# RISK-BASED MAINTENANCE OF PHYSICAL ASSETS OF WATER INFRASTRUCTURE: A CASE STUDY OF A MUNICIPALITY

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## ABSTRACT

South Africa is experiencing serious challenges with regards to access to sustainable basic services, ensuring and maintaining service quality such as drinking water quality, wastewater management, as well as water-use efficiency. The main challenge to delivering these services is a maintenance backlog due to a lack of implementation of infrastructure asset management within municipalities and water utilities.

The current reactive management approach was deemed unsustainable due to the high cost of emergency repairs and due to increasing customer and regulatory pressures. This relates to ineffective water infrastructure management (existing infrastructure), poor planning for new infrastructure and very importantly poor infrastructure asset management (life-cycle management).

This research paper is aimed at introducing a methodology towards the successful implementation of infrastructure asset management within South African water & wastewater organisations in public sector. It focuses on the case study of Municipality X. This paper contains findings that form a baseline of the status quo of infrastructure management challenges, maintenance strategies and perceived benefits of a Risk-Based Maintenance approach.

**Key words:** Infrastructure Asset Management, Risk-Based Maintenance, Risk-Based Inspections, Decision Making, Condition-based inspection

## INTRODUCTION

The South African Water Services Act (1997) stipulates that every citizen has a right to access basic water-supply and basic sanitation in South Africa. Continuous interruptions of water service delivery and resultant dissatisfaction of the public throughout South Africa has gained attention on various spheres of government.

Past research has shown that negligence and backlog of maintenance for water & sanitation infrastructure within municipalities is one of the key challenges to provide access to water & sanitation to all citizens. Mema (2009) highlighted that declining state of municipal wastewater and sewage treatment infrastructure in South Africa is also one of the largest contributing factors to the numerous pollution problems experienced in most parts of the country and a major contributor to health problems such as cholera outbreaks in poor communities.

Also, from a financial perspective, Pienaar (2013) and DWA (2007) has indicated that the level of expenditure on the maintenance of infrastructure in South African municipalities has been too low in the past, resulting in the deterioration of infrastructure conditions.

This challenge was well recognised by government as former Minister of Water & Environmental Affairs Minister-Edna Molewa indicated in 2013 that about R671 billion will be needed in the next ten years in order to bridge the gaps of ageing infrastructure, maintenance backlogs as well as lack of skills within municipalities.

It has become evident that municipalities need to focus their maintenance expenditure on those assets that need it most, and also to quantify the extent of maintenance required, so that appropriate planning and budgeting can be implemented to address the maintenance backlog (Pienaar, 2013).

We therefore propose the application of a Risk Based Maintenance (RBM) approach to water infrastructure as a proactive and innovative method to deal with ageing water and sanitation infrastructure. Through such an approach failure impact analysis based on a system condition assessment may assist in developing maintenance action plans to maximise planned maintenance and b) minimise service delivery interruptions as well as unplanned maintenance.

**PROBLEM STATEMENT**

**Status of Water & Sanitation Infrastructure in South Africa**

From DWA (2011) Water Services Infrastructure Asset Management Strategy it has been indicated that municipalities and water utilities need to be conscientious about water services infrastructure by improving Infrastructure Asset Management since the cost of unplanned repairs and replacement may have to be prioritised over the new construction, which would severely limit the programme for addressing backlogs and expanding service delivery.

SAICE Infrastructure Report Card for South Africa (2011) reveals that:

DWA monitor and regulate 250portable water schemes, this water infrastructure has a weighted average age of 39 years which is subjected to ageing effects associated with internal and external stresses and other impacts. There has been further deterioration in the ageing bulk water infrastructure portfolio as a result of insufficient maintenance and neglect of ongoing capital renewal. This infrastructure requires an estimated R1.4 billion reinvestment annually in order to maintain current water infrastructure.

South Africa has extensive wastewater infrastructure, comprising 850 wastewater treatment plants that transport and treat an average of 7 589 mega-litres per day. However, this infrastructure also needs urgent maintenance and replacement.

According to the report on the State of Water Services Infrastructure and its Management (2005), in 2003 DWA conducted a survey which revealed the following:

1. More than 61% of bulk infrastructure components required substantial refurbishment to reinstate their original design functionality; and reasons for refurbishment included normal ageing, lack of maintenance, vandalism and abuse.

2. The condition of 188 water treatment works was described as poor for 10%, average for 45% and good for 37%. 8% of water treatment works were not functioning at all. Inadequate maintenance was given as the main reason for failure at 17% of works.
3. 75% of bulk pipelines have breakages of once per year or less, 17% on a monthly basis, and up to 8% on a weekly basis;
4. The condition of 75 wastewater treatment works was described as poor for 25%, average for 40% and good for 29%. 5% were not functioning at all. Inadequate maintenance was given as the main reason of failure for 20% of the works

Underlying factors on above statistics included gross under-budgeting by the municipalities for water & wastewater operations, maintenance and management.

**Risk based/informed decision making process**

Zio & Pedroni (2012) define risk-informed decision making as a deliberative process that uses a set of performance measures, together with other considerations to inform decision making.

According to AwwaRF (2008), in practice, water and wastewater utilities do not use risk assessment formally or consistently in making asset decisions. Some argue this is due to lack of understanding on how risk should be analysed as well as the lack of simple practical tools for risk assessment in water and wastewater industries. Without these practical tools, utilities are also unsure about what kind of data should be collected to support risk assessment approach.

**Research Objectives**

The study aims to analyse the application of risk-based maintenance approach within Municipality X Water Services as a strategic decision making tool to ensure physical assets are maintained and prioritised based on their risks of failure and consequences which includes costs, environment, safety and service delivery, efficiency and effectiveness.

The study's key aim is to generate fundamental baseline knowledge and insights of the key priority areas top address to assist Municipality X in moving forward towards implementing risk-based maintenance (RBM) approach when dealing with infrastructure asset management for water and sanitation in South Africa.

