APPLICABILITY OF PRIORITY BASED FIXED ASSET MAINTENANCE IN CONSTRUCTION CONTRACTORS: A CASE FROM SRI LANKA

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Construction Project Management

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October 2022

DECLARATION PAGE OF THE CANDIDATE & SUPERVISOR

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ABSTRACT

Construction industry is identified as one of the most asset intensive industries. The dependance on fixed assets such as construction machinery, equipment, plant and vehicles has made industry vulnerable to failures due to not having standard practices of utilization of these fixed assets. Being a fast-moving economy in South Asia, Sri Lanka is yet to fully standardize its Construction Industry and resources utilization. The published literature suggest that it heavily depends on utilization of better Fixed Assets and Fixed Asset Maintenance Systems (FAMS). Implementation of FAMS has been a challenging task for local contractors as failure cases have seen in the recent past frequently. Delays, idling, accidents, environment damage, low service level and less efficiency of fixed assets could be identified as major drawbacks, which in return produced finance outflow from the organizations. This paper elaborates on existing maintenance approaches like corrective, preventive and predictive while aiming to research the validity of Priority based Fixed Asset Maintenance approach (PFAM) in local Construction Contractors. Based on previously conducted relevant researches of more than 5 authors, it was decided to conduct a questionnaire survey followed by a Delphi consensus to establish priority parameters on a randomly selected sample of 56 organizations to develop a suitable priority score framework. Based on the survey responses and expert opinion, Physical Condition (PC), Performance (PER), and Criticality (C) were identified as three main priority categories under which sub-priority factors were determined. 33 construction equipment were selected from a road construction company and assigned priority scores to validate the suggested methodology as a case study. 54.4% of all the contractor organizations have classified their fixed asset register including construction equipment, office equipment, spare parts or service units, furniture and fittings, plant and machinery, building and land and building fixed asset categories which are stated by IAS 16 global standard and LKAS 15 local standard. It could be concluded that majority of contractors still utilizes ‘fail and fix’ or ‘preventive’ maintenance approaches, where there is technical possibility implement PBFAM practices. The priority score framework has shown substantial validity while testing with the local road contractors with real world data.

Key words : Fixed asset management, priority based fixed asset maintenance, corrective, preventive and predictive maintenance.

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LIST OF ABBREVIATIONS

Abbreviation	Description
BC	Before Christ
C	Criticality
CBRM	Condition based risk management
CIDA	Construction industry development authority
CORM	Corrective maintenance
FAM	Fixed asset management
GDP	Gross domestic production
IAS	International accounting standards
ISO	International standards organization
LKAS	Sri Lankan accounting standards
PBFAM	Priority based fixed asset maintenance
PC	Physical condition
PE	Performance
PREDM	Predictive maintenance
PREVM	Preventive maintenance

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1 INTRODUCTION

1.1 Background of the Study

1.1.1 Maintenance of fixed assets

Taking technical and administrative actions under the supervision of the technical management in order to make sure fixed assets are ready to take up their routinely works is understood as maintenance and repair in general (Reason, 2000). Maintenance and repairing of fixed assets are considered as one of the most troublesome and delaying process in any organization. The same is applied in much amplified terms in construction contractor organizations. If a generic piece of machinery is considered, the unit costs that exert throughout the lifecycle events are broken down as follows: 25% for depreciation and decay, 15% for overhead, 23% for daily utility and operation, and 37% for repairing and maintenance (2002, Peurify). It can be clearly understood that repairing and maintenance can save time and money if the process is properly planned.

1.1.2 Pre-historical non-asset intensive construction approach

The earliest evidence of construction has shown an in-depth understanding of the environment, surroundings, climate and materials which didn't utilize too much machinery and Assets. The first Shelters have been constructed based on stone, mud and other materials collected from nearby Forest and lands. The evidence suggests that it was done not only by the experts but also by the Members of the community (Ngovi, 2005). In the early European and Greek settlements, Communities have attacked other nearby settlements after which conquest of infrastructure has been performed. A Revolutionization of Stone and marble construction and infrastructure could be seen in the Roman empire. More than 75 million people have been lived within the Roman headquarters In the first century BC (Cowan, 1987). The first ever manuscript on design, architecture, construction process and building materials has been produced by Marcus Vitruvius Pollo under the supervision of the Roman Emperor. The mediaeval age, the successor to the fall of the Roman empire, has not been that famous for construction activities. Anyhow,

the written history proves the passing of construction knowledge from generation to the other within the mediaeval age as well. The middle age followed by the mediaeval age was the first era to establish formal education of construction practices and art of producing tools and machinery (Singer, 1958). It was the Renaissance era when Construction was established as a formal industry. The writings of Andrea Palladio reinvestigated the initial concepts of architecture and building science.

1.1.3 Fixed asset management and lean construction approach

Classical construction requires more workforce, assets and resources. Recently, modern methods which consume less resources have been invented (Katayama, 1996). Materials scarcity has been one of the factors for humans to come up with alternative methods To classical construction practices (Kohler, 2013). Lean construction has become the modern day art of building infrastructure (Salem, 2006). Lean construction practices depict the lessons learnt from the manufacturing industry. Manufacturing is process orientated whereas construction is project oriented. Each and every construction project is unique (PMI, 2017).

The thorough involvement of the sponsor and key stakeholders in a construction project makes it difficult to manage compared to manufacturing of some product. Therefore unlike in the manufacturing industry, construction is less likely to get automated with production lines and manufacturing assemblies. However, Global construction Giants have adopted lean best practices into their construction process in order to better manage fixed assets and materials (Salem, 2006).

1.1.4 Fixed assets utilized in construction industry

Physical component of a production or service facility, which has value, enables services to be provided, and has an economic life greater than twelve months is defined as a Fixed Asset (Haider & Koronois, 2005). The International Accounting Standard categorizes property, plant, equipment and machinery under fixed assets (IAS16, 2020). Performance of any business heavily depends on how well the business assets are managed. Construction utilizes human resources, fixed assets, Finance, technology, etc. to produce infrastructure. An asset is defined as a

foreseeable future economic benefit (Williams, 2003). Chart of accounts of any organization includes two kinds of assets, namely Liquid assets and Fixed assets (Muftinisa, 2017). Fix assets are defined as any property plant to equipment that is owned by an organisation which will be used For more than one financial year and which is not taken under consumables (CA Sri Lanka, 2013). Implementation of better fixed asset management systems has substantially reduced downtime cost, repair cost and the total cost of quality (Desai, 2017).

1.1.5 Importance of asset maintenance planning and decision making

The fixed asset maintenance planning and decision making is constrained due to the Internal and external technical capabilities, financial capabilities Environmental and safety And design and operation (Tahan,2017). Organizations approach asset maintenance based on three concepts. Those are Reactive based, time based and condition based approaches. In reaction based approach, with minimum expenditure and supervision corrective maintenance are processed, whereas in time based approach routinely preventive maintenance plan is followed. A much advanced approach would be to monitor the condition of asset and predict future possible failures and schedule maintenance accordingly (Bechini, 2010). Having a much accurate Priority based Fixed Asset Maintenance (PBFAM) plan can optimize the operational cost and maximized availability of assets which can directly impact the cash inflow of the company.

1.1.6 Adverse outcomes of existing asset management approaches

Property plant and equipment are considered as one of the most impactful cost centers to any construction contractor. It directly has dependency to site works and quality of output work. When the total life cycle cost of a piece of general equipment is considered, it is believed that, majority exerts as a maintenance cost. In fact, the breakdown of the unit costs are 25% for any depreciation and decaying, 15% for overhead, 23% for daily utility and operation and 37% for repairing and maintenance (Peurify, 2002).

