Chapter 1
Introduction to Asset Management for Infrastructure

1.1 Infrastructure

Oxford dictionary (2020) defines infrastructure as "the basic physical and organizational structures and facilities (e.g., buildings, roads, power supplies) needed for the operation of a society or enterprise.

A more technical definition has been provided by the American Society of Civil Engineering (ASCE): Civil infrastructure systems enable thriving societies and healthy ecosystems. Civil infrastructure systems support transportation; energy production and distribution; water resources management; waste management; civic facilities in urban and rural communities; communications; sustainable resources development; and environmental protection. These physical, social, ecological, economic, and technological systems are complex and interrelated" (ASCE, 2021).

Infrastructure UK encompasses economic and system perspectives to explain infrastructure roles: "the networks and systems in energy, transport, digital communication, flood protection, water, and waste management. These are all critical to support economic growth through the expansion of private sector businesses across all regions and industries, to enable competitiveness and to improve the quality of life of everyone in the UK" (Treasury, 2010).

Most references agree on similar major sectors as Critical Infrastructure (CI) including transport; energy; water and wastewater; and communication systems, which typically are categorized as "hard" infrastructure referring to physical assets. ASCE (2017) expanded this to 16 categories of Transit, Aviation, Bridges, Roads, Ports, Rail, Energy, Inland Waterways, Dams, Drinking Water, Wastewater, Solid Waste, Hazardous Waste, Levees, Schools, and Parks and Recreation. Green infrastructures such as food, agriculture, and chemicals as well as soft infrastructures such as health, education, and legal systems are also included by other sources (Dawson, 2013).

A. Mohammadi, L. Amador Jimenez, *Asset Management Decision-Making For Infrastructure Systems*, https://doi.org/10.1007/978-3-030-97614-9_1

Among all different views and definitions for hard infrastructure, there are key common, agreed aspects that are central to the role of infrastructure in modern societies and are the pillars of the treatment in this book.

1.1.1 Physical Bases

Infrastructure is commonly referred to as physical components, structures, and assets, which can be built, installed, repaired, and replaced. Infrastructure assets are touchable; however, the commodities that flow through them such as oil and gas or electric power are not part of the system although may physically or financially impact the system (Fulmer, 2009).

1.1.2 Criticality

People's human life and well-being are highly dependent on the major infrastructure, commonly named CI. In many societies, it would not be possible to imagine a single day without using electric power, transportation, and communication systems. The government of Canada (2020) says that "CI refers to processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government. Disruptions of CI could result in catastrophic loss of life, adverse economic effects, and significant harm to public confidence." The criticality of major services such as food supply, electricity grids, transportation, communications, and public safety incorporates managing infrastructure to cybersecurity and resiliency.

1.1.3 Economic and Human Development

Investing in infrastructure is always very expensive, however globally is recognized as a key source of running the business and facilitating economic growth. One main requirement for sustainable economic and social development is providing adequate infrastructure services (UN, 1994).

Identified Sustainable Development Goals (SDGs) by the United Nations (UN, 2016) including access to safe and reliable transport; clean water and sanitation; affordable and clean energy; quality education; good health and well-being; and empowerment of women, persons with disabilities, and other vulnerable groups are directly influenced by the quality of provided services by the infrastructure.

1.1.4 Public Facilities

Major infrastructure is often monopolistic in terms of provided facilities (Fulmer, 2009), and the governments and municipalities are responsible to invest, maintaining, and upkeeping these services. Thus, the term "Public Infrastructure" most likely covers all CI as is defined by the Corporate Finance Institute (CFI): "Public infrastructure refers to infrastructure facilities, systems, and structures that are owned and operated by the "public," (i.e., the government). It includes all infrastructural facilities that are open to the general public for use. Infrastructure includes all essential systems and facilities that facilitate the smooth flow of an economy's day-to-day activities and enhance the people's standard of living. It includes basic facilities such as roads, water supply, electricity, and telecommunications (CFI, 2020)".