The associated research questions that are the focus of this study, within the context of the Municipality X Water Services Department are as follows:

- What are the water & wastewater main challenges that impact negatively on public service delivery?
- What is the current status of maintenance strategies at Municipality X?
- What role do maintenance strategies play in infrastructure planning at Municipality X
- What elements of risk-based prioritization are currently implemented for strategic decision making at Municipality X?
- What are the perceived benefits of a risk-based maintenance approach for assets?

- What is the status of IT systems and processes in the department to support risk-based maintenance?

**LITERATURE REVIEW**

According to Prescott and Andrews (2011) risk-based maintenance approach considers not only the asset's condition but also takes account of failure consequences and its impact on the performance of the system. The main aim of RBM is to reduce the overall risk as a consequence of unexpected failures. The high-risk components of such a system should then be inspected and maintained with greater frequency and thoroughness than lower-risk components.

According to Khan & Haddara (2003), the dominating objectives of adopting RBM in most industries have been found to be:

- Meeting key regulatory requirements
- Reducing operational and maintenance costs on high risk failures
- Acting as a guide for asset decision making whether is worthwhile to continue with maintenance & repairs or asset renewal & replacement is the best option.
- Striking balance focus  or achieve trade-off between safety and economic risk by considering safety of assets, personnel and environment
- Maximising service delivery or productivity
- Pre-empting and prevent catastrophic failures based on conducted diagnosis
- Being able to deal with continuous ageing of physical assets based on accumulated data

**Role played by Risk-based inspections (RBI) in RBM**

One of the steps towards developing a successful risk-based maintenance framework is to know the performance and status quo of assets. According to Boshoff et al, (2007), condition assessment aims to provide adequate information on the condition of physical assets for purposes of strategic planning decision-making in order to refurbish or rebuild, capitalise and depreciate infrastructure assets based on informed residual value.

According to Apeland et al (2001), in cases whereby risk analyses are conducted with little or no relevant historical hard data, engineering judgement needs to be used. The application of judgement depends on which probabilistic approach to risk and risk analysis that is applied.

Goyet & Esteve (2007) defines risk-based inspections as a systematic/logical process that involves structured planning and inspection on the basis of the information obtained from a risk analysis of the equipment concerned. The main aim of risk-based inspections is to collect data which can be used in future. Risk-based inspections results forms part of those engineering judgements which guides risk analysis approaches to be taken.

API (2002) proclaims risk analysis as systematic use of information to identify sources and to estimate the risk and further provides the basis for risk evaluation, risk mitigation and risk acceptance. Information can include historical data, theoretical analysis, informed opinions and concerns of stakeholders.

In the context of physical asset management, RBI is an approach of identifying potential deterioration trends and threats which is likely to compromise the integrity of the equipment with an objective of assessing risk of failures and consequences.

**Extant theories, models and methods for RBM**

Most of current risk-based maintenance models and methodologies are derived from basic risk management process available in ISO31000:2009 as indicated in Figure 2.1 below.

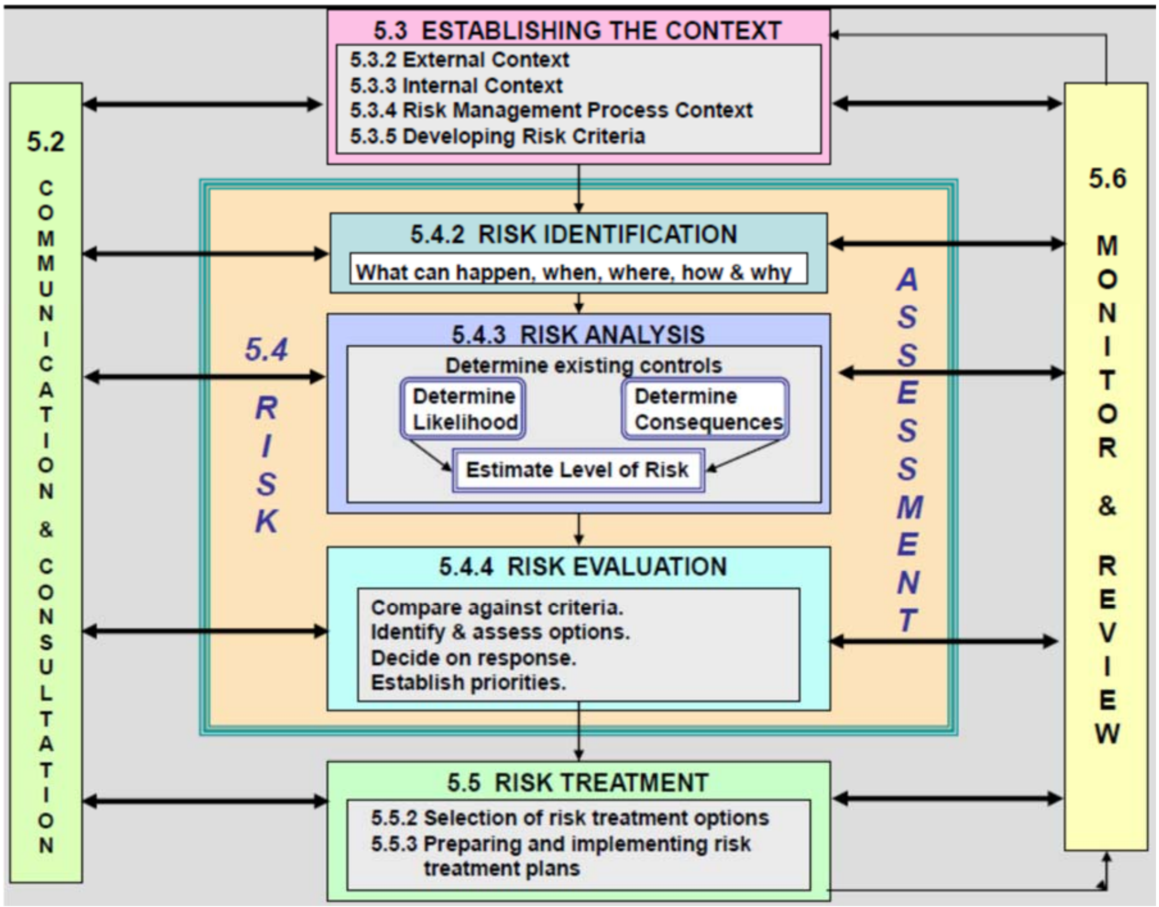


*Figure 1: Detailed Risk Management Process (Source: Copied from ISO31000:2009)*

Harb(2009) provides a detailed step-by step risk management process as follows:

**Establish the context**: Is about setting the parameters or boundaries around the organisation risk appetite and risk management activities.

