Implementation Details to Support a Generalized Framework for Municipal Infrastructure Management

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Municipal Infrastructure Investment Planning (MIIP)

Implementation Details to Support a Generalized Framework for Municipal Infrastructure Management

for

City of Calgary

City of Edmonton

City of Hamilton

City of Ottawa

City of Prince George

City of Regina

Department of National Defence

Regional Municipality of Durham

Regional Municipality of Halton

Regional Municipality of Niagara

December 2009

Municipal Infrastructure Investment Planning (MIIP)

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Table of Contents

List of Figures

List of Tables

Implementation Details to Support a Generalized Framework for Municipal Infrastructure Management

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1. Overview of this Report

The *Framework for Municipal Infrastructure Management for Canadian Municipalities* (the "*MIM Framework*") is described in two Municipal Infrastructure Investment Planning (MIIP, 2009) reports. The first report, written by Vanier et al in 2006, details the "top level" processes for municipal infrastructure management (MIM); it deals primarily with the information needed by senior management to manage municipal assets. In essence, it describes "WHY" asset management is important. This second report, entitled *Implementation Details to Support a Generalized Framework for Municipal Infrastructure Management*, delves into the details of the "WHAT" and the "HOW" of the proposed *MIM Framework*; it outlines implementation issues faced by technical staff in municipalities, describes available opportunities and technologies to address these opportunities, and suggests potential solutions to the current municipal infrastructure management challenges. In all, the *MIM Framework* is a collection of knowledge and expertise relating to municipal infrastructure asset management and directions towards implementing an asset management plans for Canadian municipalities.

1.1 Background

Municipal Infrastructure Investment Planning (MIIP) is a completed research project of the National Research Council (NRC). The MIIP project received financial support from a consortium that included nine municipal partners and two Canadian federal departments (MIIP, 2009). *Implementation Details to Support a Generalized Framework for Municipal Infrastructure Management* (*MIM Framework*) is the final deliverable of this NRC research project.

An earlier MIIP deliverable titled *Primer on Municipal Infrastructure Asset Management* (Vanier and Rahman, 2004) defines municipal infrastructure as:

> *Those assets managed by municipalities. These typically include …: buried utilities, roads, transit systems, bridges, water/sewage treatment plants and parks … police stations, fire halls, indoor swimming pools, arenas and community centres … social housing, schools and vehicle maintenance depots.*

These assets compete with each other for a share of funding for inspection, repair and renewal, and also compete with other municipal funding priorities. Municipal infrastructure management (and the supporting tools and equipment) generally falls under a recently adopted term in the industry called "asset management."

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Asset management is defined in the MIIP *Primer* (Vanier and Rahman, 2004) as:

> *A business process and decision-support framework that: (1) covers the extended service life of an asset; (2) draws from engineering as well as economics; and (3) considers a diverse range of assets.*

Generally, the *MIM Framework* is limited to the scope of the strategic asset management of municipal infrastructure; that is, the *MIM Framework* deals with capital planning beyond both the operational and tactical planning horizons of an organization.

1.2 Overview of the MIM Framework

A "Value Engineering" technique[3] was used by the MIIP project team to identify the "goals" of municipal infrastructure management and to identify the individual tasks needed to manage the diverse infrastructure portfolios of small, medium and large municipalities. The *MIM Framework* was developed through extensive consultation and collaboration with knowledgeable researchers and practitioners over an extended period of time.

The *MIM Framework* is premised on multi-objective decision-making (Vanier and Rahman, 2004). That is, multiple and conflicting objectives always exist when deciding upon which interventions are the best for the short (operational), the intermediate (tactical), *and* the long (strategic) term of the asset portfolio and its users. The objectives taken into consideration in the *MIM Framework* are to: maximize performance, minimize life cycle costs (LCC) and minimize risk of failure. In fact, the difficulties arise for decision making at all three planning horizons (operational, tactical and strategic), but more so at the strategic level (beyond the five year planning horizon), because these three objectives are conflicting: it is extremely difficult to increase performance of an asset or asset class, or to reduce risk, while managers are instructed to reduce costs. If needed, other objectives can also be integrated in the *MIM Framework*.

This report describes the major sequential processes that encompass management-related activities typically performed by municipal asset managers, namely: select protocols, itemize assets, inspect assets, rate assets, forecast needs, integrate needs, recommend resources, and optimize investment. This report also outlines the different facets of infrastructure data/information management that are required to support these eight processes, namely data and information about: inventory, performance, service life, life cycle cost, criticality and alternatives.

The following figure identifies the 122 individual tasks of the *MIM Framework* and their position *vis-à-vis* the processes, as columns in this matrix, and the facets, as rows of the matrix.

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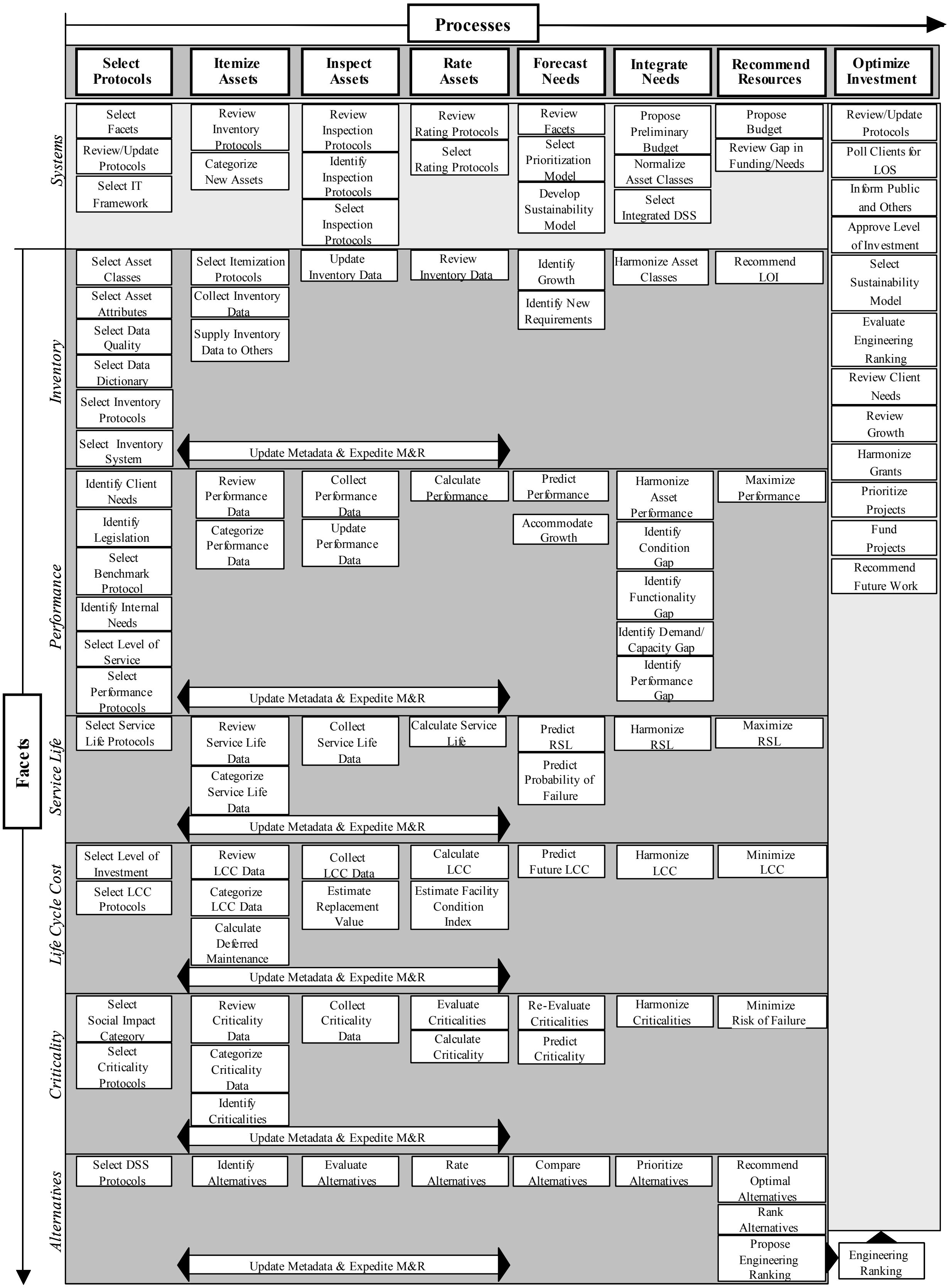
[3] The "Value Engineering" technique called "Function Analysis System Technique" (FAST) was used (FAA, 2007; SAFE, 2007).

Select Protocols Process



Select Protocols Process

2. Overview of the MIM Framework

2.1 Eight Processes

The *MIM Framework* attempts to define, in the context of Canadian municipalities, "what is asset management" or "what is infrastructure management?" and then address how this can be accomplished in a systematic and objective fashion. In this report, the terms asset management and infrastructure management are used interchangeably.

The 122 tasks identified by the MIIP project team (See Appendices A and F) reveals that these tasks can be grouped into the six "whats" of asset management described in earlier MIIP publications (MIIP, 2009) and in the Canadian InfraGuide (InfraGuide, 2003):

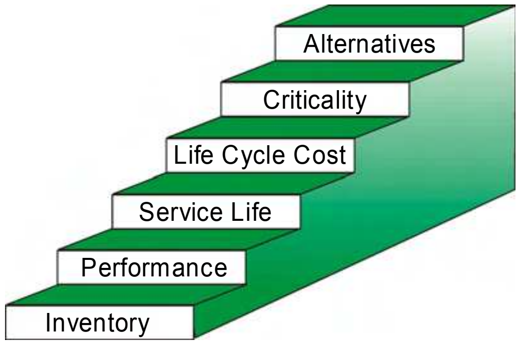
- What do you own? (and where is it?)
- What is it worth?
- What is deferred?
- What is the condition?
- What is the remaining service life?
- What do you fix first?

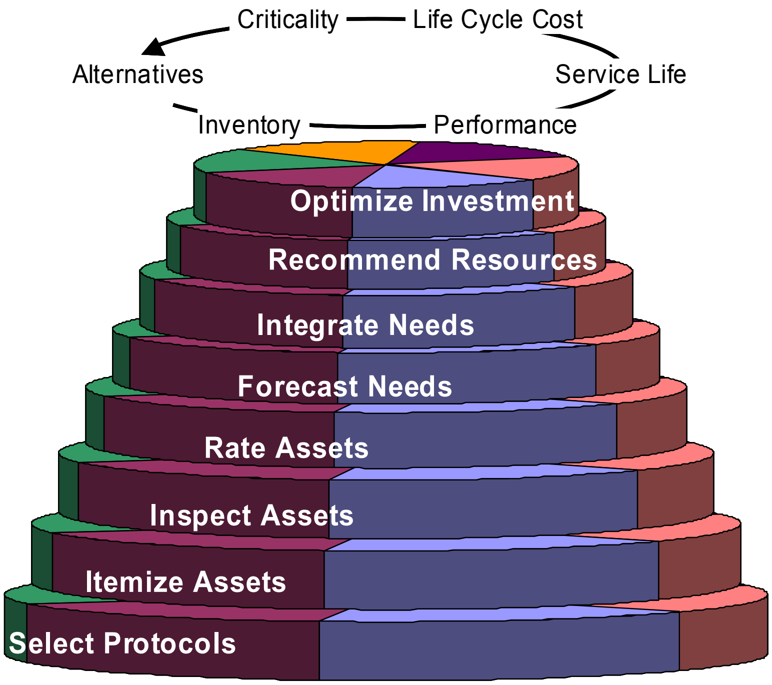
An MIIP "Value Engineering" exercise identified that there are eight, well-defined sequential processes needed to implement municipal infrastructure management: the ultimate goal of asset management being to "optimize investment."

To attain this ultimate goal, the *MIM Framework* is subdivided into a number of sub-goals, or processes, as shown in the accompanying figure. At the foundation of this structure is: (i) *select protocols*. All the other processes build on this foundation. For example, once the required asset management protocols are selected, the municipality can: (ii) *itemize assets*, (iii) *inspect assets*, and then (iv) *rate assets*. Municipalities typically identify their needs individually for each asset class (e.g. roads, water, wastewater, etc.), as most departments still function as "silos" and receive their own individual budgets. At this juncture, the municipality typically: (v) *forecast needs* for the individual asset classes. However to optimize the investment across the entire infrastructure portfolio, there is a requirement to: (vi) *integrate needs*. After these portfolio-wide needs are identified, it is then possible to: (vii) *recommend resources*. Having identified the resources required at the operational, tactical and strategic planning horizons, it is possible to rank the proposed projects (as there are always more project requests than resources) to reach the ultimate goal to (viii) *optimize investment.*

2.2 Six Facets

These eight sub-goals can appear "too strategic" for many practitioners; that is, the technical staff in municipalities and consultancies needs more details to implement the *MIM Framework*. Analysis of the individual tasks identified in the "Value Engineering" exercise classified these tasks into six general facets of municipal infrastructure management. The 122 tasks were classified into facets related to: *inventory*, *performance*, *service life*, *life cycle cost*, *criticality* and the evaluation of *alternatives*. These six facets are similar to the aforementioned questions, or “Six Whats” of asset management. The figure below presents one possible visualization for the combination of the processes and the facets, and how these two parts of the *MIM Framework* interrelate. Another visualization in the form of a matrix of tasks is included as Appendix A.





An asset management plan for a municipality can take years, if not decades, to evolve and be implemented fully; not all processes, facets or tasks can be put into action immediately, as the municipality must select which processes and which facets have the highest priority. This side figure illustrates a sequential approach to implementing the *MIM Framework* and how municipalities can progress from one lower process level (i.e. Select Protocols) to the next higher, and so on, until they reach the top of the structure. This figure also illustrates that the identified facets must also be addressed sequentially, starting from Inventory, then Performance, and so on. One can think of the six facets as a series of progressive steps each leading to attaining the next sub-goal or process. For example, for the first sub-goal or “select protocols” process, the municipality must select which combination of protocols to implement first: *inventory*, *performance*, *service life*, *life cycle cost*, *criticality* or *alternatives*. The ultimate goal is to reach a point where all decisions are based on the Optimize Investment process.

In general, it is recommended to select first those facets that are to be included in the initial implementation of the *MIM Framework*. That is, if the municipality decides that *criticality* of the assets will not be addressed, then inventory data about *criticality* need not be collected. The same holds true for *life cycle costs (LCC),* if it is deemed to be non-essential then there is no need to collect valuation data about the assets.

In the **Select Protocol** process, information about the *inventory* protocols is required to support the other facets. The asset’s *performance* protocols can only be collected once the appropriate *inventory* protocols are known. The *service life* protocols can only be identified after the *performance* protocols are identified. The *LCC* protocols cannot be established until the *performance* protocols are known (required to calculate the future maintenance costs) and until the *service life* protocols are selected. The *criticality* protocols can only be determined after the other protocols from the *inventory*, *performance* calculations, and *service life* assessment and the *LCC* calculations are chosen. For example, the calculations required to determine *criticality* are dependant on data related to the performance, remaining service life, probability of failure, life cycle costs and the cost of emergency repairs. The *alternative* selection protocols can only be selected last because they are dependant on all the other five facets.

This approach can be carried sequentially to the other processes: **itemize assets**, **inspect assets**, **rate assets**, **forecast needs**, **integrate needs**, **recommend resources** and **optimize investment**.

2.3 Who does What and Why?

The images in this section provide a visualization of many of the challenges of implementing the *MIM Framework*, or any asset management plan, for that matter. In essence, the progress towards attaining asset management goals should be seen as a series of small, progressive improvements that move the municipality towards an ultimate goal. The ultimate goal is to be able to optimize the investment portfolio. In fact, the progress appears to be linear in direction, like walking down a hall; however, these illustrations show that the municipality is constantly moving up the structure (advancing) and tightening up procedures (improving). It must be recognized that it is impossible to accomplish everything in even a couple of years and it might be decades before all asset classes have the data required to support the *MIM Framework*. Typically, it is the technical staff and operations staff who provide the data and information to support the *MIM Framework*, as it is they who must itemize, inspect and rate the individual assets.

Middle managers typically deal with the tactical and strategic processes related to forecasting needs, integrating needs and recommending resources. Strategic planners or the asset management team members are assisting them in this task in larger municipalities. Senior managers and elected officials have the responsibility to decide which of these strategic interventions provide the best return on investment. This is based on the advantages and disadvantages of the alternatives. That is, what are the change in performance, the change in criticality and the change in life cycle cost for both the individual asset and the entire portfolio with any investment decision.

2.4 Implementing the MIM Framework Locally

The goal of the municipality is to climb to the top of the pyramid, shown Section 2.2 for all asset classes; however, this is not always possible as all municipalities are different:

- DIFFERENT FACETS ARE IMPORTANT: In the *MIM Framework*, municipalities can also augment these six facets with others needed to satisfy their own internal or external requirements. For example, community sustainability, life cycle assessment and the effects of climate change are three areas of concerns for many municipalities and these facets could be added to the *MIM Framework*. Some municipalities might choose not to implement all of the six facets shown in Section 2.2.
- DIFFERENT EXPERTISE IN MUNICIPALITY: Municipalities have varying degrees of expertise for different asset classes; for example, the roads or bridge department can have considerable experience in condition assessment, service life prediction and project

prioritization, whereas identification of the existing inventory might be a challenge to another department.

- DIFFERENT SEQUENCING IS POSSIBLE: The relationship between the various individual tasks within each process (see Appendix A) can be sequential, or not. For example, in a large municipality, there could be many people from many different departments involved in one individual task such as data collection for the *performance* facet; whereas in a small municipality this might involve one person.
- DIFFERENT IMPLEMENTATION SCHEDULES: The implementation of the *MIM Framework* can vary (e.g. degree of accuracy, quality of data, extent of data collection) in any one municipality over time, between regions in that municipality, and across different asset classes. For example, some tasks, and even an entire process or facet, can be performed by the same individual (this can even be done from memory for a limited number of assets) or at the same time (e.g. in small municipalities one person could itemize, rate, inspect and fix the asset in the same afternoon). In large municipalities however, these tasks are considered as discrete ones typically performed by any number of different teams or individuals (in-house staff, consultants, etc.) working independently.

2.5 Organization of MIM Framework

The description of the detailed tasks of the *MIM Framework* in this report concentrates on wastewater systems; however, the *MIM Framework* is generalized to suit most municipal infrastructure asset classes such as roads, bridges, water systems and facilities. The *MIM Framework* can also be applied to a wider selection of assets that are owned and managed by organizations similar to municipalities such as university campuses, school boards, government campuses or even penitentiaries.

The following sections of this report detail the eight major processes and six facets of the *MIM Framework*. In this report each of the eight major processes is **bolded,** facet names are *italicized* and task names are underlined (the 122 tasks are listed alphabetically in Appendix F with cross-references to page numbers in this report).

In many instances, standard paragraphs about specific tasks (e.g. Update Metadata, Expedite M&R) are repeated almost *verbatim*; this is done intentionally to permit the reader to read all the tasks in a specific process in sequence and in context.

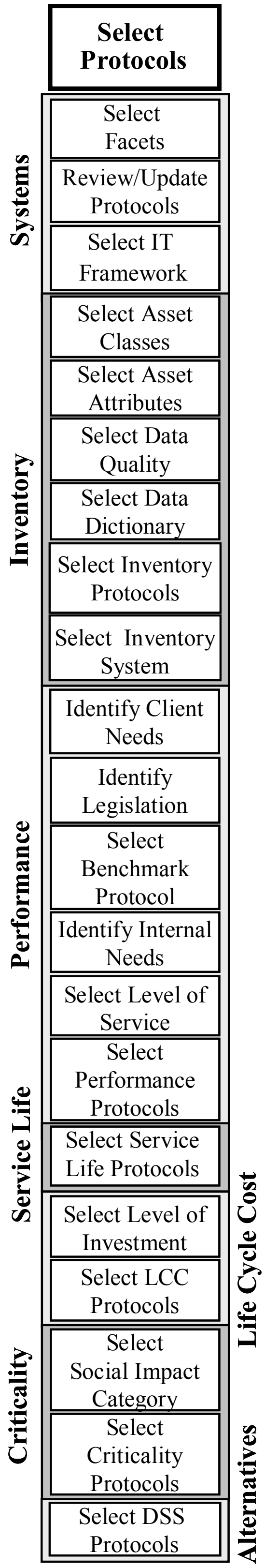
In developing the *MIM Framework*, it was found that a number of tasks did not relate directly to a specific facet, however these tasks did relate directly to a specific process. In this case, these tasks are included in an overarching facet called *systems* and they must be done in parallel with the other facets. These *systems* tasks are listed at the top of the *MIM Framework* in Appendix A.

2.6 Using the MIM Framework

This report is structured as an interactive document and is not intended to be read sequentially, although this is possible. As noted earlier, there are many similar tasks in different sections of the report that are intentionally repeated to ensure continuity of sequencing for those only reading specific sections.

- Hypertext links (names of tasks, processes, figures, and tables when they are not adjacent, and all bibliographic references) are included throughout the document so the reader can quickly navigate through the electronic version of this report.
- Sections 3 through 10 detail the processes of the *MIM Framework*. A vertical flowchart duplicating the tasks in each process is included on the first page of each section.
- Appendix A provides the matrix identifying all of the 122 *MIM Framework* tasks.
- Appendix B provides a list of abbreviations used in this report.
- Each task in Appendix A consists of an “Action Verb” and an “Action Outcome”; this is a result of the Value Engineering exercise. For example, in Select Facets the Action Verb (e.g. Select) is followed by an Action Outcome (e.g. Facets).
- Appendix C includes a list of the Action Verbs that are used in describing the *MIM Framework;* a parsimonious selection of Action Verbs has been selected in order to eliminate redundant, contradictory or ambiguous terms.
- Appendix D includes the descriptions of the Action Outcomes of the *MIM Framework*; it is based on a glossary of terms from the MIIP *Primer* (Vanier and Rahman, 2004).
- Appendix E provides a description of different types of data structures for asset management.
- Appendix F contains an alphabetical subject index of the 122 *MIM Framework* tasks; it can be used to locate the description of individual tasks in the text.

Select Protocols Process



3. Select Protocols

This section describes the first process to be completed in the *MIM Framework*. It is the starting point for establishing a comprehensive infrastructure management system within any municipality. Whether the municipality is small or large, the first step must be to itemize the current municipal infrastructure management asset management practices and to select which protocols are appropriate for each asset class.

This section also describes all of the facets and tasks to **Select Protocols**. Since this section describes all the necessary protocols for the *MIM Framework* it is considerably longer (and more detailed) than the other sections of this report.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

3.1 Select Protocols > *Systems*

Three tasks are included in *systems*. Typically, these three tasks should be completed in the sequence shown in the side figure; however, the Select Facets task must be completed before the other tasks in the **Select Protocols** process are started. The Review/Update Protocols task can be done immediately after the Select Facets task.

Large municipalities can have many types of infrastructure asset classes including buried utilities, roads, bridges, buildings, etc. each having their own asset management protocols. Each municipality can also contain several different regions, each with its own protocols (a reflection of the individual needs of the various regions or their history). In contrast, a small municipality in a rural area might not have responsibility for buried utilities or may not have any bridges in its portfolio simply because these assets do not exist or they are the responsibility of a regional government. Their internal protocols used to itemize the asset therefore, depend not only upon the asset class and its physical components in the portfolio but also upon the size and structure of the municipality.

The selection of protocols also depends on local administrative, technical or financial resources. For example, if life cycle costs are needed, then accurate inventory, performance and service life data are required.

Legislative requirements (national, provincial, regional or local) can also dictate the selection of internal protocols. For example, the Public Sector Accounting Board (PSAB 3150, 2009) in Canada is mandating proper “stewardship’ of municipal “Tangible Capital Assets” by January 2009.

The Statement of Principles issued by the PSAB deals with municipal infrastructure “tangible capital assets” which include roadways, telecommunications, ports and waterways, public transit, water and sewer, electrical power and communications and gas and liquid fuels etc. The purpose of PSAB 3150 is to improve the asset reporting system and to provide financial statements to assist making informed investment decisions and to itemize infrastructure services to the ratepayers in an accountable fashion. "The central feature to developing these plans is having an inventory of infrastructure" (PSAB 3150, 2009). Similar requirements exist in other countries such as the USA (GASB, 2001) and Australia (ANAO, 1996).

PSAB 3150 now requires that municipalities collect information about the:

- inventory of the infrastructure,
- life cycle needs and costs,
- preventative strategies, and
- condition assessment models used to address the various types of:
    - infrastructure, and
    - appropriate economic valuation tools.

- Select Facets

As indicated earlier, the *MIM Framework* is premised on multi-objective decision-making; that is, in order to optimize the investment, the municipality must maximize the performance, minimize the life cycle costs (LCC), and minimize the risk of failure for the entire asset portfolio. If the municipality desires other requirements to be included in the decision-making, then the *MIM Framework* and its facets must be extended accordingly.

In general, the six facets of the *MIM Framework* are sequential in nature.

- The *inventory* facet deals with the itemization of each asset in the different asset classes. The *inventory* is primarily concerned with the "original" physical attributes of the asset: location, type, size, thickness, etc.
- The *performance* facet deals with meeting the technical needs for the asset. The performance rating can have many categories: condition, functionality and demand/ capacity (Edmonton, 2004, 2007). If the current performance of the asset can be established and the deterioration can be modelled, then the remaining service life can be estimated.
- The *service life* facet establishes an average service life for each asset and calculates the remaining service life of this asset. These data are required to estimate life cycle costs.
- The *life cycle cost* facet deals with projected maintenance, repair and renewal costs of an asset for its service life. The life cycle cost can only be accurately estimated after determining the current performance of the asset and estimating its remaining service life.
- *Criticality* in the *MIM Framework* relates to the importance of the asset to the municipality. The conventional notion of *criticality* is known and understood (Moteff and Parfomak, 2004); however, in terms of the life cycle performance of infrastructure assets, and the *MIM Framework*, the probability of failure must also be taken into account in determining whether or not an infrastructure asset is critical. In the *MIM Framework*, *criticality* is synonymous with the conventional definition of "risk of failure"; that is, criticality and "risk of failure" are the product of the consequence of failure and the probability of failure.

  The *Criticality* of an asset relates to how critical an asset is to the municipal portfolio or the municipal network (e.g. how fast can it be replaced, how much will it cost, what are the financial, political, or environmental consequences of failure, what are the probabilities of failure, etc.). However, the *MIM Framework* places an emphasis on *Criticality* issues related also to the risk of failure of the physical asset and its two components: consequence of failure and probability of failure. In fact, these two components should be statistically independent; meaning, one of these components should not affect the other. The consequence of failure of an asset can include costs such as emergency interventions, additional unplanned expenditures, altered life cycle costs, loss of remaining service life, and premature replacement costs, but may include other tangible or intangible social costs (Rahman et al, 2005). The probability of failure, on the other hand, is typically based on factors such as the physical condition, projected deterioration, expected loadings and the performance, but can be related to events not related to asset condition such as the weather, temporary loadings, or even accidents. As such, if two assets have the same consequence of failure but the first has a high probability of failure and the other a much lower probability of failure, then the former could be considered more critical, as failure is imminent.

- The *alternatives* facet deals with the enumeration and comparison of viable repair and renewal interventions. The *alternatives* facet must also take into account changes to the asset inventory data, to the outcome performance, to the modified remaining service life, to the updated life cycle costs, and to the changes in criticality.

Therefore, data collected for the first few facets are integral to the subsequent facets. The data and information collected about the *inventory* are required to support the data requirements of the other facets. The *performance* data can only be collected after the *inventory* data are available. The *service life* data can only be calculated after *performance* is ascertained. The *life cycle cost* information cannot be calculated until the future performance is predicted (i.e. it is required to calculate the future maintenance costs) and until the remaining service life is calculated. The *criticality* data are dependent on *inventory*, *performance, service life* and *LCC* data. *Alternatives* cannot be compared objectively until all other facet data are collected and analysed.

A municipality can select which of these six facets are to be used and which additional ones are required to support their internal and external functions (legislative, etc.). The municipality can include any number of additional facets in the *MIM Framework* including: environment, quality of life, aesthetics, leisure, sports, etc. For example, a municipality may desire to include a facet on urban sustainability. The same type of protocols described in the *MIM Framework* would have to be developed to support these new facets, plus they would have to be harmonized with the existing *MIM Framework* facets.

- <u>Review/Update Protocols</u>

Reviewing and updating existing municipal practices is the next task in establishing an infrastructure management system. A review of existing protocols involves identifying internal practices or methods already in use in a municipality. These protocols might even vary within a municipality, as some protocols may have been implemented in one region and not another.

Smaller municipalities may not need to enumerate individual protocols for all disciplines and/or all facets, but it is assumed that larger municipalities need to identify all protocols for all disciplines and all facets. Table 1 provides a guide and a checklist for recording which protocols are currently in use. This table should be expanded to include all the selected asset classes and all the selected facets. The protocols identified in Table 1 are described in detail in the appropriate section in this report. The selected protocols should also be updated on a regular basis.

Select Protocols Process

Table 1: Examples of Infrastructure Management Protocols

Department	Asset Class	Facet	Protocol	Region 1 (MM:YYYY)* *Date protocol last reviewed	Region 2 (MM:YYYY)*	Region X (MM:YYYY)*
Wastewater	**Collection Pipes**	**Inventory**	▪ Asset Classes	Figure 1	Same	Same
			▪ Asset Attributes	Table 2		
			▪ Data Quality	Table 22, SUE		
			▪ Data Dictionary	Table 3		
			▪ Inventory Protocols	Table 3		
			▪ Inventory System	XYZ Version 1.0		
		Performance	▪ Clients Needs	Survey	Same	Same
			▪ Legislative Requirements	PSAB 3150		
			▪ Benchmarking	Nat. W/WW Benchmarking		
			▪ Level of Service	Survey		
			▪ Performance Measures	WRc 3rd Edition (1>5)		
			▪ Growth Requirements	4%		
			▪ Gap Analysis			
			▪ Performance Protocols			
		Service Life	▪ Service Life Calculation	Simple age calculation	Probabilistic	Same
			▪ Predict Probability of Failure	Condition-based		
			▪ Service Life Protocols			
		Life Cycle Cost	▪ Level of Investment	Maintenance funds per year		
			▪ Deferred Maintenance	Identified outstanding work		
			▪ Current Replacement Values	RSMeans – Infrastructure		
			▪ LCC Protocols	ASTM E917 (1994)		
		Criticality	▪ Social Impact Category			
			▪ Criticality Protocols	Subjective Scale 1>5		
		Alternatives	▪ Decision Support System	Weighted criteria		
	Manholes	**Example Only**	-	-	-	-
	Treatment Structures	**Example Only**	-	-	-	-
	Pumps	**Example Only**	-	-	-	-
Bridges		**Example Only**	-	-	-	-
Roads		**Example Only**	-	-	-	-

- Select IT Framework

Although this task appears at the beginning of this process, it can only be implemented after all the protocols for the various facets are selected. Once the necessary protocols are identified and the data requirements are known, then and only then, can the appropriate department in the municipality Select IT Framework. Many municipalities may be restricted as to how they implement their *MIM Framework* owing to legacy software constraints, financial considerations and human resource issues. A smaller municipality may be able to use linked spreadsheets if only a limited number of people are accessing the data; however, a larger municipality requires an enterprise business solution complete with a central database, Geographic Information System (GIS) system, interoperability protocols, web access and custom software development.

As an introduction to the database technologies, an excerpt describing simple, relational and object-oriented databases from the *Primer on Municipal Infrastructure Asset Management* (Vanier and Rahman, 2004) is included as Appendix E.