1.2 Infrastructure Network

Our societies are built around and served by infrastructure networks. Major systems such as transportation, energy, and communication have mostly been managed individually; however, infrastructure now functions as a system of systems with complex interdependencies (Grafius et al., 2020). Infrastructure systems or networks are interrelated components functioning together in a dependent system in order to deliver services to end-users. Several interdependencies can be identified including supply and demand (e.g., water system relies on electricity); physical dependencies (e.g., installing the antenna on a building or buried utilities under a road); geographic dependency (e.g., close spatial proximity); economic dependencies (e.g., investment cycles for each system); and finally, technological dependency (e.g., managing highway traffic by sensors) (Fulmer, 2009) (Fig. 1.1).

Widespread use of information across infrastructure systems, future reliance on communication technology (e.g., vehicle to infrastructure and V2i technology), and integration of technology have improved the efficiency of infrastructure while dropping resilience and increasing the chance of systemic failure (i.e., technology vulnerability) (Treasury, 2010).

Provided services by infrastructure networks are firstly dependent on the quality, reliability, and availability of each system; however, from a network perspective, managing infrastructure is beyond each system considering interdependencies and addressing the network resiliency, which can be also influenced by losing functionality due to abnormal failure (e.g., natural thread as well as terrorist attacks). CI protection is usually discussed separately addressing several system challenges such as cybersecurity, which is out of the scope of this book. More discussions can be found in several sources such as the *International Journal of Critical Infrastructure Protection (IJCIP)* (Elsevier, 2020).

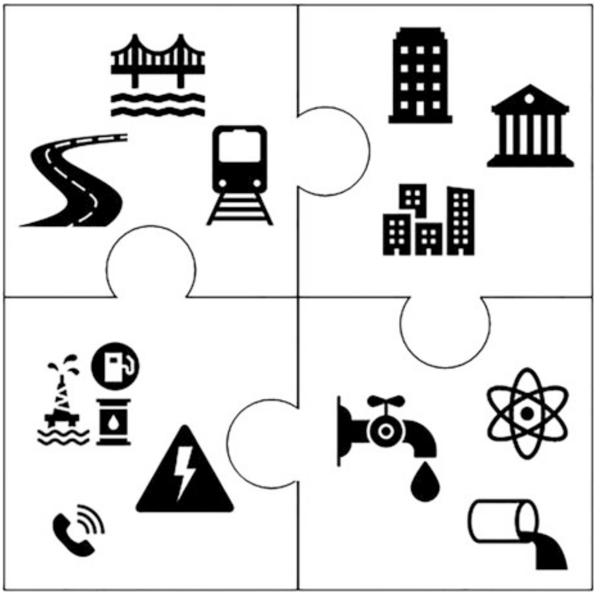

Fig. 1.1 Infrastructure facilities interdependencies

1.3 Infrastructure Asset Management (IAM)

Managing infrastructure assets especially public services is a complex and multi-dimensional task touching commercial, social, economic, and political aspects. Cambridge dictionary defines an asset as "something having value, such as a possession or property, that is owned by a person, business, or organization" (Cambridge, 2020). The ISO (2014a) defines an asset as "an item, thing, or entity that has potential or actual value to an organization". Therefore, different sorts of assets including physical, financial, human, information, and intangible assets can be identified within any organization, while physical assets in infrastructure refer to tangible elements of buildings, roads, pipelines, plants, and communication equipment (Hastings, 2015). Assets in the context of this book are those physical components and systems.

All organizations that manage our infrastructure such as governments, municipalities, and all private parties own, maintain, and deal with assets that drive the quality of provided services. To assure quality and availability of expected services, assets should be designed, installed, built, operated, repaired, replaced, and upgraded, and overall managed properly in order to return the highest value to the owners as well as end-users. This is not new for industry; however, the growing responsibility of organizations, increasing in number and complexity of assets, operating under a restricted budget, and rising demands lead to the need to use a systematic approach to maintain assets and systems called asset management (AM).