Existing fixed asset maintenance approaches can be subdivided in to three categories as, Corrective, Preventive and Predictive. All of these approaches have their own pros and cons. Corrective maintenances are carried out once the fixed asset runs to a failure. Therefore, it is also known as “fail and fix” approach. Even though corrective approach make sure asset is not over maintained and kept under a bearable cost the particular piece of equipment can undergo secondary failure in the future with unscheduled long downtimes which can also be sudden and hazardous to staff working nearby. This can also result elongated labor schedules due to unpredictability (Hao, 2010).

Preventive maintenance approach is done on a periodical method which has a known time interval between maintenances. This is also known as “routinely maintenance”. Even though this approach can control catastrophic disasters, still breakdowns cannot be 100% avoided. Considerable amount of spare parts can be stored in warehouses and cost controlling is much feasible. Yet, there should be enough space and overhead to manage these warehouses so that routinely maintenances can be done without external market’s help (Hao, 2010).

Predictive approach has always initial time and cost investment where measures are taken to monitor assets to a pre agreed level of accuracy so that the next breakdown can be predicted with good precision. This approach can drastically reduce unexpected failures but initial investment would be much higher compared to other approaches. Spare parts ordering can be done on “just in time” basis. This exerts more cost centers as it requires more skill and practice to monitor assets and also operational cost would increase too (Hao, 2010).

1.2 Applicability of priority based fixed asset maintenance (PBFAM) in Sri Lankan construction industry

As per the findings of many Sri Lankan authors, Construction Industry can be considered as one of the most asset-intensive industries. Pre Covid19-Era of local industry has been identified as an investment booming period for many Construction Projects (Wedikkara, 2019). In such an environment most of the Contractors have invested in their property plant and equipment. Therefore, maintenance of those has to

be pre-planned and scheduled. This study aims to examine the applicability of PBFAM due to that reason. Sri Lankan economy has direct links to its construction industry. In fact, GDP generated due to construction works accounts to a total percentage of 7.5% in year 2019. In 2013, construction industry leads in terms of annual worth of output generated per person among all economic sections in Sri Lanka. This suggests that people management and labor productivity in construction industry is matured compared to its management of fixed assets (2020, Economic and Social Statistics of Sri Lanka). Therefore it is really important to consider implementing advanced maintenance strategies to overcome the existing adverse outcomes.

1.3 Similar studies conducted in the world

Research has been conducted in United Kingdom to determine optimum time of repair and maintenance of bridge infrastructure based on criticality and risk scores. It has been done as a case study work to prioritize infrastructure maintenance so that cost can be reduced (Adams, 2016). Somewhat similar study has been carried out in the same country to develop a software toolset which could determine repair and maintenance schedules based on reliability and risk of machinery and equipment present in a Naval base (Dikis, 2015). In Welmington, USA, a case study has been conducted to determine rehabilitation of pipeline infrastructure using condition and criticality. These researches were directly referred in determining the methodology to conduct the research.

1.4 Research problem

Lack of qualitative and quantitative information about fixed assets have made most of Construction Contractors depend on outdated Fixed Asset Maintenance methods. These “Fail and Fix method” based approaches have caused many ground level as well as management level problems. Priority based Fixed Asset Maintenance (PBFAM) approach is yet to be researched and validated in the context of the Sri Lankan Construction Industry.

1.5 Research questions

In determining the Challenges of Implementing Asset Management Systems for Sri Lankan Contractors, the following research questions will be answered in the study.

- What type of FAM approaches do organizations follow? Corrective, Preventive, Predictive or a combination of above and whether existing practices are sound enough?
- Is there opportunity to implement PBFAM in Sri Lankan Contractors?
- Can we validate the above method with real world data?

1.6 Research objectives

The objective of this study is to determine the Challenges of Implementing Asset Management Systems for Sri Lankan Contractors. Therefore, on achieving this general objective, the following specific objectives are achieved.

- To examine existing FAM approaches in Sri Lankan Contractors.
- Whether there is opportunity to implement PBFAM in Sri Lankan Contractors.
- To validate the methodology with real world data.

1.7 Significance of the study

As per the registration records of Construction Industry Development Authority, as of January 2022, more than 4100 Construction Contractors have been registered to practice construction works. This population lacks publications regarding Asset Management best practices. Senior managers of these organizations will be directly benefitted with the new knowledge gained. The validation of the PBFAM approach with real world data will give positive motivation to these organizations to implement PAS55 and ISO55000 in them. Furthermore, researchers around the world will have access to Sri Lankan data regarding Asset Management practices.

1.8 Limitations of the study

Even though Furniture and Fittings, Office equipment, Land and Buildings are accounted under Fixed Assets in an organization, this study consider Construction Equipment, Plant and Machinery and Tools only.

1.9 Research methodology

The presented research is conducted based on primary data collected via a questionnaire survey, one-to-one interviews and Delphi consensus. The main priority categories are based on previously published similar works and validation of that was carried out with expert opinion. Determination of priority sub factors were done through a three stage Delphi consensus. The proposed priority-based score system is validated based on real world data collected from a contractor organization at last.

1.10 Guide to thesis

The flow of the research reports is described in this paragraph. First chapter discuses about the background of the study and it funnels up the research scope to measurable portions. Researchers' motivation to conduct this research is emphasized and research problem statement is the ultimate result of this chapter. Furthermore, brief summary of the applied methodology is also included. Finally, limitations and the scope boundary are defined. The second chapter is all about the literature survey. The broad aspect of the research scope and its historical routes are discussed at the first place. The excising issues of fixed asset maintenance approaches and its validity in Sri Lankan context is also described. Similar research works on prioritization of fixed asset maintenance decision are also included. Third chapter is dedicated to the research methodology. How technical terms and definitions shaped the research conceptual framework is mentioned. The statistics related to the population and sample are also mentioned in this chapter. Reader is able to collect details about data collection, its analysis at the later part of chapter 03. Analysis and discussion of the survey results is the man inclusion in chapter four. Step by step approach of data analysis is presented through series of graphical illustrations. Chapter five encloses the research findings under conclusions and recommendations. How the research questions were solved and whether objectives were reached at satisfactory level are discussed. At last, but not least, the all the valid references are summarized under the chapter six. In addition to that some valuable documents are also attached for in detail justification.

2 LITERATURE REVIEW

2.1 Introduction

Literature review is globally recognized as the heart of any study. The utilization of primary and secondary data sources for the purpose of shaping a research scope is idealized as literature review (Saunders & Lewis, 1997–2012). In this chapter researcher aims to span the collected literature relevant to the study in a way reader will be more and more focused like filtering through funnel. The broad background of the study and its historical routes are mentioned at first. The technical terminology is also defined then and there as necessarily.

2.2 Dependency of construction on assets

There is a direct technical dependency between assets and construction work output. First published term which has discussed the technical dependency between assets and work output is "equipment cost per unit physical output". Within the time period of 1920 to 1970 there has been an increasing trend of using more assets in construction works hence equipment cost per unit physical output has increased (Koch, 1979). Modern-day construction organizations follow established accounting standards to account overall assets used in the business. Manufacturing and construction organizations are highly dependent of assets in their inventory. This greater dependency makes them vulnerable to market price variation of different tangible and intangible assets (Sanvido, 1990).

The International Accounting Standards Board defines as any resource which is governed by the particular organization of entity that enables futuristic economic

benefits flown in favor of the organization. This definition can be applied to any construction organization as well. Following are the key technical properties which further define "assets in construction".

(a) *resources*. Any resources brought to the premises which has a specific destination in the construction process are considered as assets. 'Resources are bound to a destination in the worth generation' (Pallot, 1992).

(b) *legally owned by the entity.* Legally any asset is owned by the construction organization also similarly mentioned as 'having proprietary rights' to the assets.

(c) *not futural expected events and assets.* Any futuristic event which can gain ownership of assets are not considered as assets. Assets accountable are only ones which are established, owned in the past as of current date.

(d) *enables economic benefits.* Assets are believed to be having capability to bring economic benefits to the entity such as futuristic cash flows and cash equivalents.

