining assets. Insufficient OpEx compels proactive work deferrals that can increase lifecycle costs and risk exposure and lower the required performance over time.

5. *Digital Transformation*. Digitizing O&M processes with CMMS built for modern use cases and emerging technologies such as BIM and DT will be essential for operational efficiency. Organizations increasingly switch from reactive to proactive monitoring and maintaining critical equipment and spaces.

6. *Predictive Analytics.* Predictive tools using IoT devices such as sensors, artificial intelligence, DT, and augmented reality can help identify patterns and predict equipment

behaviour to enable timely maintenance and improve reliability. For example, augmented reality lets professionals place a camera before the machine and provide real-time information, aiding timely maintenance and inspections. Notably, the predictive maintenance market will grow to $10.79 billion in 2023 (Rao, 2023).

7. *Maintenance Capabilities and Capacity to Deliver Work in Alignment with Asset Design and Value Drive.* Maintenance teams should possess the competencies, tools, and resources scaled in alignment with maintainable Infrastructure. In addition, the ability to articulate the value deliverables e.g. cost, performance, and risk. At its most superficial level, maintenance is a treatment function to prevent and correct component-level deterioration and its source. Municipal maintenance has two main functions at a high level:
    a. maintain as-built condition grades, which can be achieved by executing the optimum maintenance mix of tactics and
    b. restore as-built condition grades, which can be achieved by applying the appropriate repair and refurbishment plans.

8. *Staff Capability and Capacity.* There is a balance between provisioning and executing work. Sufficient training of operations and maintenance staff on asset-specific care plans, maintenance execution, fault diagnostics, equipment operation, and related competencies pays dividends in maximized asset availability, extended useful life, and optimized total lifecycle cost. Lifelong learning further enhances the outcomes.

6.4 Benefits of MDRR Realization

The comprehensive benefits of implementing enhanced MDRR include strategic advantages, operation and maintenance lifecycle improvements, financial gains, environmental and social impacts, and long-term benefits. The following are descriptions of these benefits:

(a) Strategic Advantages

- Improved Asset Intelligence*:* Data-driven MDRR strategies offer deeper insights into asset performance and lifecycle management, aiding in informed strategic decisions.
- *Enabling Asset Management Plans:* MDRR aligns maintenance strategies with AM objectives, enabling the organization to realize the value of its assets.

(b) Operation and Maintenance Lifecycle Improvements

- Increased Operational Efficiency: Streamlining maintenance processes reduces downtime and enhances operational reliability, leading to more efficient service delivery.
- Predictive Maintenance Prowess: Advanced predictive maintenance techniques prevent unexpected failures, ensuring smoother operations and better resource allocation.

(c) Financial Benefits

- Preventing Premature Deterioration of Assets: Proactive MDRR identifies and addresses issues early, preserving asset integrity and functionality.
- Cost Avoidance and Optimized Maintenance Spending: Early intervention reduces emergency repairs and unplanned downtime, enabling more efficient resource allocation.
- Risk Reduction: Regular MR checks enhance safety and compliance, reducing operational risks.
- Extended Mean Time Between Capital Replacements: Effective MDRR results in prolonged asset lifespans and strategic asset lifecycle management.
- Budgetary Predictability: Enhanced MDRR provides more apparent foresight into future maintenance needs, leading to optimized budgeting.

(d) Environmental and Social Benefits

- Sustainability Enhancement: MDRR practices optimize resource use and minimize waste, contributing to environmental sustainability.
- Community Trust and Satisfaction: Improved MDRR results in reliable and efficient public services, which boost community trust and satisfaction and enhance the public sector’s image.

(e) Long-Term Benefits

- Performance, Risk, and Cost Improvements: Implementing MDRR strategies leads to long-term financial savings, improved operational reliability, and enhanced service delivery quality.
- Sustainability: This approach is crucial for building a resilient and sustainable public sector infrastructure.

6.5 Looking Ahead

Looking forward to a resilient future in asset management, several recommendations are identified to promote this project's initiatives further.

First, MDRR strategies should continually adapt to emerging technologies. Implementing advanced technologies, such as digital twins, is expected to grow and substantially streamline the MDRR throughout the asset lifecycle stages as technologies evolve.

Second, asset management is an ever-evolving field, and PSOs must continually seek to improve and refine their practices. This involves promoting an M & R culture, adapting to changing regulations, and being responsive to the evolving needs of their communities.