**Risk Assessment** which consists of:

- **Identification of the risks**- establishes the exposure of the organisation to risk and uncertainty. There are techniques such as brainstorming, work breakdown analysis which can be used for risk identification.
- **Analysis and evaluation of the risks:** This stage considers possible causes, sources, likelihood and consequences to establish the inherent risk. This will include knowledge of the factors critical to success, the threats and opportunities related to the achievement of

objectives. After this analysis, an evaluation of the level of risk is required to makes decisions about further risk treatment.

- **Risk Treatment:** This is an activity of selecting and implementing appropriate control measures to modify the risk. Where the level of risk remains intolerable, risk treatment is necessary. Risk owners can treat risks by avoiding the risk, treating the risk sources, modifying likelihood, changing consequences or sharing elements of the risk. The remaining level of risk retained should be within risk appetite.

ISO 31000 recognises the importance of feedback by way of two mechanisms which are very important concepts and applied to every aspect of risk management. Those mechanisms are:

- **Communication & Consultation**: Is concerned with engaging internal and external stakeholders throughout the risk management process with an aim of promoting consultative team approach
- **Monitor& Review**: involves confirmation that the various risk management elements and activities are actually working effectively in line with expectations. Any gaps identified will need to be documented and remediated. This stage is critical for keeping the risk management framework relevant to the changing needs of the environment and external influences.

Khan & Haddara (2003) proposed detailed risk-based maintenance and inspection methodology which integrates quantitative risk assessment and evaluation methods with proven reliability analysis techniques.

Lanquetin ,Rouhan, & Gourdet (2007) designed an approach to cater infrastructure with complex and large diversity of equipment with enormous amount of different components as well which needs to considered during risk-based maintenance and inspections.

Khalifa (2012) has proposed the quantitative Risk Based Inspection and Maintenance methodology for optimal inspection and maintenance planning for assets subjected to fatigue and corrosion. This methodology aims to contribute towards making informed inspection and maintenance decisions to improve safety, integrity of assets in a cost effective manner with optimal utilization of physical and financial resources.

The table below indicates steps similarities on all these models as compared to risk management process:

| Steps | Risk Management Process | RBI Stepwise approach | Khalifa's RBM methodology | Khan & Haddara's RBM Methodology |
|---|---|---|---|---|
| 1 | Establishing the context | Risk Acceptance criteria | Classification of the asset's components/areas according to criticality of deterioration | Identification of the scope |
| 2 | Risk Identification | Collection of information | Asset degradation modelling | Risk Estimation |
| 3 | Risk Analysis | Risk Screening | Risk assessment (Probability of failure X | |

| Steps | Risk Management Process | RBI Stepwise approach | Khalifa's RBM methodology | Khan & Haddara's RBM Methodology |
|---|---|---|---|---|
| | | | Consequences) | |
| 4 | Risk Evaluation | Detailed RBI | Estimate cost of inspections and repairs over life time | Risk Evaluation |
| 5 | Risk Treatment | Scheduling | Inspection and maintenance planning | Maintenance Planning |
| 6 | Monitor and review | Inspection and Update according to inspection results | Optimization of the inspection intervals | |

The common criteria from all these methods are that risk is identified through various methods which include results collected from inspections as well data trends analysis and degradation modelling. It has been noticed as well that scheduling and planning is common way treating risk on all three methods presented.

However, means of monitoring and review used on Stepwise Approach and Khalifa differ from Khan & Haddara's methods. Stepwise Approach and Khalifa review inspection intervals based on results obtained from inspections whereas Khan & Haddara's approach prefers repeating the process of risk estimation and re-evaluation after risk treatment (scheduling & planning) instead of monitoring and review.

All these methods presented were developed based on ISO31000:2009 risk management process but all developed with a focus from maintenance and engineering aspects. These methods were not developed to apply throughout the structures of an organisation. As it has been gathered that risk management of these methods is one dimensional (maintenance & engineering), it is then required to develop a sustainable framework which encompasses all organisational objectives and driven from all organisational levels using top-down and bottom-up methods of risk management.

## PROPOSED MODEL OR CONCEPTUAL METHOD

### Municipality X Water Infrastructure Asset Management

Municipality X Water Services operate over water & wastewater infrastructure which comprises of 71 water reservoirs, 32 portable water towers,181 bulk connections, 9 948km water pipes, 124 water distribution zones and over 300 water & wastewater pumping facilities which includes wastewater lifting stations and fresh water booster pump stations. Municipality X operate 19 wastewater treatment plants ranging from 0.5 Mega litres/day up to 165 Mega litres/day.

In 2009 Municipality X launched a multi-year integrated infrastructure asset management programme, objectives of the plans within that programme included:

- Describing the extent, value, capacities and risks associated with assets supporting growth and social upliftment;

- Reporting on the state of infrastructure and social services provision and existing backlog;
- Describing the standards of service and performances against the assets; and
- Assessing the state of existing infrastructure asset management practice

Application of engineering asset management principles provides the improved asset knowledge to quantify the most cost-effective levels of reliability and risk, from which maintenance regimes can be optimised. These will continue to deliver benefits from reliability centred maintenance first will continued improvement towards fully developed risk based maintenance regimes.

Equipment installed within water & sanitation infrastructure suffer a decline over their life-cycle due to unstable working conditions to which they are subjected, material fatigue, damage and deformation, wear of rotating mechanical parts and to other problems depending on each process.