Assets are further divided in to two main categories based on International Accounting Standards (IAS) as current assets and non-current assets. Non-current assets are also commonly described as fixed assets.

2.3 Equipment and machinery used in construction

Mainly plant, machinery and equipment are accounted under tangible fixed assets (International Accounting Standards, 2018). Construction works require general equipment and specific equipment also. Generally used construction equipment are sub divided as follows based on the function of them (Day et al, 1991).

(a) *Power units*. It includes power sources that provide energy for any construction works. Generators, air compressors, internal combustion engines, hydraulic pumps are some of examples for power units.

(b) *Prime movers*. This equipment makes stationary and non-stationary fixed assets moving for required construction works. Cables run due to a power unit is an example for a stationary prime mover in a stationary fixed asset. A crawler tractor is an example for a non-stationary prime mover that is used to tow a scraper or a compactor.

(c) *Excavating equipment.* Any machinery or equipment used to materialize earth and rock are called excavating equipment. One such example is a tractor mounted bulldozer with a universal blade.

(d) *Material handling equipment.* Machinery, equipment and vehicles in specific which are used to handle and transport materials on land and air are defined as such. Mobile cranes do handle material vertically to serve building levels on the other hand a dump truck might carry material on land horizontally.

(e) *Material processing equipment.* This equipment produces required material products like cement, mortar, aggregates and bituminous paving materials using raw materials provided. Such examples are concrete mixers, mix silos, batching plants, storage bins, feeders and screens.

(f) *Finishing and placing equipment.* Maneuvering, placing of mixtures and materials in relevant locations and furnishing up to standard compacting is the function of finishers. Screeds, compactors, pavers are ideal examples for these categories.

2.4 Classification of fixed assets

Organizations around the world have implemented a standard called IAS 16 to account their fixed assets. IAS 16 the accounting standard developed specific to property plant and equipment by International Accounting Standards Committee. A classification for fixed assets is mentioned in the above accounting standard.

Table 1 Classification of fixed assets

IAS Category	Relevance to the construction industry
land	Company owned non developed land area.

	Ex- Car park land area
land and buildings	Land with a fully or partially constructed facility in it. Ex – Vehicle yard
machinery	A system of processes that has many moving parts and has a work output. Ex – Concrete mixer
ships	Not relevant
aircraft	Not relevant
motor vehicles	An automobile that run on fuel or solar energy which carries either passengers or goods. Ex – Tipper truck
furniture and fixtures	Interior elements made out of timber that are utilized for daily requirements. Ex – Wooden cupboard
office equipment	Electronic appliances that are used for official purposes. Ex – Desktop computer

2.5 Standards in physical asset management

In early 1980s, with the scaling up of the power sector in the United Kingdom It was understood as mission critical to develop the status assessment system in order to improve loopholes that were there in the existing asset replacement methodology. Ultimately, Condition Based Risk Management (CBRM) methodology came into practice. In the 20th century, within Europe, many asset intensive Business models were established. The Institute of Asset Management and British standards took initiatives to develop the PAS 55 standard on how modern day organizations should maintain assets. Major Tech companies and oil and gas companies started implementing PAS 55 since then. In 2008 the standard was revised, improving some areas (Woodhouse, 2014). The same concept was thoroughly looked at by the ISO committee and in 2014 ISO55000 International stand was released.

Table 2 ISO Standards for Fixed Asset Management

ISO55000	Overview Principles and Terminology
ISO55001	Management system - Requirements
ISO55002	Management system - Guidelines for application

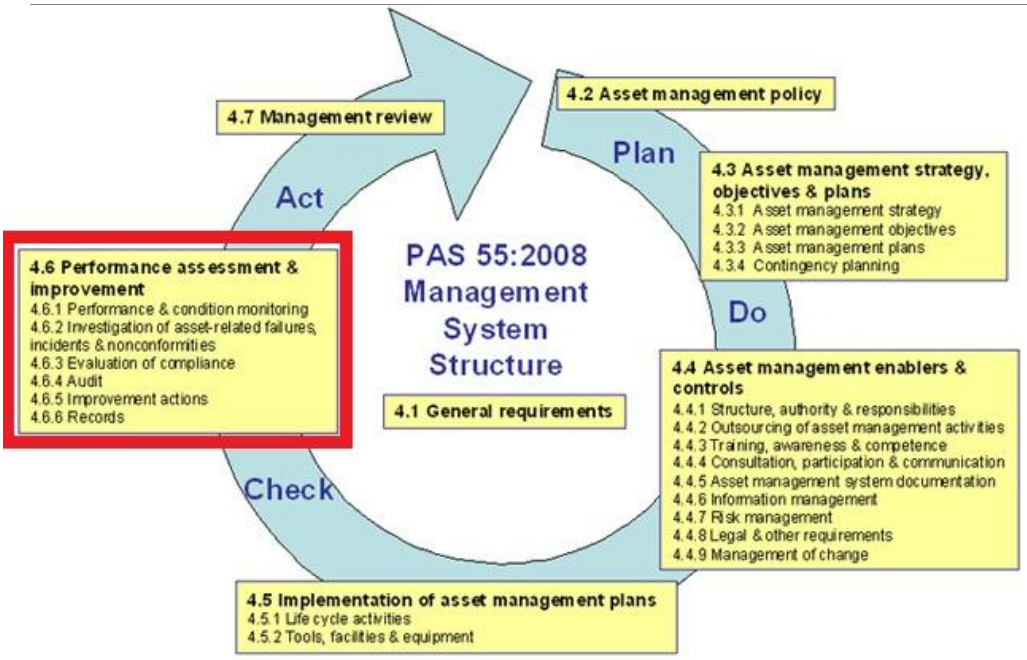


Figure 1 PAS55 - Condition Monitoring

The PAS55 structure, spans over a classification as follows. Having required functional, technical and managerial provision to understand, legalize and implement PAS55 is first looked at under 'General requirement'. A gathered group of people whom given authority to act towards PAS55 implementation then undergoes a procedure to establish the standard policy framework within their organization so that whenever a discrepancy arises, technical team can review the policy framework under 'Asset management policy'. The elected project manager and the project team establishes the PAS55 goals and implementation schedule under 'Strategy objectives and plans'. The next phase is the most critical phase as the entire organization takes arrangements to let go previous procedures and implement PAS55 system to moderate fixed asset management standard under 'Implementation of asset management plans'. This research work emphasizes the importance of the next step of the process 'Performance assessment and improvements' as the study discusses about methodologies which organizations can adopt to improve maintenance and repair

decision making process through assigned priorities. At last the management gathers and record lessons learned under 'Management review' phase

2.6 Poor fixed asset management as a root cause for construction project failures

A situation where a project manager is incapable of delivering agreed scope on time and budget or a non-completed/ abandoned work are identified as a construction project failure (Shahhossein et al, 2018). Most of the published literature found in Sri Lanka and other countries have established the fact that management of fixed assets used for construction play a major role in project failures. Following are the collected publications.

Table 3 Causes of Construction Project Failure

Country	Research Author	Poor Workmanship	Poor Organizational Management	Poor Equipment (FA)	Aged/Dated Technology	Poor Industrial Relationships (Communication)	External Factors
China	(Tam et al, 2004)	✓	✓	✓	✓	✓	
Ghana	(Danso, 2014)	✓		✓		✓	
US	(Baldwin, 1971)	✓	✓	✓	✓	✓	
US	(Odeh & Battianneh, 2002)	✓		✓			✓
Australia	(Love & Li, 2010)	✓	✓	✓	✓	✓	
Palestine	(AL.Hallaq, 2003)	✓	✓	✓	✓	✓	
Iran	(Shahhossein et al, 2018)	✓	✓	✓		✓	✓

Sri Lanka	(Silva et al, 2016)	✓	✓		✓	✓	✓

Majority of the authors have mentioned accidents, delays, adverse environmental and impacts on work quality because of conventional fixed asset management practices used in contractor companies.