Third, it is recommended to promote ongoing collaboration with industry experts, professional organizations (like PEMAC and GFMAM), and stakeholders to foster innovation and continual enhancement of MDRR practices.

Finally, as more engagement occurs across municipalities, TMU and PEMAC will seek to learn and explore objective inputs and ideas further to update and continually improve, as necessary, the foundation work on maintenance management and reliability engineering created in this project.

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A1. Section 1 Results: General Information

Geographical Distribution

The survey generated responses from a diverse range of provinces and territories, offering a panoramic view of asset management practices across Canada. Ontario emerged as the most represented province (55.7%), indicating its significant urban population and extensive public infrastructure. Alberta (17.1%) and British Columbia (12.9%) followed, highlighting their active engagement in asset management discussions. The survey, however, noted a lesser representation from smaller provinces and territories like New Brunswick, Newfoundland and Labrador, and the Northern Territories, suggesting a potential area for further outreach and research to ensure a more comprehensive national perspective.

Municipality Size

The size of the population served by the PSOs of the respondents varied significantly, reflecting the diverse urban and rural landscapes of Canada. A significant 33.3% of the respondents were from very large PSOs serving populations exceeding 400,000, indicating a strong focus on asset management in major urban centers. The survey also observed substantial participation (14.5%) from PSOs serving smaller populations (less than 5000 people), underlining the prevalence of asset management practices across various scales of PSO governance.

Sectional Representation

The survey's sectoral analysis provides insight into the multi-disciplinary nature of asset management. Most respondents (51.4%) were from Asset Management, emphasizing its central role in PSO operations. Maintenance Management (15.7%) and Operations (7.1%) also saw notable representation, revealing the cross-sectoral collaboration necessary for effective asset management. These findings underscore the importance of a holistic approach to asset management, encompassing various departments and functions within a PSO.

Asset Classes Managed

The survey responses revealed a wide array of asset classes managed by PSOs, reflecting the multifaceted nature of PSO services and infrastructure. The following are the primary asset classes indicated by the survey participants, highlighting their prevalence and significance in asset management:

- *Water and Wastewater Systems*: A significant portion of respondents manage Water and Wastewater Systems, both vertical (66.7%) and linear (56.5%). This underscores the AM critical role of water infrastructure in PSO services, encompassing treatment plants, stations, and extensive pipe networks.

- *Transportation Infrastructure:* Roads (58.0%) are another primary asset class, signifying the importance of transportation infrastructure in urban planning and community connectivity.

- *Other Transportation-Related Assets.* Transit (18.8%), Bridges (53.6%), and Culverts (56.5%) also form a substantial part of the asset portfolio, indicating the need for comprehensive management strategies that encompass various facets of transportation infrastructure.

- *Public Facilities and Spaces*: The management of Public Buildings (55.1%) and Parks and Recreational Facilities (46.4%) highlights the role of PSOs in providing essential public spaces and facilities.

- *Solid Waste Management* (43.5%) and Fleet Services (49.3%) are also notable, reflecting the logistical and operational aspects of PSO services.

- *Other Asset Classes*: A smaller yet significant focus is on specialized assets like Public Housing (13.0%), Lands (36.2%), and Information Technology (30.4%), illustrating the diverse range of services and infrastructure under PSO purview.

Job Titles of Respondents

The job titles of the survey respondents provide a window into the organizational hierarchy and the range of professionals involved in asset management. This diversity of roles indicates the multifaceted nature of asset management and the various perspectives that contribute to effective management practices. The following are the survey results regarding job titles:

- *Managerial Roles*: Managers formed the largest group of respondents (41.2%), signifying their pivotal role in decision-making and strategic planning in asset management. This high representation suggests that middle management is crucial in implementing and overseeing asset management policies and practices.

- *Specialists and Technical Experts*: Analysts/Specialists (14.7%) and Supervisors (11.8%) were also significantly represented. These roles often involve specialized knowledge and technical expertise, crucial for the detailed planning, execution, and monitoring of asset management activities.

- *Other Key Roles:* Although less represented, Directors (2.9%) and Commissioners (0.0%) are likely to be involved in higher-level strategic decisions and policy formulation in asset management. Also, the presence of Technicians and other specified roles (not quantified in the quoted data) suggests the involvement of ground-level operational staff, who are integral to the day-to-day management and maintenance of PSO assets.