Asset Information plays a vital role since it supports all the primary decisions and activity components covered in an asset management framework, including the development of optimised asset policies and implementation of asset plans. The scope of asset information is broad, covering all meaningful data relating to assets and asset management, this includes asset type / location, age, capability, and condition. It also includes failure histories and consequences, work histories, unit costs and as-built drawings. Asset information is critical to maintenance and renewal decision making at both the strategic and tactical levels.

Therefore in order to construct an infrastructure baseline, it requires analysis of equipment system risks which includes social risk to customers caused by lack of water service delivery and added severity of system caused by equipment failure.

It was also necessary to understand other infrastructure challenges which the municipality is facing, hence part of the survey required participants who manage, maintain and operate assets on daily basis to highlight measure challenges which they impact service delivery.

The survey aimed to ascertain the status quo of water infrastructure assets with regards to:

- The influence of maintenance strategies to future infrastructure planning and decision making
- Acquisition of new data on degradation, reliability & failure modes.
- Effect of failures on performance and costs taking account of actual water & sanitation service demands.
- Records of planned and unplanned maintenance activities
- Financial data comprising unit costs of capital and maintenance activities, impact of failure, modern equivalent replacement values.

Proper implementation of asset management strategies coupled with maintenance strategies which are integrated in risk management provides certain benefits to operations and maintenance of infrastructure. Hence, the survey aimed to ascertain the value-add of asset management and risk-based maintenance strategy.

The survey questionnaire was developed to assess the application of asset management principles and various maintenance strategies including risk-based maintenance. Principles from national &

international standards, guidelines and best practices were also adopted. Those standards, guidelines and best practices included:

- S.A Local Government Infrastructure Asset Management Guidelines;
- International Infrastructure Management Manual – IIMM;
- Asset Management Standards -ISO 55000, 55001& 55002;
- Risk Management Standards - ISO 31000:2009
- DWS - Water Infrastructure Asset Management Scorecard;
- DWS Incentive-based Regulation Programs - Blue Drop, Green Drop and No Drop compliance systems.

**RESEARCH METHODOLOGY**

**Target Group**

Of the 68 questionnaires that were sent out, 35 responses were received (51% response rate). The study targeted Operations Managers at various levels, Chief Area Engineers, Operations Engineers, Technicians and Operations Officers within Municipality X. All these targeted groups are involved water & wastewater infrastructure operations and management.

**Research Instrument and data sources**

The primary data gathering took place through a web-based survey. The questionnaire was developed to cover a broad spectrum of asset management and risk-based maintenance issues. The survey questionnaire objective was to develop a base-line to understand the application of infrastructure asset management and risk-based maintenance within Municipality X.

The research approach and methodology was guided by the following research questions:

- What is the current status of RBM in relation to effectiveness and efficiency of service delivery to the public?
- Does current daily maintenance activities at Ekurhuleni Metropolitan Municipality Water Services assists in indicating the assets failure risks and assist on future water services infrastructure planning?
- Does information obtained from maintenance activities assist in risk-based prioritization and provides direction for strategic decision making?
- What are challenges water & wastewater main challenges which impacts negatively to public service delivery?
- Can the application of asset management risk-based maintenance approach be beneficial to Department of Water & Sanitation?

Survey questions which were divided in sections as follows:

- Section A: Questions 1 to 4 served the purpose of providing general information about group of respondents participated in the survey.

- Section B: Questions 5 to 7 seeks to evaluate effectiveness and role played by maintenance strategies in future infrastructure planning and evaluates the application of current maintenance strategies to influence decision making.
- Section C: Questions 8 intended to identify water & wastewater main challenges which impacts negatively to public service delivery.
- Section D: Question 9 aimed to evaluate the benefits of Risk based Maintenance (RBM) within water & wastewater infrastructure.

To validate the data obtained, application of triangulation was adopted whereby documentation such as policies, IT systems such as QMS and Pragma ONKEY was used as well as observations form daily operational activities.

**RESULTS AND ANALYSIS**

*Water & wastewater main challenges that impact negatively on public service delivery*

Here we intended to identify water & wastewater main challenges which impacts negatively on public service delivery. From the graph we could extract a range of challenges that mostly pertain to poor management of Municipality X with the major impacts of a lack of maintenance and budgetary issues(See Figure 1).

From the analysis we found that a lack of relevant technical skills, shortage of funding for maintenance & capital projects and lack of infrastructure maintenance indicates that there may be a distinct lack of planning from management. Even challenges such as theft and vandalism can be traced back to slack management as it is their responsibility to ensure security measures and develop awareness programmes to the community about the importance of protecting municipal infrastructure.

A contributing factor that was raised by respondents was that high turn-over of management within organisations leads to a lack of business continuity and this eventually reflects to management to be perceived as being incompetent. These management problems hamper business operations and compromise the health of infrastructure.

A second main finding from this analysis is that infrastructure is ageing uncontrollable due to lack of information and external service providers take advantage of this situation by delivering poor services as well.

Due to the condition of infrastructure which cannot deliver the services as required, community and public as whole are not willing to pay for services resulting in reduced collection of revenues.