2.7 Approaches to maintain fixed assets

2.7.1 Corrective maintenance (CORM)

The corrective maintenance strategy is based on the "fail and fix" concept. Based on previously published literature, it can be observed that many of the manufacturing companies have adopted corrective maintenance approach to improve the existing non planned repair procedures in 1970 (Gilbert and Finch, 1985). Following are some of the very first attempts taken to streamline corrective maintenance in companies.

1. Recruiting more people to the maintenance team
2. Conducting training sessions to improve maintenance process
3. Enhance repairing work shop facilities
4. Keeping alternative fixed asset to replace assets under maintenance

It does not require details and complex data analysis tools to proceed corrective maintenance. Most of these are unscheduled maintenance. Main objectives of the corrective maintenance approach are to reduce impact to the business process and bring back fixed assets under maintenance quickly.

2.7.2 Preventive maintenance (PREVM)

Preventive maintenance is somewhat advanced compared to corrective maintenance approach. Repairing of equipment are planned to do be done before it is broken. The main process of this approach is to determine time period that a piece of machinery can be used without maintenances. Based on these time values repairing works are scheduled on a periodic manner. The routine Maintenances/Repair and Services are taken under preventive maintenance. Critical decisions to be taken while undertaking preventive maintenance are when and at what intervals the asset should be repaired.

Previous failure events and service records have to be routinely monitored if an organization is having this strategy (Tahan,2017).

2.7.3 Predictive maintenance (PREDM)

In medicine doctors do predictions based on tests like blood pressure, urine, full blood count, similarly technicians use testing procedures such as vibration tests, visual inspections, oil tests, emission tests and many more to predict future breakdowns and failures. Much advanced and sophisticated tools and techniques are used to predict repair and maintenance. Organizations practicing just in time and lean are more towards this strategy. Mechanical and electrical performance of the Asset should be accurately monitored for this purpose. Condition based maintenance and Predictive maintenance strategy often share the same concept and principles (Tahan,2017). Unlike corrective and preventive maintenance approaches, predictive approach require beforehand measurements of all fixed assets so that repair schedules can be placed.

2.8 Priority based fixed asset maintenance (PBFAM)

The prioritization process makes sure that maximum benefits are gained on consumed time, effort and resources to maintain physical assets. It is essential to determine on what basis and factors the prioritization process should be done. Ultimately fixed assets will be ordered and sorted based on their priority values. Authors throughout the world referring to different industries have come up with a variety of factors by their own research. The main factors and the relevant industry are listed in Table 3.

Table 4 Main Factors to prioritize maintenance decision

Author	Industry/Work	Suggested Priority main categories

		Condition	Criticality	Performance
Miles 2007	Pipe Rehabilitation	✓	✓	
Marques 2007	Manufacturing Plants	✓		
Tahan 2017	Energy and Solar sector	✓		✓
Małgorzata 2021	Production Facilities		✓	✓

(a) *Condition.* Any physically measurable parameter which can predict underlying malfunctions are considered under the condition priority main category. In similar research to set condition-based priorities to rehabilitate sewers and pipelines, an American researcher has used structural condition, previous maintenance records and capacity as sub categories under condition main priority category. Similar sub categories to be used in this research are planned to be defined based on expert judgement and questionnaire survey responses.

(b) *Criticality.* The level of importance of a particular fixed asset is meant by criticality. Similarly, it can be considered as the level of adverse impact that absence of a piece of instrument can generate. In the above-mentioned American research, the researched has used Impact on transportation, Impact on environment, size and ease of repair sub categories under criticality main priority category.

(c) *Performance*. The level of work output of the asset is measured as performance. A vehicle which had a 16 km/liter initial fuel consumption can only perform up to 10 km/liter in the current circumstance. This is a fine example for performance criteria. Similar to condition and criticality sub priority categorizations are planed to be defined based on expert judgement and questionnaire responses.

2.9 Sri Lankan construction industry and its recent trends

2.9.1 Industrial economic sector in Sri Lanka

Economic activities conducted in Sri Lanka can be classified under three categories as the "Agriculture Forestry and fishing", the "Industrial" economic sector and the "Services" economic sector. The "Industrial" economic sector contains works related to construction of infrastructure, production of electricity, gas, water and sewerage, manufacturing, mining and quarrying. Construction sector has been included under the economic sector of industry. The construction activities alone have contributed 7.5% to the national GDP year 2019. Therefore even a slightest improvement in the construction industry can uplift the national GDP substantially (2020, Economic and Social Statistics of Sri Lanka).

2.9.2 Statistics of Sri Lankan construction industry

Construction Industry Development Authority in Sri Lanka has the statutory power to classify and register organizations related to construction sector in the local context. Organizations are initially classified as shown in the below table.

Table 5 Construction contractor classification - CIDA

Main Class	Sub Class	Grade
Main Contractor	Building Construction	CS2 CS1 C1 C2 C3 C4 C5 C6 C7 C8 C9
	Highway Construction	
	Bridge Construction	
	Water Supply and Sewerage	
	Irrigation and Drainage Canals	
	Dredging and Reclamation	
	Storm Water disposal and Land Drainage	
	Maritime Construction	
	Heavy Construction	
Specialist Contractor	Electrical & Mechanical Services (EM)	EM 1 EM 2 EM 3 EM 4 EM 5
	Specialised Construction Contractors (SP-C)	SP-1 SP-2 SP-3 SP-4 SP-5
	Piling	GP-P GP-B1 GP-B2

4121 Construction contractors registered under CIDA as of January 2022 are considered as the population for this research.

2.9.3 Lessons to be learned from manufacturing industry

Manufacturing industry in Sri Lanka has a wide variety of diversifications. Manufacturing of food beverages and tobacco products, textile apparel and Leather products, wood and furniture, paper products and printing, coke and petroleum products, chemicals, Pharmaceutical products, rubber and plastic, metals and Minerals, machinery and equipment are accounted for in the economic census. On the other hand, housing, building construction, road and Bridge construction and all Civil works are accounted for under the classification of construction activities.

Contribution to the national gross domestic production from manufacturing and construction has increased 39.7% and 37.8% respectively between 2014 to 2019. This can be taken as clear evidence to prove better management of resources and assets in the manufacturing industry compared to the construction industry. In 2019, the construction industry has shown an employment percentage of 8.5% whereas in the manufacturing industry it has shown a value of 18.4%. In 2013, the construction sector showed the most annual output per person engaged by any Economic Section. It emphasizes the better human resources management techniques adopted within the construction industry compared to other industries in Sri Lanka. The majority of locally published literature regarding implementation of ISO 55000 and PAS 55 are related to Manufacturing industry. It can be concluded that in terms of management of assets, manufacturing industry is much matured.

2.10 Applicability of priority based fixed asset maintenance in local contractors

Improper utility and maintenance of especially heavy cranes, loaders have been identified as the third most cause for “struck by” accidents happening in construction

sites (Rameezdeen, 2006). In the Sri Lankan context, delay of mobilization of critical fixed assets is identified as one of the main 10 causes for overall civil engineering project delays (Kesavan, 2015). Even though companies practice considerable level of asset management practices still there are a lot of areas to be improved. Based on local publications it could be identified that contractors are yet to establish standards for fixed asset management. Many organizations perform ad hoc maintenances without any smart analysis. Based on above facts researcher was motivated to conduct the research on applicability of priority based fixed asset maintenance in Sri Lankan context.

2.11 Summary of literature survey

Any resource which is governed by the particular organization of entity that enables futuristic economic benefits flown in favor of the organization is defined as an asset. Construction industry depends on fixed assets like machinery, motor vehicles, land and buildings, plant, furniture and office equipment. Standards like PAS55, IAS and LKAS discusses the best practices of utilization of these fixed assets. Many authors from all around the world have discussed poor fixed asset management as one of the key parameters which aligns with construction project failures. Previously published literature has discussed about popular fixed asset maintenance approaches such as corrective, preventive and predictive methods. Recently many European and Asian researchers have conducted researches on priority based fixed asset maintenance, where physical condition, performance and criticality have been discussed as main priority factors. The local statistics related to construction industry suggests that it needs improvements related fixed asset management where as good positive trends are shown regarding human resources management as a comparison.