The Federation of Canadian Municipalities (FCM) and National Research Council (NRC) (2005) defined AM as "the combination of management, financial, economic, engineering, and other practices applied to physical assets with the

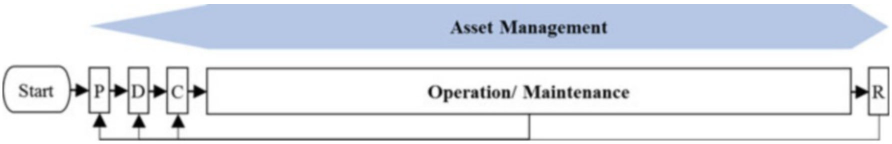

Fig. 1.2 Asset life cycle and AM

objective of providing the required level of service in the most cost-effective manner." United States Army Corps of Engineers (USACE) the Institute for Water Resources (IWR) (2013) explained AM as a disciplined corporate approach requiring collaboration at the organization level.

Figure 1.2 shows the asset life cycle: starting from Planning (P) and Design (D), moving to Construction and Commissioning (C), then Operation (O), which assets spend the longest time up to Replacement and Retirement (R), where the asset has completed its useful life and will be decommissioned. AM mainly focuses on the operation and maintenance phase while contributing to other phases and providing feedback to the entire asset life cycle. For instance, how the decommissioned asset should be redesigned, reinstalled, or handed over to improve the service in the operation phase. AM helps an organization to maintain assets proactively and efficiently by finding the optimum time and strategy for the maintenance and replacement of assets.

All organizations may establish their own understanding of AM; however, to achieve the highest benefit, it would be highly recommended to follow best practices as a baseline and then begin from that point to address local concerns through adjustments.

Davis (2012) introduced AM for beginners in a simple way of what it is and what it is not. AM is:

- "A mindset which sees physical assets not as inanimate and unchanging lumps of metal/plastic/concrete, but as objects and systems which respond to their environment, change and normally deteriorate with use, and progressively grow old then fail, stop working, and eventually die!
- **Is** a recognition that assets have a life cycle
- **Is** as important for those working in finance as it is for engineers
- **Is** an approach that looks to get the best out of the assets for the benefit of the organization and/or its stakeholders
- **Is** about understanding and managing the risk associated with owning assets

And

- **Is not** just about maintenance. Maintenance is part of the stewardship of assets, but so is design, procurement, installation, commissioning, operation, etc.
- **Is not** a substitute for quality management. AM, like other management processes, should be subject to scrutiny through a quality process to ensure rigour.
- **Is not** a project management system
- **Is not** just for engineers. Everyone working in a company that owns or operates assets should be interested. This includes those working in procurement, finance, personnel, service, planning, design, operations, administration, leadership, marketing, and sales

- **Is not** just an accounting exercise. Whilst it may help you understand the deterioration and hence depreciation of an asset, it is of interest to every part of the organization
- **Is not** a purely academic discipline. Whilst it is a worthy subject for academic review and advancement, it is primarily a pragmatic, hands-on subject".

Historically, AM has been first applied a long time ago in manufacturing systems with the main objective of avoiding any shutdown in the production line. Then, the idea was expanded to infrastructure, firstly applying to industrial-based systems such as oil and gas and later to civil infrastructure. Over time, IAM became more critical where infrastructure such as transit systems and buildings became bigger, older, more complex, and more financially dependent.

Let us terminate this section with another comprehensive asset management definition provided by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highways, Planning Subcommittee on Asset Management (FHWA, 2021): "a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based on quality information and well-defined objectives."