As there is a multitude of differences between municipalities (size, history, resources, competencies, etc.), it is virtually impossible to suggest when and how to start the task to Select IT Framework. A simple "rule of thumb" is to define the requirements first then to select the software, and NOT the reverse. A review of a limited selection of asset management software programs is available (Halfawy et al, 2006).

3.2 Select Protocols > *Inventory*

- Select Asset Classes

The asset classes selected for the municipality's implementation of the *MIM Framework* must reflect its entire asset portfolio. It is recommended to use a simple hierarchy to represent the different asset classes. The obvious municipal departments: roads, bridges, water systems, wastewater systems, buildings (facilities), parks, fleet, etc must be at the top of the hierarchy. The subclasses for each of these major asset classes form the next level of granularity. Typically, these subclasses should be related to the structure of the operational unit. For example, wastewater systems consist of collection systems and treatment plants. Wastewater collection systems can be further divided into pipes and then into pipe segments, valves, etc. Each of these assets must have a unique identifier so they are counted, inspected and rated individually. Some of these asset subclasses can be broken down further into components; for example, manholes include components such as prefabricated concrete containers, connectors, covers, and ladders.

It is always difficult to select whether components in a network are a subclass of an asset class or an attribute of an asset class. For example, should wastewater collection systems be divided into sanitary, combined and storm water subclasses or should sanitary sewer, combined sewer and storm sewer be attributes of a pipe segment? The same holds true for road networks: should arterial, collector and local roads be subclasses or should they be attributes of a road segment? In "object-oriented" terms this relates to the differences between "composition (Has_A)" and "aggregation (Is_A)" networks (please refer to Appendix E for a discussion on data structures). In many large municipalities this decision has already been made and these protocols are already implemented in the existing software and it may be difficult to alter. For smaller municipalities it is recommended to minimize the number of subclasses (minimize aggregation), to maximize the amount of "composition", and to maximize the usage of attributes: this allows the data to be more portable and robust. Since the full integration of data over the life cycle of the portfolio is the ultimate goal; the data must be portable and robust. An example of a hierarchy for wastewater collection systems is illustrated in Figure 1.

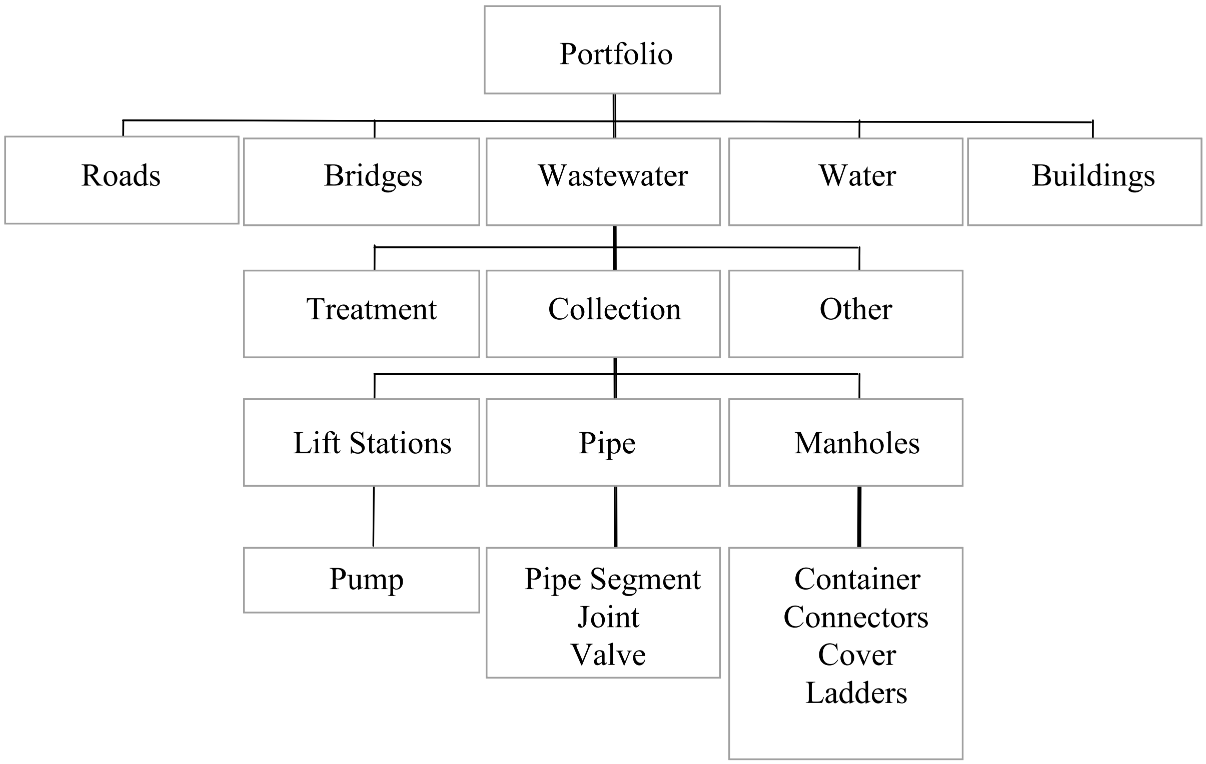


Figure 1: Examples of Hierarchies for Infrastructure Systems

- <u>Select Asset Attributes</u>

The identification of attributes is one of the more difficult, and most important, in setting up the *MIM Framework.* There has been very little standardization of this type of data for municipal infrastructure at the current time (Halfway et al, 2006). Efforts are moving forward on a number of initiatives (MIDS, 2009; NWWBI, 2009; CSA, 2009; WERF, 2009), but the work is still in progress.

In network management, “an attribute is a property of a managed object that has a value” (Wikipedia, 2009). The attribute is that aspect or property of the asset class that is common to all instances of that asset class or subclass. Figures E-1 to E-3 in Appendix E illustrates these relationships for simple, relational and object-oriented data structures, respectively.

Attributes for pipe segment in a wastewater collection system include pipe material, pipe length, wall thickness, and pipe depth. A more exhaustive list for the attributes of a wastewater collection system includes x-y-z location of start and end of pipe segment, soil conditions, amount of flow and pipe slope. Table 2 provides a list and categorization of attributes for wastewater collection systems.

Table 2: Attribute Importance Categories for Pipes Segments in Wastewater Collection Systems

Mandatory	Desirable	Exhaustive
Municipality/Region (List)	**Construction Date (Date Format) ***	Entry Date (Date Format)
Pipe ID (Unique)	**Consequence of Failure (List)**	Inspector (List)
Pipe Diameter (Units)	**Remaining Service Life (Units)**	Media Device (List)
Wastewater Type (List)	**Average Service Life (Units)**	Video File Size (Units)
Network Type (List)	**Cost per unit (Units)**	Requisition Number (List)
Starting Manhole (List)	**Current Replacement Value (Units)**	Operator Name (List)
Ending Manhole (List)	**WRc Pipe Grade (Units)**	Video File Name (Name)
Total Length (Units)	**Peak Score – Structural (Units)**	Reversal Required (Yes/No)
Pipe Material (List)	**Inspection Date (Date Format)**	Soil Conditions (Name)
Comments (Name)	XYZ Start (Units X, Y, Z)	Survey Length (Units)
	XYZ End (Units X, Y, Z)	Flow (Units)
	Break (Name) + Date (Date Format)	Flow Direction (List)
	Life Cycle Status (List: In use, decommissioned)	Drawing Number (List)
	Shape (List)	Street Name (List)
	Pipe Wall Thickness (Units)	End Street Location (List)
	Pipe Defect (List) + Location (Units)	Cross Street 1 (List)
	Total Deducts (Units)	Cross Street 2 (List)
	Inspection Project Number (List)	Repair (Name) + Date (Date Format) + Cost (Units)
	Inspection Contractor Name (List)	Surface Type (List)
	CCTV Inspection ID (Unique)	Bedding (Name)
	Distance to Peak Structural Defect (Units)	Backfill (Name)
	Pipe Average Depth (Units)	Diameter 2 (Units)
	Pipe Slope (Units)	Pipe Manufacturer (Name)
	Type of Corrosion Protection (List)	Date of Manufacture (Date Format)
	Lining Type (List) + Date of Lining (Date Format)	Upstream Invert (Units)
	Exterior Coating (List)	Downstream Invert (Units)
	Roughness (List)	
	Joint Type (List)	
	Connection Type (List)	

* Many of the bolded Desirable Attributes are Mandatory for some municipalities.
Pipe and Pipe Segment have the same meaning in this table.
List is a "controlled vocabulary" list of permissible alternatives.
Unique means a unique identifier for each asset.
Name means that any combination of letters, numbers and symbols are permissible.
Units mean that this attribute accepts specific measurement units (e.g. metres, mms, kms, m^2, m^3, ft., etc.).
Date Format means a date format that can contain time, day, month and year (e.g. HH:SS DD/MM/YYYY, MM/YYYY, DD Month YYYY).

After the attributes are selected, a number of other specifics about the attribute are also identified:

1. The attribute "importance" category is selected: mandatory, desired, or exhaustive. This categorization should not be "cast in concrete", as the costs or the resources needed to collect "mandatory" attributes could be prohibitive. Questions like "why is this attribute mandatory?" should be asked. As a result, attributes naturally migrate from one Attribute Importance Category (AIC) to another and back during this task depending on any number

of reasons: importance, availability of data, cost, resources, etc. Selecting which attributes are mandatory, desirable or exhaustive is not a trivial decision. For example, for wastewater collection systems the following attributes are deemed to be mandatory: name of municipality, unique pipe identifier, wastewater type (e.g. sanitary, combined, storm), as well as specifics about the pipe such as material, diameter, construction date, pipe length and pipe shape.

2. The permissible "values" for an attribute are then identified. At the early stages of this task it is only necessary to identify the data format of the permissible values, these include: a selection from a list, a unique identifier, a specific unit of measure, a "free-form" name, or a date format. Details about which specific values are permissible (e.g. range of values, data dictionary) are described in later tasks (Select Data Quality, Select Data Dictionary).

Table 2 lists three categories of attributes for wastewater collection systems. It is obvious from Table 2 that this enumeration includes more than inventory attributes. The performance, service life, life cycle cost and criticality attributes are included for the sake of presenting a complete list of attributes.

The mandatory categories in Table 2 are those deemed by the authors to represent the essential data that must be collected by any municipality. Although many can argue that other attributes (e.g. condition rating, XYZ location) are mandatory, these data are both difficult and expensive for most municipalities to collect, and therefore cannot be considered mandatory. Similar tables can be developed for other asset classes (e.g. roads, bridges). The distinctions between which attributes are in the "desirable" or "exhaustive" AIC are left to the municipality; however, many municipalities currently consider the bolded "desirable" attributes as "mandatory."

The list of attributes and the AIC that were initially selected by the municipality also must be modified, updated and even deleted whenever the protocols are reviewed/updated. This should be done on a regular basis.

- Select Data Quality

One of the first inventory protocols to be selected is data quality. As few systems exist to date (this field is still maturing), the Subsurface Utility Engineering (SUE) system developed for ASCE (2002) and Purdue University (Lew, 1997), and used in the Regional Municipality of Niagara, is recommended. In this system there are four levels of data quality: A, B, C, and D.

- Quality D refers to data as they appear on plans and in files.
- Quality C data are verified by means of a site visit.
- Quality B data have accurate two-dimensional data.
- Quality A data have accurate three-dimensional data.

The definition of "accurate" is currently left up to the municipality, but accuracy below one metre can be defined as "accurate" for most civil infrastructure networks. This degree of accuracy means that the physical location of the asset can be within one metre of its stated "absolute" location. The data quality can vary between different asset classes according to requirements, but can also vary over time as more accurate data are collected. Although SUE data quality relates specifically to spatial attributes (ASCE, 2002), the principles can be readily extended to some other attributes such as the material of the pipe where Quality D (plans) data should be validated with Quality C data (site inspection) if replacement is in the offing.

- Select Data Dictionary

A restricted definition of data dictionary is used in this report. Typically, a data dictionary is a "set of metadata that contains definitions and representations of data elements" (Wikipedia, 2009a); in this report the term data dictionary is used specifically to identify the definition of the attribute table (i.e. attributes, data format, values).

Each attribute, as described earlier, can be either: mandatory, desired or exhaustive. The permissible data formats in Table 2 for an attribute should be from a selection such as: list, unique identifier, specific unit of measure, "free-form" name, or date format:

- List is a "controlled vocabulary" list of permissible alternatives. This list will eliminate typing errors in the field, improve searching and sorting operations, and standardize the data for data analysis. In some cases, the list of options include only "yes" or "no."
- Unique means that a unique identifier is required for each instance of an asset in asset class.
- Unit of measure means that this attribute accepts only one unit of measurement (e.g. metres, mms, kms, m2, m3, ft., etc.). Typically, a range of values is permissible and values that are not permissible are also identified (e.g.> 0.00, <$10,000, etc.)
- Name is a "free-form" name that can be any combination of letters, numbers and symbols are permissible. This means that data verification on data entry does NOT take place.
- Date format is selected according to requirements. HH:MM:SS-DD:MM:YYYY is not necessary for a specific date as it is too precise. MM:YYYY implies a date format where month is represented by 2 numbers and year is represented by 4 numbers.

Table 3: Data Dictionary for Sample Attributes for Wastewater Collection Systems

Attribute Name	Data Format	Data Quality	Permissible Values
Municipality/Region	List	N/A	Ottawa-Carleton, Ottawa, Gloucester, Kanata, Nepean, Vanier, Cumberland, Rockcliffe Park, Goulburn, West Carleton, Rideau, Osgoode
Pipe ID	Unique	N/A	RMOC-####, OTT-###, KAN-###, N_####, VAN####
Pipe Diameter	mm	A	>200, <3000
Wastewater Type	List	A	Sanitary, Combined, Storm
Network Type	List	A	Trunk, Main, Service
Starting Manhole	List	A	MH_####
Ending Manhole	List	A	MH_####
Total Length	m	A	>1.00, <100.00
Pipe Material	List	B	Asbestos Cement, Vitrified Clay, Concrete, Reinforced Concrete, PVC, PE, HDPE, …
Comments	Name	N/A	Letter, number, character, any sequence or combination
Construction Date	Date Format	D	MM:YYYY
Average Service Life	Years	C	>0, <200
Cost per Unit	CAD$	B	>$0.00, <$10,000.00
WRc Pipe Grade	Grade	A	1, 2, 3, 4, 5, Unknown

Select Protocols Process

Once the asset class hierarchy, asset attributes and data quality are determined, it is possible to select the controlled vocabulary for the data dictionary for the asset attributes, as shown in Table 3. For example, for wastewater collection systems a selection of pipe materials can be used (e.g. Asbestos Cement, Vitrified Clay, Concrete, Reinforced Concrete, PVC).

A properly constructed data dictionary controls the input during on-site data collection by reducing the opportunities for typing errors; it also standardizes the data fields to assist in the data analysis (i.e. data searching).

- Select Inventory Protocols

It must be remembered that at this stage in the *MIM Framework* only the inventory protocols are under consideration. As the *inventory* facet is critical in municipal infrastructure management, its protocols should be established early in the implementation of the *MIM Framework*. However, analysis of the other facets necessitates collection of additional inventory data.

As discussed earlier, the *inventory* attributes first selected by the municipality will be modified over time as the experience of the municipality increases, their AIC will vary, and the data quality will change and improve in the future. Once the existing *inventory* protocols are identified, they are reviewed to determine what resources (time, cost, people etc.) are required to implement each method and whether the protocol accurately itemizes the asset at the level of detail and data quality required in the other major processes. This cost-benefit analysis can change the AIC of some attributes, as well as their data quality.

Once the existing inventory protocols are identified and reviewed, the appropriate inventory protocols for enumerating each asset class in a municipality's inventory are selected. This involves validating each method currently used to itemize the asset. It may be that the protocols currently used are inappropriate in that they require too much data or not enough. Validating the protocols involves the following considerations:

- Does the protocol provide the necessary level of data quality needed for the asset?
- Is the protocol the most economical and efficient method of itemizing the asset?
- Is the protocol flexible? If so, how can it accommodate changes?
- If the protocol is electronic, will it require upgrading? Is it compatible with other protocols?

The acts of thinking about, analysing and selecting the appropriate asset classes, asset attributes, AIC, data quality, data dictionary and inventory protocols greatly assist the establishment of a strong foundation for the *MIM Framework* in a municipality.

The final step in the selection of inventory protocols is to plan how the inventory protocols are to be implemented. This step must prioritize the implementation of the inventory protocols, budget for and purchase software or records systems, identify training requirements for staff, and prepare a timeframe for when and how new protocols are introduced. Depending upon the complexity of the plan, it could be years before it is fully implemented.

Once suitable inventory protocols are selected, there are subsequent tasks needed to select performance, service life, life cycle costs and criticality protocols.

Owing to the requirement of reporting of Tangible Capital Assets (PSAB 3150, 2009), all municipalities in Canada must have a comprehensive inventory system in near future (Jan 2010).

- Select Inventory System

Regardless of the size (small, medium, large) or type (urban, rural, village, town, city, region, etc.) of municipality, the next task in implementing the *MIM Framework* is to identify what assets are the responsibility of the municipality and what protocols and systems (electronic or manual), if any, are currently used to itemize the assets.

An example of the tabulation of the results is shown for buried utilities assets in Table 4. All infrastructure assets are listed across the top of the table and the inventory systems used to itemize each asset are listed down the side of the matrix. Assets may require further sub-categorization by component and region (R1, R2, etc.) depending upon the nature of the asset.

Consider the Buried Utilities Class in Table 4; this asset category can include collection systems as well as the treatment plants. Each subclass could also be further divided, according to its components. For example, a wastewater system includes pipes, manholes, valves, etc. Each of these components can have different inventory systems; for example, one operator might have a spreadsheet or database containing a region's pump data.

Table 4: Asset Inventory Systems Table

Class	**Buried Utilities**								
Subclass	**Collection**			**Treatment**			**Other**		
Region	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Paper/manual									
Personal experience	●	●	●	●	●	●	●	●	●
Record drawings	●	●	●	●	●	●	●	●	●
Property records		●	●		●	●		●	●
Maps		●			●			●	
Electronic									
Spreadsheets		●	●		●	●		●	
Database		●	●		●	●		●	
Computer-Aided Design (CAD)		●	●		●	●		●	
Inventory system		●	●		●	●		●	●
Work order system	●	●	●		●	●	●	●	●
Geographic Information System (GIS)		●			●			●	
Integrated Management		●			●			●	

The systems used to inventory these assets can be as simple as personnel notes, record cards, spreadsheets, databases, work order systems or maps, or as complex as a computerized maintenance management system (CMMS) or a fully integrated management system linked to a GIS.[4] In addition, the systems used to inventory the wastewater component can differ between regions in a municipality because of historical reasons. As shown in Table 4, Region 2 (R2) uses a GIS protocol whereas R1 and R3 do not. This is very common where municipalities have been

[4] For an in-depth discussion on GIS and municipal infrastructure please refer to the MIIP client report entitled *Geographic Information Systems (GIS) and Interoperability of Software for Municipal Infrastructure Applications* (Vanier, 2004).

formed from the amalgamation or fusion of several other municipalities. The list shown in Table 4 is by no means exhaustive.

After completing the protocol review, the municipality may identify that the following problems exist with using spreadsheets in the organization:

- Spreadsheets are very cumbersome to keep updated and typically only one person can use them at a time.
- Consistency is difficult to achieve in spreadsheets.
- It is difficult and unreliable to search for data in spreadsheets.
- It is extremely difficult to geographically represent inventory data in a spreadsheet.

Given these difficulties, this municipality may decide to invest in a basic infrastructure management system, or it could elect to integrate its inventory itemization with one or more of the other key public works disciplines.

Having determined the municipal requirements, two options exist: it is now possible to investigate the logical integration of these requirements with the existing inventory system or systems, or it is time to select an integrated inventory system that can record the data for the municipality. Unfortunately, the inventory system is often selected and purchased well *before* all the decisions are finalized regarding what attributes should be saved, what are the data quality requirements, and what protocols are currently in use. The inventory system should be selected based on municipal requirements and not on an evaluation of available products. This does not imply that every municipality requires a computerized inventory system; however, even the smallest municipality (i.e. less than 5000 population) would benefit from using a simple database to record and update their inventory.

Note: If a municipality is not in a position to define its asset classes, asset attributes, data quality, or inventory protocols, then purchasing a well-designed off-the-shelf product is probably the best course of action. Other municipalities that have purchased the product and use it rigorously should be consulted and visited.

3.3 Select Protocols > *Performance*

- <u>Identify Client Needs</u>

The first task in the *performance* facet is to <u>Identify Client Needs</u>. In this report, “client” is a person or organization paying for a good or service, either directly or indirectly. This task involves determining the technical requirements of the municipal staff and the public on an asset-by-asset basis. There are many clients and stakeholders in every municipality, each with their own needs. This may lead to the following conflicts between different stakeholders:

- technical needs of engineering staff versus public,
- societal needs of the citizens and local commerce,
- needs of different levels of government (region, province federal), and
- differences between rural, suburban and urban needs

So, how does one identify these needs and what happens when these needs are conflicting? The first step can be a “needs analysis” study. In order to identify needs, it is important to (1) know what services are required and (2) how those services can be provided. As a bare minimum, each asset must perform at a level that will not compromise the health and safety of the users. The extent of municipal infrastructure has grown over time and many assets are now essential for health and safety of society as a whole. In many municipalities these include the provision of: drinking water, wastewater removal, solid waste collection, transportation and electricity. In addition to these fundamental needs, municipalities typically provide essential services such as emergency response (fire, police, ambulance, etc.), social housing, and mass transit.

It is equally important to differentiate between the "needs" and "wants" of the client. Consider garbage collection as an example. A client (the public in this case) may "want" twice weekly garbage pick up, but only "needs" it weekly. This is known as the level of service, and it will be discussed later in the section of the report in the task entitled Select Level of Service.

A comprehensive "needs analysis" study on water and sanitation service delivery is available on the Internet from the Department of Water Affairs and Forestry, Australia (DWAF, 2009).

- Identify Legislation

In addition to client needs, provincial or federal legislation can also exist. These take the form of regulations that dictate the need for specific methods or operations in a municipality or that mandate a set level of service. For example, although the U.S. Environmental Protection Agency has legislation regarding water quality (USEPA, 2009), in Canada there are only guidelines from Health Canada on drinking water quality (GCDWQ, 2009).

At the provincial level, Ontario has introduced Bill 175, the *Sustainable Water and Sewage Systems Act* (Ontario, 2002) that requires annual reporting on the full cost of water and wastewater services. More specifically, it mandates that every "regulated entity that provides water [and wastewater] services to the public shall prepare and approve a written report about those services … [and the] … report must contain … [an] inventory of and management plan for the infrastructure needed to provide the water [and wastewater] services, prepared and certified by a professional engineer." Other examples of provincial legislative requirements are the *Safe Drinking Water Act* (Ontario, 2002a) and British Columbia's *Drinking Water Protection Act* and *Drinking Water Protection Regulation* (BC, 2001).

It is not the intention of this report to be exhaustive on the enumeration of legislation; but rather to indicate that legislation dictates mandatory processes, methods or data collection and this, in turn, dictates that specific inventory and performance protocols must be in place.

- Select Benchmark Protocol

A municipality may also need to incorporate provincial performance measures as well as its own measures into its infrastructure management. In Ontario, the Municipal Performance Measurement Program (MPMP, 2009) requires that municipalities measure and report to taxpayers on their service delivery performance. It includes 52 performance measures in 12 municipal service areas; a number of these are related specifically to benchmarking municipal infrastructure. In the wastewater area, some of the "Efficiency Measures" for wastewater systems include: Wastewater Integrated System – Efficiency (i.e. operating costs for collection, treatment and disposal per mega litre), Wastewater Main Backups (i.e. number per 100 kilometres per year), and Wastewater Bypasses Treatment (percentage of bypassed wastewater). "Efficiency

Measures" for water services include: Drinking Water Integrated System – Efficiency (operating costs for treatment and distribution per mega litre), Boil Water Advisories, and Breaks in Water Mains (i.e. number per 100 kilometres). For the roads network, the "Efficiency Measures" include: Paved Roads – Efficiency (i.e. costs per paved lane kilometre) and Adequacy of Paved Roads (i.e. percentage of roads rated good to very good condition).

The National Water and Wastewater Benchmarking Initiative (NWWBI, 2009) is assisting municipalities to benchmark detailed performance measures for these two services. The NWWBI has identified a wide selection of over 100 performance measures including: percentage annual change in operations and maintenance costs, level of infrastructure reinvestment (capital replacement/current replacement value), and cost of in-house closed-circuit TV (CCTV) per length of CCTV inspected.

- Identify Internal Needs

Internal requirements such as administrative and political needs must be recognized and considered before the task Select Level of Service can be implemented. These needs may arise from local election promises to upgrade infrastructure in a particular zone or ward. If traffic or sewer backups are a problem in one area, councillors or representatives running for election in that area are likely to promise to "address the situation" if elected.

Administrative needs may arise from administrative requirements unique to the municipality. For example, the city fire fighters need to know the location of the existing fire hydrants and their water flow capacity. In addition, if the city has a number of crews devoted to specific tasks (road patching, CCTV inspection, bridge painting) then these crews have to be kept working despite priorities in other disciplines.

- Select Level of Service

Once all needs are identified, it is time to Select Level of Service (LOS). A LOS is a qualitative or quantitative measure of how well, or poorly, a service is provided. Different classes of assets have different LOS for different regions. Selecting a LOS must take into consideration both client needs and the related service costs. The basic LOS must consider those needs that are mandatory, as discussed in Identify Client Needs. These needs must be met because these assets provide essential services. One such service is the frequency of garbage collection or snow ploughing within a municipality.

Factors determining LOS of Garbage collection, for example, include frequency (weekly or bi-weekly), level of recycling, limits to bags permitted, charge for extra bags, etc. In Leicester (UK) there is weekly garbage collection with a limit to one garbage bag, one green and one clear recycling bag (these are provided by collection service to every household for each collection). In Ottawa the garbage collection is weekly, there are no limits to number of bags, recycling alternates between blue (plastics, cans, glass) and black box (paper), and there is scheduled yard waste pick up (Ottawa, 2009). Both of these levels of service have different costs to the municipality and can have different infrastructure requirements.

In the case of snow ploughing, Table 5 is provided directly from the City of Ottawa maintenance quality standards for snow and ice control on city roads (Ottawa, 2009a).

Table 5: City of Ottawa Maintenance Standards for Snow and Ice Control

Road Maintenance Class		Road Type	Minimum Depth of Snow Accumulation for Deployment of Resources	Time to Clear Snow Accumulation From the End of Snow Accumulation or Time to Treat Icy Conditions	Treatment Standard		
					Bare Pavement	Centre Bare	Snow Packed
1	A	High Priority Roads	As accumulation begins	2 h	X		
	B				X		
2	A	Most Arterials		3 h	X		
	B				X		
3	A	Most Major Collectors		4 h	X		
	B				X		
4	A	Most Minor Collectors	5 cm	6 h	X		
	B					X	
	C						X
5	A, C	Residential Roads and Lanes	7 cm	10 h			X
	B		10 cm	16 h			X

Each LOS could have sub-levels that are based on a benchmarking protocol. Considerations to upgrade the LOS can be capacity-related or based on client expectations. Ideally, the technical criteria to upgrade LOS should be clearly defined by the asset manager.

According to InfraGuide's *Managing Infrastructure Assets* Best Practice (InfraGuide, 2003), there are several alternatives for renewal of municipal infrastructure, each producing a different LOS at a different cost. But what if the assets are not providing essential services? Most citizens would agree that parks and museums, libraries or recreation trails are important assets that add value and enhance the quality of life in a municipality. Few would question, the need for such assets. Ultimately, the task to Select Level of Service is a balancing act between what can be afforded and what adds value.

- Select Performance Protocols

Performance data are qualitative or quantitative ratings of how an asset performs its intended function or functions (assets can have a primary and a number of secondary functions, all of which require ratings). System performance can be measured using key performance indicators (KPI). For example, wastewater system KPIs could include, but are not limited to, the possible targets provided in Table 6 (Rahman 2009).

Table 6: Possible KPI Targets for Water and Wastewater Services

Water		Wastewater	
Measured Indicators	**Targets**	**Measured Indicators**	**Targets**
Per capita consumption (litres/day)	<350	Inflow ($I_{peak\ day}/I_{average\ day}$)	<5
System water loss (%)	<10	Hydraulic capacity (metres)	>0.3
Residual Chlorine	Detectible	Basement flooding (per year)	<20
Taste and Odour	None	Number of blockages (per year)	<50
Service interruptions (per 100 km/year)	<20	Service interruptions (per 100 km/year)	<40
Breakage rate (per 100 km/year)	<5	Surcharge (per year)	<20
Response time (hours)	<3	Response time (hours)	<3
Head loss (metres/km)	>1.5		
Drink water guidelines:			
F. Coliform/E. Coli (#/100 ml)	0		
Color	<15 TCU		
Turbidity	<1 NTU		
Number of complains: taste, color and chlorine residuals (per year)	<20	Number of complains: pollution, contamination (per year)	<10
Repair cost/year (last 5 years)	$$	Repair cost/year (last 5 years)	$$

In some cases, the term "performance" means asset suitability to perform a function. Therefore, an asset often has several requirements against which performance is measured. For example, sewer system performance may be evaluated using measures of the following:

- hydraulic (functional) performance;
- environmental influences;
- structural integrity (structural condition); and

In contrast, the performance measure for a park may be the number of users. A park located in a wilderness area could have a more esoteric measure such as number of bear sightings.

Performance can also be rated in terms of reliability. For equipment, measures of reliability, such as mean time to failure (MTTF), are often used.

It is important to understand the difference between qualitative (subjective) and quantitative (objective) performance measures. A qualitative measure is subjective in nature in that it rates a person's level of satisfaction on a predetermined scale. Thus, different people can rate the same asset differently depending upon how the asset meets their individual needs or their subjective rating scale. For a general discussion on a subjective performance rating system, please refer to Tables 33, 34 and 35 in the Normalize Asset Classes task in Section 8.1.

Quantitative ratings are objective ratings, in that an asset is assigned a specific "number" or "value" relating directly to the performance of the asset. As an example, identifying the number of major defects per kilometre (km) of sewer pipe using CCTV inspections is a quantitative measurement. It is important to ensure that the protocols selected to collect performance data provide the appropriate rating of how the asset performs its intended function.

To be valid, a performance protocol must collect data that are repeatable and comparable over several inspection periods otherwise the resulting asset condition is meaningless. The performance protocol must also stand the test of time and cannot be constantly changing, unless it is upwardly compatible. Standardized performance protocols ensure that data are collected consistently. The performance protocols used to collect performance data are both asset- and municipality-specific. They can also be site-specific as some sites or regions within a municipality may vary geographically and thus, warrant different performance protocols.

Examples of widely used condition assessment protocols for pavements include the riding comfort index (RCI) or the international roughness index (IRI). The pavement condition index (PCI) quantifies the condition of a roadway based on an evaluation of the frequency and severity of distresses in the roadway. The IRI is a measure of pavement condition based on the vertical movement of a typical vehicle as it travels along a roadway; it is meant to simulate the "comfort" level of the user, i.e. the rougher the road, the worse its condition. These condition assessment protocols are the basis of many of the current pavement management systems (PMS). Information on these protocols is available from many sources including the Federal Highways Authority (FHWA, 2009) and the Transportation Association of Canada (TAC, 1997).