3 METHODOLOGY

3.1 Introduction

This chapter presents the scientific research approach which was followed to conduct this research work. Even though there are enough research publications available globally within the scope of fixed asset management, still a methodology to research the stated objectives are not found in the Sri Lankan context. Therefore, the proposed methodology holds a unique approach which combines both qualitative and quantitative research components. A thorough insight of the inclusions of this chapter are given in the below paragraph.

Referring to the first part of this chapter, reader is able to understand scientific theorems, definitions, standards and other terminology defined within the research scope. The continuation of the chapter carries in detail explanations of the conceptual framework of the study its development and the establishment of research methodology on top of it. In the middle of the chapter reader may find the assumptions made by the author. At the later part of the chapter, diversity of the population and the sample and the sampling procedure are discussed. At the end, collected data and its analysis techniques are explained with validation also.

3.2 Development of the research methodology

Establishment of the research methodology was a stepwise process. The initial step was to idealize the broad research scope based on scientific technical terms and theories found on initial literature survey. Initial discussions with industrial experts

and supervisor also shaped the research scope considerably. Already published literature was the main source considered. One of the directly related publications found from United States has the following research steps.

S. Wayne Myles and Frank C from Wilmington, USA have suggested a five-step process of prioritizing pipelines for rehabilitation. The first step is the identification of condition and criticality factors which determine the level of priority. Then a ground survey has been conducted to determine details of the pipeline infrastructure system. Then all the factors were assigned levels. Every pump station was then given a calculated priority score. Finally, these scores were considered to list and prioritize the maintenance of the pump stations.

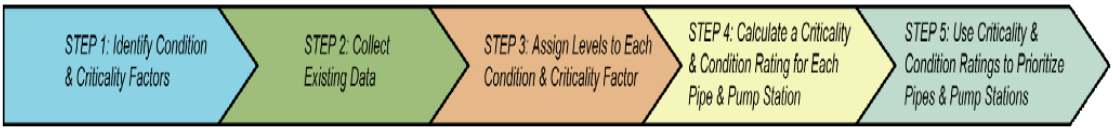


Figure 2 Suggested prioritization process by S. Wayne Myles and Frank C

Narrowing down to the suggested methodology was done based on this above mentioned previously published process. In the proposal stage multiple methodologies were alternatively evaluated by which the optimum approach was selected. Expert views suggested that main priority categories have to be redesigned in a way which addresses Sri Lankan situation. Therefore, a Delphi consensus was followed to arrive at short listed priority categories. Many authors have used the same technique whenever a score framework has been their main research methodology. Establishment of risk frameworks has been studied by publishers and most of them were based on Delphi technique (Cunliffe, 2002). A questionnaire survey was the optimum way of collecting written responses from organizations. Ease of sending and receiving, simplicity, online accessibility have been pros of this technique compared to meetings and one to one interviews (Cunliffe, 2002). Ultimately, validation of the suggested priority score framework was done as a case study work. The overall research methodology is presented in the below flow chart.

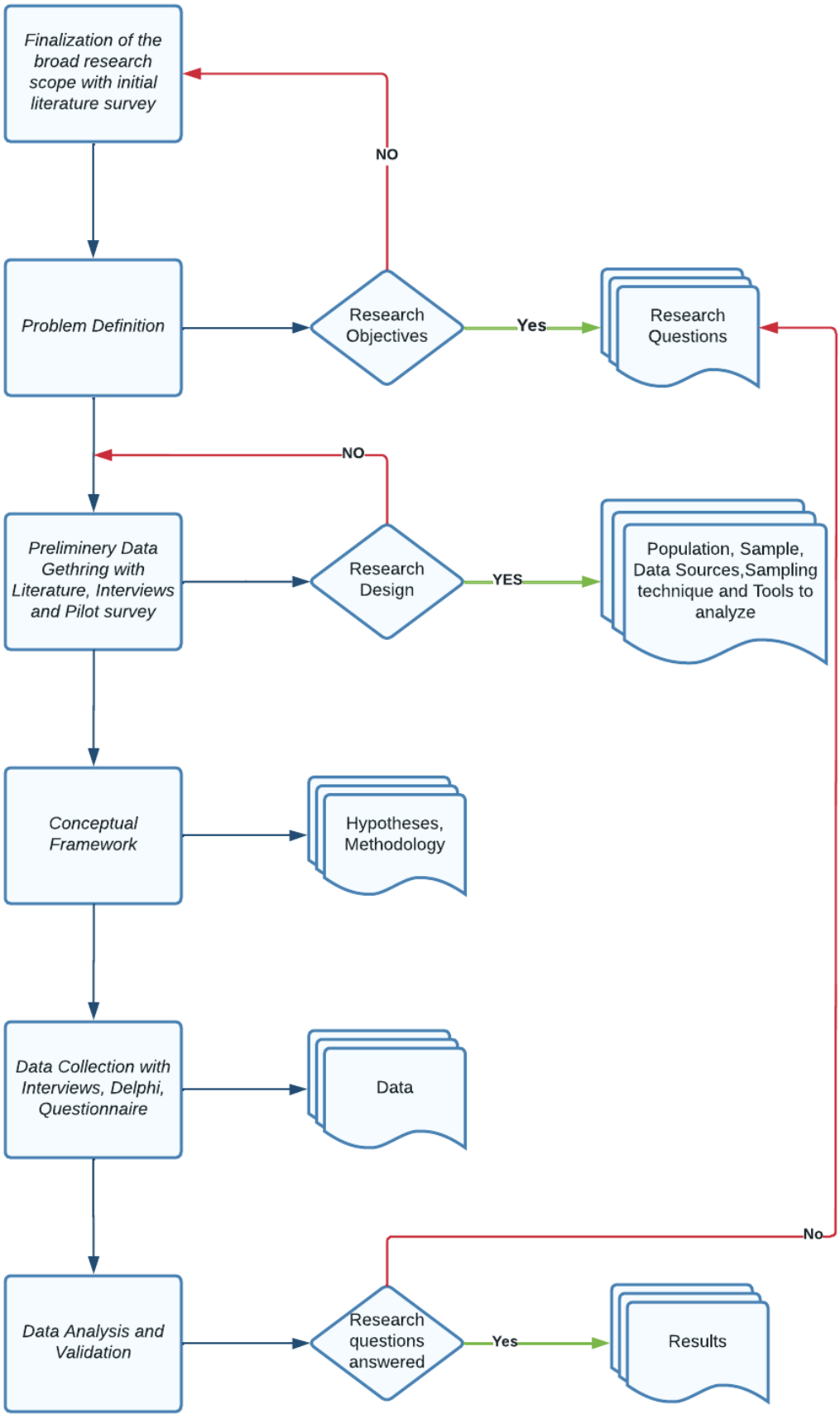


Figure 3 Research methodology framework

3.3 Definitions of key technical terms

Assets and fixed asset

Any resource which is governed by the particular organization of entity that enables futuristic economic benefits flown in favor of the organization are defined as an Asset by International Accounting Standards Committee. Assets are sub divided in to current assets and non-current assets for ease of financial reporting. Non-current assets are usually considered as fixed assets. Fixed assets are defined as any long term held property, plant, machinery of equipment that will be used in the operation to generate income to the organization (IAS 16).

Maintenance of fixed assets

Taking technical and administrative actions under the supervision of the technical management in order to make sure fixed assets are ready to take up their routinely works is understood as maintenance and repair in general. Commonly organizations use corrective, preventive and predictive maintenance approaches.