A2. Section 2 Results: Asset Master Data

A2.1 Equipment ID Number/Code Data: Lifecycle Stages

The survey inquired about collecting and utilizing Equipment ID Number/Code data, a critical component in asset management for tracking and maintaining PSOs assets. The findings provide insights into how this data is integrated into the asset management lifecycle.

Lifecycle Stages of Data Collection

The data is predominantly collected during the O & M stage (61.7%), followed by D & ABC (58.3%) and lifecycle planning (15.0%). This distribution suggests a focus on tracking equipment through its operational life, ensuring effective maintenance and management.

Methods of Data Collection

The methods of collecting Equipment ID data vary, with a notable emphasis on 'Tabularized established connections to other asset master data' (41.7%) and 'Scattered exists throughout one or multiple design/project documents' (36.7%). The variety in methods reflects the diverse systems and practices employed across PSOs.

A2.2 Data Storage Systems

The storage of asset master data is critical to asset management, impacting data accessibility, reliability, and security. The survey respondents provided information about the primary systems and locations where asset master data is stored in their PSOs. Spreadsheet-based methods are commonly used for data storage. A notable portion of respondents (22.0%) mentioned using 'Other' software solutions, highlighting the diversity of tools employed across different PSOs. This diversity reflects varying levels of technological adoption and possibly differing requirements based on the scale and complexity of the assets managed.

A2.3 Primary Users of Data

The survey also explored who the primary users of the Equipment ID Number/Code and Asset Description data are within the PSOs. This aspect is vital for understanding the cross-functional nature of asset management and the collaboration required among various PSO departments.

Users of Equipment ID Number/Code Data

- The data indicates a broad usage of Equipment ID Number/Code data across multiple departments. Maintenance (76.3%) and Operations (69.5%) departments are the primary users, reflecting the data's importance in daily asset management activities.
- Capital (35.6%) and Finance (39.9%) departments also utilize this data, suggesting its relevance in long-term asset planning and budgetary considerations.

Users of Asset Description Data

- Similar to Equipment ID data, Asset Description data is extensively used by Maintenance (80.4%) and Operations (80.4%) departments, emphasizing its role in operational and maintenance tasks.

- Its use by Capital (39.3%) and Finance (50.0%) departments highlights its importance in strategic asset management and financial planning.

A2.4 Asset Description Data

Asset description data is a key component in asset management, providing detailed information about each asset's characteristics, purpose, and status. The survey responses shed light on the nature of this data collected by PSOs and its role in asset lifecycle management.

Types of Asset Description Data Collected

- The survey revealed a wide range of asset description data being collected. Notably, 'Serial numbers' (74.1%) and 'Function' (67.2%) were among the most commonly collected types, emphasizing detailed tracking and functional categorization of assets.
- Other types of data such as 'Purpose' (60.3%), 'Criticality' (24.1%), and 'Regulatory flags' (17.2%) also play significant roles, reflecting the need for comprehensive data to support decision-making and compliance.

Lifecycle Stages for Data Collection

- Most Asset Description data is collected during ABC (74.1%) and O & M (63.8%) stages. This suggests that asset data is primarily gathered at the point of asset creation and continuously updated throughout its operational life.
- The collection at the 'Planning & Design' stage (22.4%) indicates early-stage data integration into asset management processes.

Methods of Data Collection

Various methods are used for collecting Asset Description data, with 'Tabularized established connections to other asset master data' (41.4%) and 'Scattered exists throughout one or multiple design/project documents' (39.7%) being prominent. This variety reflects the different levels of data management sophistication and integration within PSO systems.

A2.5 Storage Systems and Accessibility of Asset Data

Understanding where and how PSOs store their asset data is crucial for assessing the efficiency and effectiveness of asset management practices. The survey responses provide insights into the primary data storage systems used and the accessibility of this data to various users.

Primary Data Storage Systems

- The most used data storage systems include CMMS (46.6%) and GIS (58.6%). The high usage of CMMS indicates its importance in maintenance management, while GIS's prevalence highlights the significance of spatial data in managing PSO assets.
- Other systems, such as Financial Fixed Registry (13.8%), ERP (12.1%), and Excel (37.9%), are also utilized, showcasing a mix of sophisticated and essential data management tools across PSOs.

User Accessibility

- Maintenance (86.4%) and Operations (83.1%) departments are the primary users of relevance in asset management.