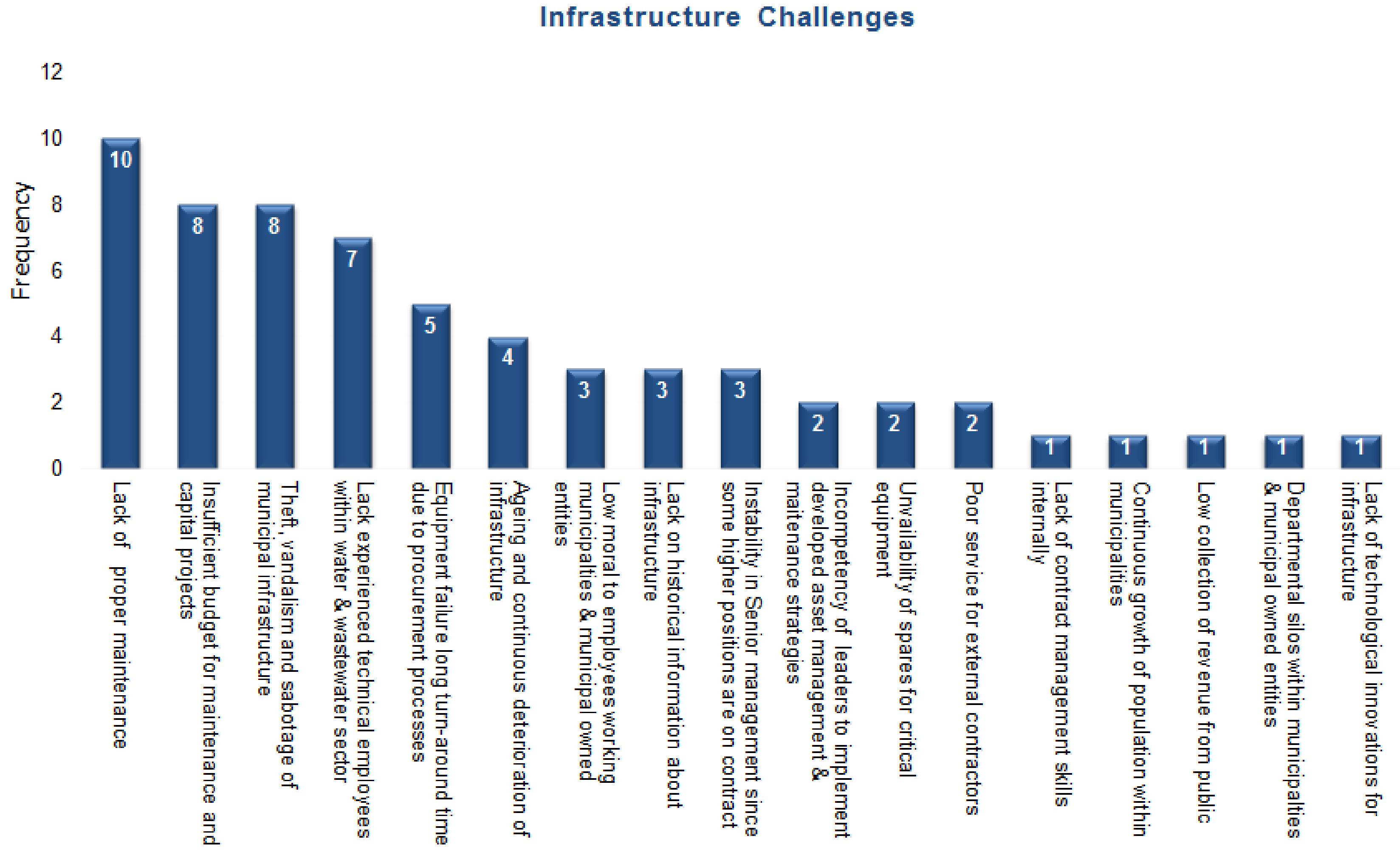


*Figure 1: Water & wastewater main challenges that impact negatively on public service delivery*

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*Current status of maintenance strategies*

This part of the study sought to establish the application of current maintenance strategies to influence decision making. The obtained results from respondents are as follows (see Figure 2):

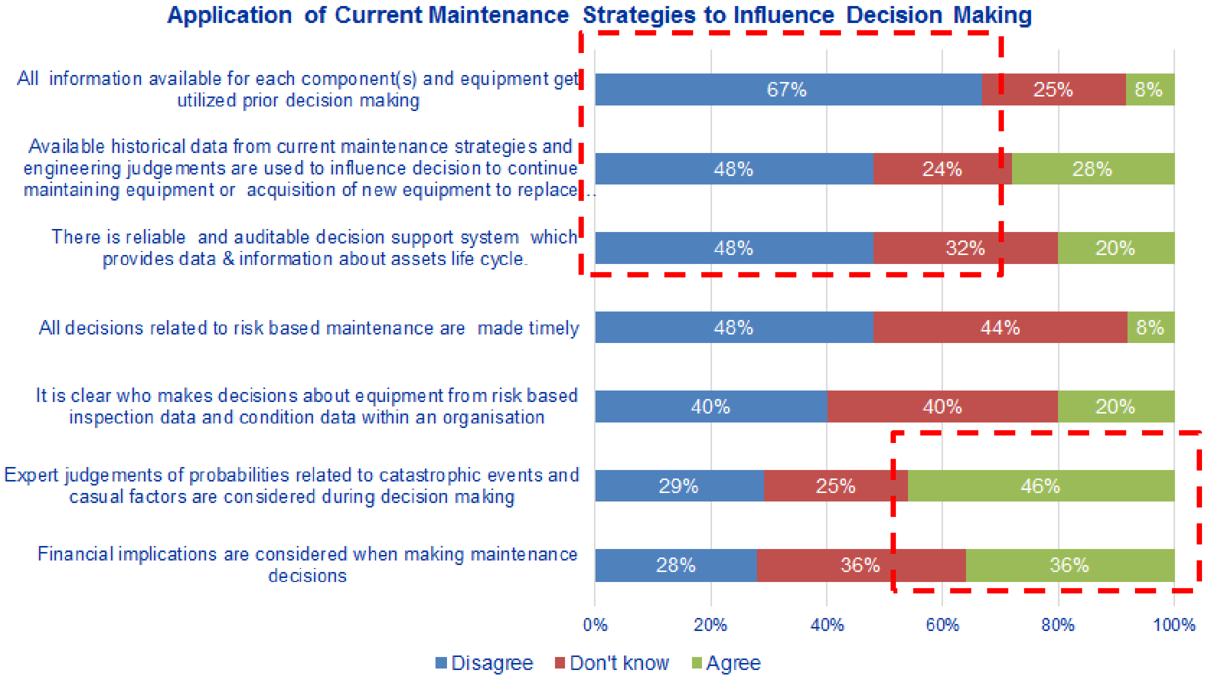


*Figure 2: Application of current maintenance strategies to influence decision making*

From the survey results it was found that the highest ranking short-comings relating to current processes and systems to manage decision making is a lack of information and support systems to base decisions on. This indicates a need for an intervention where detailed mapping and data gathering of the condition of assets need to take place and be recorded.