Prioritization of maintenance decision

A particular fixed asset is given more priority that another once prioritization of maintenance decision is implemented in an organization. The prioritization is performed based on priority score of each individual fixed asset. The priority score is calculated based on sub scores of the priority categories and sub priority factors. This research aims to determine priority categorization and factors as well.

Priority categorization of construction fixed assets

Physical Condition

Physical condition was identified as a strong indicator of underlying malfunctions in any construction equipment. Based on initial literature survey it was noticed that

physical condition can be accurately measured with even bare minimum availability of skill and instrumentation. Many overseas publishers have mentioned Noise and Vibration, Oil and fuel leakages, Body corrosion and Mechanical defects as physical condition factors to consider (Miles, 2007), (Marques, 2007).

Performance

Performance of fixed assets is defined specific to three dimensions, they are capacity, downtime and fuel/liquid and power consumption. All of the parameters are measured under current situation of the asset. Capacity of motor vehicles used in construction are measured in terms of load carried. When curb weight is subtracted from its gross vehicle weight rating, capacity carried can be determined. For other machinery and equipment capacity is measured by determining maximum work output that it can produce. If the machinery, equipment or vehicle is utilizing fuel/liquids or/and power to run, how efficient the use of those resources is a measurement of performance. This can also become a cost center as most of these resources are leading to cash out flows from the organization.

Criticality

The third priority category is criticality and it emphasize how important a particular asset over the others. Prioritization based on criticality makes maintenance decision biased to importance of critical assets. The first priority factor considered is expected level of service. Certain assets are required on daily basis and other are not required. If construction work demands a particular asset over the others, then its criticality is set to be high. Second priority factor considered was impact on health, safety and environment. Availability of some construction equipment make construction work site safe for staff members. One such example is light post. The night works have to completely depend on availability of proper lighting. Environmental damage is also considered as one major aspect defining criticality. Some construction equipment directly impacts the quality deliverables of the construction work. For an example, bitumen pavers needed to be given more priority since quality of the paving directly depends on it. Therefore, the third factor considered was impact on construction quality. The last priority factor is reliability and age. Newly bought instruments are

much reliable than old ones. Therefore, priority score of an old machinery is set to be high in value.

3.4 Key components of the research methodology

The above-mentioned technical terms were idealized as the core components of the research work conducted. One the basis provided based on the said technical terms following steps were carried out to come up with the research methodology framework.

3.4.1 Preliminary literature review and data collection

Global publications were initial reviewed to get a clear picture of the research scope and key terms to search on engines. Terms such as ‘fixed asset management’, ‘maintenance strategy’, ‘predictive maintenance’, ‘priority-based maintenance’ were the outcome of this preliminary review. With these results availability of local publications was searched by which it was found that the level of availability is at null to less.

Before beginning the detail literature review, technical experts were approached to get the basic understanding of the subject matters. With the non-formal discussion had, the research scope and the objective were revisited and finally research problem and research questions were developed. Preliminary stage of the research work made literature review easier and quicker to conduct too.

3.4.2 Detail literature review

Secondary data sources such as published journal articles, thesis, standards, regulatory organization’s websites and many other sources were reviewed using above mentioned research key words. A total of 3 months was taken to complete the literature review as repercussions of new findings impacted the research scope in the initial stage of the study. Abstracts of more than 70 articles were read and 37 articles were in detail referred within this research work. Priority was given to latest publications and some of the earliest publications were also reviewed to understand the historical routes.

3.4.3 One to one interview and Delphi consensus

As a pilot study initially few experts and the supervisors were called to fix appointments to discuss the research scope and sub research areas. With the knowledge gained 7 experts were approached to gather in detail details about their ideas on the research and its sub areas. An average of 20 mins time was spent with a list of open-ended questions for them to elaborate more via online means. The main objective of the interviews was to identify and streamline a pilot questionnaire with established sub research areas. Same experts were able to respond to a three round Delphi process to define priority sub factors. This method was composed of three rounds which didn't have a specific questionnaire since the objective was to reduce and validate priority sub factors to suit the industrial circumstances. A similar method has been used in research on healthcare improvement parameters refining in United Kingdom (Fink et al, 1991).

3.4.4 Questionnaire survey

With a number of 15 questions a pilot questionnaire survey was conducted using Google Forms to validate questions and results. The main questionnaire was then formed on the University of Moratuwa Lime survey platform. Questionnaire was composed of four main areas as shown in the below table.

Table 6 Questionnaire sub sections

Questionnaire sub section	Explanation
User and organization details	To gather details about respondent and his organization
Existing Fixed asset management practices	To determine whether organizations have successfully implemented corrective, preventive, predictive or combination of those approaches in their organizations
Priority based fixed asset maintenance	Technical, functional and managerial possibility to implement priority based

	fixed asset maintenance method in their organizations

3.4.5 Case study - Data validation ground survey

A field survey is proposed to collect priority figures of Construction Equipment, Vehicles and Plant and Machinery from a selected Organization. The chief mechanical engineer of one of the leading road construction companies was approached and a presentation of the research was done. With the approval granted by him, four sites were visited to gather details of fixed assets used in construction. Details of the sites are as follows.

Table 7 Road construction Company's sites visited for data validation

Site name	Description	Head personal involved
B161 Widening and Improvements to Imbulgoda – Weliweriya Road	Construction instruments being used for widening an existing road	Residing Civil Engineer
Company Vehicle Maintenance yart at Ranala	Inspection and repairing of construction machinery at a warehouse	Warehouse Manager
Widening of Kirimandala Mawatha	Construction instruments being used for rehabilitation of a broken road	Civil Engineer

Organization	–	A Road Construction Company
CIDA Registration Category	–	C1 for Road
Type of Fixed Asset categories	–	Vehicles, Construction Equipment and Plant and Machinery

Number of Fixed Assets surveyed – 33

Every piece of construction machinery was observed individually to assign priority scores based on following conceptual framework. The technical help was provided by the warehouse technician and site engineer. Onsite inspections of all the priority aspects were carried out within three office days. The prioritized fixed asset list was rediscussed with the warehouse manager and his consent was finally taken to validate the results.