1.3.1 Why Asset Management (AM) for Infrastructure?

Implementing AM for infrastructure in public or private organizations is time-consuming and requires financial resources and sufficient personnel. It often involves an action plan to build up organizational capabilities, change management to accomplish buy-in from the employees, and the development of enhanced information technology systems. Therefore, it must be worth an investment in the eyes of asset owners and policymakers.

Answers to the two key questions of why we need IAM and what would be the benefits of this investment should be well prepared and articulated, particularly for senior managers.

Below are some of the reasons why an organization may be willing to develop and implement an AM platform:

- Community well-being is paramount and properly linked to infrastructure availability and services reliability.
- There is a desire to optimize the management of local infrastructure systems, which are big and more complex in nature.
- There is a need to handle existent major infrastructure, which is suffering from aging while is under operation.
- The annual budget is limited, and this is perceived as an obstacle to upkeep assets in good operational condition.
- Increased demand because of the growing population and urbanization is observed and/or expected.

- Higher standards for lean operation, safety, and health are expected by end-users.
- Environmental protection concerns and sustainability issues are a top priority for the stakeholders.

This situation brings a need to maintain and upgrade existing infrastructure assets addressing challenges, which would not be achievable unless putting a systematic approach for managing assets. AM is intended to build this systematic practice.

1.3.2 Benefits of IAM

IAM can work as a process to consistently and actively maintain infrastructure and to achieve a state of good repair (SGR). The following benefits can be gained in different degrees:

- Providing better and consistent levels of service for the customers.
- Improving safety, security, customer satisfaction, sustainability, and resiliency.
- Allowing for better data-driven, smart, and optimal decisions when allocating maintenance, rehabilitation, upgrade, and expansion of IAM systems.
- A reduction in cost during the life cycle of infrastructure and an increase in their life span.
- Facilitating more effective financial planning with more cost-effective use of resources.
- Avoiding service disruptions and minimizing potential risks.

1.3.3 State of Good Repair

Federal Transportation Administration (FTA) (FTA, 2010) defines state of good repair (SGR) as “a state in which a transit agency preserves its physical assets in compliance with a policy that minimizes asset life-cycle costs while preventing adverse consequential impacts to its service.” SGR actually is a bridge that links IAM practices to organization strategic objectives. Predefined SGR measures such as performance and condition indicators as well as the age of assets define objectives and targets to build AM platform and to ultimately achieve organizational key performance indicators (KPIs).

This book further develops an understanding of IAM strategic objectives through the challenges presented in Sect. 1.4; performance assessment (Chap. 2) and performance forecast (Chaps. 3 and 4); as well as the decision support platforms (Chap. 5) needed to accomplish the minimization of asset life cycle cost and the maximization of organization KPIs.

1.3.4 A Multi-discipline Process

IAM is not either engineering or finance. It is a multi-disciplinary process supported by various knowledge areas (Fig. 1.3).

1.3.4.1 Management

AM is all about management. The process should be built on management pillars including strategy, goals, policies, cost, time, quality, and definitely people.

1.3.4.2 Engineering

Infrastructures are engineering systems where operation and maintenance are tied to engineering aspects of the asset's life cycle. Choosing the right treatment action at the right time is directly linked to engineering practices.

Fig. 1.3 Multi-disciplinary contributions in IAM

1.3.4.3 Economics

Infrastructure runs economics in any society while is expensive to be maintained. Meanwhile, governments are economically struggling to invest in infrastructure as the public side of the service limits making high revenue. Therefore, minimizing lifecycle costs and economically optimizing restricted budgets is critical.

1.3.4.4 Sociology

Dependency on provided services by infrastructure systems and their influence on the quality of life are undeniable for societies. Besides that, IAM means dealing with under-operation systems. This requires considering all side effects on day to day life of end-users.

1.4 IAM Challenges

Although IAM has been advanced through time by taking advantage of new principles, tools, techniques, and technology, the novel raised concerns that resulted from multiple challenges complicated the capital investment for infrastructure (Mohammadi et al., 2017). IAM leaders should be aware of the obstacles to prepare organizations for this journey and mitigate risks. The most common challenges to implementing AM for infrastructure are identified in the following subsections.