Furthermore respondents indicated uncertainty regarding the structures which indicates who should be responsible and accountable for making assets decisions. This may result in delays on taking decisions timeously and forces the organisations to rely on experts such as consultants to provide their opinion in cases of catastrophic failures.

*The role of maintenance strategies for infrastructure planning*

This section seeks to explore the role played by maintenance strategies in future infrastructure planning. The obtained results from respondents are as follows:

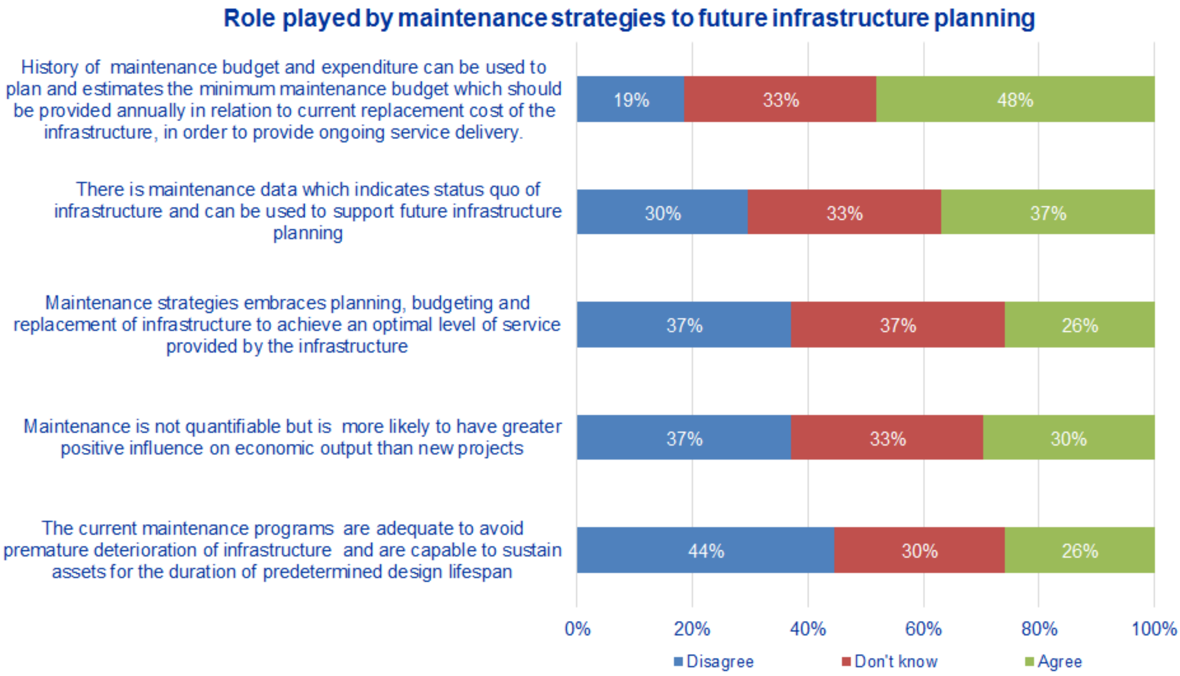


*Figure 3: Role played by maintenance strategies to future infrastructure planning*

The results indicate that there is data which indicates status quo and historical financial data can be used for forecasting future infrastructure planning. But the perception is that maintenance strategies are inadequate, they do not add value to infrastructure planning and do not influence new projects.

*Evaluation of risk-based prioritization for strategic decision making at Municipality X*

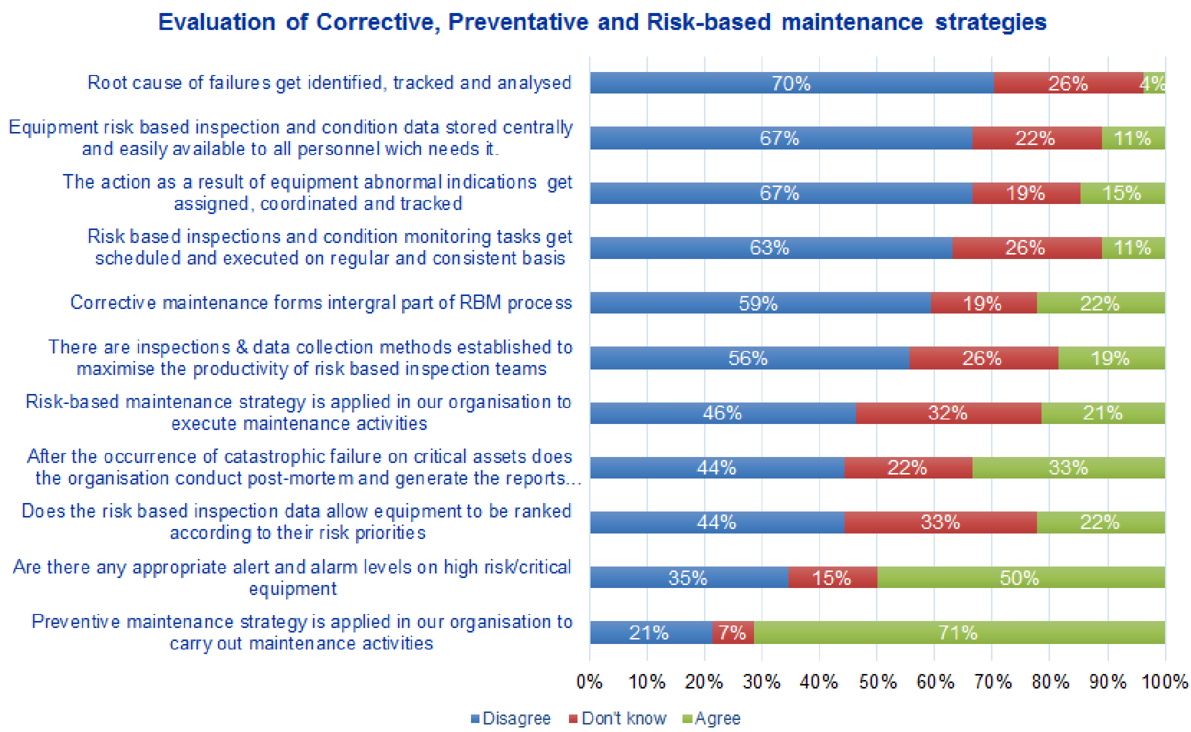


*Figure 5: Evaluation of risk-based prioritization for strategic decision making at Municipality X*

The results confirm the presence of asset management processes & systems with organisations but the absence of condition-based maintenance simply means the condition of infrastructure is unknown which makes it difficult to maintain asset without knowing their condition. Even though there maybe preventative maintenance being executed it does not add any value since the conditions of assets is unknown. Due to the absence of condition monitoring and inspections, this results to non-existence of risk-based maintenance.