Many municipalities use the Water Research Center (WRc, 1994, 2001) protocols to inspect and rate the structural and hydraulic performance of sewers. Rahman and Vanier (2004a) compared a number of performance protocols. These protocols are based on observed defects in a segment of pipe. Each defect has an associated score and the highest defect score in a segment of pipe is used to determine the structural pipe grade for that segment. The structural pipe grade is a five-point scale where an excellent pipe has condition grade 1 and a failed pipe has condition grade 5. The range of defect scores for each pipe condition grade is shown in Table 7 (WRc, 1994).

Table 7: Defect Score Range for Structural Pipe Grade

Condition Grade	Defect Score
1	<10
2	10 – 39
3	40 – 79
4	80-164
5	≥ 165

It may also be beneficial to combine two or more performance measures to form a multi-criteria rating system. This is common for asset classes, such as roads, wastewater systems and buildings, where the performance of an asset is based on several measures. An example of a multi-criteria rating system is provided in Table 8.

Table 8: Multi-Criteria Rating System

Asset Type	Performance Measure	Weighting Factor (100%)	Metric
Sewer	Structural condition	30	WRc 4th Edition (WRc, 2001)
	Age	30	Remaining service life
	Hydraulic performance	40	m^3 per second
Road	Serviceability	50	Riding Comfort Index (RCI)
	Surface condition	50	Pavement Condition Index (PCI)

Techniques such as Fuzzy Synthetic Evaluation (FSE) have been used to interpret distress indicators and to translate these into condition ratings (Kleiner et al, 2007). This technique reflects the fact that currently data are scarce for the assessment of pipe segments (and other linear assets, for that matter) and that a discrete condition grade does not represent the "real world" situation (i.e. 30% of road segment is fair and 70% is poor or inspector 1 places the pipe segment in condition grade 4 while inspector 2 says it is condition grade 3). Although still experimental in nature, the technique appears promising.

Data requirements are typically defined by the protocols that are selected by the municipality; municipalities are reminded that data collected for the *performance* facet are in addition to the data collected for the *inventory* facet. *Performance* data are needed to facilitate the **Inspect Assets** process that follows. The *performance* data is specifically needed to assist the asset manager to rate and rank the performance of the assets.

If the data are complete and the protocols selected do not require an inordinate amount of new data, then the missing and new data can be collected using in-house resources. If little or no data can be collected in-house, it may be necessary to hire additional staff or a consultant to gather the information. Depending on the asset, collecting good performance data is expensive; collecting accurate performance data is more expensive.

As technology advances, the use of integrated inspection tools to collect performance will become more prevalent. Examples of some current inspection tools are presented in Table 9.

Table 9: Sewer and Pavement Performance Data Collection

Asset Class	Performance Measure	Performance Data Collection
Sewer	Structural	CCTV
		Sewer Scanner and Evaluation Technology (SSET)
		Visual inspection (large sewers)
Road Pavement[1]	Structural	Falling Weight Deflectometer (FWD)
		Benekelman beam
	Serviceability	Response type road roughness meters
		e.g. Quarter-car test
	Condition	Visual inspection
		PAVER (inspection software)[2]
		Ground penetrating radar (GPR)

[1] www.asphaltwa.com/wapa_web/modules/08_evaluation/08_categories.htm
[2] www.cecer.army.mil/paver/Support.htm

3.4 Select Protocols > *Service Life*

In practice, the end of an asset's service life occurs when the asset:

- becomes structurally unsafe;
- becomes functionally obsolete;
- ceases to perform its primary functions adequately;
- causes delays and inconveniences to users, e.g. load restrictions, poor quality of services, or
- is too costly to operate and maintain (energy, manpower, social costs).

The service life of an asset is normally defined as the "actual period of time during which … the asset or any of its components performs without unforeseen costs or disruption for maintenance or repair" (CSA, 1995). This is a very general definition of service life but does not take into account many of the vagaries that exist in the "real life" of assets such as accidents, overloadings, poor materials, poor maintenance practices, etc. The service life of an asset is not necessarily related to functional aspects of its usage; it can also be related to technical, functional, or economic issues.

The estimates for the technical service life can be experiential, theoretical or a combination of both. Experiential models use historical information to generate an average service life for different classes of assets. Theoretical models can also us the results of accelerated testing of materials to predict asset service life. Finally, historical data can be combined with theoretical data to predict service life. The model selected depends upon the asset and its value in the portfolio (i.e. how much accurate data are required). Likely sources of service life data are:

- historical data, such as past performance of an existing or retired asset in the inventory or historical trends in public use;
- related industry standards for similar assets (e.g. HAPM, 1992 and CSA, 1995);
- anticipated regulatory changes, and
- expected performance based on accelerated testing of materials or components.

The functional and economic service life of an asset is determined by factors other than the technical life of asset components. In fact, an asset may need rehabilitation before the end of its technical life for any of the following reasons (Lemer, 1996):

- obsolescence due to technological changes that affect the level of service provided by the asset or due to regulatory changes;
- economic or social changes; and
- changes in values or behaviours of people that affect the provision of service.

There are currently few examples of good service life data for infrastructure assets. Different assets have different types of service life data and have different protocols for determining service life. Service life data can be obtained from historical data, such as past performance of an existing or retired asset in the inventory, or from related industry standards and research findings for similar assets. Table 10 lists examples of average service life for major infrastructure assets.

Table 10: Municipal Infrastructure Asset Service Life

Asset Class	Average Service Life (years)	Source
Bridges	75 -100	Hudson et al (1997)
Buildings	40 - 100	CSA S478-95 (1995)
Dams	100	Hudson et al (1997)
Monuments	100+	CSA S478-95
Roads	15-30	Hudson et al (1997)
Sewers systems	75-150	Newton and Vanier (2005)
Water distribution	~100	Seiko et al (2002)

All of the assets listed in the Table 10 may also have a functional service life that can be less than the technical service. As an example, a road may not fail structurally after 30 years, but it can become functionally inadequate due to increased traffic loads. The highways in and around major urban centres in Canada are examples of this state of affairs. Likewise a wastewater system backup may not be due to pipe failure but to the inability of a pipe to handle the increased flow.

Thus, the technical, functional and economic service life must also be considered when selecting the service life for an asset class.

- Select Service Life Protocols

The internal protocols used to determine the service life of an asset class, depend not only on the needs of the municipality but also on the characteristics of the asset class and the physical components of the individual assets. The level of data accuracy required for each asset can also dictate which protocols are used to determine the service life. The level of accuracy can vary from "best guess", to experimental testing, or to complex calculations using advanced probabilistic modeling techniques such as Markov modeling methods proposed by Kleiner (2001) and Wirahadikusumah et al (2001). A detailed description of method for modeling the service life of wastewater collection networks is included in a related MIIP report (Newton and Vanier, 2006).

The level of accuracy required is also related to the criticality of the asset. The more critical the asset, the more confidence is required in the accuracy of the service life data. This is covered in subsequent subsections related to *criticality* protocols. Typical protocols to determine the service life include the following four techniques:(1) Age-based: The simplest service life protocol is past experience or "rule of thumb" experience. In this technique the remaining service life equals average service life of the asset class minus the current age of the asset. A subjective rating scheme (1=new to 5=beyond service life) is proposed to approximate which quarter of the service life is the asset. If the service life of a bridge is 60 years, then a bridge that is 0-15 years old has a service life rating of 1, and so on. A bridge older than the service life of 60 years has a service life rating of 5. For a general illustration of a subjective performance rating system, please refer to Table 35 in the Normalize Asset Classes task in Section 8.1.

(2) Factor Method: Another protocol for estimating or predicting service life is the *Factor Method*. The *Factor Method* for estimating service life (ISO 15686-1:2000) identifies the following six factors as contributing to service life:

- A - Quality of components in construction;
- B - Design level;
- C - Construction quality;
- D - Maintenance level;
- E - Environmental conditions (internal and external); and
- F - In-use conditions.

Each factor is assigned a weighting factor (e.g. below average, average, above average) where "1" is average. The predicted service life (PSL) is then calculated based on the simple equation:

$$PSL = \text{Asset Design Life} \times A \times B \times C \times D \times E \times F \quad (1)$$

The estimated remaining service life is simply the difference between the actual age of the asset and the PSL. Examples of factors related to the service life of sewer pipes are shown in Table 11.

Table 11: Factors Affecting the Predicted Service Life of Sewers

Factor	Example
A	Pipe material, joint sealants, bedding material
B	Pipe diameter, number of connections, length of pipe segments, slope of pipe
C	Expertise of contractor and work crew
D	Frequency of inspection and cleaning of sewer line
E	Ground water level, depth of pipe, chemical properties of soil
F	Incidents of surcharging, chemical properties of wastewater

(3) Deterministic Empirical Modeling: A more widely used protocol is deterministic empirical modeling using historical or theoretical data to predict future performance and hence, service life. Deterministic modeling uses statistical regression analysis to generate curves that predict how an asset performs over time. It is useful to determine what factors, other than time, may affect the performance of the asset. For sewer pipes, the pipe material, pipe-bedding material, pipe depth and pipe diameter are all factors that are known to affect performance. An example of a deterioration curve, based on a regression analysis of sewer structural pipe grade (SPG), is shown in Figure 2.

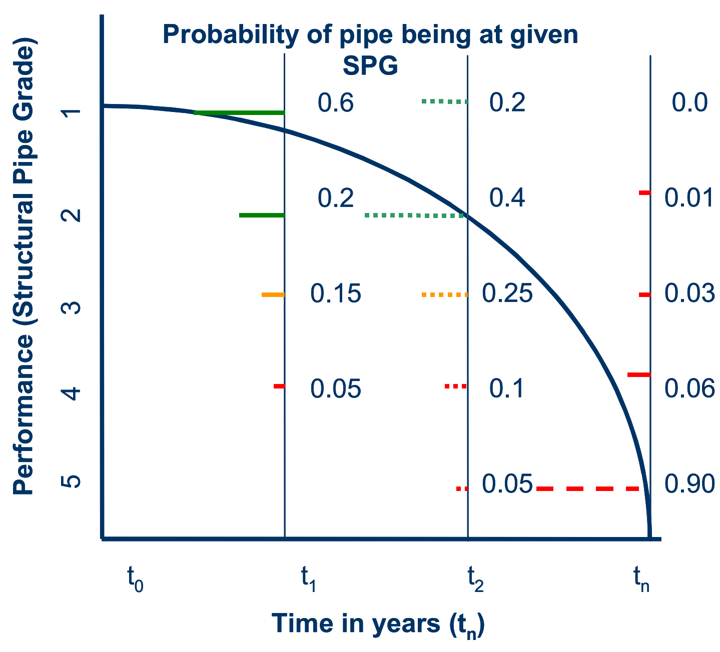


Figure 2: Regression Analysis Deterioration Curve.

In the deterministic method, a curve is fitted (i.e. curve fitting using regression analysis) to match a set of data points representing the age and the respective performance rating of the asset. Equation (2) represents the deterioration for generic sewer pipes (Newton and Vanier, 2006) and can be used to calculate the performance at any time in the future as well as the potential service life (i.e. when it reaches its failure state.

$$y = 0.0004x^2 - 0.005x + 1.00 \qquad R^2 = 0.9887 \qquad (2)$$

Where, y = condition grade; x = age in years, and R^2 = "goodness of fit" (e.g. an R^2 of 1.00 is a perfect curve fit where all data points are on the curve).

(4) Probabilistic Methods: For some assets, knowing that the "average" pipe will be at SPG 2 at time (t_2) may not be accurate enough. It can be seen from the vertical lines on the graph that the overall pipe inventory will be distributed from SPG 1 to SPG 5, at any one point in time. There is a probability at time (t) that some pipes will still be at SPG 1, while others may already have failed. Thus, a deterministic model relates to the mean behaviour of pipes (e.g., on average pipes will be at state *i* at time -t_n) but cannot predict the probability that an individual pipe will be in a given state at a given time.

Probabilistic methods can be used to determine the probability that an asset will be in a specific condition at a specific time (Vanier and Rahman, 2004). As mentioned previously, Markov chain modeling is one method that can be used for probabilistic modeling. Markov chain modeling is a common form of probabilistic modeling, as is logistic regression modeling. The basic premise of a Markov model is that the past state or condition of a system (in this case pipe deterioration) is irrelevant to the future state, only the present state i, at the present time (t) is important because it already is reflecting the sum total of the asset history. When applied to sewer pipes under certain assumptions (Newton and Vanier, 2006), this means that at a future time (t_n) a pipe will either stay at its current state or deteriorate to a worse state. This is known as a transition. A pipe cannot improve, or move "backwards", without repair or rehabilitative measures. The time to move from one state to another is known as the transition time. A Markov model gives the probability that a pipe will either remain in its current state or move to the next state during one transition period. In the model shown in Figure 3 (Lounis et al, 1998), a pipe at condition grade 1 can either remain in that state or move to condition grade 2 during one transition period. The transition period can be one year or several years, depending upon the asset's typical deterioration pattern. Figure 3 has been simplified for the sake of clarity, in that it does not illustrate that a pipe in condition grade 1 can move to condition grade 2, 3, 4 or even 5 during the transition period.

The major result of this type of analysis is the ability to predict the probability that an asset class will be in a specific condition grade at some time in the future. Transition matrices are the means for using Markovian probability methods. Transition matrices for generic sewer pipes were developed in a related MIIP project (Newton and Vanier, 2006). Examples of the transition matrices for two vintages of pipes are shown in Table 12.

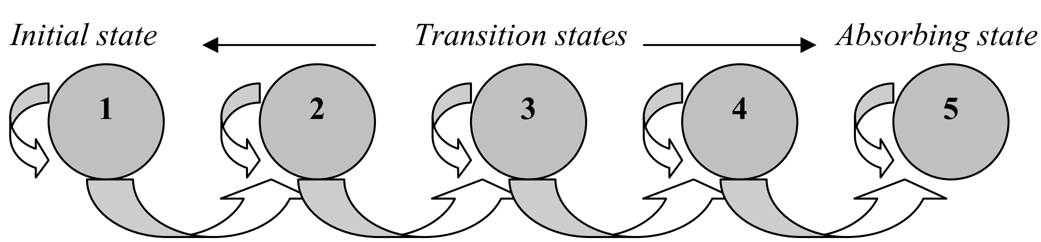


Figure 3: Sanitary Sewer System Markov Chain Model

Table 12(a) illustrates that a pipe of age 0-10 years in Structure Performance Grade 1 (SPG 1) has a 91% probability of remaining in SPG 1 for the designated transition period of 10 years (Newton and Vanier, 2006), and a 9% probability of moving to SPG 2. Whereas, in Table 12(b) the probabilities of transition for an SPG 1 pipe are notably different having only a 83%

probability of remaining SPG 1 in the 10-year period, a 15% probability of moving to SPG 2 and a 2% probability that it can move to SPG 3.

Table 12: Generic Sanitary Sewers Markovian Transition Matrices (Pipe Dia. ≤ 600 mm)

(a)

Pipe age 0-10 years	Probability of transition from one SPG to the next				
	1	2	3	4	5
1	0.91	0.09	0.00	0.00	0.00
2	0.00	0.76	0.24	0.00	0.00
3	0.00	0.00	0.69	0.31	0.00
4	0.00	0.00	0.00	0.64	0.36
5	0.00	0.00	0.00	0.00	1.00

(b)

Pipe age 11-20 years	Probability of transition from one SPG to the next				
	1	2	3	4	5
1	0.83	0.15	0.02	0.00	0.00
2	0.00	0.58	0.35	0.08	0.00
3	0.00	0.00	0.47	0.42	0.11
4	0.00	0.00	0.00	0.41	0.59
5	0.00	0.00	0.00	0.00	1.00

The transition matrices, such as those shown in Table 12, can also be used for calculating the life cycle costs for maintenance. For example, if maintenance data were available for pipes in SPG 1 through 5 (e.g. $2 per metre for SPG 1, $10 per metre for SPG 2, etc.), then the life cycle costs for maintaining the pipes could be obtained by cross-multiplying the probabilities for each vintage of pipe by the individual SPG maintenance costs.

Table 13 summarizes possible protocols for the calculation of service life for various asset classes; protocols selected by the municipality should be added to their version of Table 1.

Table 13: Service Life Calculation Protocols

Asset Class	Asset Subclass	Protocol	Method
Wastewater Collection	Pipe Segment	Probabilistic	Regression Analysis and Markov Chain (Newton and Vanier, 2005)
Wastewater	Manhole	Simple Age Calculation	Average age – asset age
Wastewater	Pump	Custom	Mean time to failure (MTTF)
Building	Envelope	Factor Method	RSL=Average Life x A x B x C x D x E x F A Quality of components in construction B Design level C Construction quality D Maintenance level E Environmental conditions F In-use conditions
Road Network	Road Surface	Deterministic	Deterioration Curve (Paver, 2009)

3.5 Select Protocols > *LCC*

Maintenance and repair cost data are extremely important to three *MIM Framework* processes: **Inspect Assets**, **Rate Assets** and finally **Optimize Investment.** Challenges to maintaining accurate costs records in a municipality include the inability to relate costs to specific assets thereby making it difficult to obtain costs for more than one or two years and failure to retain historic costs when repairs or renewal are implemented. If historical costs are not available then representative costs can be obtained from companies such as Hanscomb's *Yardsticks for Costing* (Hanscomb, 2009), RSMeans (2009) or Whitestone Research (2009).

- <u>Select Level of Investment</u>

Appendix D defines the Level of Investment (LOI) as "the amount of funds available to maintain existing assets, as a percentage of the replacement value (i.e. 2%)." Typically, LOI relates to maintenance expenditures and not recapitalization (replacement). LOI should not include the funds required to replace or renew the existing assets at the end of their service life (i.e. recapitalization). Recapitalization should be based on the service life of the asset and this is described later in this report.

The body of literature on facility maintenance recommends that 2% to 4% of the capital replacement value (CRV) of the asset should be spent on maintenance and repairs (NRC US, 1996). Unfortunately, there is little supporting research for this 2% to 4% level of investment (LOI) outside of empirical data (CERF, 1996). This recommended LOI range is based on experiential information and provides too wide a range of variance for practitioners. This range is also an average for the entire construction domain and therefore is not representative of one specific discipline; for example, a 2% LOI might be sufficient for sewage treatment plants, whereas 4% might be the bare minimum for a high volume, high load, local road. It also does not take into account the past municipality practices (i.e. good or bad) for maintenance and repair intervention. In addition, the denominator in the CRV ratio is not defined (i.e. what is meant by replacement cost: historical cost, appreciate historical cost, replacement cost, etc.) and could greatly affects the calculation of the LOI (Vanier and Rahman, 2004).

However, the 2% to 4% recommendation on LOI is the only guideline currently available and it is well referenced by many in the industry (NRC US, 1996). Selecting an LOI should be seen as an interim step in the *MIM Framework* on the way to the ultimate goal to **Optimize Investment,** and it should be seen as a *temporary* metric to evaluate how a municipality of performing *vis-à-vis* this type of benchmark..

- <u>Select LCC Protocols</u>

PSAB 3150 (2009, 2009a) has identified requirements for collecting cost data for Canadian municipalities in their new Tangible Capital Assets regulations, as shown in Tables 14 and 15. PSAB 3150 does not specifically identify how to calculate the historical cost or the average replacement cost per measured unit, but many tools and techniques exist, as mentioned earlier.

Table 14: PSAB 3150 Principle 10 - Assessment of Tangible Capital Assets

<u>Principle 10:</u> For each category of tangible capital assets, governments should provide a further breakdown of the overall average physical condition by each rating showing:	
(a)	measurement unit and quantity;
(b)	average age and average remaining expected life; and
(c)	average replacement cost per measurement unit.

Table 15: PSAB 3150 Principle 9- Tangible Capital Asset Data Requirements

<u>Principle 9</u>: "Governments should provide the following information for each category of tangible capital assets":	
(a)	historical cost;
(b)	average overall physical condition rating;
(c)	average age;
(d)	average expected life;
(e)	measurement unit and quantity; and
(f)	planned and approved expenditures.

A municipality must first select whether historical, appreciated historical, current replacement values or another valuation method (Vanier and Rahman, 2004) is to be used. Secondly, it must select a consistent method to calculate the average replacement cost and state the basis for this method (i.e. experiential knowledge, existing construction record, computer database, web service, etc.). The databases and web services are normally discipline-specific, so they would relate to a limited number of asset classes. Lastly, the municipality must decide if life cycle costs are to be collected (and which discount rate is to be used).

ASTM published their *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems* over two decades ago (ASTM E917, 1994). The *Standard Practice* also applies to infrastructure assets. The remainder of this subsection has been extracted and modified from Rahman and Vanier (2004) as it summarizes the theories and mathematics behind LCC.

Every municipal infrastructure asset has a series of life cycle phases from the time it is conceived, through the planning phases, during construction and service life phases, until the asset is declared surplus and is decommissioned. Figure 4 illustrates typical infrastructure life cycle phases, each contributing different types of costs.

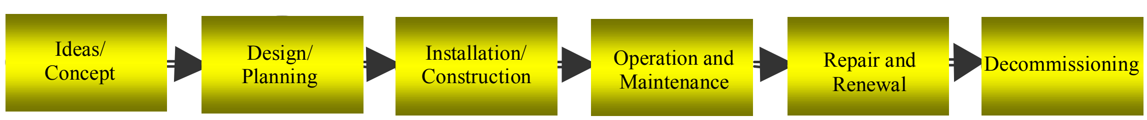


Figure 4: Life Cycle Phases for Municipal Infrastructure

Municipal infrastructure managers depend on reliable cost data to make responsible engineering decisions. For example, the decision makers must take into account: the different methods of LCC analysis, the typical acquisition expenses, the anticipated ownership costs, the probability of future LCCs, and the uncertainties in the LCC calculations.

The most commonly used LCC methods are: (1) the present value (PV) method and (2) the uniform annualized cost method.

The present value (PV) is determined for future expenses by taking account of the anticipated inflation of future dollars and discounting that amount by a predetermined rate over the period between the anticipated time of future expenses and present time. The discount rate is discussed later in the section.

$$PV = FV\left[\frac{1}{(1+i)^{n}}\right] \tag{3}$$

Where, PV = present value; FV = future value of expenses; n = number of years between time of analysis and time of expense; and *i* = discount rate.

The Uniform Annualized Cost Method is used to transform present value (PV) costs and a discount rate (*i)* into an equivalent series of uniform annual cash outlays (A) and is computed by:

$$A = PV\left\{\frac{\left[i(1+i)^n\right]}{\left[(1+i)^n-1\right]}\right\} \qquad (4)$$

Equation (4) is a way to calculate that a cost (PV) at year 0 can be equated to the sum of a series of annual costs (A) over the service life of the asset (*n),* or inversely that an annual maintenance cost (A) over *n* years can equal a present value (PV) at year 0.

LCC should include all costs associated with the planning, development, acquisition, operation, repair and renewal, logistical support, and disposal of an asset: The LCC for municipal infrastructure should also take into account social costs:

$$\text{Life Cycle Cost (LCC)} = \text{Acquisition Cost} + \text{Ownership Cost} + \text{Social Cost} \qquad (5)$$

Acquisition costs are incurred mostly during the first three life cycle phases shown in Figure 4. Costs in this category include, but are not restricted to: land purchase costs, right of way costs, purchase expenses, purchase commissions, legal services, taxes, land survey fees, design fees, construction costs, lost opportunity costs, bridge financing, capital equipment leases, purchase commissions, site inspection expenses, project management fees, and administrative and technical overhead.

Ownership costs can accrue during every phase of the infrastructure life cycle. As it is difficult to completely predict the service life of an infrastructure asset, it is equally difficult to anticipate or forecast its LCC. Ownership costs include all direct costs such as energy costs, preventive maintenance expenses, inspection costs, and repair and renewal costs. In some instances, it is possible to predict asset failure and to calculate the resulting repair, lost opportunity, and disruption costs. In some organizations, operational costs such as custodial or janitorial services and snow removal are attributed directly to an infrastructure asset (water treatment plants, community centres, etc.). Additionally, there are many indirect costs that should be taken into account in calculating the LCC, including: interest on borrowed funds, administrative and staffing costs, and legal expenses.

Social costs include all intangible costs incurred by the general public owing to disruptions of services to the community. These can include costs during construction, maintenance, or repair projects that relate to additional physical stress and loads on detour routes, disruptions to merchants, environmental costs and additional expenses incurred by taxpayers such as vehicular wear and tear (Rahman et al, 2005).

The present value (PV) and discounting for LCC is calculated as (ASTM E917, 1994):

$$PV = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \qquad (6)$$

Where, PV = present value of life cycle costs, C_t = sum of all relevant costs (e.g. maintenance, social, repair) occurring in year *t*, *n* = length of analyzed period, and *i* = discount rate.

$$C_t = AC + EC + MC + RC + OC - SV \qquad (7)$$

Where, AC = acquisition cost, EC = energy cost, MC = direct and indirect maintenance cost, RC = renewal cost, OC = direct and indirect operations cost, and SV = salvage value.

It is necessary to describe the remaining factor in the calculation of the LCC: the Discount Rate. In most cases, a dollar today is worth more than a dollar in ten years time. For example, $82 today can be banked for 10 years at an interest rate of, say, 2%, so that at the end of 10 years (with compounded interest) will be worth approximately $100. Therefore it can be said that the present value of $100 in 10 years is about $82, considering a discount rate (in our example discount rate = interest rate) of 2%. It is clear that the higher the discount rate the lower the present value of a given future amount.

Discounting takes into account the changing value of money over time. The discount rate is an agreed upon/accepted factor to reflect this time-value of money. The discount rate in the private sector is normally taken as the guaranteed return on a risk-free investment (often taken as 10-year or 30-year return on a US Treasury bond, or T-Bill). The discount rate (*i*) has three components: the actual opportunity cost of capital (cc); the premium for financial risk for investment (fr); and the anticipated rate for inflation or deflation (pi). Each component is typically stated as percentage of the rate of annual increase or decrease, thus current discount rate can be calculated as (TRB, 2003):

$$\text{Discount rate } (i) = cc + fr + pi \qquad (8)$$

There are two types of discount rates: financial and social. The financial discount rate is used to reflect the time-value of money as compared to a benchmark cost of capital. The financial discount rate in public organizations is often based on the organization's cost of raising capital. The financial discount rate in the private sector is often based on "risk free" annual return rate such as a commercial bank certificate of deposit or a government treasury bond. The social discount rate is used to reflect social values and preferences when comparing or measuring economic activities involving large public assets (e.g. infrastructure) with cost/benefit streams spanning very long time periods. A higher social discount rate reflects a greater tendency to defer costs to future generations.

The Public Sector Accounting Board, mentioned earlier, has “strongly” recommended that the historical costs of infrastructure assets appear in municipal financial statements, as indicated in Table 15 (PSAB 3150, 2009, 2009a).

Although PSAB 3150 allows the use of current replacement value (CRV) when historical costs are not available, many organizations (OMBI, 2009) are using the Construction or the Building Cost Index from the Engineering News Record (ENR, 1999) to bring historical costs into current dollars and *visa versa* to calculate the historical costs knowing the CRV. The ENR data are based on historical cost data (averaged over 20 cities in the USA) for two weeks of skilled labour from representative tradesmen and the cost of a standard weight of structural steel, Portland cement, and processed lumber. This historical cost updating therefore takes into account annual inflation or deflation. ENR uses 1913 as the base year (value = 100). To use this approach, an asset constructed in 1960 has a multiplier of 559, whereas a multiplier of 3767 is applied to an asset built in January of 2004. Therefore, a facility constructed in 1960 for $ 1 million can be constructed in 2004 for $ 1 million X 3767 / 559 or $ 6.74 million. The conversion tables found in ENR (1999) can be easily input into a spreadsheet, database or computer program.

PSAB 3150 (2009a) also recommends the use of LCC for "operational planning, which would include life-cycle costing together with estimates of useful life, required maintenance and timing of major repair and replacements."

Full cost accounting (FCA) is becoming an accepted practice for asset accounting in many government agencies. It includes not only the "hard" costs of the asset such as those described above but also "soft" costs such as social and environmental costs. FCA for a municipal asset, such as a road, would include the construction, maintenance, repair and renewal costs over its service life as well as the costs associated with traffic delays, noise, loss of business for local shops and services, etc incurred by the public-at-large during construction or repair and renewal activities. FCA has far reaching implications for municipalities as the question, "Who pays?" is highly controversial.

More details regarding a proposed LCC analysis approach, probabilistic approaches to LCC, LCC reference manuals, and available LCC information technology (IT) tools can be found in Rahman and Vanier (2004).

For a general illustration of a life cycle cost rating system, please refer to Table 35 in the Normalize Asset Classes task in Section 8.1.

3.6 Select Protocols > *Criticality*

The criticality of an asset relates directly to the importance of an asset in the portfolio, where the importance can be determined by factors such as the consequences of failure of the asset (Andrews and Moss, 2002). In this definition, if the consequences of failure are higher, then the asset is more critical.

Factors that contribute to the criticality of an asset include any or all of the following:

- threats to public health and safety;
- immediate impact of loss of service (i.e. hospital, major arterial road);
- condition of the asset;
- construction material (e.g. are replacement parts of materials available?);
- size (e.g. extent, length);
- physical environment (e.g. above ground, below grade, marine);
- geographical location (e.g. urban high density area, urban low density area, industrial, rural, parkland);
- usage;
- public health and safety;
- placement in network (i.e. road network, water network, wastewater network), and
- location of services to support the asset.

Typically, the only way to quantify the consequence of failure is in terms of cost, albeit not always a good metric. These consequence of failure costs can be tangible and predictable cash outlays (e.g. repair costs, emergency intervention costs, or direct social costs such as loss of revenue) or can be intangible costs such as difficult-to quantify costs to society, environmental costs, etc.) Where the consequence of failure is predominantly characterized by tangible costs, the factors that affect the criticality of the asset should relate to the health and safety of the users of the asset. This usually applies to buildings (CSA, 1995) and other structural assets such as bridges (Lounis, 2006).

The frequency of the occurrence is directly related to the probability of failure of the asset or asset class. As noted earlier, the probability of failure can be related to any number of factors including the asset condition, environmental events, asset use, asset loadings, or even accident events. Currently, there exists very little information for practitioners on the quantification of risk for civil engineering works. A number of protocols are suggested:

(1) Qualified Criticality Rating: A simple order of magnitude method is proposed in Tables 16, 17 and 18 for assets that are not health-critical or safety-critical. This Qualified Criticality Rating protocol relates the criticality of an asset in the portfolio to the total cost of the repairs in an emergency intervention situation and a qualified probability of failure.

Table 16: Consequence Rating

Cost of Emergency Intervention	Consequence Rating
<\$1,000	1
<\$10,000	2
<\$100,000	3
<\$1,000,000	4
<\$10,000,000	5
<\$ 10^n	n-2

If the probability of failure is only condition-dependant (and not based on other events such as accidents), then the Probability Rating protocol shown in Table 17 is directly related to the condition (and could even use the same rating system as a qualified condition rating system).

Table 17: Probability of Failure

Probability in current year	Probability and/or Condition Rating
Near impossible	1
Highly unlikely	2
Unlikely	3
Possible	4
Certain	5

The calculation for the Qualified Criticality Ratings in Table 18 is based on the average of the Probability Rating and the Consequence Rating and “rounded up” to the nearest integer. However, municipalities can adopt their own conventions to calculate the Qualified Criticality Rating, including the number of rating grades (1 to 5, 1 to 7, etc.).