A2.6 Lifecycle Stages and Collection Methods

The effective management of PSO assets requires tracking and updating data across various stages of the asset lifecycle. The survey responses give insight into when and how PSOs collect different types of asset data, which is critical for planning, maintenance, and decision-making.

Lifecycle Stages of Data Collection

- Data collection predominantly occurs during the O&M and ABC stages, focusing on maintaining accurate records from the acquisition of an asset through its operational life.
- The collection of data in the 'Planning & Design' stage, though less common, is vital for proactive asset management, ensuring that assets are designed and built with future maintenance and operational considerations in mind.

Methods of Data Collection

- The diversity in data collection methods ranges from 'Tabularized established connections to other asset master data' to 'Scattered exists throughout one or multiple design/project documents.' This reflects varying practices across PSOs, from structured and integrated systems to more fragmented approaches.
- The use of standalone reports or documents, although less prevalent, points to traditional methods still in use, which might hinder quick data retrieval and integration.

A2.7 Asset Data Collected

PSOs collect various asset data types throughout the asset lifecycle, each serving specific purposes in asset management. The survey responses provide insights into these data types, offering a comprehensive view of the information crucial for effective asset management.

Types of Asset Data Collected

- A significant focus is on collecting asset identity and condition data, such as serial numbers, function, purpose, and criticality. This data type is fundamental for tracking, maintaining, and prioritizing assets.
- Other specific data types include climate change impact assessments, regulatory flags, and physical addresses, reflecting the broad scope of modern asset management considerations.

Lifecycle Stage-Specific Data

- Data types like the start and end dates of acquisition, planning, and operation are collected at different lifecycle stages. This temporal data is critical for planning maintenance schedules, budgeting, and replacement strategies.

- The start and end dates of maintenance and decommission further illustrate the comprehensive tracking of assets from inception to disposal.

Financial and Performance-Related Data

- Financial data such as purchase price, depreciated value, and replacement value are essential for financial planning and asset valuation.
- Performance-related data, including schedule, maintenance type, and estimated job duration, are crucial to assessing and optimizing asset management practices' efficiency and effectiveness.

A3. Section 3 Results: Asset Management Systems

The survey shows gaps in reliability practices, data handoff, maintenance planning, and lifecycle cost viewpoints. The following are survey-based opportunities that validate the need for MDRR:

1. *Addressing climate change*. Some municipalities have considered climate change in their policy (36.0%). However, how to implement that is unclear. Other municipalities considered it in anticipated cost (5%), mitigation and adaptation approaches (22%), and risk and disaster planning (5%).

2. *Limited Adoption of Reliability Engineering*: Only 27.8% of respondents indicated having a reliable engineering structure and team, and 55.6% do not currently have one. This shows that reliability engineering practices are not widespread, highlighting the need for greater emphasis on MDRR.

3. *Reactive Maintenance Predominance:* On average, only 37.3% of maintenance work executed by trades is captured in a single system. This implies that most work is likely reactive rather than proactive maintenance enabled by MDRR.

4. *Informal Maintenance Planning:* Only 33.3% of respondents indicated having a full-time resourced maintenance planning function with formal processes. This suggests that maintenance planning maturity needs improvement, which MDRR training could provide.

5. *Lifecycle Cost Consideration:* 55.6% of respondents said future lifecycle costs are not considered in asset procurement, revealing the need for a greater lifecycle cost perspective tied to MDRR. Looking beyond initial costs and considering long-term costs supports cost-effective asset lifecycle management and informed procurement decisions.

6. *Existing Asset Management Plans:* Many municipalities have already developed AM plans (46.9%) that provide a strategic framework for managing their assets.

These plans outline the characteristics, conditions, and desired service levels for infrastructure assets, helping guide decision-making and resource allocation.

7. *Maintenance Management Systems*: Many municipalities (53.1%) use maintenance management systems, such as GIS, Building Information Modelling (BIM), Cityworks, and SAP PM, to streamline maintenance operations and capture relevant data. These systems enable efficient work order management, resource allocation, and tracking of maintenance activities.

8. *Asset Data Inventory*: Municipalities (30.6%) have progressed in maintaining asset data inventories, ranging from limited to comprehensive. This includes capturing essential attributes for critical assets, providing basic information for all assets, and linking attributes to performance indicators, enabling informed decision-making and analysis.