*Perceived benefits of an asset management risk-based maintenance approach*

These results indicates good organisation governance can be obtained by implementing RBM, since it address DWA compliance as well financial benefits  perceived to have as its major benefits savings from improved planned maintenance and reduction of reactive maintenance.

Respondents rated improvements on infrastructure planning, reduction of catastrophic failures, an increase in equipment reliability while improving safety standards and assist in development of relevant maintenance strategies which includes condition monitoring. Other cost benefits of implementing RBM includes correct allocation of resources and prioritisation of assets or components.

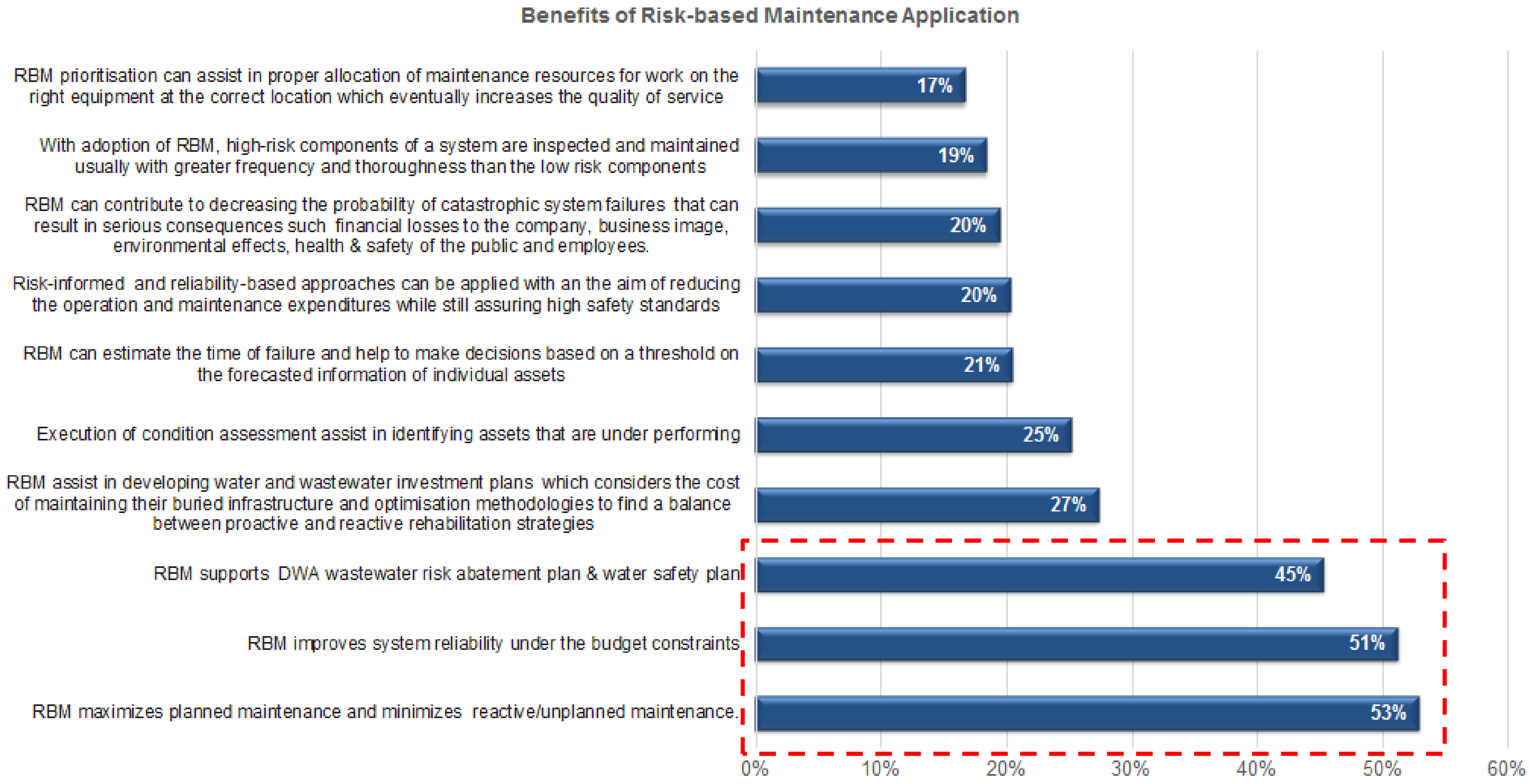


*Figure 6: Benefits of Risk-based Maintemenance Application*

**Findings from IT systems and documents**

Evaluation of IT systems and documentation was done simultaneously at Municipality X Water Services, some of the findings were found to be common for both organisations.

*Computerised management systems*

Municipality X uses a computerised maintenance management system (CMMS). A key finding is that the system is not used effectively:

- Only three of the seven modules currently in use namely:  maintenance manager, asset care developer and asset manager;
- Data is not updated regularly and therefore the asset register was found to be outdated;
- The maintenance manager is also not used effectively with field feedback data from artisans and technicians is not captured in the system. This has means history of repairs executed cannot be properly traced on this system.
- The system is used for planning preventative/routine maintenance work while other activities are done on ad-hoc basis which means there is a huge data gap in terms of maintenance planning.
- Although there is scheduled preventative maintenance work condition monitoring maintenance, risk-based maintenance activities are not implemented.
- Maintenance systems between Municipality X Water Service  and  other departments are not linked which means job requests from Operations department to Engineering department are done manually or via e-mails – with no centralised record being kept on such activities.