1.4.1 Budget Limitation

Perhaps budget shrinkage is globally the most common challenge to take care of infrastructure. US infrastructure for many sectors has a huge backlog. For example, $836 billion backlogs of highway and bridge capital needs (i.e., mainly repair and partially expansion-enhancement) (ASCE, 2017). UK local highways backlog has been estimated at £10 billion (Treasury, 2013). This situation brings to matters the need to count on a data-driven decision support model that can dynamically optimize the budget allocation (will be discussed in Chap. 5).

1.4.2 Increasing Demand

The demand for public infrastructure has increased due to fast urbanization and a growing population. American transit systems carried 10.5 billion passenger trips in 2015, which is 33% higher than 20 years ago. Also, an increase in energy consumption of 0.4% per year has been announced from 2015 through 2040 for the energy sector (ASCE, 2017). Increasing demand means a need for upgrading and expanding the infrastructure and imposes additional budget requirements at present for the upgrade or expansion and in the future to preserve and maintain the newly built (and the legacy) assets. This leads to complicating IAM where the impacts of change in demand should be captured in decision-making methodology (Mohammadi et al., 2020) matching with the appropriate upgrade or expansion investments through time-horizon.

1.4.3 Aging Infrastructure

In most developed countries, existing infrastructure has been operating since the 1960s and 1970s and in some cases built after World War II. The extensive deterioration of already aged systems complicates managing the network. Therefore, decision-makers need to develop models to simulate the operation and mimic practice. This is the basis for tracking the performance and forecasting future conditions and levels of service for each element necessary to accomplish a safe, reliable, and convenient service. As a tool, the role of deterioration models in the IAM process is to predict the future trend of degradation addressing aging assets (will be discussed in Chap. 3).

1.4.4 Higher Society Expectations

CI are social facilities impacting day-to-day public well-being and society economic growth. Expectations to receive higher-quality services and dependency on infrastructure is unlike 20 years or even 10 years ago, while this adds more complexity to managing infrastructure and limits the flexibility.

1.4.5 Climate Change

Climate change can't be ignored especially for long-term and forward-thinking strategy while it adds a new criterion in multi-criteria decision making (MCDM) in IAM. For instance, the impacts of future climate in rainfall intensity should be captured in stormwater pipelines (Amador et al., 2020), and increasing the number of freezing cycles needs to be addressed in the pavement maintenance planning (Mohammadi et al., 2019b) (will be discussed in Chap. 6).

1.4.6 Sustainability and Human Development Concerns

Sustainability is a raised public concern and expectation. Sustainability concerns such as energy efficiency and greenhouse gas (GHG) emissions (Faghih-Imani & Amador Jimenez, 2013) as well as human development goals like poverty alleviation; access to health, education, and fresh water; and gender equity (Mohammadi et al., 2019a) are expected to be addressed in the upcoming plans for public infrastructure (will be discussed in Chap. 6).

1.4.7 Infrastructure Interdependency

Asset systems within a facility or between different infrastructures are often interdependent. Hence, maintenance of one facility or system often impacts the maintenance activities (or conditions the performance) of other facilities or systems, both economically and functionally. Thus, this interdependency cannot be ignored.

1.5 IAM Best Practices

Many governments, municipalities, and institutes recognized the need for developing guidelines and standards to implement IAM. The most common and well-known best practices are:

- *ISO 55000 series,* published by the International Organization for Standardization (ISO) to provide a global language including three guidelines.
  - ISO 55000 (2014a): Asset management—Overview, principles, and terminology.
  - ISO 55001 (2014b): Asset management—Management systems—Requirements.
  - ISO 55002 (2014c): Asset management—Management systems—Guidelines for the application of ISO 55001.
- *International Infrastructure Management Manual (IIMM),* published by the Institute of Public Works Engineering Australasia (IPWEA) (IPWEA, 2020).
- *BSI PAS 55* (IAM and BSI, 2008) *and Asset Management—an Anatomy* (IAM, 2015), published by the British Standards Institution and was initiated by the Institute of Asset Management (IAM).
- *Transportation Asset Management Guide—A Focus on Implementation* (AASHTO, 2013), published by AASHTO.
- *InfraGuide series* (NRC, 2001-2006), published by the Canadian National Research Center (NRC).