Table 18: Qualified Criticality Rating

Probability Rating / Consequence Rating	1	2	3	4	5
	Criticality Rating				
1	1	2	2	3	3
2	2	2	3	3	4
3	2	3	3	4	4
4	3	3	4	4	5
5	3	4	4	5	5
n			← 5 →		

As an example, there are two segments of wastewater pipes. Pipe1 is 100 years old and is located in the downtown core and is very deep, hence the emergency intervention costs are extremely high. Tables 16 and 17 show that Pipe1 has a Consequence Rating = 5, and a Condition Rating = 4. Using Table 18, Pipe1 has a Qualified Criticality Rating = 5. On the other hand, Pipe2 is 60 years old and is located in an exclusive residential district where the emergency repairs would not be too high, but the pipe would have to be completely replaced. Pipe2 has a Consequence Rating = 3, and a Condition Rating = 4 based on Tables 16 and 17. Using Table 18, Pipe1 has a Qualified Criticality Rating = 4. Pipe1 is more critical than Pipe2.

(2) Failure Impact Assessment (FIA): FIA is a related term to criticality and is used in the *Guidelines for Condition Assessment and Rehabilitation of Large Sewers* (Zhao et al, 2001). Factors such as sewer location, embedment soil, sewer size, burial depth, sewer function and seismic zone all contribute to the determination of the impact rating from 1 (negligible) to 5 (high).

(3) WRc: Another method to calculate the criticality is that adopted by the WRc (2001), the American Society for Civil Engineers (ASCE 1994), and Winnipeg (2001) where the criticality is a function of the ratio between rehabilitation/renewal costs and failure consequence cost, as shown in Table 19 (Rahman and Vanier, 2004a); however, this method does not take into account the probability of failure.

Table 19: Comparison of Critical Sewer Categories

Sewer Category	ASCE	WRc and Winnipeg
Category A	Post-failure rehab cost is greater than 2 times planned renewal cost and 3 to 4 times the cost of rehabilitation	Post-failure rehab cost is greater than 6 times planned repair cost
Category B	Less critical but preventive action will be cost effective	Post-failure cost is between 3 and 6 times the planned repair cost
Category C	Less critical and pre-emptive work will not be cost effective	Post-failure cost less than 3 times planned repair cost

For example, the WRc (2001) protocol defines the overall criticality of a pipe in terms of only the post-failure rehabilitation cost. Category A pipes have a post-failure cost greater than six times the planned repair cost while Category C pipes have a post-failure cost less than three times the planned repair cost. An older, large pipe that is located in poor soil under a busy road

(Pipe 1) would cost more to replace in an emergency situation and therefore, would be more critical that than an identical pipe (Pipe 2) through a field. Depending upon the replacement method chosen, the potential additional costs associated with Pipe 1 that would not be associated with Pipe 2 include:

- cost to dig up the road and repair it after the pipe is repaired;
- costs to divert or limit traffic around the work site;
- compensatory costs due to damages resulting from failure; and
- social costs incurred by the public (delay time, loss of business, etc.)

Table 20 (Rahman and Vanier, 2004a) identifies rehabilitation priorities based on WRc condition grades and criticality.

Table 20: Rehabilitation Priorities

Condition Grades	Criticality	Re-inspection Frequencies		Rehabilitation Priority
		Category A	Category B	
5	High	N/A	N/A	Immediate
4	High	-	5 years	High
3	Medium	3 years	15 years	Medium
2	Low	5 years	20 years	Low
1	Low	10 years	20 years	Not required

- <u>Select Social Impact Category</u>

Rahman et al (2005) uses categorization of social costs based on the work of Peters (1984) and McKim (1997). It groups social costs into the three categories shown in Figure 5.

- Category I – project-specific, occurs before or during construction, and the costs are borne by municipality. For example, the police might be required to direct traffic during an emergency intervention. Typically, Category I costs can be anticipated and these costs are naturally charged against the construction project. Many of the Category I costs identified in Figure 5 appear to be standard administrative costs; however, in many instances these are never directly attributed to the project cost.
- Category II – broadly attributable to a specific project but the extent to which they are attributed is an estimation. These are typically borne by citizens or other corporations other than municipality. For example, the additional costs to citizens on the wear and tear to their vehicles owing to additional distances travelled in a detour.
- Category III – intangible and difficult to quantify. These occur typically after the project has been completed and/or can be probabilistic in nature. For example, these costs could include environmental or noise pollution that is difficult to predict, let alone quantify,

Cost comparisons for the social costs of alternative intervention strategies for pipe rehabilitation are presented in Table 21. The original data for Table 21 is based on a City of Winnipeg report performed by UMA (Winnipeg, 2001). An exhaustive list of social costs for Categories I and II can be found in Rahman et al (2005).

Table 21: Comparative Study of the Relative NPV of Total Construction and Social Costs***

Projects	Methods	Construction Costs	Social Costs	Social Costs/Construction Costs
Site A	Open-cut	$ 312,800**	$ 329,200	105%
	CIPP* lining	$ 308,200	$ 109,000	35%
Site B	Open-cut	$ 167,000	$ 156,300	94%
	CIPP* lining	$ 184,500	$ 85,400	46%
Site C	Open-cut	$ 2,191,700	$ 3,767,100	172%
	CIPP* lining	$ 3,189,300	$ 877,400	28%

* CIPP – Cured-in-place product.

** All figures are in Canadian Dollars.

*** Adapted from Winnipeg (2001) report.

NPV is the Net Present Value.

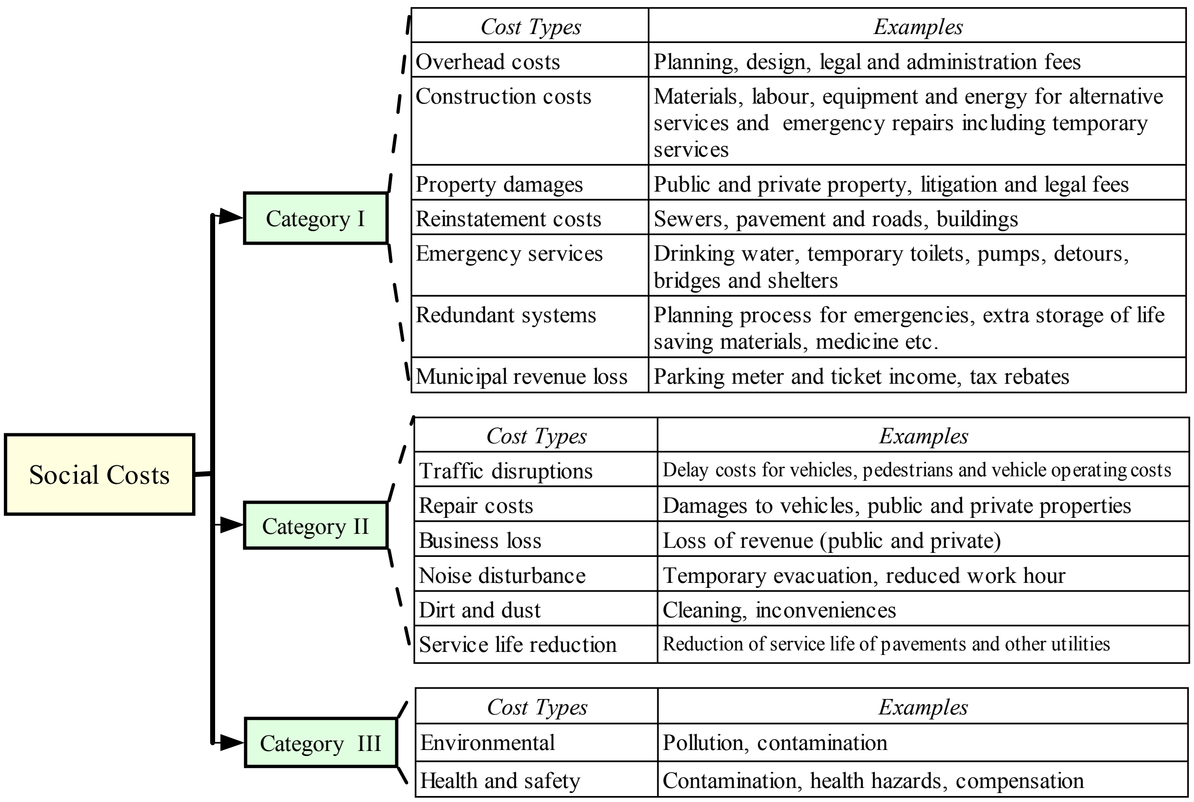


Figure 5: Social Costs Categories with Cost Types and Examples

A recent technique specifically addresses the current lack of data for risk assessment: fuzzy synthetic evaluation (FSE). FSE (Vanier et al, 2006a; Kleiner et al, 2007), mentioned earlier in Section 3.3, assigns a fuzzy number to the condition grade of the asset. FSE can also be used to determine the consequences of failure. As a result, the risk of failure (i.e. consequence of failure combined with probability of failure) can be plotted over the entire service life of an asset; and rehabilitation (or future inspection) can be planned when the risk of failure surpasses the organisation's Maximum Risk Tolerance (Kleiner et al, 2007).

- Select Criticality Protocols

The final step in regarding *criticality* is to select which of the aforementioned facet protocols are to be used for each of the different asset classes. As mentioned earlier, the collection of data about criticality is relatively new in the area of municipal infrastructure management and few data or protocols exist currently. Although risk-based or risk-centred maintenance management is well known in other engineering disciplines such as pipeline maintenance and shipbuilding (Ayyub, 2003), there is relatively little research, data, or information available for civil engineering infrastructure.

3.7 Select Protocols > *Alternatives*

Decision-making should be based on objective, systematic, equitable and repeatable comparisons of *alternatives*. Owing to the real costs (physical resources, consultation fees, time delays) of comparing potential engineering solutions in design and decision-making operations, the technical staff in a municipality may not be able to fully analyse all the advantages and disadvantages of the many alternatives, innovations or possible technologies for any one, much less all, the repair and renewal projects. Tools such as the Strategic and Sustainable Asset Management-Integrator (SSAM-I) have been developed within the MIIP project to automate the analysis of the multitude of possible interventions (Vanier and Abdel-Akher, 2007). A selection of software applications has also been evaluated in the context of the MIIP project (Halfawy et al, 2006).

Life cycle costing, described earlier, is a ready-to-use innovative method to compare alternatives but although it has been available for decades, unfortunately it is still rarely used in practice (NCHRP 545, 2005).

- Select DSS Protocol

Figure 6 illustrates a model proposed for a decision support system (DSS) for infrastructure management (Vanier et al, 2006a).

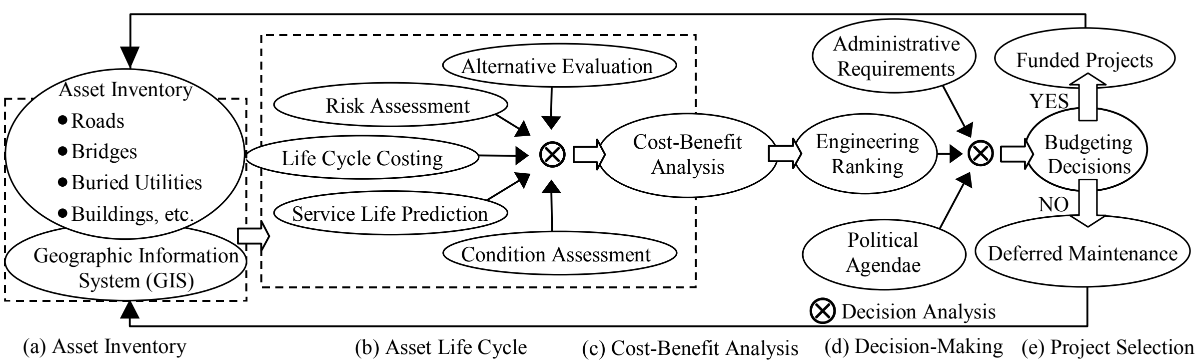


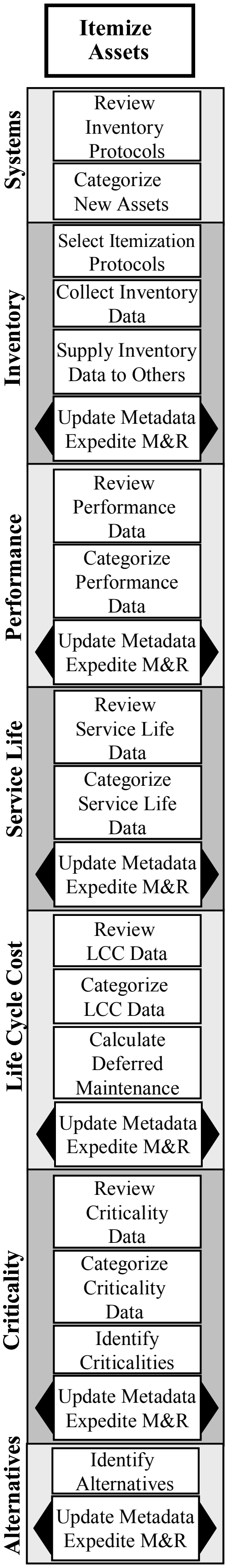
Figure 6: Proposed Model for Municipal Infrastructure Decision-making

This model is divided into five stages:

- Asset Inventory deals primarily with the recording and retrieval of asset class inventory data (including GIS data).
- Asset Life Cycle is the stage where the various decision attributes (condition assessment, service life prediction, etc.) are integrated. Any type of decision analysis technique can be

employed including cost-benefit analysis, multi-objective optimization (Kyle et al, 2002; Vanier et al, 2006a).

- Cost-Benefit Analysis stage is where the projects are ranked according to their benefits and the costs. The cost-benefit analysis permits the Engineering Ranking identified in Stage (d).
- Decision-Making is a second decision analysis stage where the different priorities from the municipality (administrative, infrastructure, and political) are compared, rated and ranked.
- Project Selection is the stage for the decision-making about budgeting. In some cases the projects may be worthy of funding but the budgets may not be sufficient to fund the worthwhile projects. The final decision regarding the project and the relevant data should be recorded in the asset management system (i.e. funded – change in condition, renewal cost, type of reconstruction, or deferred – continued deterioration, value of deferred maintenance).



4. Itemize Assets

The second major process in the *MIM Framework* is to itemize infrastructure assets. This process is critical to answering the six "whats" of asset management.

Appendix C defines to itemize as "to enumerate items in an inventory." In this case, the items are assets or physical components of a facility that have value, that enable services to be provided, and that typically have an economic service life greater than 12 months.

The next subsections identify each of the itemization tasks in the six facets described earlier and are preceded by a subsection on *systems.*

4.1 Itemize Assets > *Systems*

Two tasks are included in *systems*. Typically, these tasks should be completed in the sequence shown in the side figure.

Select Itemization Protocols first involves choosing what internal practices or methods are used to quantify or **Itemize Assets**. As discussed in the **Select Protocols** process**,** the protocols selected depend on the size of the municipality and the types of assets in the portfolio. It may appear redundant at this point to review the itemization protocols, but in large or regionally-dispersed municipalities poor communications can exist and a quick review of existing protocols can ensure that current protocols are applicable. This task should also be reviewed regularly because additional assets may be continually added to the portfolio, correspondingly new asset classes may be created. The personnel collecting inventory data are typically responsible for carrying out this task.

- Review Inventory Protocols

At the very start of implementing the **Itemize Assets** process of the *MIM Framework* it is necessary to catalogue all the existing protocols for itemizing infrastructure assets. A table, such as that shown in Table 22 can be used to record the existing itemization protocols. As can be seen in Table 22, not all assets need to be itemized at the current time (e.g. To be Determined - TBD). The data quality (Please refer to the Select Data Quality task for definitions) for each asset class dictates specifics about how the asset is itemized: for example, Data Quality A means that XYZ has to be verified at a sub-metre accuracy, whereas Data Quality C means on-site visual confirmation of drawing data is sufficient.

- Categorize New Assets

As the implementation of the *MIM Framework* expands, it is periodically necessary to add new asset classes to the inventory. As a result, these asset classes need new itemization protocols that can be different from other protocols currently being used in the municipality. These protocols should also be added to Table 22.

Table 22: Itemization Protocols

Asset Class	Itemization Protocol	Data Quality (refer to Table 3)
Pumps	Each pump	B
Pipes Segments	Length	A
Joints	TBD	-
Valves	Each valve	C

4.2 Itemize Assets > *Inventory*

- Select Itemization Protocols

Once all of existing asset class itemization protocols have been reviewed and the new asset classes and their protocols have been identified and selected, it is possible to Select Itemization Protocols. The requisite information should be included in Table 22, and these data should also be added to an appropriate column in Table 1.

- Collect Inventory Data

Having identified the required asset classes, asset attributes, data qualities, and itemization protocols (e.g. the demand), it is now possible to start the task to Collect Inventory Data (e.g. the supply).

Collecting inventory data provides the answer to the questions, “What do you own and where is it?” At the basic level, the data should describe what is in the inventory (as defined by the inventory protocols), where it is and how many there are (as defined by the itemization protocols). It also includes the physical attributes such as construction material and dimensions described earlier. Likely sources of inventory data include:

- memory;
- plans;
- drawings;
- record cards; and
- databases.

The first step in collecting inventory data is to identify what data are already available (hardcopy or electronic). These data must be assessed according to the following questions (WRc, 2001):

- Are the data accurate for the required level of detail?
- Are the data complete or is there missing information?
- Are the data current?
- Are the data consistent or are there discrepancies?
- Do the data conform to a common datum?
- Which piece of conflicting data is correct?
- Are the data credible?

Common data errors include gaps in the data (e.g. year of construction is only entered for some of the asset components), inconsistent descriptions or categorization of assets, and the duplication and variance of data entries. Consistency is very important. As a simple example, many large storm sewer pipes are made of reinforced concrete while other pipes are normal concrete. Failure to distinguish between these two similar types of materials can lead to erroneous inventory data when determining how many pipes there are and where they are. This in turn, can affect the understanding of the performance of the pipes, the service life, determination of criticality and ultimately, the rehabilitative measures chosen. Multiple, but different, data for the same asset attribute imply that the correct version of the data has to be selected as one entry can be more accurate (e.g. more precise, newer) than another, or one version of the data can just be wrong.

Once collected, the data are verified once again to ensure that all the inventory data entered into the database are "good." If the data are fairly complete and the protocols selected do not require an inordinate amount of new data, the missing and new data can be collected using in-house resources. If little or no data are collected, it may be necessary to hire additional staff or a consultant to gather and verify the information. A subsequent step is to identify what data still need to be collected. Data that need to be collected can be either new data (required based on the protocol selected) or missing data (data exists for some but not all assets in the asset class inventory). Consultants may have to be engaged to collect the additional data, if in-house resources are not available: having implemented the *MIM Framework*, it is easier to pass these data and processes to the consultants. A description of tools for collecting spatial information about municipal infrastructure can be found in a related MIIP report (Vanier, 2004).

Typically, this task is a "desktop" activity that is carried out in an office that has Intranet and Internet access to the full suite of the municipality's software applications (or record cards).

- Supply Inventory Data to Others

Asset managers are frequently called upon to supply data to any number of other departments, organizations or citizen groups. The data are requested to support projects or tasks of other municipal departments (internal requests) or may be requested by external organizations (external requests) such as private individuals or contractors.

In this sense, the asset management data collected typically serves as a "data repository" for the municipality and the community, and these asset management data are viewed as the "definitive" data source. It is necessary therefore, to develop standard methods to supply the data for recurring tasks as well as for unique requests. Several methods can be used to make the data available including the provision of a "hard" or paper copy of the data, electronically transmitting the data, accessing the data though an inter or intranet portal, etc.

The asset management data typically need to be restructured to suit the destination requirement. Setting protocols for structuring the data is useful if a particular set of data is commonly requested. It is also beneficial in this situation to have preformatted reports that can be accessed electronically by the data supplier and modified to suit the specific request. In general, there are three formats for data transfer: flat file, spreadsheet and custom. These are described in detail in Appendix E.

Flat file format is a common data transfer method that uses a standard text file to contain the output data (*.txt). A wide variety of options are possible in the standard text file such as: tabs delimited (e.g. *.txt), CSV (comma separated values *.CSV), SYLK (symbolic link *.slk), or DIF (Data Interchange Format *.dif). These are low-level interoperability formats that separate each data record on a single line (ended by a carriage return – ASCII Character 13), and fields are separated by a specific character such as a tab (ASCII Character 9) or a comma (ASCII Character 44). Each line of data must have the same number of fields (i.e. same number of delimiters). These flat file formats are straightforward to print or read, manually or electronically. If the actual data fields include tabs, commas or carriage returns in the data, then pre or post-processing is necessary. A description of CSV format can be found at <http://en.wikipedia.org/wiki/Comma-separated_values>.

Many other formats exist for the wide selection of "off-the-shelf" applications that are currently available. Typically, data are transferred directly to the known destination by the originating application, spreadsheet or database. In general, these formats can be visualized as a number of inter-related flat files each containing a table of data (e.g. rows and columns). The transfer of GIS data typically falls in this category.

The types of custom formats for data interoperability are innumerable. Each application in use in the municipality can have a multitude of variations of flat file and spreadsheet formats; alongside their own data transfer formats. Two custom formats for interoperability for municipal infrastructure data are the eXtensible Markup Language (XML) <en.wikipedia.org/wiki/XML> and the *Spatial Data Standard for Facilities, Infrastructure, and Environmental Applications* (SDSFIE, 2009). Developments regarding SDSFIE are continuing in the area of computer-aided design (CAD) and the Building Information Model (BIM) at the CAD/BIM Technology Center of the US Army Corps of Engineers (SDSFIE, 2009). Research work is continuing in the area of the XML for the land information (LandXML, 2009), architecture, engineering and construction sectors (aecXML, 2009) and transportation (TransXML, 2009) fields. A description and review of the aforementioned spatial data formats for the interoperability of municipal infrastructure can be found in related MIIP reports (Vanier, 2004; Halfawy et al, 2006a).

More and more municipalities are using the web and web maps as a method to supply both alphanumeric and spatial data to citizens and other data users. Canadian cities that are making a portion of their municipal data available to the public include the City of Hamilton <http://map.hamilton.ca/>, City of Nanaimo <http://www.nanaimo.ca/>, City of Prince George <http://www.city.pg.bc.ca/pgmap>, City of Red Deer <http://www.reddeer.ca/OnlineServices>, and District of West Vancouver <http://westmap.westvancouver.ca/westmapviewer>. Data that are made available include standard information such as road centrelines, parcel boundaries, polygons for buildings, civic addresses, assessed property values, aerial photos, points of interest, and mass transit routes. Innovative services relating to public works data include location of sewer and water mains, waste collection schedules, capital projects, traffic volume, bicycle and walking trails. Many cities now provide colour-coded maps with interactive layering to display user-selected combinations of information (e.g. aerial photo with lot parcels and road centrelines). Some cities such as Nanaimo <http://earth.nanaimo.ca/> have provided links to Google Earth <http://earth.google.com/> and have included 3D city data.

The <u>Supply Inventory Data to Others</u> emphasizes that the municipality must try to minimize the total work for any activity and not only minimize their tasks, That is, it may be beneficial for the data supplier to spend time to change their data export formats if there are clear advantages for the data recipient.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found, that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a new class of fire hydrant could have been identified in the **Itemize Assets >** *Inventory* Collect Inventory Data task. This new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

A failed asset may be uncovered that is not in the inventory. In this event, it is necessary to consider immediate maintenance, repair or renewal.

4.3 Itemize Assets > *Performance*

- Review Performance Data

The client needs, legislative needs, benchmarking goals, political administrative requirements, and levels of service were identified previously in the **Select Protocols** process. Having selected the appropriate performance protocols earlier, it is necessary at this time to Review Performance Data collected to date to ensure these data meet both the protocol requirements, as well as the city's performance requirements.

- Categorize Performance Data

The Categorize Performance Data task provides the opportunity to classify, rank and rate the existing performance of assets in the asset class, and therefore an opportunity to review how the portfolio is performing as a whole and which assets are underperforming.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, underperforming pumps could have been identified in the **Itemize Assets >** *Performance* Categorize Performance Data task. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

A failed asset may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal.

4.4 Itemize Assets > *Service Life*

- Review Service Life Data

The inventory and the performance requirements and data have been reviewed previously in their related facets. Having categorized the assets', asset classes' and portfolio's performance earlier, it is now possible to Review Service Life Data collected to ensure these data meet both the protocol requirements, as well as the city's service life protocols shown in Table 13.

The principles involved in collecting service life data are similar to those detailed for collecting inventory and performance data. There is one primary difference in that service life units of measurement are not normally a source of error as the service life is commonly expressed in years. Sources of service life data include:

- plans;
- drawings;
- year of construction of surrounding assets (e.g. for sanitary sewers, the age of the surrounding buildings);
- contract documentation;
- staff knowledge;
- historical records;
- research findings for similar assets, and
- inspection data.

Reviewing service life data involves bringing together existing asset data to assist in answering the question, "What is its (the asset's or portfolio's) service life?" In order to answer this question, three aspects of the service life need to be considered: (1) the age of the asset (e.g. construction date is known), (2) the average service life of the asset (or asset class) and how long was it designed to last; (3) the existing condition of the asset, (4) the deterioration curve of that asset or asset class, and (5) the predicted remaining service life.

- Categorize Service Life Data

The Categorize Service Life Data task provides the opportunity to classify, rank and rate the existing service life of assets in the asset class, and therefore the opportunity to review how the portfolio is performing as a whole and which assets are falling short of, or exceeding their service life.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, new pumps could have been identified with a short remaining service life in the Categorize Service Life Data task. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

A failed asset may be identified in the previous task. In this case, it is necessary to consider immediate maintenance, repair or renewal.

4.5 Itemize Assets > *LCC*

- Review LCC Data

The final task in the **Itemize Assets** process is to Review LCC Data. Sources of LCC data include known asset costs such as:

- historical construction, operation and maintenance, repair and rehabilitation costs of the asset;
- historical expenditures on similar assets within the municipality or within similar municipalities;
- construction and building cost indices (ENR, 1999);
- current replacement value of the asset; and
- salvage costs.

Additional sources of data can also include forecasted maintenance, repair and rehabilitation costs based on the above costs. These costs may be found on cost record cards, contract documents or in cost databases, such as Hanscomb's *Yardsticks for Costing* (Hanscomb, 2009), RSMeans (2009) or Whitestone Research (2009). Regardless of the source of life cycle cost data, these costs have to be changed to current values or to a base comparison year using the appropriate discount rate and the economic methods described earlier.

In any instance, it is imperative that a standard method for calculating the costs is adopted and used throughout all economic calculations. It can be a base year or constant year and the nature of the economic analysis (e.g. net present value or present worth method, annual cost or equivalent uniform annual cost method, etc.) must be clearly identified in the database or municipal records. This ensures that LCC data are consistent both in constant year dollars and in the costing method used to present the LCC in the asset inventory.

The inventory, performance, and service life requirements and data have been reviewed previously in their related facets. Having categorized the assets', asset classes' and portfolio's service life earlier, it is possible Review LCC Data collected to date to ensure these data meet both the protocol requirements, as well as the city's specified level of investment and its deferred maintenance limits.

Inspect Assets Process

Reviewing LCC data involves bringing together existing asset data to assist in answering the question, "What is its (the asset's or portfolio's) value?" In order to answer this question, there are four components to LCC that need to be identified: (1) the remaining service life of the asset; (2) the level of "future" maintenance investment for that asset; (3) the cost of renewal, and (4) the discount rate.

- Categorize LCC Data

The Categorize LCC Data task provides the opportunity to classify, rank and rate the life cycle costs of assets in the asset class, and therefore the opportunity to review how the portfolio is performing as a whole and which assets are costing more, or less, than others.

- Calculate Deferred Maintenance

Sufficient data are now available from the *MIM Framework* regarding the performance, service life, and LCC to determine the amount of deferred maintenance.

Deferred maintenance is defined in Appendix C as the "maintenance (and *not* capital renewal) that has not been performed or is scheduled for implementation in the future. The Deferred Maintenance is typically represented as the cost of implementing that maintenance." Deferred maintenance should not include planned interventions that are scheduled for capital renewal; that is, the cost of replacing an asset that is already beyond its service life, or even the cost of repairing an asset when it has gone beyond its service life.

Knowing the amount of deferred maintenance can serve as an "intermediate" proxy to determine the condition of an asset. The term "intermediate" is used because having the deferred maintenance, as a proxy is temporary until more quantitative methods are available, but one has to proceed up the *MIM Framework* in incremental steps, as described earlier. The deferred maintenance is also necessary in a subsequent task to Estimate Facility Condition Index in the **Rate Assets** process, which can also be used as a proxy for condition of the asset, asset classes or portfolio.

The deferred maintenance can be calculated using: the value of the work orders outstanding as well as the planned interventions (obtained from the CMMS or from the asset management system), or proxies for the *performance* of the asset. Examples are as follows:

(1) Work Order Method: In order to calculate the deferred maintenance using a CMMS or asset management system, there has to be data interoperability at an asset or component level amongst all applications. This is not a straightforward method and may involve collecting data from many sources in the municipality's organization. The Work Order Method also does not take into account maintenance and repairs that have NOT been identified (e.g. hidden defects).

(2) Optimal Performance Deferred Maintenance (DM) Method: Using performance as a proxy for the amount of outstanding maintenance is another technique to determine the deferred maintenance, as shown in Figure 7.

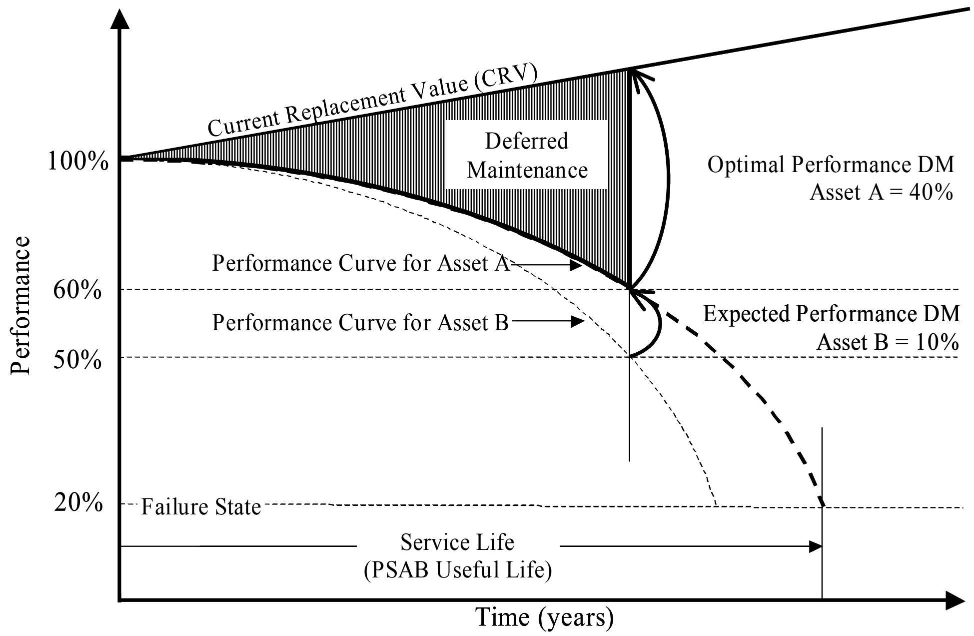


Figure 7: Proxy for Calculating Deferred Maintenance

Figure 7 shows geometric Performance Curves for Assets A and B. In this example, Assets A and B are in the same asset class but Asset A is following the expected performance for that asset class and Asset B is deteriorating more rapidly. The end of useful life of Asset A is when its performance curve reaches the Failure State at 20% of performance; Asset B has a shorter service life.

In Figure 7, the Optimal Performance DM for Asset A is equal to the distance below the current replacement value for the hypothetical 100% performance. In Figure 7, Asset A's deferred maintenance is 100% minus 60% (i.e. 40%) of the CRV. However, this calculation is based on the assumption that the asset *must* be operating at 100% performance at all times (e.g. "like new"): quite a challenge with today's infrastructure funding gap, and quite unrealistic (i.e. do we expect our 10 year old car to look, feel and perform like new?).