9. *Monitoring Asset Management Plan Implementation:* Some municipalities (16.3%) have established processes to monitor the implementation of their AM plans. Regular monitoring and evaluation help assess progress, identify gaps, and make necessary adjustments to improve AM outcomes.

10. *Emphasis on Maintenance Management*: In their AM policies, many municipalities (42.6%) have included maintenance management sections. This integration highlights the significance of maintenance practices in achieving overall AM objectives and aligning maintenance strategies with the broader AM framework.

Table B1 Summary of exemplary work (very large municipalities)

Element	Municipality	
	The Corporation of the District of Saanich (Very Large)	**Halton Region (Very Large)**
Contact	Jacqueline Weston	Philip Lawlor
Title of Exemplary Work	District of Saanich AM Strategy	Implementation of a Reliability-Centered Maintenance Strategy and Data-Driven Lifecycle Optimization
Objectives	The District of Saanich Strategic Plan, under the theme of Organizational Excellence Initiatives, includes the following objective: "We practice asset management to support the sustainability of our services."	The strategic business plan for 2019 set the stage for optimizing the maintenance function within one section of the organization, treatment Plant Maintenance; it intended to support AM's objective of ensuring 80% or more of the assets remained in good or very good condition. By leveraging Maintenance Management and Reliability Engineering good practices, the organization was able to achieve the strategic objectives and use that success to drive forward with an expansion of maintenance management from a sectional level to a public works level, setting the stage as a benchmark of public sector maintenance management good practice.
Lifecycle Stage	All stages	Operation & Maintenance Stage
Exemplary Work Related to	Asset Master Data Asset Management Systems Asset Management Decision Making Asset Management Strategy & Planning Maintenance and Reliability Organization, Culture, and Leadership	Asset Master Data Asset Information Management (Standards and Strategies) Asset Management Decision Making Risk assessment Asset Management Strategy & Planning Maintenance and Reliability Organization, Culture, and Leadership
Description of Exemplary Work.	On July 10, 2023, Saanich Council approved the district's first Asset Management Strategy, looking ahead at the future of sustainable service delivery. The AM strategy aims to establish a road map to formalize and continuously improve Saanich's AM practices.	The strategy sets the stage for the development and long-range plans to grow the capability of the maintenance function in collaboration with Asset Management, Operations, and Engineering, creating a 'one team' culture. The data-driven lifecycle optimization comprises establishing a robust equipment register and master data processes to enhance accuracy, then enhanced work order design and process to
	Municipality	

Element	The Corporation of the District of Saanich (Very Large)	Halton Region (Very Large)
		enable the capturing of effective data to drive programs such as RCM3, TOPS, Failure cause analysis, and bad actor identification, all of which lead toward optimized decisions about maintaining the reliability of assets, processes, and plants.
Benefits	The AM strategy represents a significant opportunity to increase Saanich's operational efficiency and cost-effectiveness. By improving Saanich's AM practices, taxpayers will receive better value from their investment in these assets, as their useful life will be extended and the risk of costly asset failures will be reduced. Better data and information will help ensure that assets are designed, built, operated and maintained to support service delivery for as long as possible.	The main benefits are increased visibility into asset condition and trends supporting failure prevention through optimized maintenance tactics, as well as developing new programs that further support the state of good repair objectives.
Issues	Before starting the AM strategy, the District did not have a recent replacement value estimate for its assets and, therefore, did not know the current annual replacement funding requirement. This work resulted in a current valuation of Saanich's assets at $4.7 billion ($2022) with a sustainable yearly replacement funding target of $86 million ($2022). The next step is to update Saanich's Infrastructure Replacement Funding Strategy to reach the target.	No sectional-level data management practices existed that would enable long-range optimization of asset conditions or data utilization for programs such as RCM. MM Work management practices were inconsistent, and planning processes did not align with good practices. The AM structure focused little on MM, and most activities revolved around the other lifecycle stages only.
Challenges	At the start of the work, Saanich's asset data was stored in various locations, including paper, Excel spreadsheets, GIS and several other databases. By the end of the project, the team had compiled all asset data into a central set of Excel spreadsheets, which were used along with PowerBI to create preliminary asset data. One of the next steps in the AM Strategy is to transfer all existing asset inventory data to a central database and then create a digital and dynamic AM dashboard.	1. Change Management - Leveraging the support of the council, commissioner, and director via the strategic business planning process and regular communication in meetings and events while sharing metrics and KPI performance along the way was the key to unlocking the potential of the MM function, without it, it would not have been possible. 2. Implementing robust processes defining R&R and enabling the team to take the lead in their respective function with the team.