All these best practices can be used as benchmarks by organizations seeking to implement AM at an organizational level. However, these references provide only a general understanding of the process, fundamental requirements, and steps to apply AM, while those who are dealing with AM especially for the first time (e.g., small municipalities and agencies, students, and professionals) require detailed and practical steps to fully realize the process and to be able to develop an AM platform from scratch.

This book fills the technical gaps between these guidelines and practical needs by providing and presenting step by step guide collected from the state-of-the-art solutions and already implemented industry best practices.

1.6 IAM Main Phases and Maturity

Guidelines like IAM (2015) have developed conceptual AM models which are more or less similar including main components of an organization and people, asset information, decision-making, planning, lifecycle delivery, and risk and review. Each component then will be expanded to multiple subjects. These models are very important to build an AM platform in any organization. For example, how asset management strategy/policy as a leader of the whole process should be drafted or implemented. How the work management system should be designed, maintained, and upgraded toward proactive AM.

As was discussed earlier, this book is aimed to bridge between standards/guidelines and practical needs. For instance, all standards are encouraging for efficient decision-making and being proactive by long-term planning; however, the challenging parts always would be which steps must be taken to achieve this goal, which types of information is required to be collected and prepared, how the decision-making system should be set up, and which tools and techniques can be used to improve decision-making outposts. This book explains those steps, clarifies required information, and presents the most efficient and practical solutions to enhance decision-making and long-term planning for infrastructure systems.

Figure 1.4 presents a simplified process with phases that are required to implement advanced decision-making and long-term planning for IAM. It also generally

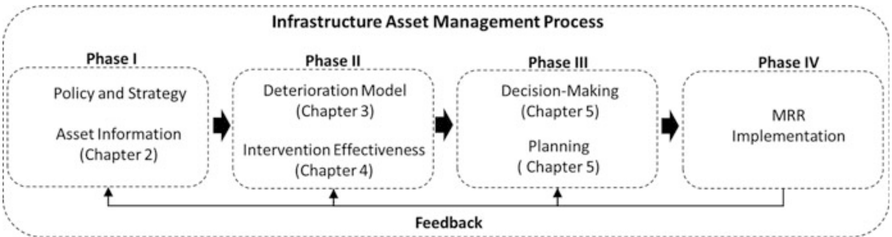

Fig. 1.4 IAM main phases

presents the scope and layout of this book by linking phases to corresponding chapters.

These phases include preparation (i.e., collecting data and providing inputs for the AM platform), analyzing collected data to provide bases for the next phase (i.e., decision-making), decision-making and planning for asset maintenance, renovation, and replacement (MRR) respecting goals and organization policy, and finally implementing the plan and operation. IAM is a live process and always should be under improvement by addressing feedback from the implementation phase.

These phases cover the required components of IAM; however, each step can be handled in extensive levels of maturities. IAM's level of maturity depends on how the entire organization has been trained and contributes to the process. Senior managers with a good understanding and experience of AM play a key role to support the idea, pushing stakeholders, and providing requirements.

Also, AM maturity is linked to how advanced methods, best practices, tools, and technology are being used and implemented in all steps to achieve the highest return value. The forthcoming chapters provide more details for very basic requirements and less mature platforms as well as more advanced solutions while, obviously, all organizations new to the topic need an evolving time.