(3) Expected Performance DM Method: A more realistic approach is the Expected Performance DM. In this method one uses performance or age data to approximate the actual performance *vis-à-vis* the expected performance curve. For Asset B in Figure 7, the deferred maintenance is 60% minus 50% (10%) of the CRV. This calculation is based on the assumption that it would then cost 10% of the CRV to bring the asset back to its expected performance. By comparison, there would be no deferred maintenance for Asset A using the Expected Performance DM Method, as its condition is on the Expected Performance curve for that asset class. Both methods are easily implemented using spreadsheets or simple computer programs.

As noted earlier, the deferred maintenance is an "intermediate" proxy for the performance of the asset; to be replaced when other portions of the *MIM Framework* has been implemented in the municipality. However, for some asset classes it may be the only way to qualify their performance.

If dependable condition or performance data is not available, the deferred maintenance can also be tracked over time to determine if proactive asset management techniques are having the desired effect. In addition, specific milestones can be used to ensure that the "condition" of the asset does not fall below a predetermined level (i.e. DM < 10% of current replacement value).

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a new class of pumps could have extremely high maintenance and renewal costs in the Categorize LCC Data task. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An extremely expensive asset may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal.

4.6 Itemize Assets > *Criticality*

As noted earlier, criticality is the importance of the asset to the municipality. As little work has been done in this field there are a limited number of protocols to determine the criticality of an asset: qualitative ratings and quantitative rating. They are described in the **Select Protocols** >*Criticality* process.

- Review Criticality Data

The final task in the **Itemize Assets** process is to Review Criticality Data. Reviewing criticality data involves bringing together existing asset data to assist in answering the question, "What will you fix first?" Typically, failure of an asset is predicated on several factors. Hence, the sources of criticality data include information and data relating to:

- performance;
- service life;
- social impact, and
- life cycle costs of existing asset and the proposed intervention alternatives

The inventory, performance, service life, and LCC requirements and data have been reviewed previously in their related facets. Having categorized the assets', asset classes' and portfolio life cycle costs earlier, it is possible Review Criticality Data collected to date to ensure these data meet both the protocol requirements, as well as the city's specified criticality limits.

Depending on the protocol selected, it may be necessary to provide a *criticality* rating for the components or the assets inspected using the *criticality* protocols selected earlier. Finally, once collected, the data are verified for accuracy and consistency.

- Categorize Criticality Data

The Categorize Criticality Data task provides the opportunity to classify, rank and rate the criticality of assets in the asset class (and the portfolio), and therefore the opportunity to review how the portfolio is performing as a whole and which critical assets need attention.

- Identify Criticalities

It is mandatory at this time to inform others if specific assets have been designated as critical. However, it may also indicate that the levels established may be too high, too low or inappropriate for a specific asset class. Further investigation of the situation may be warranted.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been identified that has an extremely high consequence of failure (owing to a change in usage of an adjacent facility) and also a very high probability of failure (owing to a change in condition). These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with high criticality may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal.

4.7 Itemize Assets > *Alternatives*

Figure 6 in the previous section proposes a generic model for decision-making. Stage (b) of this model identifies the need to compare intervention *alternatives* for each asset in each asset class. If it has been decided that a specific asset must be repaired or renewed, then a list of possible M&R interventions should be identified for each asset. This should also include the "Do Nothing" alternative, if applicable.

- Identify Alternatives

Table 23 presents such a comparison between conventional open-cut and trenchless technologies for a nominal length of pipe. In this example, full renewals of the pipe segment are compared to repairs where only the failed sections are replaced. This comparison includes the following five objectives for optimization: Project Cost, Post-Intervention Performance, Service Life, Average Life Cycle (LC) Performance, LCC Present Value (PV), and Average LC Criticality of all alternatives. The life cycle (LC) parameters for the cost and critically should be clearly established and also should be equitable between all the Interventions (that is, it should not favour one Intervention over another). A simple method is to use one planning horizon (i.e. 30 years), one discount rate, and an approximation of the CRV at the end of the planning horizon

(Vanier and Abdel-Acker, 2007). The example shown in Table 23 illustrates typical comparative values for this type of decision.

Table 23: Identify Alternative Interventions

Intervention	Project Cost ($/metre)	Post-Intervention Performance (WRc)	Service Life (years)	Average LC Performance	LC Cost PV ($/metre)	Average LC Criticality
1. **Do Nothing**	0	4	5	3.5	600	4.0
Social Cost	0					
2. **Repair** Open Cut	200	1	100	3.0	800	3.5
Social Cost	400					
3. **Repair** Trenchless	200	1	60	3.0	600	3.5
Social Cost	200					
4. **Renew** Open Cut	1000	1	100	2.5	2500	3.0
Social Cost	1000					
5. **Renew** Trenchless	1000	1	60	2.5	1200	3.0
Social Cost	500					

One can readily see the need for solid quantifiable data from all of the facets of the *MIM Framework* when at this stage of decision-making, as well as the need for a systematic method to evaluate these alternative interventions (See Evaluate Alternatives).

The Identify Alternatives task lists the possible interventions; these assets must be inspected to obtain current data, are compared in the Evaluate Alternatives task in the **Inspect Assets** process in Section 5.7 and the interventions are rated in the **Rate Assets >** *Alternative* in Section 6.7.

- Update Metadata

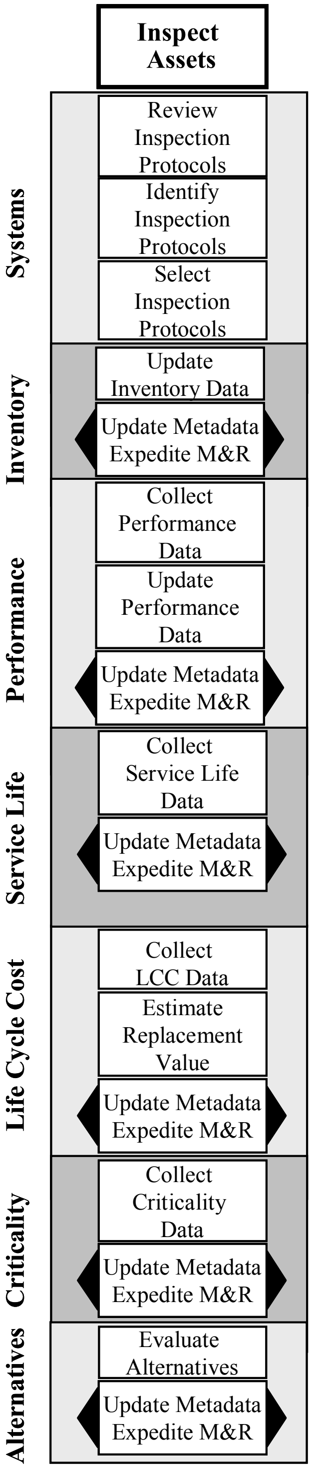
At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a comparison of the intervention alternatives could indicate that the "Do Nothing" option is not cost-effective. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with poor performance, short service life, low life cycle cost and high criticality may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.



5. Inspect Assets

The third major process in the *MIM Framework* is to inspect the infrastructure assets. This process is critical to answering the last three questions of the six "whats" of asset management": What is the condition, what is the remaining service life, and what do you fix first?

Appendix C defines "to inspect" as "to examine carefully and critically, especially for flaws." This is different from the **Itemize Assets** process where items are enumerated. The **Inspect Assets** process consists of roughly a dozen tasks all related to collecting data about current condition and/or performance of all the assets in the portfolio. During this series of tasks, other data are also collected that are unrelated to the inspection operations, mostly new data about other assets. These data are entered in the appropriate location.

In smaller municipalities the **Inspect Asset** process can occur in parallel with the previous **Itemize Asset** process; however in larger municipalities they are naturally two separate processes.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

5.1 Inspect Assets > *Systems*

Three tasks are included in *systems*. Typically, these three tasks should be completed in the sequence shown in the side figure.

- Review Inspection Protocols

It is necessary to catalogue all the existing protocols for inspecting infrastructure assets at the very start of implementing the *MIM Framework.*

The Review Inspection Protocols task records internal practices or methods already used by the municipality:

- Why is inspection needed? (A structural integrity check, to monitor quality of service, etc.)
- What is the applicability of inspection protocols?
- How does inspection relate to inventory and performance data?
- How can data be used?
- What are the costs of inspection?
- What inspection tools are available? (Visual, in-situ testing, non-destructive testing)

A table, such as Table 24 can be used to record the existing inspection protocols.

Table 24: Inspection Protocols

Asset Class	Inspection	Limits
Pumps	Pressure	<10,000 hours
Pipes Segments	WRc 3rd Edition	>5
Joints	None	-
Valves	Operations Test	Works/Failed

- Identify Inspection Protocols

As the implementation of the *MIM Framework* expands, it is periodically necessary to add new asset classes to the inventory; as a result, these asset classes need new inspection protocols that can be different from other protocols currently used in the municipality. These protocols should also be added to Table 24.

- Select Inspection Protocols

Once all of existing asset class inspection protocols have been identified and the new asset classes and their protocols have been identified and selected, it is possible to select the necessary inspection protocols. The requisite information should be included in Table 24, and these data should also be added to an appropriate column in Table 1.

5.2 Inspect Assets > *Inventory*

- Update Inventory Data

This task is added at this point in the *MIM Framework* in the **Itemize Assets** process as there may exist a time lag between when the assets were last itemized and when the assets are inspected. The first step in updating the inventory data is to identify what data are already available (hard copy or electronic) and which assets have been added to the portfolio since the last review. Also, this could include some asset classes that were not included in previous inspections

Update Inventory Data also includes correcting errors such as construction dates. Common data errors include gaps in the data (e.g. year of construction is only entered for some of the asset components), inconsistent descriptions or categorization of assets, and the duplication and variance of data entries. Also, if repaired or renewed assets appear in the portfolio, their data might conflict with existing data. If the data are fairly complete and the protocols selected do not require an inordinate amount of new data, then the missing and new data can be collected using in-house resources.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been inspected that has an extremely high consequence of failure (owing to a change in usage of an adjacent facility) and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset may be newly identified in this inventory task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

5.3 Inspect Assets > *Performance*

- Collect Performance Data

Having identified the required asset classes, asset attributes, data qualities, and itemization protocols (e.g. the demand), it is now possible to start the task to Collect Performance Data (e.g. the supply) about the performance.

Typically, this is a “field” activity that is carried out by trained personnel who have full access to the assets. Scheduling the inspections is always problematic: should it be asset-based (check everything in the same asset class) or location-based (check everything in the same area). At some point in the future, in order to support data collection, municipalities will implement remote sensing equipment such as Supervisory Control and Automatic Data Acquisition (SCADA) systems, Global Positioning Systems (GPS), Road Weather Information Systems (RWIS), or Automated Vehicle Location (AVL) to help centralize the data collection (Vanier, 2004).

- Update Performance Data

This Update Performance Data task updates the data for the qualitative or quantitative rating of how an asset performs its intended functions. It is also the task where anomalies in the performance data are analysed. A distinction is made in the *MIM Framework* between the tasks to Collect Performance Data and to Update Performance Data in an effort to illustrate the importance of comprehensive data analysis. That is, the performance data of all the assets in the asset class must be analysed together to identify challenges, trends and successes.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, underperforming pumps could have been identified in the **Inspect Assets >** *Performance* Update Performance Data task. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

A failed asset may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal.

5.4 Inspect Assets > *Service Life*

- Collect Service Life Data

Having identified the required asset classes, asset attributes, data qualities, and itemization protocols (e.g. the demand) and having collected performance data, it is now possible to start the task to Collect Service Life Data (e.g. the supply) about the service life of the individual assets.

Typically, this is a "desktop" activity that is carried out in an office that has both Intranet and Internet access to the full suite of the municipality's software applications (or record cards). Collecting or gathering service life data does not only deal with construction data but also the inspection and cost data for minor and major repairs that exist in the CMMS or an asset management system.

The Collect Service Life Data task involves bringing together existing asset data to answer the question, "What is its (the asset's or portfolio's) service life?" There are three components to service life that need to be collected: (1) age of the asset; (2) average service life of the asset, and (3) prediction of the remaining service life (RSL).

Table 25 augments Table 13 by adding actual service life data for the specific asset. The ages of the assets are obtained from property records, staff knowledge, drawings, contract documents, and sometimes "on-site" investigation, as described in the **Select Protocols** process earlier. The average service life is data available to the municipality such as presented in Table 10. The remaining service life is calculated using the *service life* facet protocols selected for each asset class.

Table 25: Remaining Service Life Calculations

Asset Subclass	Asset Instance	Protocol	Condition	Asset Age	Expected SL	Remaining SL
Manhole	MH_1234	Simple Age Calculation	-	50	100	50
Building Envelope	M20 New Facade	Factor Method	-	25	37	12
Road Surface	1200 Montreal	Deterministic	75(100>0)*	5	20	15
Pipe Segment	MH1234-1235	Probabilistic	3 (1>5)**	50	100	50
Pump	123456	Custom (MTTF)	34,567 hrs	10	10	0

* A score of 75% where the range is from 100% for excellent to 0% for failed.
** A score of 3 where the range is from 1 for excellent to 5 for failed (WRc, 1994).

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been inspected that has an extremely short service life (owing to a change in usage or loadings) and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with a short service life may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

5.5 Inspect Assets > *LCC*

- Collect LCC Data

The Collect LCC Data deals with collecting or gathering LCC data that are available in the municipality, from contractors, or from data suppliers. As discussed earlier, this must include data from all phases of the life cycle, including the construction phase and all maintenance and renewal costs for each asset. Much of these data are not resident in one master database and these data must be extracted from a selection of data sources such as Hanscomb's *Yardsticks for Costing* (Hanscomb, 2009), RSMeans (2009) or Whitestone Research (2009).

In addition, the cost of inspection and other social costs must be factored into the total costs. Table 26 is extracted from a MIIP report related to *Social Cost Considerations for Municipal Infrastructure Management* (Rahman et al, 2005).

Table 26: Example Inspection Costs for Buried Sewers

Inspection Techniques	Unit costs
CCTV	$2 -$10/m
Combined sonar/CCTV	$7 - $10/m
Person entry	$2 - $20/m
Zoom camera	$44 per man hole

LCC data should also include the collection of data about the amount of deferred maintenance described in the Calculate Deferred Maintenance task. Two methods are explained in that task: using outstanding work orders and using performance data.

- Estimate Replacement Value

Although PSAB 3150 (2009) strongly recommends recording the historical value of assets to comply with new regulations for the financial reporting, these are not a reliable metrics for determining what value a specific asset provides to the community when there are changes in the usage of assets, enhancements or infrastructure rehabilitations, high inflationary periods, or technological advances. However, if historical values are used, then the conventional LCC calculations described in the Select LCC Protocols task should be used.

Anecdotal experience has shown that the current replacement value (CRV) of an asset is a more meaningful and realistic metric for calculating the value that an asset has in a municipal portfolio. In calculating the CRV, the selected replacement cost should also reflect technological advances that have taken place; for example, conventional trenching costs should not be used when trenchless technologies are the current practice in the municipality, or are more cost-effective.

A simple, reliable method to calculate the CRV is to store and use the unit costs for specific asset classes (per metre, per metre^2, etc.); these can be obtained from historical records, personal knowledge, or from available services (Hanscomb, 2009; RSMeans, 2009; Whitestone, 2009). If the unit costs for asset classes are known and the dimensional units are saved for the assets then the standardized procedure for calculating the current replacement value is relatively simple to implement.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a specific pipe segment could have abnormally high LCC costs in the Estimate Replacement Value task. The existing asset class data should be corrected in the appropriate records.

- Expedite M&R

An extremely expensive asset may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal.

5.6 Inspect Assets > *Criticality*

- Collect Criticality Data

Tables 16, 17 and 18 provide a simplified method to calculate the criticality of an asset class as well as for instances of assets. This is suitable for assets that are neither health nor safety-critical.

If it is possible to classify the asset classes into specific criticalities, this reduces the data entry requirements; however, criticality is almost always asset specific. That is, either the consequence of failure or the probability of failure can be asset-specific, or both. Table 27 provides a format for saving asset data related to criticality. A diverse selection of potential Consequences and Probabilities of Failure are selected in Table 27 as examples. In Table 27, the Consequence of Failure is the summation of possible emergency intervention costs and the Category I and II social costs (Rahman et al, 2005). The Probabilities of Failure, for simplification purposes in this example, uses the condition rating of the asset as the proxy for the probability of failure. This can be considered a reasonable proxy, when no others exist, as the probability of failure for many types of assets is directly related to their physical condition. The criticality is derived from

Table 18. In this example, the Inspection and Rehabilitation Priorities are directly proportional to the criticality, but a municipality can select any relationship. A number rating or a description can represent the Priority values. The Inspection and Rehabilitation Priority descriptors proposed in Table 27 are similar to the rating schemes by the National Research Council of Canada (NRCC) for large trunk sewers (Zhao et al, 2003).

Table 27: Inspection and Rehabilitation Priorities

Asset Instance	Consequence of Failure (Table 16)	Probability of Failure (Table 17)	Criticality (Table 18)	Inspection Priority	Rehabilitation Priority
1	1	1	1	1 – Not Required	1 – Not Required
2	1	2	2	2 - Low	2 - Low
3	1	3	2	2 - Low	2 - Low
4	1	4	3	3 - Medium	3 - Medium
5	1	5	3	3 - Medium	3 - Medium
6	5	1	3	3 - Medium	3 - Medium
7	5	2	4	4 - High	4 - High
8	5	3	4	4 - High	4 - High
9	5	4	5	5- Immediate	5- Immediate
10	5	5	5	5- Immediate	5- Immediate

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been inspected that has an extremely high consequence of failure (owing to a change in usage of an adjacent facility) and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with high criticality may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

5.7 Inspect Assets > *Alternatives*

- Evaluate Alternatives

Table 23 in the **Itemize Assets** process lists the five alternative interventions for the pipe segment repair/renewal. Table 28 augments these data with a comparison of these five alternatives. The intervention costs listed in Table 28 are the sum of the construction and social costs that were identified in Table 23. In Table 28, a user-defined weighting schema is applied to all five-decision criteria (for simplification, all criterion are assigned a weight of 20%). The five decision criteria are listed in rows (white background) with values first identified in Table 23. These values are then normalized[5] for each decision criterion. For example in Table 28, the Project Cost for Do Nothing is zero dollars; whereas the project cost for the Open Cut Renew alternative is $2000. The lowest cost is normalized to zero (0) on a scale of 0 to 1 and the highest value ($2000) is normalized to one (1). The other three Project Costs are given a proportional value on the Normalized (grey background) line of Table 28. In this example, a low value (near 0) on the Normalized line has considerable benefits, whereas a high value (near 1) has fewer benefits. These Normalized values are multiplied by the Weights of the decision criteria (equal in this example), and are summated on the last line of Table 28. In this example, the alternative having the most benefits is assigned the lowest weights; that is, zero cost has the highest cost benefit, long service life has the best life benefit, and the lowest LCC has the best LC cost benefit. The final weighted score in Table 28 does not indicate an obvious superior intervention as Open Cut and Trenchless Repairs and Trenchless Renew rated closely (0.28, 0.32, and 0.30, respectively). Altering the weights of the Decision Criteria could also affect the final results. Additional analysis is described in Table 30 and Figure 8.

Table 28: Comparing Alternative Interventions

	Intervention		**Do Nothing**	**Repair**		**Renew**	
#	Decision criteria	Weights	Open Cut	Open Cut	Trenchless	Open Cut	Trenchless
1	Project Cost ($/metre)	20%	0	600	400	2000	1500
	Normalized		0.00	0.30	0.20	1.00	0.75
2	Service Life (years)	20%	5	100	60	100	60
	Normalized		1.00	0.00	0.42	0.00	0.42
3	Average LC Performance	20%	3.5	3.0	3.0	2.5	2.5
	Normalized		1.00	0.50	0.50	0.00	0.00
4	LCC (NPV $/metre)	20%	600	800	600	2500	1200
	Normalized		0.00	0.11	0.00	1.00	0.32
5	Average LC Criticality	20%	4.0	3.5	3.5	3.0	3.0
	Normalized		1.00	0.50	0.50	0.00	0.00
	Weighted Score	100%	0.60	0.28	0.32	0.40	0.30

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

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[5] "Normalized" means that data are weighted according to their relative position between the lowest and the highest values. One method of normalization is to assign the lowest value a score of 0 and the highest a score of 1, with the other values being assigned a weighted score (e.g. linear relationship) between 0 and 1. Normalization turns absolute values into relative values.

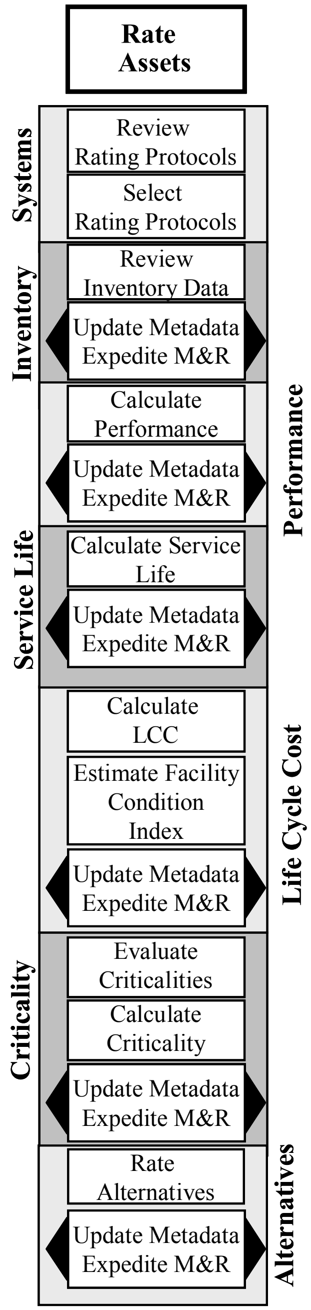
Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a comparison of the intervention alternatives could indicate that the "Do Nothing" option is not cost-effective. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with poor performance, short service life, low life cycle cost and high criticality may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

Rate Assets Process



6. Rate Assets

This next major process in the *MIM Framework* rates each of the assets from the individual asset classes. This process is critical to answering the asset management question “what is the condition?”

Appendix C defines “to rate” as “to evaluate the functionality of an asset.” The optimal asset intervention must be assigned a rating according the facets selected by the municipality (*performance*, *service life*, *LCC*, *criticality*, *alternatives*, etc.). It also implies that once all the optimal asset interventions are rated, then their relative ranking can be determined. To rank is to “place in a logical order’, and this can be done only after the interventions are rated.

The **Rate Assets** process consists of roughly a dozen tasks all related to analysing data about current condition and/or *performance*, the *service life*, the *LCC* and the *criticality* of all the assets in the portfolio. The **Inspect Assets** process described earlier provides the data that are analysed in the **Rate Assets** process.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

6.1 Rate Assets > *Systems*

Two tasks are included in *systems*. Typically, these tasks should be completed in the sequence shown in the side figure.

- Review Rating Protocols

There are many ways to rate and to rank an asset’s *performance*, *service life*, *LCC*, *criticality* or intervention *alternatives*. Since protocols for inventory, performance, service life, life cycle cost, and criticality have already been selected and the data requirements are known, then the rating system uses these data. The specific timing of this task provides the opportunity to review not only the protocols for rating the assets, but how they are integrated with the other aforementioned protocols.

Typically, in any complex environment there is the requirement for a multi-objective rating as any asset must perform a number of functions and meet a number of objectives. The *MIM Framework* has identified five facets that can be used as decision criteria (i.e. *performance*, *service life*, *LCC*, *criticality* and *alternatives*). The municipality can also have a number of other decision criteria in their decision-making.

This Review Rating Protocols task involves: (1) collecting information using the systems in place in the municipality that deal with asset management; (2) investigating other systems that could provide similar information; (3) determining if the existing rating systems optimally provide the information required for decision-making, and (4) establishing if competing systems are better or worse than those already in place.

- Select Rating Protocols

The individual facets in the *MIM Framework* (*performance*, *service life*, etc.) also have their own rating systems. These systems must be reviewed on a regular basis to ensure that the most recent and the most appropriate protocols, chosen in the **Select Protocols** process, are adopted for the facets in question.

This section of the report does not provide an overview of individual rating systems. Techniques such as multi-objective optimization, weighting factors, and the analytic hierarchy process (AHP) are described in related MIIP publications (Vanier and Rahman, 2004; Rahman and Vanier, 2004; Vanier et al, 2006a).

6.2 **Rate Assets** > *Inventory*

- Review Inventory Data

This task is added here to supplement tasks in the **Itemize Assets** process, as there may exist a time lag between when the assets were last itemized and when the assets are inspected. The first step in updating the inventory data is to identify what data are already available (hard copy or electronic) and which assets have been added to the portfolio since the last review. Also, this could include some asset classes that were not included in previous inspections

This task ensures that the required inventory data to support the rating of the assets are available. Collecting inventory data is expensive and time-consuming, the inventory data required to support a specific *performance*, *service life*, *LCC*, *or criticality* protocols may not exist. For example, to rate the condition of a sewer pipe using WRc (1994) requires mandatory background inventory data such as pipe length, pipe material, and pipe diameter. Additional inventory information that is beneficial, but not mandatory, includes the manhole ID, pipe depth, pipe thickness and construction date. It is imperative that the proper inventory data are available before the rating takes place.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been inventoried that has an extremely high consequence of failure (owing to a change in usage of an adjacent facility) and is in poor condition, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset may be newly identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

6.3 Rate Assets > *Performance*

- Calculate Performance

The term "performance" can have many contributing factors (e.g. condition, functionality, demand/capacity). This task attempts to calculate or "to determine by computation", as defined in Appendix C, the overall performance of the asset. Table 8 in a previous section provides an example of how a weighting factor method can be used to integrate a number of performance measures in the performance calculation. However, this is only an observation at one point in time (i.e. at last inspection); it is more comprehensive to analyse the life cycle performance of the asset in question. That is, compare the outcomes intervention alternatives over a long period of time. Table 29 provides a life cycle comparison using the following multi-criteria rating system: structural condition (WRc rating) = 30%, RSL = 30% and hydraulic performance = 40%.

In Table 29, a spreadsheet is used to calculate the average performance rating over the next 10 years of an example wastewater asset. The weights are assigned as described earlier (30%, 30%, and 40%), the individual criteria are normalized as described in the Evaluate Alternatives task. In this case, the Structural Condition is normalized from WRc rating 1 to 5, the RSL is normalized from 1 to 100 years, and the Hydraulic Performance is normalized from 0 to 100%. The Performance Rating is calculated annually for the 10 remaining years of service life of the asset by cross-multiplying the weights for each criterion by the normalized individual criteria. Assumptions are made for illustration purposes in Table 29 that the Structural Condition will transition from one WRc grade to the next every five years and the Hydraulic Performance will decrease by 10% over a period of five years.

Although the Performance Rating for the Current Year is 0.48 out of a possible 1.00 (i.e. Structural Condition = 1, RSL = 100, and Hydraulic Performance = 100%), the Average Performance Rating over the next 10-year period is 0.41.

Table 29: Multi-Criteria Performance Rating System for Sewers

Year	**Structural Condition**		**Remaining Service Life (RSL)**		**Hydraulic Performance**		**Performance Rating**
Weight	*30%*		*30%*		*40%*		*100%*
Normalization	*WRc (1 to 5)*		*1 to 100 years*		*0 to 100%*		*0 to 1 score*
Normalized	WRc	Norm.	Years	Norm.	Perf. (%)	Norm.	Result
Current Year	3	0.50	10	0.10	75	0.75	0.48
2008	3	0.50	9	0.09	75	0.75	0.48
2009	3	0.50	8	0.08	75	0.75	0.47
2010	3	0.50	7	0.07	75	0.75	0.47
2011	3	0.50	6	0.06	75	0.75	0.47
2012	4	0.25	5	0.05	65	0.65	0.35
2013	4	0.25	4	0.04	65	0.65	0.35
2014	4	0.25	3	0.03	65	0.65	0.34
2015	4	0.25	2	0.02	65	0.65	0.34
2016	4	0.25	1	0.01	65	0.65	0.34
Average	*3.50*	*0.38*	*5.50*	*0.06*	*70.00*	*0.70*	*0.41*

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, analysis of the data about the performance of sanitary sewer pipes could indicate that the overall performance of a specific type of installation is extremely poor, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with low performance may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

6.4 Rate Assets > *Service Life*

- Calculate Service Life

This task collects and updates data about the remaining service life of assets and then rates and ranks the results. In some cases, the data do not exist, in other cases the service life data are updated or recalculated owing to changes in performance. The methods to calculate the service life are described in the **Select Protocols** process.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been rated that has an extremely short remaining service life and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with short service life may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

6.5 **Rate Assets >** *LCC*

- Calculate LCC

Life cycle cost data are defined in Appendix C as "total cost, in present value or annual value, required to maintain an asset in full performance for its service life." Typically, all expenses related to a specific asset should be costed against that asset. The work order management system, whether it is streamlined or sophisticated, should record all M&R costs (i.e. in-house, in-kind, contract) against the same asset. Efforts should be made in this task to ensure that these data are validated.

The LCC protocols described in the **Select Protocols** process should be used to calculate and harmonize all the cost data. That is, the requisite data should be harmonized and use the same LCC method (i.e. present value or annualized cost), planning horizons and discount rates, and in general should use the same costing data for the same assets or asset classes.

- Estimate Facility Condition Index

Having calculated the deferred maintenance in the **Itemize Assets** process, the facility condition index (FCI) is calculated by dividing the deferred maintenance (DM) by the CRV. Although both the DM and the FCI are crude metrics for determining the overall condition of a component, asset, system, or network, there are few other techniques that are currently available.

The Calculate Facility Condition Index task can take place at many different times in the *MIM Framework*. This current placement in the *MIM Framework* is a logical placeholder as the resulting FCI calculations can be used in the **Rate Assets** process if there are other metrics for rating and ranking the condition/performance of the asset portfolio.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been rated that has an extremely high LCC (owing to a series of repairs) and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with high maintenance costs may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

6.6 **Rate Assets** > *Criticality*

- Evaluate Criticalities

It is advised at this stage to inform others if specific assets have been designated as critical. However, it may also be possible that the predetermines levels established for criticality may be too high, too low or inappropriate for a specific asset class; therefore further investigation of the situation may be warranted base on new data about the asset, its asset class and similar assets and types of assets..

Tables 16 (Consequence Rating), 17 (Probability of Failure, 18 (Qualified Criticality Rating) and 27 propose a Qualitative Criticality Rating method to estimate the criticality of an asset. This proposed five-level rating system to determine the Inspection and Rehabilitation Priorities provides a rough metric for criticality (For a detailed discussion on the rational behind a five-level rating systems, please refer to the Normalize Asset Classes task in Section 8.1).

- Calculate Criticality

As noted earlier, the *criticality* is a function of the consequence of failure and the probability of failure. The first factor could but generally does not change over time, whereas the probability of failure is a function of other variables (i.e. asset condition, environmental conditions, usage of the asset, accidental damage, or loadings). The criticality of an asset changes over time, therefore a life cycle criticality as identified in Tables 23 and 28 can be more representative. The life cycle criticality can be calculated as the average of the annual criticalities for the duration of the planning horizon, as calculated in Table 29.

- Update Metadata

At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are “data about data” and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been rated that has an extremely high consequence of failure (owing to a change in usage of an adjacent facility) and is about to fail, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with a high criticality may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.

6.7 **Rate Assets** > *Alternatives*

- Rate Alternatives

Table 30 rates the five intervention alternatives for one asset against the five decision criteria (normalized) described earlier using data from Table 28 and then ranks the weighted scores.