Element	Municipality	
	The Corporation of	Halton Region

	the District of Saanich (Very Large)	(Very Large)
		3. Focus on training and development of the team and sharing information with stakeholders, programs like the MMP, and other micro-credentials related to planning, reliability and SAP. 4. We showed results in the work planning and control processes, which are closest to operations and engineering and where the program is most visible, 'the tip of the iceberg.' By demonstrating a high level of professionalism, reducing the backlog, and completing work as agreed and scheduled, we increased the confidence of the MM function.
Other Comments	This project was prepared with assistance from the Government of Canada and the FCM. The British Columbia Ministry of Municipal Affairs supported this project under the Union of British Columbia Municipalities 2022 AM Planning program. Further information regarding Saanich's AM Program is found here https://www.saanich.ca/EN/main/local-government/asset-management-program.html	It's critical to frame maintenance management as an essential element of AM. If the need is to extend the life of owned assets and maintain as designed 'proactive' costs while ensuring 'reactive' costs and risks do not impact asset performance, then it should be clear, that in the right hands, Maintenance management has the potential to significantly improve the desired outcomes from our assets and the communities that rely on those assets to live, work and enjoy life.

Table B2 Summary of exemplary work (very small to large municipalities)

Element	Municipality		
	City of Guelph (Large)	**Town of Newmarket (Medium)**	**RM of Torch River No.488 (Very Small)**
Contact	Kevin Nelson	Lisa Ellis	David Yorke
Title of Exemplary Work	Forecasting asset needs at a corridor level	Developing Condition assessment framework for all asset classes	Condition inspections and Introduction of software in the work order system.
Objectives	When examining the future needs of the City's services, we wanted to look at all the different types of assets in a road right-of-way, and not just the needs of the road, the water main, the sanitary main, or the stormwater main individually. This maximizes the benefit of the limited infrastructure renewal budgets compared to the increasing costs of infrastructure work - making needed improvements to as many assets as possible simultaneously while reducing the repetition or duplication of work that can occur when each asset class is evaluated individually.	Improve decision-making. This information will help inform future financial needs and allow the town to plan accordingly.	Reduce the paper prints by introducing the AST work order management software. With this software, the asset data is centralized now.
Lifecycle Stage	All stages	All stages	All stages
Exemplary Work Related to	Asset Master Data Asset Information Management (Standards and Strategies) Asset Management Systems Asset Management Decision Making Risk Assessment Financial Reporting Asset Management Strategy & Planning Maintenance and Reliability Organization, Culture, and Leadership	Asset Master Data Asset Information Management (Standards and Strategies) Asset Management Decision Making Risk Assessment Financial Reporting	Asset Master Data Asset Information Management (Standards and Strategies) Asset Management Systems Asset Management Decision Making Risk Assessment Asset Management Strategy & Planning
	Municipality		

Element	City of Guelph (Large)	Town of Newmarket (Medium)	RM of Torch River No.488 (Very Small)
Description of Exemplary Work.	With the road right-of-way segments being used to define corridors and using baseline information about the assets (age, material etc.), combining consultant-provided condition information about the assets, a series of numerical values were applied to each asset type in the right-of-way using defined variables based on road type (arterial or collector or local), is the right-of-way a bus or truck route, what is the criticality of failure, what is the likelihood of failure, are critical services served by the right-of-way (ex.: hospital), pipe material (cast iron or concrete etc.). Consideration was given to those assets that may cross multiple corridors (water mains, for example). A mathematical algorithm was developed to determine a score for each corridor. The corridor scores are ranked, with the worst-scoring corridors being given higher priority in developing future capital projects.	(For further information, please get in touch with me)	Introducing the AST work order management software to reduce the paper prints. With this software, the asset data is centralized now.
Benefits	We are breaking the traditional 'silos' of assessing each asset class individually and not being able to quantitively determine if, for example, the work for Road A was more critical than the work for water main X. Mapping the results to GIS provided an easy to view visualization of where the priority works in the city are located.	Based on recent work, we have reduced the backlog by $28M	Data is stored and updated on the server. Hard-copy prints have been reduced. The asset can be viewed on the satellite image.
Issues	We had no quantitative, data-based method to understand the condition and needs of rights-of-way, only single asset classes. So, the limited capital budgets - while not wasted - can now be more effectively used.	No condition data	Data was stored in a spreadsheet. It is challenging to update the maintenance data.
Challenges	We looked for examples of corridor-type analysis being used anywhere but did not find a clear solution. Or the price for a software tool was out of budget and came with complex IT requirements that could not be resolved within an acceptable timeframe. Additionally, when we trialed software tools, the results generated did not match the reality of the assets as understood by staff. So, our technique and algorithm were developed from scratch.	Organizational buy-in	Finding the right tool was challenging. We discussed our intentions on municipal forums, internet searches, and demos and spoke with software clients in rural municipal environments.
	Municipality		