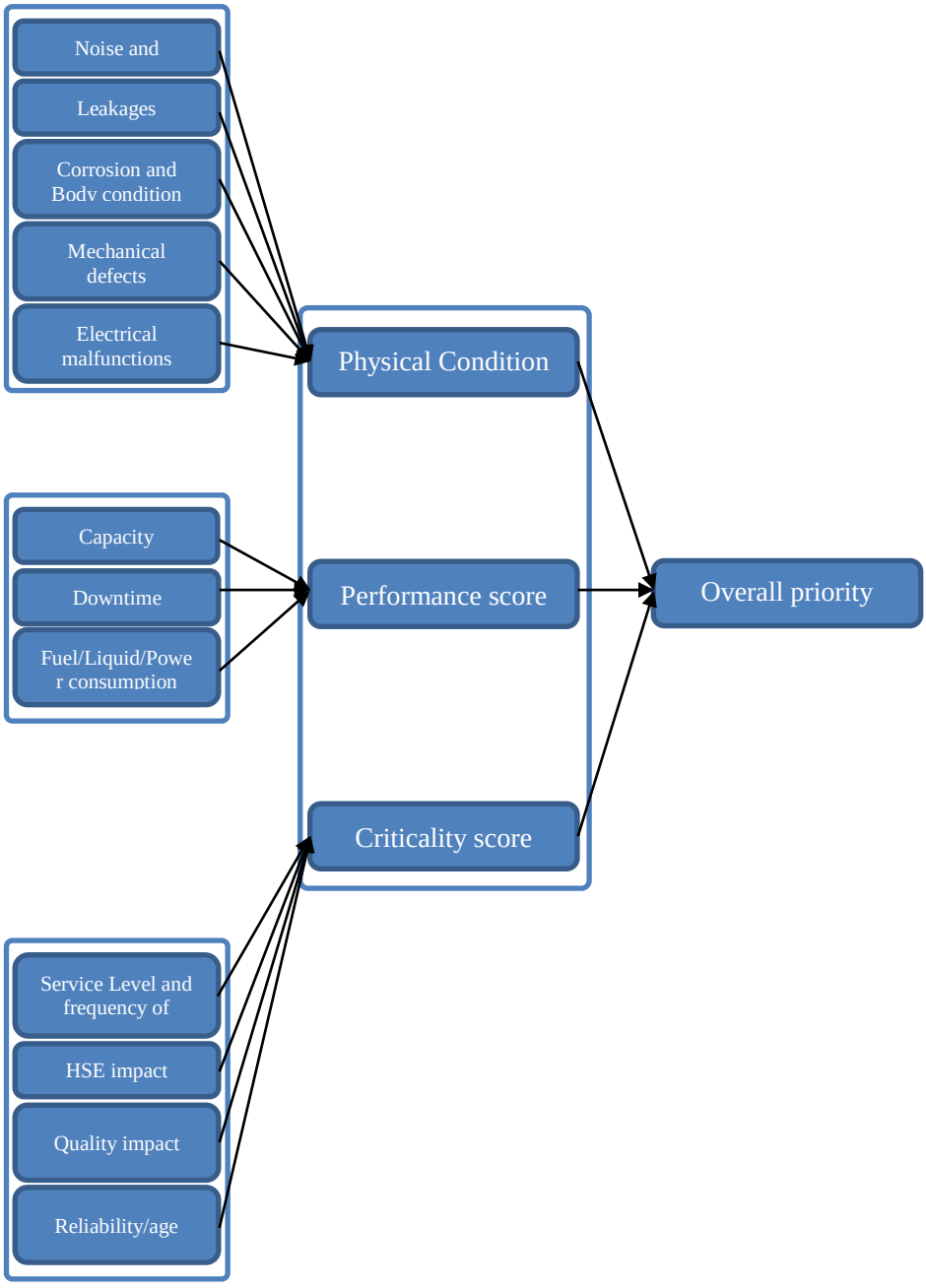
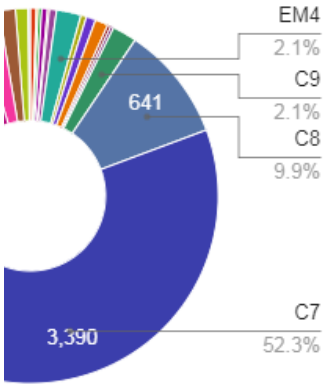


Figure 4 Conceptual framework for PBFAM approach validation

3.5 Population

All the Construction



Population

contractors registered under CIDA as of January 2022

(4121 Organizations) are considered as the population for this research. The classification of organizations in the population are as follows (Figure 3).

3.6 Sample

A sample of 56 Organizations were self-selected as a non-probability sample and the volunteer sampling method was approached (Saunders & Lewis, 1997–2012).

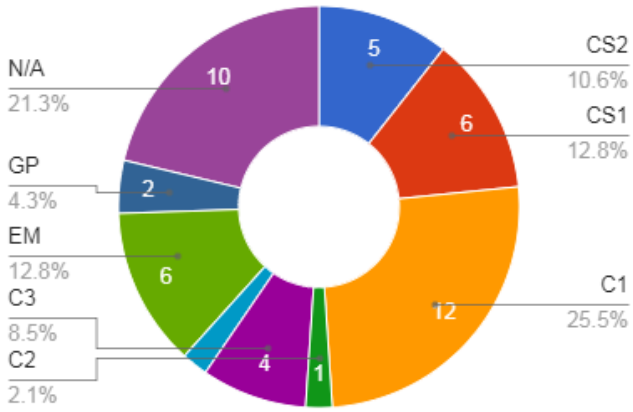


Figure 6 Characteristics of the Sample

3.7 Analytical Techniques

3.7.1 Descriptive statistics

Descriptive statistics of the data set is considered as the first step of the Analysis. Even Though it is simple and less time consuming, this method makes the Analysis more valid and presentable. These are the numerical and the graphical which can be utilized in organizing, presenting and analysing data (Oja, 1983). Following statistics were considered of the Data collected.

Table 8 Descriptive statistics

Measures of Central Tendency		
Statistic	Definition	Equation

Mean	Average of the data set	$\bar{X} = \frac{\sum x}{n}$
Measures of Deviation and Dispersion		
Standard Deviation	How varying the data set with respect to the Mean	$s = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$
Skewness	How distorted the data set with respect to the symmetrical bell curve	$\mu_3 = \frac{\sum(x-\bar{x})^3}{(N-1)\sigma^3}$
Kurtosis	How tailed the data set	$Kurt = \frac{\mu_4}{\sigma^4}$

3.7.2 Central limit theorem

Consider a substantially large (usually $n \geq 30$) sample collected with replacement on random basis, which was collected from a population having a mean of μ and standard deviation σ, then it is approximated that distribution of sample means will be normally distributed. (Kwak, 2017)

Calculated mean of the sample means = μ

Calculated standard deviation of the sample means = $\frac{\sigma}{\sqrt{n}}$; where n is sample size.

The list of 56 organizations collected for the purpose of this study spans more than 30 sample size where total number of CIDA registered organizations (population) is 4121, which sufficiently justifies the application of central limit theorem for statistical analysis.

4 ANALYSIS AND DISCUSSION OF RESULTS

The process followed to analyze the collected data can be visually represented as follows.

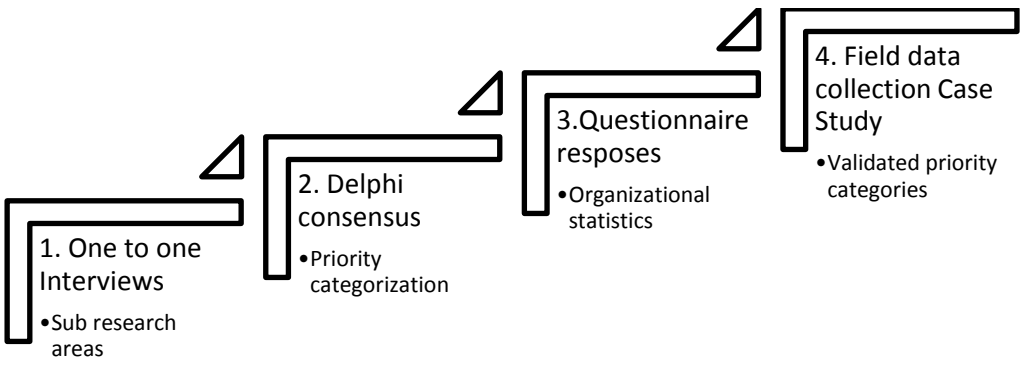


Figure 7 Data analysis process flow

4.1 Analysis of one-to-one interviews

A total of 7 one to one interviews were conducted with industrial experts from different organizations.