Table 30: Ranking Alternative Interventions for an Example Sewer Asset

	Intervention		Do Nothing	Repair		Renew	
#	Decision criteria	Weights	Open Cut	Open Cut	Trenchless	Open Cut	Trenchless
1	Project Cost ($/metre)	20%	0.00	0.30	0.20	1.00	0.75
2	Service Life (years)	20%	1.00	0.00	0.42	0.00	0.42
3	Average LC Performance	20%	1.00	0.50	0.50	0.00	0.00
4	LCC (NPV $/metre)	20%	0.00	0.11	0.00	1.00	0.32
5	Average LC Criticality	20%	1.00	0.50	0.50	0.00	0.00
	Weighted Score	100%	0.60	0.28	0.32	0.40	0.30
	Alternative	#	(a)	(b)	(c)	(d)	(e)
	Priority	#	5	1	3	4	2

Although Alternative (b) is ranked as the highest priority (i.e. lowest value), it is weighted only slightly lower than Alternative (e) and Alternative (c). Figure 8 illustrates how sensitivity analysis can be used to determine how sensitive the results are when the weights for the decision criteria are altered. In the case study shown in Figure 8, 100 combinations of the five decision criteria are randomly selected; where the weights for the decision criteria are within a predetermined range. The ranking (1 to 5) of each intervention alternative is plotted on the vertical axis. This "randomizing" technique provides similar results to plotting the permutations and combinations possible, in considerably less time. The final rankings are on the vertical scale and a ranking average closer to 1.0 is deemed to be the best intervention alternative, as an intervention that consistently ranks as Number 5 is not a good choice.

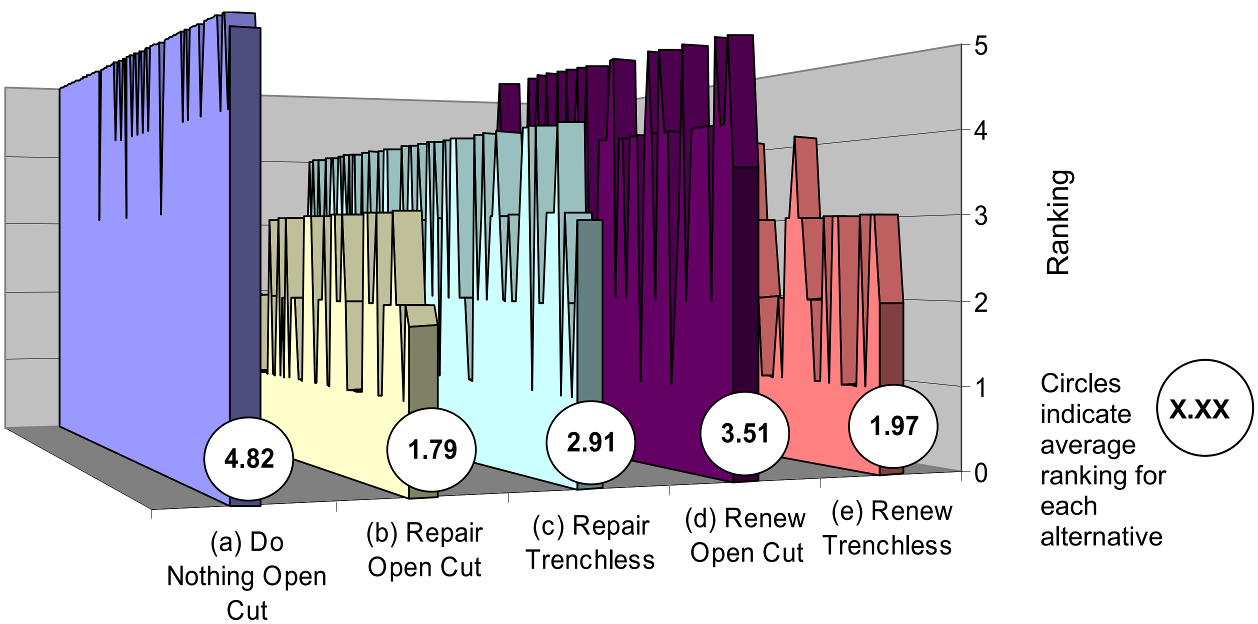


Figure 8: Sensitivity Analysis of Intervention Alternatives

Figure 8 shows the highest priority intervention alternative is Alternative (b) "Repair Open Cut", as it has the lowest average ranking of 1.79 (primarily rankings 1, 2 and some 3s) for the wide range of different weighting schemes selected. Alternative (e) has scores to (b) for both Table 30 and Figure 8. For a discussion on alternative rating systems and decision-making, please refer to Vanier et al (2006).

- Update Metadata

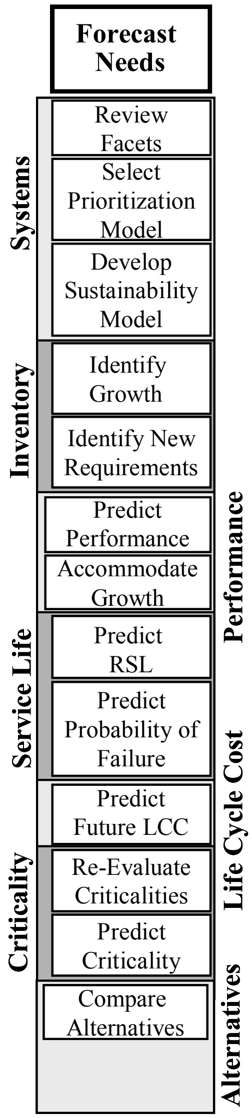
At the bottom of all facets for all the processes of the *MIM Framework* is a horizontal arrow representing the Update Metadata and Expedite M&R tasks. It points to the other processes to indicate that if additional data are found that data may necessitate changes in a protocol or in scheduling a repair (see next task).

Collecting data can result in a requirement to update the metadata. Metadata are "data about data" and includes information such as when the data were entered into the database, who entered the data, what is the source, etc. Metadata also includes information in the data dictionary that may need to be updated.

For example, a pipe segment could have been rated that has an extremely high ranking for M&R, even though the asset is relatively new. These new data should be entered into the appropriate records and these data could necessitate new protocols.

- Expedite M&R

An asset with a high ranking may be identified in the previous task; it is necessary to consider immediate maintenance, repair or renewal, or at least a scheduled inspection in the near future.



7. Forecast Needs

This process in the *MIM Framework* forecasts needs for all assets. This process is critical to answering the asset management question "what do you fix first?"

Appendix C defines "to forecast" as "to estimate or calculate in advance, especially to predict."

Rate Assets, described earlier, provides the data that are analysed in the **Forecast Needs** process. The **Forecast Needs** process consists of roughly a dozen tasks all related to estimating the condition and/or *performance*, *service life*, *LCC* and *criticality* of assets in the portfolio.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

7.1 Forecast Needs > *Systems*

Three tasks are included in *systems*. Typically, these tasks should be completed in the sequence shown in the side figure.

- Review Facets

This is an opportunity to examine those facets under consideration in the municipality's implementation of the *MIM Framework*. The *MIM Framework* considers the following facets: *performance*, *service life*, *life cycle cost*, *criticality*, and *alternatives*. As mentioned earlier, any number of additional facets can be included and some of the six identified can be omitted (or postponed) from the implementation. It is also an opportunity to review the selection of facets in light of all the protocols selected to date.

- Select Prioritization Model

A prioritization model for M&R can be as simple as "worst first" or "oldest first", or can be as sophisticated as the multi-criteria decision-making proposed in the *MIM Framework*. In any case, an objective and repeatable system is strongly recommended.

Logically, there can be different prioritization models for each asset class, as data may not exist to support the same type of prioritization model for the water network as for the road network.

Decision-making under uncertainty is a difficult process. The level of knowledge about municipal infrastructure decision-making is low and existing maintenance and renewal data are sparse,.

Regarding the dearth of existing M&R data, there is currently only anecdotal information about the benefits of which alternative M&R strategies are better or are the best. For example, "best first" maintenance (i.e. where the newest, best and most suitable assets are given high priority and are maintained in "as new" condition) appears counter-intuitive, computer models can simulate the advantages of a prioritization model (e.g. Vanier and Abdel-Akher, 2007) in the strategic planning horizon.

A recent case study on decision-making identified that objective comparison of a limited number of projects with a limited number of alternative interventions produced interesting results (Vanier et al, 2006a). Table 31 presents the results of that case study where seven different projects are compared using variations of the age, condition, risk of failure, life cycle cost, and project costs as the decision-making criteria. The ranking (1 to 7) of the combinations of the 26 prioritization models are listed horizontally in Table 31. The top five priorities in each scheme are shaded. There is no "clear cut" winner in this case study, projects D, E, F and G appear to be favoured by the majority of prioritization models. The authors conclude by saying "[e]ven with a limited number of projects (i.e. seven), a short selection of decision criteria (i.e. five), and a manageable scale for ratings (i.e. 1 to 5), it is a daunting task to select the 'correct projects' for funding, even for the first year of a strategic plan. Decision-making becomes increasingly more difficult when it involves selecting "correct projects" in future years of a 10 or 20-year strategic plan."

Table 31: Project Prioritization and Decision-making

Project	Normalized Age	Normal. Age Rank	Condition	Condition Rank	Risk	Risk Rank	LCC ($1000)	LCC Rank	Normalized Cost	Normal. Cost Rank	5 Criteria Rank	3 Criteria Rank	Case 1	Case 1 Rank	Case 2	Case 2 Rank	Case 3	Case 3 Rank	Case 4	Case 4 Rank	MOO unweight.	MOO unweight. Rank	MOO Weighted	MOO Weighted Rank	FSE	FSE Rank
A	5.0	1	2	6	1	7	16	7	1.0	7	7	7	2.3	7	1.1	7	1.3	7	1.2	7	0.3	5	0.7	7	0.03	7
B	4.2	2	2	6	5	1	8	6	3.7	6	6	6	3.7	2	3.7	6	3.5	5	3.5	6	0.4	6	0.3	6	0.68	6
C	3.1	3	5	1	3	3	6	5	4.2	5	3	2	3.8	1	4.1	5	4.0	1	4.2	1	0.4	7	0.2	5	0.76	5
D	2.6	4	3	4	4	2	5	3	4.5	3	2	2	3.5	3	4.2	1	3.8	2	4.1	5	0.3	3	0.2	4	0.80	1
E	1.8	6	4	2	3	3	5	3	4.5	3	3	1	3.3	5	4.1	3	3.8	2	4.1	3	0.3	3	0.2	3	0.78	3
F	2.6	4	4	2	2	5	4	2	4.7	2	1	2	3.3	4	4.1	4	3.5	4	4.1	2	0.3	2	0.1	2	0.77	4
G	1.0	7	3	4	2	5	3	1	5.0	1	5	5	2.8	6	4.2	2	3.3	6	4.1	4	0.2	1	0.1	1	0.79	2

MOO – Multi-objective optimization
FSE – Fuzzy Synthetic Evaluation
Cases 1, 2, 3, and 4 are for different Analytic Hierarchy Process (AHP) weights to age, condition, risk, LCC and project cost criteria

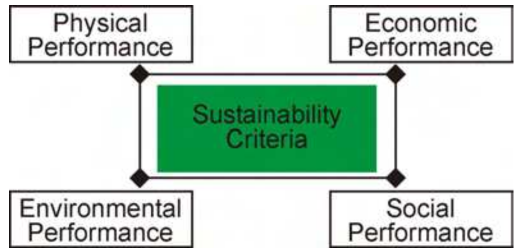
- <u>Develop Sustainability Model</u>

There is considerable interest from municipalities regarding sustainability at the current time. However, there is very little consensus about what sustainability means in the context of municipal infrastructure. The much-quoted Brundtland report (1987) defines sustainable development as the:

> *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

To follow and complement this succinct definition of sustainable development, the National Research Council of Canada has identified its own pillars of sustainability in the context of its initiative on the Sustainable Built Environment (NRCC, 2009). These pillars include physical performance, economic performance, environmental performance, and social performance. NRCC (2009) identifies some key components of the life cycle performance of the sustainable built environment (*extracted from NRCC, 2009*):

- *To achieve the objectives of sustainable design and management of the built environment, rigorous predictions of its performance are required at all key stages within [the built environment's] life cycle, including: initial design, extraction of materials, production of components, construction, use, inspection, deterioration, maintenance, rehabilitation, demolition, disposal, recycling, and renewal.*
- *The life cycle performance and management of the built environment must be optimized to maximize the return on investment and ensure that the needs of our society and future generations are met, taking into consideration the requirements of health, safety, functionality, durability, economy, environmental, and societal impacts."*



- *This prediction of life cycle performance will also optimize the reliability, functionality, service life, costs, and environmental impacts over the life cycle of materials, components, systems, networks or portfolios under consideration (i.e. from "cradle-to-grave").*
- *Such detailed information about the life cycle performance is very important in selecting the optimal materials, products, systems for the built environment and will provide effective decision support to designers, owners and regulators for a comprehensive evaluation of the performance of built environment with regard to the key sustainability criteria, including: physical performance, economic performance, environmental performance and social performance.*

Figure 9 identifies a number of criteria and sub criteria identified by Vanier (2006a) that should be considered when establishing a municipal sustainability plan. Figure 9 identifies three main criteria for sustainability (i.e. social, environmental and economic) and Vanier (2006a) proposes using the analytic hierarchy process (AHP) to analyse and aggregate the individual contributions of a large selection of sub criteria. In Vanier's research (2006a), each of the three sustainability criteria identified and their sub criteria is assigned weights that assist in rating the alternatives (i.e. sustainability project). In this proposed Goal Model illustrated in Figure 9, the "physical performance pillar" described earlier is not examined as it is well-handled in other research literature; however there is little research and data about the other three pillars. Each alternative can be scored according to how they satisfy each criteria or sub criteria. The model also permits individual voters (i.e. members of council, engineering staff) to assign their individual weights to the criteria. More information on the AHP process can be found in Saaty (1980, 2001).

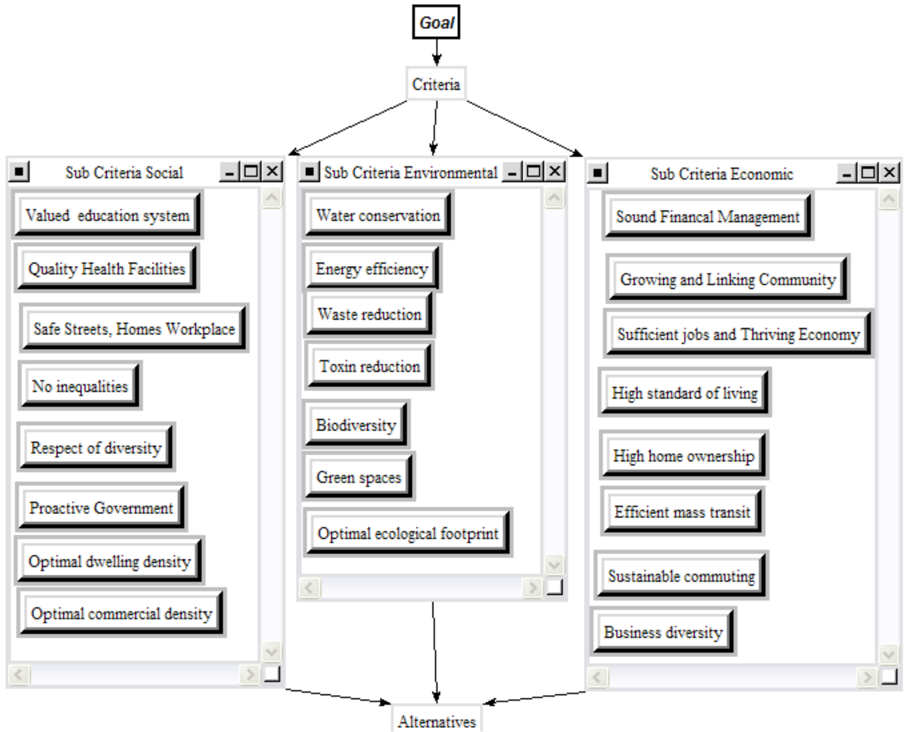


Figure 9: Criteria for Implementing a Municipal Sustainability Plan

A number of Canadian municipalities and provincial/territorial and federal governments now provide examples of municipal sustainability plans and the number of examples is growing steadily. Excellent plans and information exist from Infrastructure Canada (INFC, 2006), the Province of Alberta (Alberta, 2009), the Region of Niagara (2007), and the Resort Municipality of Whistler (Whistler, 2009). In addition, there is a good selection of international publications related to urban sustainability and strategic infrastructure planning (sue-MoT, 2004; COST, 2006; Goodman and Hastak, 2006; Munier, 2006).

7.2 **Forecast Needs >** *Inventory*

- <u>Identify Growth</u>

The amount of infrastructure in Canada has nearly doubled in the past 20 years, as shown in Figure 10, which is based on construction start data obtained from Statistics Canada (Vanier, 2000). This trend will continue if municipalities grow at rates of 4% or more *per annum*. Communities continue to expand outside the core of major metropolitan areas and population densities are also increasing in the inner core of cities; thereby placing more demands on the existing infrastructure. These factors must be taken into account when dealing with the strategic planning horizon (greater than 5 years).

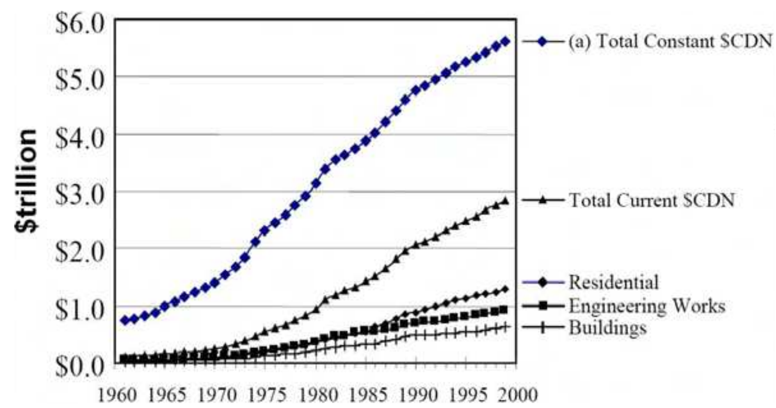


Figure 10: Infrastructure Growth in Canada (1960-2000)

Municipal infrastructure must be maintained: additional M&R funds are required in the strategic planning horizon to maintain this growing infrastructure portfolio. Typically in Canada, the funding comes from utility rates and property taxes. However, the Gas Tax Agreements between the federal and the provincial governments are providing additional funds to the cities and communities on projects related to *Capacity Building* and *Environmentally Sustainable Municipal Infrastructure* (INFC, 2009).

- Identify New Requirements

Legislative, political, financial, administrative, or technical changes may necessitate new requirements for new data or information about the infrastructure in the municipality. For example, the proposed *Assessment of Tangible Capital Assets* (PSAB 3150, 2009a) or Ontario's *Sustainable Water and Sewage Systems Act* (Ontario, 2002) influences the amount and type of inventory data required to **Forecast Needs**.

7.3 **Forecast Needs** > *Performance*

- Predict Performance

The previous tasks in the **Rate Assets** process use the performance protocols selected and the performance data collected to Calculate Performance. These data are needed to Predict Performance.

However, the performance of the asset is difficult to predict without knowledge about the remaining service life of the asset, or the average service life of the asset class, these are identified in previous processes.

Knowing the asset remaining service life, and/or its asset class' average service life, it can be as straightforward as using experiential knowledge or as sophisticated as the Markovian transition matrices described in Select Service Life Protocols task in Section 3.4. The following are some techniques that can be used to Predict Performance:

(1) Experiential Knowledge: Typically, the minimum data required from a local expert is "the asset is good for another 10 years"; meaning the performance of the asset will be above the failure state for 10 years."

(2) Qualitative Ratings: The proposed *Assessment of Tangible Capital Assets* (PSAB 3150, 2009a) requires detail about both the current and future condition of the assets in the municipal portfolio. The following are excerpts from PSAB:

.019 Evaluation of an asset's physical condition should be completed by qualified evaluators with knowledge of the asset, its performance capacity and the expectations for its continued performance. The assessment of the physical condition of a tangible capital asset should be completed by reference to physical characteristics and technical, engineering and other specifications of the asset. It should take into consideration:

(a) the asset's durability;

(b) the quality of its design and construction;

(c) its use;

(d) the adequacy of maintenance that has been performed; and

(e) other factors including accidents, catastrophes, disasters and obsolescence.

.071 Condition assessments should be based on generally accepted methods and standards where available and consistently applied. Methods of measurement should be an easy-to-understand reference that can be updated regularly to track the results of the government's asset management strategies. It should also allow users to predict the status of assets into the future based on the current asset management policies.

To meet the need for a qualitative rating scheme a linear and geometric deterioration model is proposed in Figure 11. In this example, the asset class moves from Condition Rating 1 to 7 in an average service life of 20 years. If the Condition Rating and asset age are known, then the future performance can be estimated. The calculations are relatively easy to program in a spreadsheet.

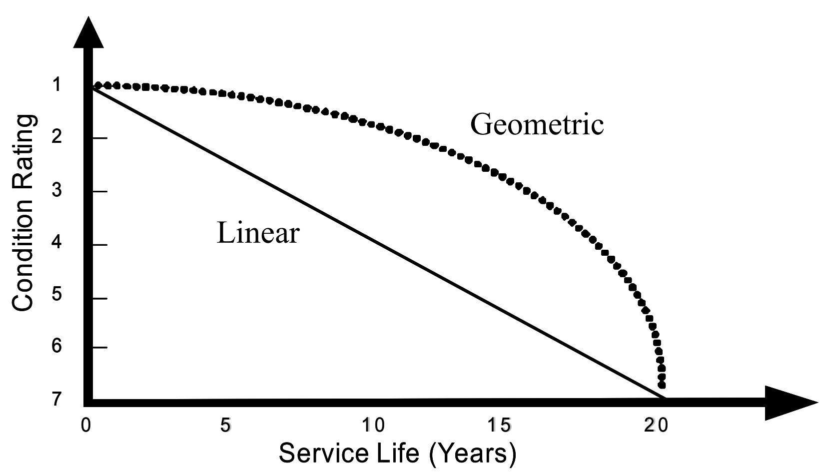


Figure 11: Examples of Asset Class Deterioration Curves

(3) Quantitative Ratings: Techniques such as Markovian transition matrices can estimate the performance of assets. These techniques are described in Select Service Life Protocols task in Section 3.4.

- Accommodate Growth

Although the current performance has been estimated/calculated, it is also necessary to re-examine the Identify Growth task in the *inventory* facet to determine if the predicted performance meets the expected growth. For example, expansion into the suburbs requires additional infrastructure and in-fill projects put more demand on existing central infrastructure. In addition, changes in demographics can reduce or increase the requirements for specific infrastructure (e.g. primary schools, community centres, social housing).

7.4 Forecast Needs > *Service Life*

- Predict Remaining Service Life

A number of techniques can be used to Predict Remaining Service Life:

(1) Experiential Knowledge: Simple calculations are possible when absolutely no data are available. For example, if the average service life of an asset class is 50 years and the asset was built 25 years ago, then the remaining service life is 25 years. Again, the minimum data required about a specific asset should be an educated judgement: "the asset is good for another 10 years', meaning the remaining service life is 10 years."

(2) Qualitative Ratings: The model used in Figure 11 can also be used to calculate the remaining service life. If the current Condition Rating or age is known, then the remaining service life can be estimated.

(3) Quantitative Ratings: Techniques such as Markovian transition matrices can estimate the remaining service life of assets. These techniques are described in Select Service Life Protocols task in Section 3.4.

- Predict Probability of Failure

Having estimated/calculated the performance and the remaining service life in the previous facets, it is possible at this time to Predict Probability of Failure. As noted earlier, the probability of failure is typically based on factors such as the condition, remaining service life or the current performance, but it can also be related to outside events such as the weather, temporary loadings, or even accidents. The probability of failure is required to calculate the criticality of the asset. A number of techniques can be used to Predict Probability of Failure:

(1) Experiential Knowledge: Again, the minimum data required from a local expert is "there is no risk of failure" or "the risk of failure is high." However, a simple rating scheme of 1 to 5 would qualify the data better and permit an integrated comparison of different alternatives, assets, or asset classes.

(2) Qualitative Ratings: The model in Figure 11 can also be used to calculate the probability of failure if it is only condition-based. If the current Condition Rating or age is known, then the probability of failure can be estimated from Figure 11 if the condition of the asset is used as a proxy for the probability of failure.

(3) Quantitative Ratings: Techniques such as Markovian transition matrices can estimate/calculate the probability of failure. These techniques are described in Select Service Life Protocols task in Section 3.4.

7.5 Forecast Needs > *LCC*

- Predict Future LCC

The previous three tasks attempted to predict the current asset *performance*, *service life* and *criticality*. Predicting the *LCC* is further complicated by the fact that it involves decisions about the asset that will be taken in the future, and sometimes by another management team. That is, will the asset be maintained at the same level of investment, will the asset require emergency repairs, will the level of usage for the asset increase/decrease, or when will the asset be renewed or surplused? Clearly there is a large number of future interventions and levels of investment; therefore there is a large number of possible life cycle costs.

In addition, there are other uncertainties in the costs of future level of investment or asset renewal. For example, uncertainties in the discount rate, cost of borrowing, technological advancements for inspection or renewal, and costs of maintenance, repair or renewal also exist.

A model proposed by Vanier and Abdel-Akher (2007) addresses some of these issues by analysing a wide, but limited, number of possible future interventions for a number of assets and by calculating the future maintenance and renewal cost for a specific planning horizon. The small case study in Figure 12 illustrates how calculations are performed for a selected 40 year planning horizon.

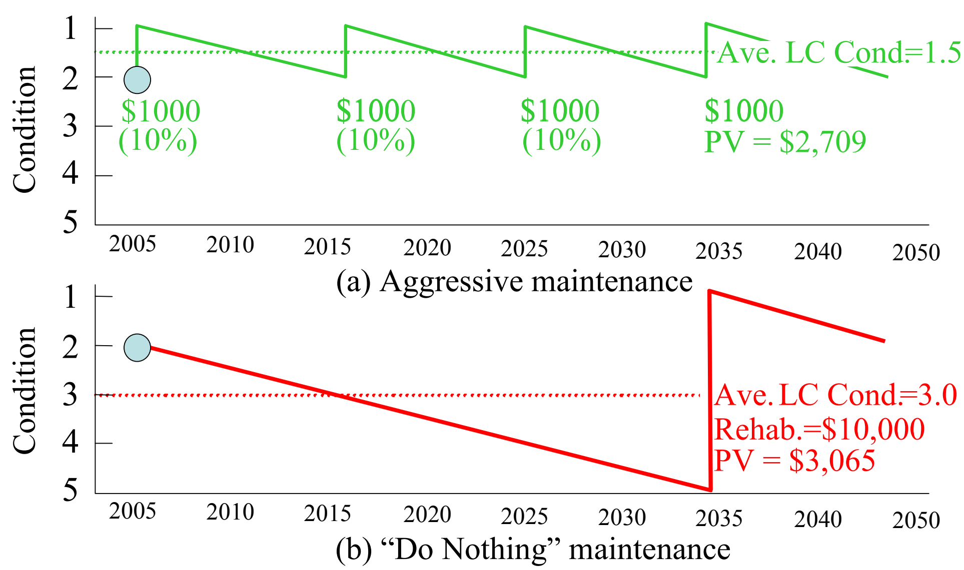


Figure 12: Illustrative Example of Intervention Comparison

Although SSAM-I typically compares 100 interventions for each asset, for simplicity Figure 12 compares two interventions starting and finishing at condition grade 2. Figure 12(a) illustrates the life cycle costs (PV = $2,709) for an aggressive maintenance strategy (10% of CRV spent every 10 years for repairs). Figure 12(b) illustrates an inferior (Rehabilitation cost = $10,000 or PV = $3,065) "Do Nothing" maintenance strategy (renew the asset after 30 years in service). Figure 12 also shows that the user selected a linear change in condition; it also demonstrates a simple technique to calculate the life cycle (LC) condition for each scenario: (a) average LC condition = 1.5, (b) average LC condition = 3.0.

In this simple case study, the aggressive maintenance approach in Figure 12(a) has a lower life cycle cost, a better average life cycle condition, and its average condition in the next 10 years will be 1.5 as opposed to 2.5 for the "Do Nothing" maintenance, as shown graphically in Figure 12(b).

7.6 Forecast Needs > *Criticality*

- Re-Evaluate Criticalities

A review of the criticality protocols should take place at this time. *Criticality* is asset-specific as it is typically dependent on the consequence of failure of the specific asset as well as the probability of failure of that asset. The Qualitative Criticality Rating outlined in Table 27 may have to be updated to reflect changes in the criticality protocols of the organization.

- Predict Criticality

Having estimated/calculated the *performance* and the remaining *service life* of the assets, it was possible to Predict Probability of Failure in an earlier task. This being done, it is possible to Predict Criticality. As noted earlier, an asset's *criticality* is typically based on the qualification or quantification of both its consequence and its probability of failure. This can be calculated using one of the following techniques:

(1) Experiential Knowledge: Again, the minimum data required from a local expert is "if we lose this asset it becomes a critical situation." However, a simple rating scheme of 1 to 5 would qualify the data better and permit an integrated comparison of different alternatives, assets, or asset classes. Although this is not advisable for assets such as bridge, road, water or wastewater networks, it is sufficient for many other asset inventories such as sidewalks, curbs, parks, etc.

(2) Qualitative Ratings: The proposed Qualitative Criticality Rating used in Table 27 can also be used to calculate the criticality of an asset when it is not health or safety-critical. If the *criticality* protocols are based entirely on the condition of the asset, then the asset class deterioration curve shown in Figure 11 can be used to calculate the criticality of an asset.

(3) Quantitative Ratings: Techniques such as Markovian transition matrices can estimate/calculate the probability of failure of an asset. These techniques are described in Select Service Life Protocols task in Section 3.4.

In addition to the asset's inspection and rehabilitation priority based on physical condition and related issues, other "possible" events such as traffic accidents events or natural catastrophes (e.g. likelihood of major storms, floods, earthquakes, etc.) must be taken into account. This area is outside of the scope of this report; however, Andrews and Moss (2002) have itemized a number of levels of risk for assets:

- risks that are unacceptable or intolerable (e.g. public health and safety – water contamination or bridge failure)
- risks that are low and thus acceptable (e.g. flooding during 100-year event)

- risks where trade-offs need to be considered (risk of failure versus benefit or cost to mitigate) (e.g. dykes and dams - allow risk of flooding one area to flood and accept costs to reduce or prevent risk of flooding in another area with higher costs)

7.7 Forecast Needs > *Alternatives*

- Compare Alternatives

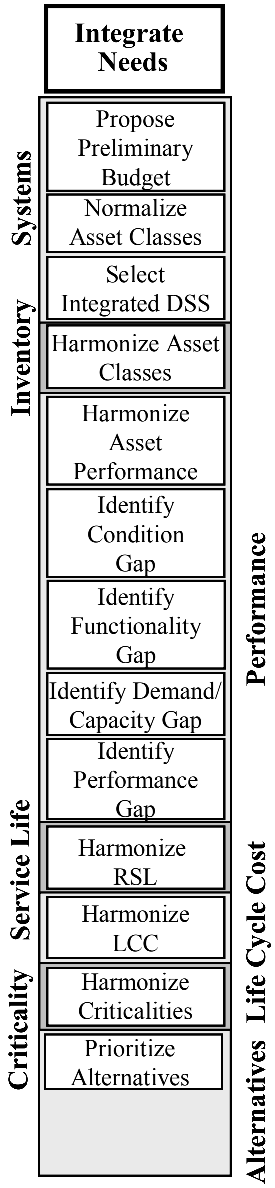
Figure 6 proposes a decision-making model for municipal infrastructure. This model takes into account the six facets of the *MIM Framework* and identifies two specific times in the model that can be used for decision analysis (identified by the "⊗" in Figure 6). Although this model does not stipulate a specific decision analysis technique, it suggests cost-benefit analysis as one alternative. However, any type of decision analysis such as multi-objective optimization, AHP, weighting schemes, etc. can be substituted.