Other IT systems which included Procurement system and financial management systems were also evaluated. The findings were as follows:

- There is no integration amongst the systems within departments and as such all the systems are operating in isolation;
- Operational activities are not interlinked e.g if orders are placed by the Supply Chain Management department it is impossible for other departments to trace the progress of the orders hence other departments cannot plan properly;
- There are a limited number of employees who are fully trained on some of these IT systems which becomes a problem when those trained individuals are not at work.

Municipality X Water Services have infrastructure management system which contains data on all the networks, pump stations and wastewater plants in Municipality X. The following findings were made:

- This system was not live because updates are only done once after 3-6 months by external service providers
- The system is not linked to  Planning and Engineering departments, whereas sewer networks are feeding Operations wastewater plants

- Some of the assets such as mechanical equipment (pumps, valves, screens) and electrical equipment (motors, distribution boards, telemetry system) are not reflecting on the system.

*Documentary analysis*

The hard copy documents such as printed preventative maintenance & reactive maintenance job cards were also scrutinised:

- It was found that some of the information on the activities are poorly recorded which means it cannot assist technical experts to ascertain real problems or trends on assets.

Engineering asset management documents were also evaluated to establish the *maturity of engineering asset management* within Municipality X Water Services. The findings were as follows:

- Asset management policy is more relevant to finance department, it does not include maintenance, projects and other business units. This means asset management is driven by Finance Department as main custodian other departments are not participating.
- Depreciation of assets was only based on finances even if the assets has been refurbished the value of assets were never re-evaluated.
- There was lot of confusion on defining assets and how it should be broken down in components, e.g it was difficult to establish what should be an asset and what should be a component, should it be based on value or should it be based on functionality.

**Findings from observations**

During the day to day operations and through discussions with employees, the following observations were gathered. Most of field employees who operate and maintain the plants are not keen to know the details about infrastructure management. This is because employees feel management does not involve them and take their opinions about daily operations and maintenance.

It was discovered that there are no control measures for inventory control, artisans requests components for maintenance activities but nobody verifies if those components were used for their purpose. This observation also prompted the researcher to question the process of equipment failure post-mortem and root cause analysis. It was discovered that root-cause failure analysis is an office exercise whereby technicians are depending on CMMS information instead of consulting field artisans.

Even though there is Failure Response Plan which is a document which provides priorities on how equipment should maintained, it was found that artisans do not follow this document when attending to maintenance work. This was not only the artisans practice, but even maintenance supervisors were not using Failure Response Plan document as their base of planning daily maintenance work.

Municipality X Water Services are outsourcing lot of maintenance work to contractors, but it was discovered that there is no process of managing the quality of work and services rendered by external service providers.

## CONCLUSION

The survey results revealed water & sanitation infrastructure challenges which Municipality X are facing. Due to the lack of strict service delivery performance monitoring measures, local government does not take full responsibility and accountability of poor service delivery. Therefore, national & provincial government must improve methods and strategies for performance monitoring within local government to ensure that services are delivered effectively.

The majority of the challenges reported by respondents which included inadequate funding for infrastructure maintenance, lack of relevant technical & management skills and many others was concluded to emanate from poor planning and insufficient coordination throughout structures of government from strategic level to micro level.

Addressing these constraints will need improvements to service delivery planning driven together with detailed-coordinated programmes at provincial and national level. Those service delivery plans and programmes must be integrated to local government plans in order to support municipalities in delivering services efficiently and effectively.

The fundamental feature of a proposed RBM framework is the capability of integrating asset management, risk management and organisational strategic objectives. This framework is complemented by risk based/informed decision making process informed by analysis from collected data, managerial reviews and expert judgements.

Initial costs of implementing RBM can very high and consume a lot of time since this will include assessment of all equipment on various locations by a team of experts in the field. However RBM is a powerful tool to improve competitive advantage through informed decision making processes.

## RECOMMENDATIONS

Healthy database of equipment failures and knowledge backed-up by information from experienced technical experts is required in order to successfully apply RBM effectively and efficiently with water & sanitation infrastructure. At present the IT systems are not used effectively and in some cases best practice was found to be ill implemented.

RBM Key Performance Indicators should be incorporated to organisational strategic objectives in order gain smooth integration of asset management and risk management.

Communication needs to improved, at times resistance and negative attitude during implementation stages is mostly caused by lack of knowledge and consultation between management and employees at lower levels.

Implementation of Proposed Water Infrastructure Risk-Based Maintenance Management Framework requires the following steps:

- **Setting-up RBM Team**: It is required RBM team who will establish and develop the objectives of the RBM and execute tasks in accordance to RBM methodology to achieve stated objectives.
- **Equipment Grouping and Baseline development:** The team should begin with development of baseline whereby there will be identification and grouping of equipment

- **Risk-Based Screening**: This step requires screening of equipment based on risk priorities from most critical to less critical considering safety, financial impact and process or operational impact.
- **Development of Inspection Plan:** Based on risk prioritization information, then inspection plans will be developed to ensure failure risks are below at acceptable levels or even below.
- **Execution of Inspections and Inspection Results Analysis**: The appointed team should execute inspections or collect equipment data as planned then after conduct results analysis to identify the risks levels.
- **Development of solutions or corrective action plans**: Based on the results, RBM team will develop corrective action plans to address the risks identified.
- **Implementation of action plans and Performance Monitoring**: This is final step whereby developed solutions needs to be communicated to all relevant stakeholders and partner with stakeholders during implementation process then after performance of equipment needs to be monitored.

Future scope of researching should be on exploring the benefits, efficiencies and effectiveness of proposed RBM approach with water & sanitation infrastructure. This could also be applied on other public service delivery areas suffering from reaching objectives due to infrastructure asset management challenges.

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