Element	City of Guelph (Large)	Town of Newmarket (Medium)	RM of Torch River No.488 (Very Small)
Other Comments	The first results in fall 2022 and Winter 2023 were promising, but more refinement is needed. This is ongoing. We are looking to include the corridor level analysis as an item in the next AMP that is being prepared. Still, given the general requirement to look at each asset class singularly, we're not yet entirely sure how that will be done. One of our next modifications is to include deterioration modelling in the corridor analysis so that we can better predict the timeline for when infrastructure work will be required. The challenge with this is the lack of standardized accepted deterioration models for each asset class. It would be very helpful if some National body or group could help establish these as it would benefit all municipalities and provide valuable resources to those municipalities who may not have the in-house capability to do this.	None	There are very few tools available for rural municipal operations. We do not want complicated software as we have few asset types, and the maintenance crew is not always highly tech learners.

As previously mentioned, the training course included five assignments related to the national online survey (Assignment 1), asset failure (Assignment 2), maintenance readiness optimization (Assignment 3), gap interoperability analysis (Assignment 4), and lesson discussion questions (Assignment 4). Assignments 2-4 are mini-case studies conducted by each municipality and graded by the instructors. This appendix provides detailed descriptions of these three assignments.

C1. Assignment 2: Study an Asset that Failed (due in Lesson 2)

Assignment Objectives

- Apply Lesson 1 concepts to a real-world asset failure case. - Identify opportunities to improve maintenance data, tactics, and readiness.
- Strengthen foundational understanding of maintenance fundamentals.
- Practice scoping improvement initiatives based on conceptual learning.

Instructions

1. Identify an asset in your organization that required reactive or corrective maintenance or early disposals due to premature failures. Select an example that adversely impacts one or more objectives: cost, safety, compliance, performance, or service level.

2. Analyze the asset Master data records to identify the level of detail for the following:
    a. Maintenance tactics—What preventive, predictive, or run-to-failure tactics are used? Evaluate how to optimize PM and PdM practices.
    b. Asset data and types - Is there a complete asset hierarchy with attributes like criticality, failure modes, and redundancies? Assess what data is leveraged in maintenance decisions.
    c. Resource allocation - Are maintenance work orders resourced with accurate time estimates, materials, and skills? How can resource allocation be improved?
    d. Maintenance maturity - Does reactive maintenance point to gaps in maintenance practices? Consider metrics like wrench time, PM compliance, and PdM coverage.

3. Concerning the O & M stage only, suggest potential enhancements to master data to support improved maintenance readiness based on Lesson 1 material and discussions. Examples may include:
    e. Improving Master data coding
    f. Improve failure and criticality assignments
    g. Adding condition monitoring

h. Optimizing PM frequencies - Developing a reliability-centred maintenance program - Planning and scheduling enhancements.

C2. Assignment 3: Individual Mini-Case Studies – Optimizing Maintenance Readiness (due in Lesson 6)

Assignment Objectives

- Demonstrate ability to analyze and optimize maintenance readiness for an asset.
- Apply risk-based analysis to inform maintenance priorities and strategies.
- Develop targeted data-driven improvements across the asset lifecycle stages.
- Protect confidential municipal information while conveying insights.