Table 30 compared five weighted criteria for the five intervention alternatives, and Figure 8 displayed the sensitivity of the decision to changes in the weighting schemes. Table 32 goes further into the analysis in this case study using normalization techniques described in Evaluate Alternatives; it also uses cost-benefit analysis to compare the two alternatives illustrated in Figure 12. Table 32 is intended to demonstrate the concept and show the mathematics involved; it is not intended to be an exhaustive comparison of alternatives.

Table 32: Calculation of Cost-Benefit Ratio

Criteria	**Weight (%)**	**Fig. 12 (a)**	**Fig. 12 (b)**
LC Condition	50%	1.5	3.0
LCC	40%	$2709	$3065
Risk*	10%	3.0	3.0
Normalized LC Condition	50%	1.00	0.00
Normalized LCC	40%	1.00	0.00
Normalized Risk	10%	1.00	1.00
Weighted Condition	(Condition x weight)	1.00 x 0.50	0.00 x 0.50
Weighted LCC	(LCC x weight)	1.00 x 0.40	0.00 x 0.40
Weighted Risk	(Risk x weight)	1.00 x 0.10	1.00 x 0.10
Weighted Benefit	Score	0.5+0.4+0.1	0.0+0.0+0.1
Weighted Benefit	Score	1.0	0.1
Cost/Benefit Ratio	$ per weighted benefit	2709	30,655
Intervention	**Priority**	**1**	**2**

* For the sake of simplicity and for comparison in this example, the same risk was assigned to all three interventions and the risk criterion was purposely assigned a low weight of 10% so as not to affect the results.



8. Integrate Needs

This next major process in the *MIM Framework* integrates the various assets classes. This process is critical to answering the asset management question "what do you fix first?"

Appendix C defines "to integrate" as "to make part of a larger whole." Not all assets are considered equal, therefore methods must be adopted to ensure that proper weighting are assigned to each asset class and that asset classes can be handled objectively, systematically, equitably and in a repeatable fashion.

The **Integrate Needs** process consists of roughly a dozen tasks all related to integrating disparate data about current condition and/or *performance*, the *service life*, the *LCC*, and the *criticality* of all the assets in the portfolio. The **Forecast Needs** process described earlier provides the data that are analysed in the **Integrate Needs** process.

The term "disparate data" is used because the **Integrate Needs** process can be seen from three different views. "Everything is connected to everything", "the sum is greater than the parts" and "compare apples to apples" are called the "holistic", "summation" and "comparison" views, respectively:

(1) Holistic: The "holistic" view of **Integrate Needs** relates to the integration of all components in the infrastructure network. For example, the traffic carrying capacity of a bridge affects the traffic capacity of the adjoining roads, as well as the load conditions and wear and tear on individual lanes. This is extremely difficult to measure at this time given the current state of knowledge and data collection.

(2) Summation: The "summation" view of **Integrate Needs** relates the integration of the individual components in a specific Right of Way (ROW). That is, if the road is in poor or failed condition and both the water line and sewer line are in the last quarter of their service life, it is recommended to initiate a joint ROW project.

(3) Comparison: The "comparison" view of **Integrate Needs** relates to the need to harmonize and normalize metrics across a diverse selection of assets, some having no performance metrics. That is, how to rate, rank and prioritize and fund projects related to parks, wetlands and play structures when they are competing with the funding for safety- and health-critical assets such as bridges and water treatment plants.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

8.1 Integrate Needs > *Systems*

Infrastructure budgeting by Canadian municipalities is typically based on historical precedence. That is, this year's budget is equal to last year's budget plus an inflation percentage (or not). Typically, each discipline (in their own "silo") is appropriated their share of the budget based on some historical allocation. The *MIM Framework* follows this model by proposing that the five first processes are discipline-based; however, the **Integrate Needs** process must harmonize the discipline-based **Forecast Needs** to meet the over-arching needs of the municipality. That is, the overall needs of the municipality are more important than the individual needs of a specific discipline; sometimes, an integrated solution has more benefits than the sum of individual interventions (i.e. the holistic and summation views). In addition, in order to **Integrate Needs** there is a requirement for commensurate metrics or performance measures between the different disciplines to "compare apples to apples" (i.e. comparison view).

- <u>Propose Preliminary Budget</u>

Many in the industry believe that budgeting practices will not radically change in the near future and that historical precedence budgeting will continue in many municipalities.

In response to this *status quo*, the *MIM Framework* contains a task to <u>Propose Preliminary Budget</u> in order to establish a target for M&R planning. This target could be based on the historical precedence budget but must also be directly related to the current LOI (see Select Level of Investment task in Section 3.5) as well as the need for maintenance funding for newly acquired assets (see <u>Identify Growth</u> task in Section 7.2).

- <u>Normalize Asset Classes</u>

This task recognizes the wide variety of disparate data and information that are managed by municipalities. Table 33 attempts to juxtapose a number of asset classes with the related facet data. This is primarily a "comparison" view of the **Integrate Needs** process to compare asset classes such as roads or bridges to buried utilities on a "level playing field": as determined by the municipality.

Table 33: Subjective Descriptors using a Five-Level Rating Scale

Level	Performance	Service Life	Maintenance Cost	Criticality	Combined
1	Excellent	First Quarter of Life	Very Low	Low	Excellent
2	Good	Second Quarter of Life	Low	Fair	Good
3	Fair	Third Quarter of Life	Average	Medium	Fair
4	Poor	Fourth Quarter of Life	High	High	Poor
5	Failed	Beyond Service Life	Very High	Critical	Failed

Table 33 provides descriptors for the subjective rating system for the four of the decision criteria in the *MIM Framework* (Edmonton, 2004; Hamilton, 2009). The terms used in Table 33 are used for evaluating infrastructure assets in some municipalities; however, few systems currently exist in practice. When a municipality can only provide one metric for all facets combined, then simple descriptors are provided in the "Combined" column in Table 33.

Using a five-level rating scheme has been proposed throughout the *MIM Framework*, and this continues for the task to <u>Normalize Asset Classes</u>: for example, the City of Hamilton (2007) uses a five-level rating scheme for their performance metrics, as does Edmonton (2004). Since the *MIM Framework* addresses the strategic planning horizon (i.e. beyond five years), the level of detail for the rating scheme is commensurate with the accuracy of the available data. That is, an integer scale of 0 to 100 could be too fine and a "good – fair – poor" scale is probably too coarse for most asset classes. It is left to the municipality to choose if a three, five, seven or nine-level scale is required for the **Integrate Needs** process; please keep in mind that if a higher number of rating levels is selected then more accurate data are required. Also note that an odd number of levels are preferred to permit the users to select quickly an average or mid point.

Table 34 provides a subjective rating system for the *performance* facet based on work done at the Cities of Edmonton (2004) and Hamilton (2009). A municipality can decide how each of the condition, demand/capacity and functionality factors are weighed and how the overall performance rating is calculated for its own situation. An integer value for the performance rating should be the final result.Functionality is described by Edmonton (2004) as "the ability of the physical infrastructure to meet program, technology, regulatory and /or Code requirements." Edmonton (2004) describes Demand/Capacity as the "capacity of the physical infrastructure and its ability to meet the service needs." Hence, an asset meeting less than 40% of its Functionality demand would have a rating of 5 and an asset meeting less than 80% of its Demand/Capacity need would have a rating of 4. Similarly, an asset in poor condition would have a rating of 4. The combined rating using the three weighting scores would be (0.30 X 4) + (0.30 X 5) + (0.40 X 4) or 4.3.

Table 34: Detailed Performance Factor Descriptors for Five-Level Rating Scale

	Factor	**Condition**	**Functionality**	**Demand/Capacity**
Rating	*Weight*	*30%*	*30%*	*40%*
1		Excellent	>90% of demand	100% of need
2		Good	>70% of demand	>90% of need
3		Fair	>50% of demand	>80% of need
4		Poor	>40% of demand	>70% of need
5		Failed	<40% of demand	<70% of need

The task of mapping the various facet ratings to a common and normalized scheme is demonstrated in Table 35. A spreadsheet can be used to implement this mapping function. As can be seen with the "Bridge" asset class in Table 35, the municipality can select any range of performance ratings and map these to a "Normalized Performance" rating. As shown in Table 35, these can be different from the "Road" and the "Building" asset classes. The "Building" example in Table 35 illustrates how a seven-level rating scheme can be mapped to a five-level rating scheme and the "Water" example demonstrates how a three-level rating scheme can be mapped to a five-level rating scheme. In the "Building" example, the "A" and "B" ratings are mapped to "1" on the Normalized Performance Rating, and in the "Water" example, "Good" mains are automatically mapped to "2" and "Bad" mains are mapped to "4".

The examples shown in Table 35 are used for illustration only and to provide a general overall method to normalize multi-asset comparisons (Bridge, Road, Water, Wastewater, and Building) on a limited number of Facets (e.g. Current Performance, Remaining Service Life, Estimated Life Cycle Cost and Current Criticality).

Integrate Needs Process

- Select Integrated DSS

The type of integrated DSS selected should assist the municipality to make informed and meaningful decisions, to be objective in the decision-making process, and to ensure that the decisions are repeatable.

Table 35: Mapping and Normalizing the Asset Class Facets

Facet	Current Performance		Remaining Service Life		Estimated Life Cycle Cost		Current Criticality	
Weight	**25%**		**25%**		**25%**		**25%**	
Asset Class	**Rating**	**Norm.**	**Age**	**Norm.**	**Cost**	**Norm.**	**Rating**	**Norm.**
Bridge	100 - 80	1	>60	1	$200	1	100 > 80	1
	79 - 60	2	45-60	2	$500	2	80 > 60	2
	59 - 40	3	30-45	3	$1000	3	60 > 40	3
	39 - 20	4	15-30	4	$5000	4	40 > 20	4
	19 - 0	5	0-15	5	>$10,000	5	20 > 0	5
Road	100 - 80	1	>20	1	$200	1	100 > 80	1
	79 - 60	2	15-20	2	$500	2	80 > 70	2
	59 - 40	3	10-15	3	$1000	3	70 > 60	3
	39 - 20	4	5-10	4	$5000	4	60 > 50	4
	19 - 0	5	0-5	5	>$10,000	5	50 > 0	5
Water	Good	2	>120	1	$200	1	1	1
	Fair	3	100-125	2	$500	2	2	1
	Bad	4	75-100	3	$1000	3	3	1
			50-75	4	$5000	4	4	1
			0-50	5	>$10,000	5	5	1
Wastewater	1	1	>120	1	$200	1	1	1
	2	2	100-125	2	$500	2	2	2
	3	3	75-100	3	$1000	3	3	3
	4	4	50-75	4	$5000	4	4	4
	5	5	0-50	5	>$10,000	5	5	5
Building	A	1	>40	1	$200	1	A	1
	B	1	30-40	2	$500	2	B	1
	C	2	20-30	3	$1000	3	C	2
	D	3	10-20	4	$5000	4	D	3
	E	4	0-10	5	>$10,000	5	E	4
	F	4					F	4
	G	5					G	5

8.2 Integrate Needs > *Inventory*

- Harmonize Asset Classes

The metrics selected for itemizing assets must be consistent in each asset class; that is, do not mix measurement units (i.e. mms versus inches), do not mix dimensional units (i.e. running metre versus square metre), and do not mix asset class definitions (i.e. running metre versus lane metre). Whenever possible, there should only be one unit for the dimensions for each asset class and typically only the numeric value is stored and retrieved (i.e. “600” and not “600mm” or “600 mm”). This protocol should be established in the Select Asset Attributes task for the *inventory* facet described in Section 3.2.

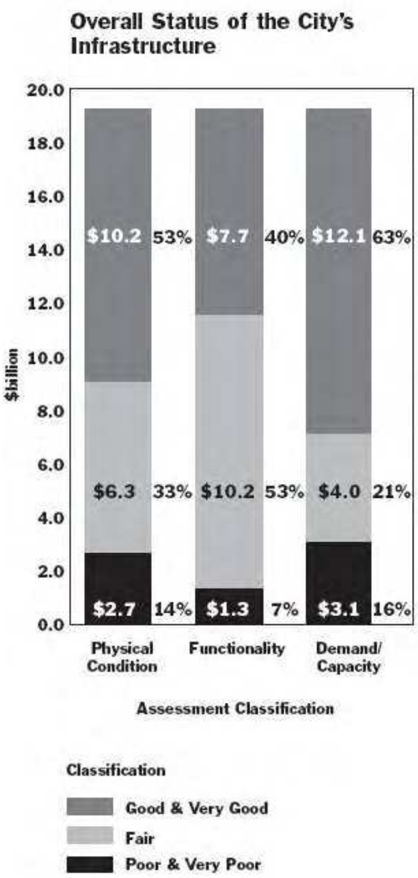


Figure 13: Edmonton’s Infrastructure Status

8.3 Integrate Needs > *Performance*

- Harmonize Asset Performance

The metrics selected to Harmonize Asset Performance must be consistent in each asset class; that is, do not mix different performance rating schemes (i.e. Riding Comfort Index – RCI), Pavement Condition Index – PCI), do not invert rating scales (i.e. 0 to 100 versus 100 to 0), and do not mix asset class definitions (i.e. running metre versus lane metre). Whenever possible, there should only be one performance rating scheme for each asset class and typically only the numeric value is stored and retrieved (i.e. “2” and not “SPG2” or “SPG 2”). This protocol should be established in the Select Performance Protocols task described in Section 3.3.

As noted earlier, the City of Edmonton has developed a three-factor categorization for performance: condition, functionality, and demand/capacity (Edmonton, 2004, 2007):

- Physical Condition: The condition of the physical infrastructure that allows it to meet the intended service life.
- Functionality: The ability of the physical infrastructure to meet program, technology, regulatory and /or Code requirements.
- Demand/Capacity: The capacity of the physical infrastructure and its ability to meet the service needs.

Edmonton also identifies a financial metric called “gap” to measure how the city is performing related to asset assessment and its three individual categories. “A gap exists between the funding required to address infrastructure needs and the funding available to do so.” (Edmonton, 2004, p. i). The overall status of the city’s infrastructure performance is shown in Figure 13. An example of their integrated performance rating system for the City of Edmonton (2007) is shown in Table 36.

Table 36: Edmonton's Performance Rating System

Mark	State	Description
		Physical Condition
Very Good	A	The sub-element/asset is physically sound and is performing its function as originally intended. Required maintenance costs are well within standards and norms. Typically, sub-element/asset is new or recently rehabilitated.
Good	B	The sub-element/asset is physically sound and is performing its function as originally intended. Required maintenance costs are within acceptable standards and norms but are increasing. Typically, sub-element/asset has been used for sometime but is within mid-stage of its expected life.
Fair	C	The sub-element/asset is showing signs of deterioration and is performing at a lower level than originally intended. Some components of the sub-element/asset are becoming physically deficient. Required maintenance costs exceed acceptable standards and norms but are increasing. Typically, sub-element/asset has been used for a long time and is within the later stage of its expected life.
Poor	D	The sub-element/asset is showing significant signs of deterioration and is performing to a much lower level than originally intended. A major portion of the sub-element/asset is physically deficient. Required maintenance costs significantly exceed acceptable standards and norms. Typically, sub-element/asset is approaching the end of its expected life.
Very Poor	F	The sub-element/asset is physically unsound and/or not performing as originally intended. Sub-element/asset has higher probability of failure or failure is imminent. Maintenance costs are unacceptable and rehabilitation is not cost effective. Replacement/major refurbishment is required.
		Functionality
Very Good	A	The sub-element/asset meets all program/service delivery needs in a fully efficient and effective manner.
Good	B	The sub-element/asset meets program/service delivery needs in an acceptable manner.
Fair	C	The sub-element/asset meets most program/service delivery needs and some inefficiencies and ineffectiveness present.
Poor	D	The sub-element/asset has a limited ability to meet program/service delivery needs.
Very Poor	F	The sub-element/asset is critically deficient and does not meet program/service delivery and is neither efficient nor effective.
		Demand/Capacity
Very Good	A	Demand corresponds well with design capacity and no operational problems experienced.
Good	B	Demand is within design capacity and occasional operational problems experienced.
Fair	C	Demand is approaching design capacity and/or operational problems occur frequently.
Poor	D	Demand exceeds design capacity and/or significant operational problems are evident.
Very Poor	F	Demand exceeds design capacity and/or operational problems are serious and ongoing.

- Identify Condition Gap

Appendix C defines condition gap as the "cost difference between the current and the required physical condition or state of an asset."

The condition gap can be considered to be analogous to the Deferred Maintenance. Three methods have been proposed previously to Calculate Deferred Maintenance: Word Order Method, Optimal Performance DM Method and the Expected Performance DM Method. The task to Calculate Deferred Maintenance is described in Section 4.5.

The Expected Performance Method can be used as a metric to Identify Condition Gap. Table 34 outlines a subjective rating system for condition, functionality and demand/capacity; these ratings can be used to produce the calculations for the condition gap. More precise methods are possible if more accurate data are available.

In the case study in Table 37, nine assets are listed in Col. (a), the CRV in Column (b) and their Current and Expected Condition in Columns (c) and (d), respectively. The Delta Condition in Column (e) is the asset Condition Gap; that is, how much the asset currently is performing above or below an Expected Condition. Column (f) calculates the percentage that each asset is above or below its Expected Performance. The cases selected illustrate the advantages and robustness of this proposed technique:

- Asset A is performing to expectation, - no contribution to the Delta Value in Column (g);
- Asset C should be in excellent condition but is in Condition 3, - at 50% its CRV;
- Asset E is "like new" and contributes positively (100% of its CRV) to overall value, and
- Asset H is performing poorly and must be replaced immediately - 100% below value.

The CRV Weighted Conditions and Delta Values are included as the last row in Table 37. In this example, the assets have a Condition Gap of $500, or 9% of the Total CRV ($5,275).

- Identify Functionality Gap

Functionality Gap is defined in Appendix C as the "difference in cost between the cost of providing the current functionality and the cost of implementing the required functionality for an asset. Functionality is defined as how well an item performs the activities expected of it."

The same technique used in Table 37 to calculate the Condition Gap can be used to calculate the Functionality Gap.

- Identify Demand/Capacity Gap

The demand/capacity gap is defined as "The cost difference between the current situation and the demand for or the required capacity of a similar asset."

The same technique used in Table 37 to calculate the Condition Gap can be used to calculate the Functionality Gap.

- Identify Performance Gap

Edmonton calculates their overall funding gap for the upcoming 10 years as illustrated in Figure 14. This is a combination of the funding gap for all the three factors: condition, demand/capacity and functionality. This funding gap must also take into account the anticipated growth in the municipality. Other municipalities can use the same technique.

Table 37: Subjective Technique to Calculate Condition Gap

(a) Asset	(b) CRV ($000)	(c) Current Condition	(d) Expected Condition	(e) Delta Condition	(f) Delta %*	(g) Delta Value ($000)
A	100	4	4	0	0%	0
B	2,000	3	2	-1	-25%	-500
C	350	3	1	-2	-50%	-175
D	100	1	1	0	0%	0
E	250	1	5	4	100%	250
F	1,250	5	5	0	0%	0
G	200	5	4	-1	-25%	-50
H	25	5	1	-4	-100%	-25
I	1,000	3	3	0	0%	0
Total	5,275	30	26	-4	-1	-500
CRV Weighted**	100%	3.45	3.07	-0.38	-9%	

* Delta Condition divided by four** Condition and Delta Value are based on percentage contribution of CRV

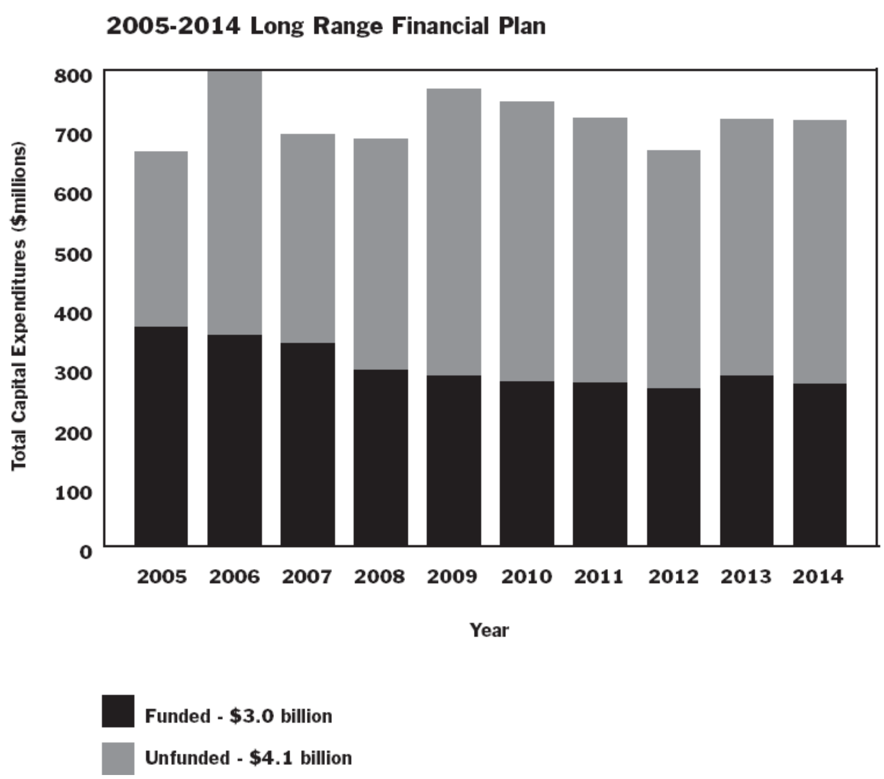


Figure 14: Edmonton's Funded and Unfunded Projects (i.e. Gap)

8.4 Integrate Needs > *Service Life*

- Harmonize Remaining Service Life

The metrics selected to Harmonize Asset Service Life must be consistent within each asset class; that is, do not mix different service life schemes (i.e. short, medium, long versus first quarter, second quarter, etc. versus remaining life), and do not mix asset class definitions (i.e. age versus remaining service life versus service life quartile). Whenever possible, there should only be one service life for each asset class and typically only the numeric value is stored and retrieved (i.e. “5” and not “5years” or “5 years” or “60 months”). This protocol should be established in the Select Service Life Protocols task described in Section 3.4. For a general illustration of a subjective *service life* scheme, please refer to Tables 33 and 35 in the Normalize Asset Classes task in Section 8.1.

8.5 Integrate Needs > *LCC*

- Harmonize LCC

The metrics selected to Harmonize LCC must be consistent within each asset class; that is, do not mix different LCC schemes (i.e. “per year” versus “present value”), and keep the same variables (i.e. discount rate, planning horizon, future interventions). Whenever possible, there should only be one LCC rating scheme for each asset class and typically only the numeric value is stored and retrieved (i.e. “20,000” and not “$20,000 per year” or “$20K/YR”). This protocol should be established in the Select LCC Protocols task described in Section 3.5. For a general illustration of a subjective *LCC* scheme, please refer to Tables 33 and 35 in the Normalize Asset Classes task in Section 8.1.

Some assets may require more funding than others (e.g. LOI > 2%) and others less depending upon where they are in their deterioration process. So, the LCC should be related to other similar assets in the same service life quartile.

8.6 Integrate Needs > *Criticality*

- Harmonize Criticalities

The metrics selected to Harmonize Criticalities must be consistent within each asset class; that is, do not mix different criticality schemes (i.e. risk versus consequence of failure versus probability of failure), and keep the same variables (i.e. discount rate, planning horizon, future interventions). Whenever possible, there should only be one criticality rating scheme for each asset class and typically only the numeric value is stored and retrieved (i.e. “20,000” and not “$20,000 per year” or “$20K/YR”). This protocol should be established in the Select Criticality Protocols task described in Section 3.6. For a general illustration of a subjective *criticality* scheme, please refer to Tables 16, 17 and 18 in Section 3.6 and to Table 35 in Section 8.1.

8.7 Integrate Needs > *Alternatives*

As noted earlier, Figure 6 proposes a decision-making model for municipal infrastructure. It takes into account the five decision criteria of the *MIM Framework* and identifies a discrete time in the model for decision-making. Although this model does not stipulate the decision analysis technique, it suggests cost-benefit analysis as one alternative. However, any type of decision analysis such as multi-objective optimization, AHP, weighting schemes, etc. can be substituted.

- Prioritize Alternatives

Table 30 compares five weighted criteria for the five intervention alternatives for the same asset class, and Figure 8 displays the sensitivity of the decision to changes in the weighting schemes. Table 32 uses cost-benefit analysis to prioritize the projects illustrated in Figure 12 (Vanier and Abdel-Akher, 2007). This technique described earlier can be used for different asset classes

Table 38 uses a case study to demonstrate an alternate method to prioritize based on changes (Delta) to four decision criteria: *performance*, *service life*, *LCC* and *criticality* in Col. (b) to (e). In addition, the project cost data in Columns (f) are also used as a decision criterion in the weighted score. Each decision criteria is weighted equally in Table 38 for display purposes but the municipality can assign their own weightings. In this example, the change (i.e. Delta) in the value of the decision criteria (i.e. Delta Performance, Delta Service Life, etc.) is calculated based on the existing decision criteria value and its value after the proposed intervention. In the case of Bridge1 in Col. (a), the proposed intervention takes the asset in Col. (b) from performance grade 5 to 1, the service life grade in Col. (c) from 5 to 1 etc. Col. (f) displays the actual project cost for each line item. Col. (g) normalizes the project costs, assigning 0 to the most expensive (least desirable project) and 4 to the least expensive (most desirable project).

Projects R1W1S1 and R2W2S2 in Table 38 are integrated projects formed by a complete ROW intervention that includes Road1, Water1, and Sewer1 and Road2, Water2, and Sewer2, respectively. The decision criteria ratings in Columns (b) through (e) for these two projects are calculated as the average of the individual ratings, respectively. A more sophisticated weighting can also be selected. In this case study, the advantage of an integrated project is a 20% reduction of the combined individual project costs, as shown in Col. (f).

The scores from each of the five decision criteria are cross-multiplied with their weight (equal weights in this example) to produce the weighted score in Col. (h). The project priorities appear in Col. (i). The Budget in the case study in Table 38 equals $12 million. Bridge1 has a project cost of $500,000 and has the highest priority, so the Budget Remaining after funding this project is $11,500,000, as shown in Col. (j). As Road1 and Water1 are funded in the R1W1S1 integrated project as Rank #5, the individual projects are not funded, as shown in Col. (k). Road2 is not funded as the $ 2,000,000 cost exceeds the Budget Remaining in Col. (j). However, Road3 is funded as it has a lower project cost, although it has a lower priority ranking. Integrated project R2W2S2 is too expensive to fund as it exceeds the Budget Remaining; however, Sewer3 is within the Budget Remaining. The selection algorithm of the projects in Table 38 is easily implemented in a spreadsheet or simple computer program; however, additional sensitivity analysis is also recommended as the weighted scores in this example are very close.

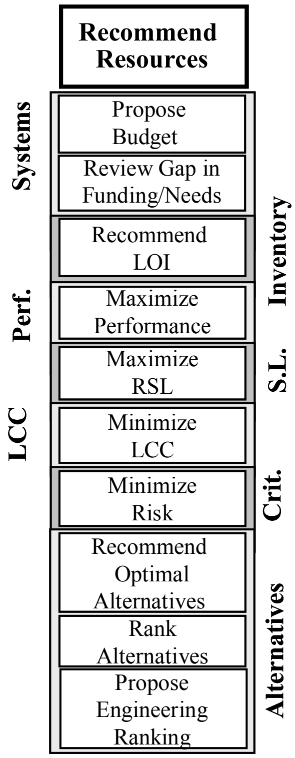
Table 38: Decision Criteria for Five-Level Rating Scale

(a) Project	(b)	(c)	(d) Delta	(e)	(f)	(g) Cost	(h)	(i)	(j) Budget	(k) =$12 M
	Perf*	Service Life	LCC	Critic**	Project	Normal#	Weight Score	Rank	($ 000)	
Weight	*20%*	*20%*	*20%*	*20%*	*($ 000)*	*20%*	*100%*		Remaining	Funded
Bridge1	4	4	4	4	500	3.81	3.96	1	11,500	√
Road1	4	4	4	4	900	3.56	3.91	2	11,500	
Bridge2	4	4	4	4	2,250	2.71	3.74	3	9,250	√
Water1	4	4	4	4	2,300	2.68	3.74	4	9,250	
R1W1S1	4.00	3.67	3.67	3.67	4,160##	1.51	3.30	5	5,090	√
Water2	4	3	3	4	3,500	1.92	3.18	6	1,590	√
Sewer1	4	3	3	3	2,000	2.87	3.17	7	1,590	
Road2	3	4	3	3	2,000	2.87	3.17	8	1,590	
Road3	2	2	3	3	2,00	4.00	2.80	9	1,390	√
R2W2S2	3.33	2.33	3.00	3.33	6,560##	0.00	2.40	10	1,390	
Sewer2	3	0	3	3	2,700	2.43	2.29	11	1,390	
Sewer3	4	2	0	2	1,200	3.37	2.27	12	190	√

* Performance ** Criticality # Normalized ## 20% reduction on integrated projects

This case study in Table 38 demonstrates that it is possible to rate, rank and select the highest priority projects using objective data. However, there is room for considerable interpretation.

Integrate Needs Process



9. Recommend Resources

This penultimate process in the *MIM Framework* recommends the resources to fund the proposed projects. This process is critical to answering the asset management question "what do you fix first?"

Appendix C defines "to recommend" as "to advise or counsel". The *MIM Framework* is premised on the fact that the technical staff has to Propose Engineering Ranking, as illustrated in the bottom right corner of Appendix A and in Stage (d) of Figure 6, respectively. It is the city manager, senior managers, or elected officials who make the decisions.

The **Recommend Resources** process consists of roughly a dozen tasks all related to analysing data about current condition and/or performance, the service life, the criticality and the life cycle costs of all the assets in the portfolio. The **Integrate Needs** process described earlier provides the data that are analysed in the **Recommend Resources** process.

The next subsections identify each of the tasks in the six facets described earlier and are preceded by a subsection on *systems.*

9.1 Recommend Resources > *Systems*

The exercise in Table 38 illustrates how objective project prioritization is a difficult task, and how sensitive the results are to slight changes. This phenomenon is evident from previous studies related to decision-making (Vanier et al, 2006a) and from the sensitivity analysis used to generate Figure 8.

- Propose Budget

Having ranked the projects and knowing the sensitivity of the rankings, as well as the benefits of the individual interventions, it is possible to propose a budget. In the case study in Table 38, it is a judgement call whether to fund the R2W2S2 project. The same holds true in Table 24 and the SSAM-I manual (Vanier and Abdel-Akher, 2007), as demonstrated in Figure 15.

Figure 15 is described in detail in the SSAM-I manual (Vanier and Abdel-Akher, 2007). In essence, Curve (a) in Figure 15(b) shows the plot of the Cumulative Score of the AHP weighted Risk – Condition – LCC for individual projects versus the cumulative project costs on the X-axis. The Penalty Function in Figure 15(a) is a simple algorithm to demonstrate a pragmatic and practical decision-support method; apply a penalty function to projects that have quantifiable benefits but that exceed the annual budget. Curve (b) shows the modified score after the Penalty Function is applied.