1.6.1 Phase I: Preparation and Data Collection

There are different types of required inputs to develop an AM platform for infrastructure.

1.6.1.1 Policy and Strategy

At first, the asset owner needs to define principle goals and mandated requirements for this journey. Several factors contribute to how organizations select targets, schedule goals, and prioritize investments. The AM team is responsible to interpret goals (e.g., having safe, comfortable, and reliable subway trains) to measurable SGR targets (e.g., achieving more than 95% reliability in systems/assets or limiting backlogs), and KPIs (e.g., 95% punctuality), around which the whole AM process will be built later. Constraints and limitations (e.g., available budget) also play key roles and must be identified. Best practices like ISO 55000 recommend discussing and developing AM policy at the organization level, which is required to be approved and supported by top managers for the best possible outputs.

1.6.1.2 Asset Information

Asset information is the foundation of IAM, which is always challenging especially at the starting point. Chapter 2 in this book explains what types of data need to be accurately collected, stored, and maintained consistently to build a data inventory for the purpose of IAM.

1.6.2 Phase II: Data Analysis

Collected data must be technically analyzed to extract prediction engines (deterioration models and intervention effectiveness), which are key elements of being proactive and projecting long-term plans.

1.6.2.1 Deterioration Model

To develop cost-effective medium-term and long-term plans, decision-makers need to predict potential future decay in the asset lifecycle. Chapter 3 provides the best practice as well as simplified methods to develop deterioration models.

1.6.2.2 Intervention Effectiveness

Having a real understanding of maintenance effectiveness enhances decision-making and planning to pick more cost-effective solutions (Chap. 4).

1.6.3 Phase III: Decision-Making and Planning

By gathering and analyzing data, the asset management team will be prepared to enter the next phase of planning and decision-making, seeking optimal and cost-effective solutions.

1.6.3.1 Decision-Making

Generally, there are two types of planning during the life cycle of assets: routine and preventive (i.e., proactive) actions, which are typically predefined by manufacturers for electrical and mechanical-based assets or recommended by best practices such as potholes for road pavement and sealing cracks in a concrete building. Another type would be corrective (i.e., reactive) maintenance planning covering major refurbishment, rehabilitation, and replacement actions, commonly named SGR projects. Although, both are part of AM planning, decision-making is more meaningful for corrective, refurbishment, major overhaul, and replacement types of actions, which are financially categorized as capital expenses (CAPEX) compared to operating expenses (OPEX) for routine and preventive maintenance. Decision-making and planning for CAPEX will be discussed in more detail in Chap. 5.

1.6.3.2 Asset Management Plan

The provided interventions for assets should be presented in a practical way to take full advantage of this process by providing an Asset Management Plan (AMP) (Chap. 5).

1.6.4 Phase IV: MRR Implementation

Finally, the planned interventions must be implemented through tactical and operational plans. These cover managing all tasks of implementing preventive and corrective actions, preparing work orders, selecting executors, and asset replacement (i.e., decommissioning and commissioning assets). Typically, organizations take care of routine/preventive maintenance internally and outsource the major corrective works like rehabilitation and replacements. The nature of major rehabilitation and replacement projects is the same as construction/installation projects with all required stages from design to handover.

1.7 Exercises

Exercise 1.1
Your company has been developing an AM system for the Government of ABC country; so far you have conducted data collection for the entire road network preparing yourself to apply AM for this country. However, in the last Sunday elections, the government lost and there is uncertainty that the new government will abandon the implementation of the Pavement Management Systems (PMS). In an attempt to rescue the project from going into the garbage bin, you have secured a meeting with the new prime minister. Answer the following according to this context.

- Explain what an AM system is; do not use the technical wording; convey a simple message easy to understand by anybody from the public at large, but bear in mind your target is the new prime minister.
- Explain why the AM system is useful and will be used in the future.

Exercise 1.2
Identify the main infrastructure systems in your community and explore potential interdependencies.

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