Instructions

1. Provide a detailed overview of the selected asset from Assignment 2, including all available master data such as (format this data in a table for clarity):
    - Asset specifications (e.g., make, model, and size)
    - Location
    - Criticality ranking
    - Components (bill of material - stock and non-stock)
    - Maintenance history - percentage of reactive work of total work completed (hours or work order counts)
    - Other

Required Analysis

1. Outline the asset's current maintenance strategies and intervals. Describe the resources allocated to execute the strategies by trade type.
2. Identify potential future state improvements to strategies and resourcing.
3. Conduct a risk assessment to determine the potential impact of asset failure in four areas (performance, cost, environment, and level of service). Use a 4-point scale to score the severity of the impact for each area (4 = Very High, 3 = High, 2 = Medium, and 1 = Low).
4. Develop a future state improvement plan to optimize MDRR across each asset lifecycle stage and make recommendations for each. Consider enhancements related to data management, maintenance strategies, technologies, resourcing, lessons learned, training and reliability practices.
5. Compile your analysis into a report. Do not disclose sensitive information, such as municipalities' names or staff names; substitute names should be used. Submit the report by the end of Lesson 6.

C3. Assignment 4: Individual Gap Analysis and Improvement – Interoperability (due two weeks after Lesson 6)

This assignment focuses on developing a basic understanding of asset data needs across the lifecycle and the potential benefits of improving interoperability. The analysis can be kept high-level and straightforward.

Assignment Objectives

- Develop skills in analyzing and describing data requirements and integration opportunities.
- Demonstrate understanding of asset data needs across lifecycle stages.
- Identify data-sharing opportunities between asset acquisition, operations, and disposal.
- Recognize potential benefits of improving data flows between stages.
- Practice scoping an essential data integration improvement initiative.
- Apply concepts to a real-world asset-type example.

Instructions

Select one municipal asset type (e.g. water pump, vehicle, road, building), then:

1. Identify critical data needs at each stage:
    - Lifecycle planning stage
    - D & ABC stage
    - O & M stage
    - D & D stage
2. Describe how data flows or is shared between the stages. Give at least two examples of data sharing between stages for your asset type.
3. Identify one opportunity to improve data flow between stages. This could include:
    - Automating manual data entry
    - Improving data collection processes
    - Enhancing system integration
4. Explain how this improvement could impact long-term asset management for your example asset type.

C4. Assignment 5: Lesson Discussion Topics (due in the following lesson)

This assignment was given for each lesson and included questions related to the various topics covered in the lesson. The purpose of this assignment was to encourage participants to reflect on the lesson’s topics and encourage participants for further reading and investigations. The discussion assignment for Lesson 1 is presented here as an example. The assignment included the following questions:

Q1. What's on your wish list of discussion or pain points you hope will be addressed during the course?

Q2. What obstacles do you already observe with making this statement achievable?

Q3. What is your organization doing to keep your assets reliable, and is it effective?

Q4. What are your strengths or weaknesses in enabling and sustaining maintenance management readiness?

Q5. If operational assets are made ready without any means to execute proactive maintenance work, what would you call that maintenance strategy?

Q6. How does your organization define their optimum mix of maintenance tactics for each asset?

Q7. How does your organization know if it is generating value from its assets, and are there opportunities to improve?

Q8. What can we do better to link AM practices with climate change and circular economy objectives?

Q9. How would you describe your organizational level of maturity in making asset maintenance ready?

Q10. Are these successes familiar or in line with what you are seeing in your organization?

REVISION HISTORY

v.1.00 – March 19, 2024 – The initial versions of the white paper and accompanying business case and guide documents.

ORGANIZATIONAL INFORMATION

PEMAC Asset Management Association of Canada
Canadian Leaders in Asset Management

PEMAC is a Canadian not-for-profit association enabling excellence in maintenance, reliability, and asset management through collaboration, applied learning, and leadership.

www.pemac.org

Toronto Metropolitan University
A student-focused institution of higher education

Toronto Metropolitan University is Canada's leader in innovative, career-oriented education and a university clearly on the move. With a mission to serve societal need, and a long-standing commitment to engaging its community, the university offers more than 100 undergraduate and graduate programs. Distinctly urban, culturally diverse and inclusive, the university is home to more than 45,000 students, including 2,400 master's and PhD students, 3,200 faculty and staff, and nearly 170,000 alumni worldwide.

www.torontomu.ca

To access the accompanying Business Case and Guide, visit:

Lawlor, P. and Easa, S. (2024). *Leveraging municipal asset master data and information for maintenance and reliability readiness: Business case*. PEMAC Asset Management Association of Canada, Mississauga, Ontario, Canada.

Lawlor, P., Easa, S., Lash, R., and Lewis, P. (2024). *Guide: Leveraging asset master data on acquisitions (capital projects, maintenance).* PEMAC Asset Management Association of Canada, Mississauga, Ontario, Canada.

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