The first six projects are funded as they are below the annual budget of roughly $150K. Project 7 is also funded because the Cumulative Score is "slightly" higher than the first six funded project score even when the Penalty Function is applied to all projects exceeding the budget. However, the remaining proposed projects are not funded, as there is a decreasing Cumulative Score after Project 7.

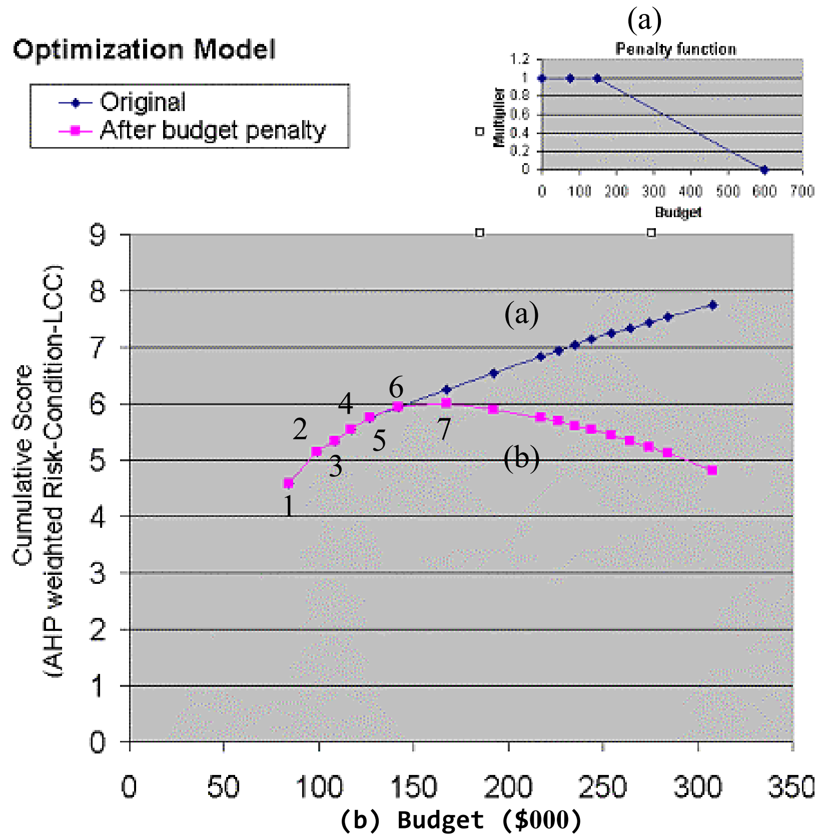


Figure 15: SSAM-I Optimization Model

- <u>Review Gap in Funding/Needs</u>

The previous task proposed a budget based on the benefits received from the proposed projects and on needs of the organization. Table 38 outlined a subjective scheme to select the projects and Figure 15(b) illustrated how an optimization technique could be used to select the projects. At this time, it must be remembered that these two techniques, or others selected by the municipality, propose projects that eventually form the final engineering ranking.

Four previous tasks (i.e. <u>Identify Condition Gap</u>, <u>Identify Functionality Gap</u>, <u>Identify Demand/Capacity Gap</u> and <u>Identify Performance Gap</u>) illustrate methods to identify the gap. The numbers calculated are a good indication of the financial health of the municipality's infrastructure. At this time, there are no reference points, case studies, rules of thumb or indicators as to what is a poor, fair, good or acceptable gap for municipal infrastructure. However, in the case of Edmonton's identified gap in Figure 14, the graph does indicate that the gap will not increase in the upcoming 10 years.

9.2 Recommend Resources > *Inventory*

- <u>Recommend Level of Investment</u>

Based on the review of the funding gap in the previous task, it is possible to <u>Recommend Level of Investment</u>. Section 3.5 details the rational behind the process to <u>Select Level of Investment</u>. As noted earlier, 2% to 4% of the CRV is a recommendation for expenditures on maintenance and repairs, on average (NRC US, 1996). However, the previous task may have identified a need to be spending more on maintenance and repairs if the funding gap is becoming unmanageable in the very near future. As noted earlier, there is currently little guidance available regarding recommended minimum, adequate or sustainable levels of investment funding for municipalities; there is lesser information for LOI funding for specific infrastructure asset classes or for different age vintages of infrastructure.

9.3 Recommend Resources > *Performance*

Each of the following five sections deal with optimizing five *MIM Framework* decision criteria, individually: *performance*, *service life*, *life cycle cost*, *criticality*, and *alternatives*. Although it may appear that each of the facets is handled individually, the final intent is to recommend the resources that maximize *performance*, maximize *service life*, minimize *life cycle cost*, and minimize *risk of failure* of the entire network, in order to select the optimal *alternatives* and to Propose Engineering Ranking. It must be remembered that these are conflicting objectives and the goal is to achieve the best possible solution for the four facets; possibly one or more of them (e.g. *risk of failure* or *LCC*) may not be minimized because the overall benefits from maximizing the performance or service life may outweigh the former benefits. For example, the optimal intervention could involve betterment and as a result performance can increase but life cycle costs will also increase.

- Maximize Performance

The resources recommended to implement any one proposed individual alternative must ensure that the overall performance of the network is increased after the intervention. In fact, for a given selection of proposed interventions, the overall performance of the network after the inventions should be the maximum of all possible performance levels for any combination of possible interventions. As noted earlier in Section 3.3, multi-criteria rating systems can be used to prioritize the possible alternatives.

9.4 Recommend Resources > *Service Life*

- Maximize RSL

The resources recommended to implement any one proposed individual alternative must ensure that the overall remaining service life of the network is increased after the intervention. In fact, for a given selection of proposed interventions, the overall RSL of the network after the inventions should be the maximum of all possible RSLs for any combination of possible interventions. As noted earlier in Section 3.4, different service life calculation protocols can be used to calculate the RSLs of all possible alternatives.

9.5 Recommend Resources > *LCC*

- Minimize LCC

The resources recommended to implement any one proposed individual alternative must ensure that the overall LCC of the network is decreased after the intervention, providing that the capacity or performance has not been increased with the intervention. In fact, for a given selection of proposed interventions, the overall LCC of the network after the interventions should be the minimum of all possible LCCs for any combination of possible interventions. As noted earlier in Section 3.5, different LCC calculation protocols and attributes (e.g. discount rate, planning horizon) can be used to calculate the LCCs of the possible alternatives.

9.6 Recommend Resources > *Criticality*

- Minimize Risk of Failure

The resources recommended to implement any one proposed individual alternative must ensure that the overall risk of the network is decreased after the intervention. In fact, for a given selection of proposed interventions, the overall risk of failure of the network after the inventions should be the minimum of all possible risks of failure for any combination of possible interventions. As noted earlier in Section 3.6, different risk assessment protocols can be used to calculate the risk of failure of the possible alternatives.

9.7 Recommend Resources > *Alternatives*

- Recommend Optimal Alternatives

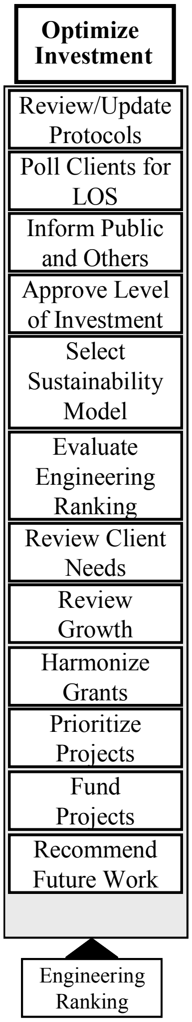
The resources recommended to implement any one proposed individual alternative must ensure that the overall performance, RSL, LCC and criticality of the network are optimized after the intervention. In fact, for a given selection of proposed interventions, the overall *performance*, *service life*, *LCC* and *criticality* of the network after the inventions should be the maximum of all possible *performance* and *service life* and the minimum *LCC* and *criticality* for any combination of possible interventions. As noted earlier in Section 3.7, a formalized decision support system protocol can be used to select the optimal alternatives.

- Rank Alternatives

There are never enough funds to implement the optimal selection of alternatives. Those optimal alternatives should be identified, evaluated, rated, compared and ranked according to the DSS Protocol selected in Section 3.7.

- Propose Engineering Ranking

The previous task to Prioritize Alternatives produces the list of projects recommended for funding in the upcoming budget cycle. It includes projects that are mandatory, projects that are desirable and projects that are discretionary.



10. Optimize Investment

The last process in the *MIM Framework* is somewhat different from the other processes in that there are some tasks that are related to *systems* but there are no strong relationships to each of the other individual facets. As such, the **Optimize Investment** process is positioned to the right and outside of the conventional structure for the *MIM Framework* in Appendix A. This process is critical to answering the asset management question "what do you fix first?"

According to Appendix C, "to optimize" is to "make as perfect or effective as possible". Not all interventions are considered equal; therefore the selection process for intervention projects must be done objectively, systematically, equitably and in a repeatable fashion.

The **Optimize Investment** process consists of roughly a dozen tasks all related to selecting the optimal projects to be implemented in a specific budgeting year based on optimizing the future condition and/or *performance*, *service life*, *LCC*, and *criticality* of all the assets in the portfolio. The **Recommend Resources** process described earlier provides the data that are analysed in the **Optimize Investment** process.

10.1 Optimize Investment > *Systems*

- Review/Update Protocols

Reviewing and updating the current municipal decision-making protocols is the first task in establishing how to objectively, systematically and equitably select the optimal intervention projects. A review of the existing protocols involves identifying the internal practices or methods already in use in the municipality.

- Poll Client for LOS

A number of tasks identified in the *MIM Framework* development exercise could be positioned in a number of locations in the framework; this is one such task. As it ultimately is related to high-level decisions about priorities, it is in the **Optimize Investment** process and in *systems*.

This task identifies: (1) whether or not the clients (i.e. citizens) are pleased with the current Level of Service on their block, region or city; (2) what LOS they desire, and (3) current challenges with delivering a specific LOS. The questions and the answers in such a polling exercise would tend to be subjective and the actions resulting should be commensurate with the tone of the comments, suggestions and results. It is difficult to clearly identify objective steps in this task until suitable metrics are established for identifying acceptable LOSs for the delivery of municipal services. This field related to LOSs is still evolving.

- Inform Public and Others

As noted earlier, some tasks can be positioned in a number of locations in the *MIM Framework.* As this task is in *systems*, it does not necessarily precede other tasks in the **Optimize Investment** process, but it should be always under consideration when making decisions about which projects are selected. As the **Optimize Investment** process deals with issues related to LOS, Levels of Investment, sustainability, priorities, grants, project funding and deferred maintenance, the task to Inform Public and Others should include the detailed information about these metrics and should also present the situation, challenges and resulting decisions using a suitable stakeholder vernacular.

- Approve Level of Investment

At some point in the *MIM Framework* the decision-makers have to Approve Level of Investment for the municipality in general, for the majority of infrastructure disciplines, and for specific asset classes.

- Select Sustainability Model

The Develop Sustainability Model task identified in Section 7.1 and illustrated in Figure 9 describes concepts related to the pillars of sustainability and identifies criteria for implementing a municipal sustainability plan. It is the responsibility of senior public works officials and the elected officials to select a sustainability model that addresses their municipality's needs and vision and that can be implemented with current and future funding.

- Evaluate Engineering Ranking

The engineering ranking developed in the **Recommend Resources** process is the result of the objective analysis of the current and future infrastructure needs of the municipality. As the *MIM Framework* is founded on the systematic analysis of *performance*, *service life*, *life cycle cost*, and *criticality,* the prioritization of the *alternatives* and the resources recommended only relate to these facets. Although the technical staff in the municipality has done their utmost to present the results of their ranking, senior public works officials and elected officials can differ in their opinions and can reorder the engineering ranking. Figure 6 identified a number of stages in the decision-making process; the final stage was Project Selection. In this stage of the process the engineering ranking is one major component of the decision-making process: the other two are the Administrative Requirements and the Political Agendae. These stages are described in detail in Section 3.7 in the Select DSS Protocol task.

- Review Client Needs

Owing to the temporal nature of decision-making and the long time frame needed to present, evaluate and select optimal projects, it may be necessary to Review Client Needs prior to any final decision.

- Review Growth

Consistent with the previous task, it may be necessary to Review Growth of the municipality or even specific regions of the municipality prior to any final decision to evaluate and select optimal projects.

- Harmonize Grants

Grants for other levels of government must be incorporated in the final priority list: specific projects might be "ear-marked" for funding. The "ear-marked" projects can significantly alter the final priority list, as matching contributions may be necessary from the municipality and this can diminish the amount of funding available.

- Prioritize Projects

Based on the DSS protocol selected, the engineering ranking of the projects, the administrative requirements and the political agendae, the projects selected for funding can be prioritized. As illustrated in Figure 6 and as discussed in Section 3.7, the selected decision analysis technique is used to re-rank the projects based on the funding available. In some instances, as presented in Sections 5.7, 6.7, 7.7 and 8.7, techniques such as cost-benefit analysis can be used to fund projects that exceed the current budget if the tangible benefits to the municipality or community exceed the intervention costs. Some municipalities such as the City of Kitchener have used AHP tools (see Section 6.1 for more details on this technique) to allow senior managers and elected officials to vote for capital works projects (Chen et al, 2007; Kitchener, 2009). Others such as the City of Abbottsford have relied on a non-binding referendum from their citizens to select capital projects[6].

- Fund Projects

After the decisions are made, the projects are funded and the interventions can commence. In some cases the projects can be multi-year implementations and can be funded multi-year. Once the interventions are implemented, the post-intervention *performance*, *service life*, *LCC*, and *criticality* data is passed to the asset inventory system or GIS system, as illustrated in Figure 6.

- Recommend Future Work

The asset inventory files for those projects that are not selected for the current year must also be updated accordingly, as changes have occurred in the asset's *performance*, s*ervice life*, *LCC*, and *criticality*. This updated list can be used in the next fiscal year to Calculate Deferred Maintenance, as discussed in Section 4.5.

[6] "On September 25, 2006, Council voted unanimously to conduct a referendum for the borrowing of $85 million to build a Cultural Centre, Community Recreation Centre, and an Entertainment and Sports Centre. On November 25th, the majority of voters authorized Council to proceed with the three projects, thereby making the most important decision about the future of Abbotsford since amalgamation" <http://newera.abbotsford.ca/> (7 July 2007).

11. Acknowledgements

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Appendix A: MIM Framework

Processes →

Facets ↓

Facets	Select Protocols	Itemize Assets	Inspect Assets	Rate Assets	Forecast Needs	Integrate Needs	Recommend Resources	Optimize Investment
Systems	Select Facets Review/Update Protocols Select IT Framework	Review Inventory Protocols Categorize New Assets	Review Inspection Protocols Identify Inspection Protocols Select Inspection Protocols	Review Rating Protocols Select Rating Protocols	Review Facets Select Prioritization Model Develop Sustainability Model	Propose Preliminary Budget Normalize Asset Classes Select Integrated DSS	Propose Budget Review Gap in Funding/Needs	Review/Update Protocols Poll Clients for LOS Inform Public and Others Approve Level of Investment
Inventory	Select Asset Classes Select Asset Attributes Select Data Quality Select Data Dictionary Select Inventory Protocols Select Inventory System	Select Itemization Protocols Collect Inventory Data Supply Inventory Data to Others	Update Inventory Data	Review Inventory Data	Identify Growth Identify New Requirements	Harmonize Asset Classes	Recommend LOI	Select Sustainability Model Evaluate Engineering Ranking Review Client Needs Review Growth Harmonize Grants
		↔ Update Metadata & Expedite M&R ↔						
Performance	Identify Client Needs Identify Legislation Select Benchmark Protocol Identify Internal Needs Select Level of Service Select Performance Protocols	Review Performance Data Categorize Performance Data	Collect Performance Data Update Performance Data	Calculate Performance	Predict Performance Accommodate Growth	Harmonize Asset Performance Identify Condition Gap Identify Functionality Gap Identify Demand/ Capacity Gap Identify Performance Gap	Maximize Performance	Prioritize Projects Fund Projects Recommend Future Work
		↔ Update Metadata & Expedite M&R ↔						
Service Life	Select Service Life Protocols	Review Service Life Data Categorize Service Life Data	Collect Service Life Data	Calculate Service Life	Predict RSL Predict Probability of Failure	Harmonize RSL	Maximize RSL	
		↔ Update Metadata & Expedite M&R ↔						
Life Cycle Cost	Select Level of Investment Select LCC Protocols	Review LCC Data Categorize LCC Data Calculate Deferred Maintenance	Collect LCC Data Estimate Replacement Value	Calculate LCC Estimate Facility Condition Index	Predict Future LCC	Harmonize LCC	Minimize LCC	
		↔ Update Metadata & Expedite M&R ↔						
Criticality	Select Social Impact Category Select Criticality Protocols	Review Criticality Data Categorize Criticality Data Identify Criticalities	Collect Criticality Data	Evaluate Criticalities Calculate Criticality	Re-Evaluate Criticalities Predict Criticality	Harmonize Criticalities	Minimize Risk	
		↔ Update Metadata & Expedite M&R ↔						
Alternatives	Select DSS Protocols	Identify Alternatives	Evaluate Alternatives	Rate Alternatives	Compare Alternatives	Prioritize Alternatives	Recommend Optimal Alternatives Rank Alternatives Propose Engineering Ranking →	Engineering Ranking
		↔ Update Metadata & Expedite M&R ↔						

Risk of Failure

Appendix B. MIM Framework Abbreviations

AHP	Analytical Hierarchy Process
AIC	Attribute Importance Category
ASTM	American Society for Testing and Materials
CAD	Computer Aided Design
CAD$	Canadian Dollars
CCTV	Closed Circuit Television
CMMS	Computerized Maintenance and Management System
CRV	Current Replacement Value
CSA	Canadian Standard Association
DD	Day
DM	Deferred Maintenance
DSS	Decision Support System
FAST	Functional Analysis System Techniques
FCA	Full Cost Accounting
FCI	Facility Condition Index
FHWA	Federal Highway Administration
FSE	Fuzzy Synthetic Evaluation
GIS	Geographical Information System
HDPE	High Density Polyethylene
HH	Hour
IRI	International Roughness Index
IT	Information Technology
KPI	Key Performance Indicator
LCC	Life Cycle Costs
LOS	Level of Service
M&R	Maintenance and Repair
MIIP	Municipal Infrastructure Investment Planning
MIM	Municipal Infrastructure Management
MM	Month
MTTF	Mean Time To Failure
NPV	Net Present Value
NRCC	National Research Council of Canada
NWWBI	National Water and Wastewater Benchmarking Initiative
OMBI	Ontario Municipal CAO's Benchmarking Initiative
PE	Polyethylene
PVC	Poly Vinyl Chloride
PMS	Pavement Management System
PCI	Pavement Conditions Index
PSAB	Public Sector Accounting Board
PSL	Predicted Service Life
PV	Present Value
RCI	Riding Comfort Index
ROW	Right of Way
RSL	Remaining Service Life
SPG	Structural Pipe Grade
SS	Second
SUE	Subsurface Utility Engineering
WRc	Water Research Council
YYYY	Year

Appendix C. MIM Framework Action Verbs

Accommodate:	To have room for or make compatible with.
Approve:	To consent or to agree.
Calculate:	To determine by computation.
Categorize:	To place or assign into a category.
Collect:	To bring together in a group; to gather.
Compare:	To examine two or more objects in order to note similarities and differences
Develop:	To bring into being gradually.
Estimate:	To calculate approximately.
Evaluate:	To assess or appraise the value.
Expedite:	To speed up or accelerate the process or to eliminate a number of procedures.
Forecast:	To estimate or calculate in advance, especially to predict.
Fund:	To finance; to approve a project for implementation.
Harmonize:	To bring or come into agreement.
Identify:	To ascertain the origin, nature, or definitive characteristics of.
Inform:	To pass on information or data to others.
Inspect:	To examine carefully and critically, especially for flaws.
Integrate:	To make part of a larger whole.
Itemize:	To enumerate items in an inventory.
Maximize:	To raise to the highest amount (i.e. maximize asset performance).
Minimize:	To reduce to the lowest amount (i.e. minimize life cycle cost).
Normalize:	To make normal or cause to conform to a norm or standard.
Optimize:	To make as perfect or effective as possible (i.e. optimize asset condition).
Poll:	To question in a survey; to canvass.
Predict:	To make known in advance, especially on the basis of special knowledge.
Prioritize:	To arrange in order of importance.
Propose:	To suggest or plan; to put forth.
Rank:	To place in a logical order.
Rate:	To evaluate the functionality of an asset.
Recommend:	To advise or counsel.
Review:	To look over, study, or examine again.
Select:	To take as a choice from among several options; to pick out.
Supply:	To make available for use; to provide.
Update:	To bring up to date.

Appendix D. MIM Framework Action Outcomes

Alternatives: Choices or available options available when making a decision.

Assets**:** Physical component of a facility that has value, enables services to be provided, and has an economic service life of greater than 12 months.

Asset Classes: Categorization of physical assets (roads, bridges, sewers, plant, vehicles, etc.) broken down to the appropriate level of detail (e.g. sewers, sanitary sewers, trunk, laterals).

Asset Attribute: The specific physical characteristics (including units of measurement) of the asset.

Benchmark: A protocol by which something can be measured or judged. (e.g. the operating costs for the treatment and disposal of wastewater per mega litre treated or Percentage of wastewater estimated to have by-passed treatment. - OMBI).

Budget: M&R budget.

Client: A person or organization paying for a good or service, either directly or indirectly.

Condition Gap: The cost difference between the current and the required physical condition or state of an asset.

Consequences of Failure: The costs incurred by the municipality when an asset fails prematurely.

Criticality: The importance of an asset in the portfolio.

Data: A collection of facts from which conclusions may be drawn.

Data Dictionary: "Set of metadata that contains definitions and representations of data elements" (Wikipedia, 2009a). In this report the term data dictionary is used to identify the full definition of the attribute table. Typically, this includes defining the data format of the attribute and the controlled vocabulary used in entering data into a specific field for an asset class (e.g. for pipe materials - sewers: concrete, asbestos cement, vitrified clay, PVC, etc.)

Data Quality: The properties of measurement such as precision, bias, detection limit and other relevant measures such as:

- A – 3D positioning (GPS etc.)
- B – 2D positioning
- C – on-site observation
- D – on drawings or plans or from memory

Decision Support System (DSS): A tool providing decision-makers with useful summaries and analysis of data

Deferred Maintenance (DM): Refers to the maintenance (and *not* capital renewal) that has not been performed or is scheduled for implementation in the future. The Deferred Maintenance is typically represented as the cost of implementing that maintenance.

Demand/Capacity Gap: The cost difference between the current situation and the demand for or the required capacity of a similar asset. Demand/capacity is defined as the quality of having the properties that are right for a specific purpose; "an important requirement is meeting the demand for Olympic swimming events."

Engineering Ranking: An engineering prioritization based on the performance, service life, LCC and criticality of an asset.

Facets: The definable aspects that make up a system or subject.

Facility Condition Index (FCI): A financial index used to approximate condition of assets. FCI equals the Deferred Maintenance (DM) divided by the Capital Replacement Value (CRV).

Functionality Gap: The difference in cost between the cost of providing the current functionality and the cost of implementing the required functionality for an asset. Functionality is defined as how well an item performs the activities expected of it.

Future Work: Activities or projects to be done at a later time.

Gap: Difference between funds available and requirements.

Grants: Funding opportunities, typically earmarked for specific asset classes.

Growth: The expansion of a portfolio to include new infrastructure.

Infrastructure:The physical network of assets that provides services to the general public, such as transportation, utilities (water, gas, electricity), energy, telecommunications, waste disposal, recreation and accommodation.

Integrated DSS: A decision support system that takes into account all the assets in a portfolio.

Inventory System: A system used to enumerate inventory assets and record data associated with that asset.

Inventory: An itemization of assets.

Investment: Property or another possession acquired for future financial return or benefit.

IT Framework: Overall information technology (IT) implementation plan.

Legislation: Requirements mandated by senior levels of government.

Level of Investment (LOI): The amount of funds available to maintain existing assets, as a percentage of the replacement value (i.e. 2%).

Level of Service (LOS): Qualitative or quantitative measure of how well or poorly a service is provided.

Life Cycle Costs (LCC): The total cost, in present value or annual value, required to maintain an asset in full performance for its service life.

M&R;Maintenance and Repairs.

Metadata: Data about data, or how to structure the existing data.

Model: A simplified representation of a system or process.

Needs: Administrative, political, funding or client requirements.

New Assets: Assets not already included in the inventory.

New Requirements: Changes to the existing legislative, political, financial, administrative, or technical requirements in the municipality.

Normalize: Techniques where comparable data are weighted according to their relative position between the lowest and the highest values in a series. One method of normalization is to assign the lowest value a score of 0 and the highest a score of 1, with the other values being assigned a weighted score (e.g. linear relationship) between 0 and 1. Normalization turns absolute values into relative values.

Optimal Alternatives: The selection of projects that best meets the requirements of the municipality.

Performance: The qualitative or quantitative rating of how an assets performs its intended functions. (In some cases it is used to also describe an asset's condition, functionality or demand/capacity)

Probability of Failure: The probability that an asset will fail before the next inspection cycle.

Process: Top level protocols in a municipality.

Protocols: The internal processes or methods selected and used by a municipality

Projects: Specific maintenance, rehabilitation or renewal activities.

Public: Open to or concerning the people as a whole.

Rating: The identified performance or condition of an asset on a scale.

Remaining Service Life (RSL): The remaining functional life of an asset.

Replacement Value: The current cost to replace an asset with one of equal functionality.

Resources: The inputs needed to undertake a project, generally including financing, people, equipment, facilities, raw materials, and possibly physical elements such as land and water.

Risk: The "consequence of failure" multiplied by the "probability of failure."

Service Life: "the actual period of time during which [the asset] or any of its components performs without unforeseen costs of disruption for maintenance and repair" (CSA 1995).

Social Impact Category: The category used to define or characterize the effect (acceptable or unacceptable) of an asset on society-at-large.

Sustainability Model: The model used to determine if an asset meets current needs without compromising the ability of future generations to meet their needs.

System: A set of interrelated components that perform a specific process or function.

Appendix E. Data Structures for Asset Management

Excerpt from Vanier and Rahman (2004).

Every software application has an underlying data structure. It is important that users understand the application's data structure as it controls both the ways that data are collected, stored, and retrieved and the way the software can be used. In general, these tools assist in classifying, storing, and retrieving data, but the tools can also enforce a specific methodology on the users. There are three major types of database structures: simple, relational and object oriented. However, some applications use a combination of these three types of databases or can have their database emulate other types of database. In some instances the data structures are developed by the application's programmers or off-the-shelf (OTS) databases are modified to suit the application or storage requirements.

A number of asset management applications use simple databases.

This is the simplest form of database structure consisting of records each having a number of predetermined fields, as shown in Figure E-1. Because simple databases have been around and used successfully for decades, they are normally very reliable.

Field	Record ID	Type	Value ($)	Manager	Telephone	Location
Asset 1	1	Road	50,000	Bob	X-123	Laurier St.
Asset 2	2	Water	100,000	Bob	X-123	Laurier St.
Asset 3	3	Sewer	250,000	Tom	X-321	Ogilvie Ave.
Asset 4	4	Building	1,000,000	Tom	X-321	Ogilvie Ave.

Figure E-1: Simple Database Structure

A relational database is one that is based on the model developed by E.F. Codd at IBM in 1970. In relational databases, the data items and relations between them are organized in pre-described tables from which data can be accessed or reassembled in many different ways. A table is a collection of records and each record in a table contains the same fields, as shown in Figure E-2. Certain fields may be designated as keys; which means that searches for specific values of that field will use indexing to speed them up. Structured Query Language (SQL) is the application program interface to a relational database for interactive information queries and gathering data for report. Many current software tools use relational database structures. Figure E-2 illustrates a typical relational database structure. In this figure, the Asset Table (a) lists the different fields for the asset records; these are relationally linked to the Manager Table (b) containing shared data about the manager such as Name, Location, and Telephone Number.

Record ID	Type	Value ($)	Manager Key
1	Road	50,000	K1
2	Water	100,000	K1
3	Sewer	250,000	K2
4	Building	1,000,000	K2

(a) Asset Table

Manager Key	Name	Location	Tel.
K1	Bob	Laurier	X-123
K2	Tom	Ogilvie	X-321
K3	Bill	Laurier	X-456

(b) Manager Table

Figure E-2: Relational Database Structure

The advantages of a relational database over a simple database can be seen in the reduction of data duplication for specific fields (e.g. Manager, Tel # and City) in Figure E-1.

An object-oriented database (OOB) is a database in an object-oriented programming environment. Data are stored as classes of objects and as a set of operations or methods, which can be used on these data. For example as shown in Figure E-3(a), an asset is a class of objects that has a number of subclasses: road, water, sewer, or building. A road is a subclass of objects that inherits its parent's attributes and can also have of its own subclass attributes (i.e. Area = Length x Width). Whereas, a sewer is a subclass of object that can have completely different attributes to that of the road (i.e. Area = πr^2). In an object-oriented structure or "schema", the relationships are displayed in "graphs" showing both connectivity and inheritance, as shown in Figure E-3(a). The actual data are called "instances", as shown in Figure E-3(b), each having their own object identification or OID and pointing to related OIDs.

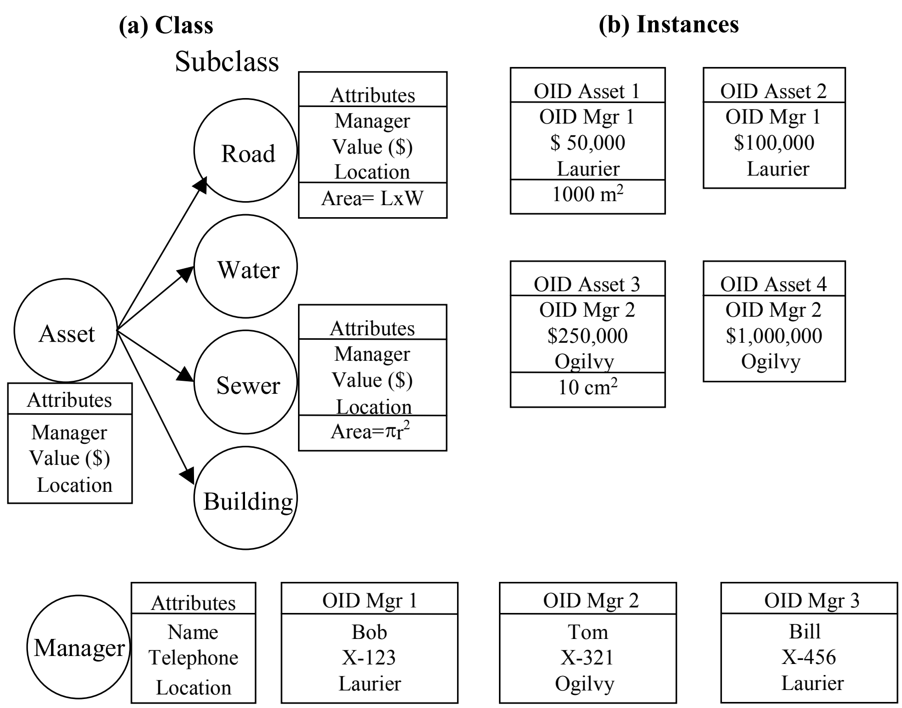

Figure E-3: Object-Oriented Database Structure or Schema

The database structure used for an application is selected by the organization developing the software; however, there can be the possibility in the program to create additional tables, records or fields, as and when required. Typically, a designated “on-site administrator” can add or modify data tables or attributes in the organization's data structure. The administrator can also check the internal integrity of the database to ensure that records are properly linked and saved.

Appendix F. Subject Index – MIM Framework Tasks