4.1.1 Analysis of statistics related to Experts

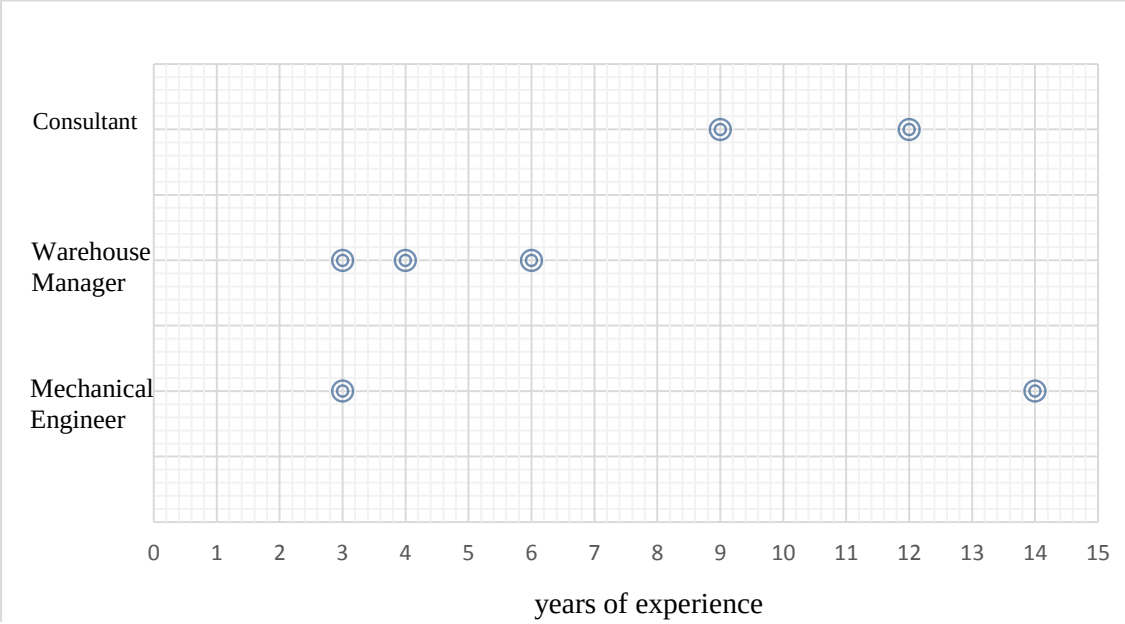


Figure 8 Statistics of the expert team

Industry experts were interviewed in order to get their expert view on sub research areas.

Table 9 Analysis of one-to-one interviews - sub research areas

Sub research area	Expanded Explanation	Summary of interviews
Measurement on existing FAM approaches	How an organization put arrangements to manage their property plant and equipment is overlooked. Specific methodologies, organizational procedures, prepared	07 out of 07 experts agreed and positively appreciated about researching about existing approaches. 07 out of 07 experts suggested to question organizations about their fixed asset register preparation process and fixed asset categorization.

	documentation are researched.	05 out of 07 experts gave positive feedback about questioning about serial number/ asset code/ QR code of fixed assets. 06 out of 07 experts asked to question documentation of fuel consumption, trip management (running chart), driver management. 04 out of 07 experts additionally asked to include questions regarding existing condition monitoring plan
Understanding the existing ground conditions related to fixed assets	Whether currently using machinery and their utility are up to their satisfaction or not. What would be the current situation of the particular company in terms of their fixed assets.	07 out of 07 experts gave positive comments about the following categorization • Satisfaction level of assets • Frequency level of happening adverse incidents 07 out of 07 experts commented on dividing satisfaction category into following sub categories • Safety • Complains and motivation of the staff • Service and capacity 05 out of 07 experts commented on dividing satisfaction category into following sub categories • Availability of critical assets 07 out of 07 experts commented on dividing adverse incidents category into following sub categories

		• Leakages, fumes and environmental damage • Accidents and incidents • Breakdown of assets 05 out of 07 experts commented on dividing satisfaction category into following sub categories • Breakdown of accessories • Mobilization delay
Classification of FAM approach	Understanding and classification of the type of management method that organizations practice currently.	07 out of 07 experts agreed on the following type of FAM methodologies which have been already published in literature. • Fail and Fix – Corrective Maintenance • Routinely - Preventive Maintenance • Condition based – Predictive Maintenance
Priority Based FAM	To research the technical possibility of prioritization of the maintenance of fixed assets based on pre assigned statistics.	Main priority categories which had readily published in literature were put to expert judgement and 07 out of 07 experts agreed on the following categorization • Physical Condition (PC) • Performance (PE) • Criticality (C)

4.2 Analysis of Delphi consensus

A three round Delphi survey was conducted to determine priority sub categories. Following are the consensus of the survey

Table 10 Delphi consensus results

Priority Main category	**Priority Sub categories**		
	Round 01 Results	**Round 02 Results**	**Round 03 Results**
Physical Condition (PC)	Noise	Noise and Vibration	Noise and Vibration
	Vibration	Leakages	Leakages
	Corrosion	Corrosion	Corrosion and Body Condition
	Body defects	Mechanical defects	Mechanical defects
	Electrical and mechanical defects	Electrical defects	Electrical Malfunctions
	Leakages		
Performance (PE)	Capacity	Capacity	Capacity
	Downtime	Downtime	Downtime
	Fuel consumption	Fuel consumption	Fuel/Liquid/Power Consumption
	Power consumption	Liquid consumption	
		Power consumption	
Criticality (C)	Service level	Service level	Service Level and frequency of usage
	Environmental, health and safety impact	Frequency of usage	Environmental, Health and Safety impact
	Quality impact	Environmental, Health and safety impact	Quality Impact
	Reliability	Quality Impact	Reliability/Age
	Age	Reliability	
		Age	

Following are the final categorization with their explanation

Table 11 Priority sub categories - Delphi output

Priority Main category	Sub Category	Explanation
Physical Condition (PC)	Noise and Vibration	Audible and felt sound of moving parts
	Leakages	Engine oil, coolant, transmission oil, gear oil or break fluid coming out
	Corrosion and Body Condition	Decay of iron and steel surfaces, dents, cracks and paint wearing off of the body
	Mechanical defects	Breaking not working, tire blow outs, damages to steering and suspension, air conditioner not working
	Electrical Malfunctions	Battery and cable defects, starter or alternator damages, fuses and plug failure, lighting system not working
Performance (PE)	Capacity	For vehicles: Gross Vehicle Weight Rating – Curb weight For machinery and equipment: Maximum output of work/power it can produce
	Downtime	Average annual planned and unplanned time of non-functioning or idling
	Fuel/Liquid/Power Consumption	Petroleum, diesel, kerosene and engine, gear, transmission fluid consumption rate and electrical units consumed if any
Criticality (C)	Service Level and frequency of usage	How often the fixed asset is required for construction work
	Environmental, Health and Safety	Dependency of any HSE aspects on the fixed asset

	impact	
	Quality Impact	How depending the quality of construction work on the particular fixed asset
	Reliability/Age	A function of how old and how dependable the fixed asset is (dependability divided by how old the asset is)

4.3 Analysis of the questionnaire survey responses

4.3.1 Diversity of the survey audience

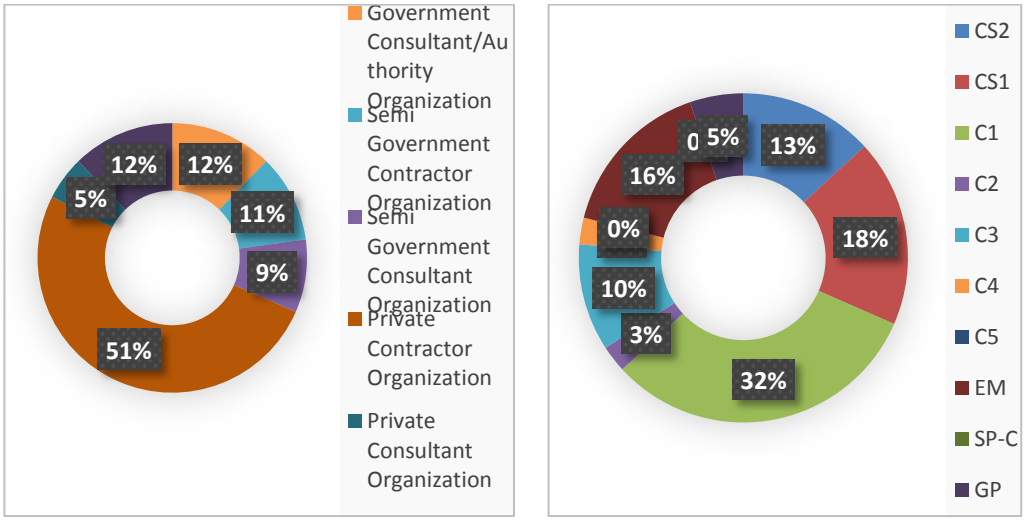


Figure 9 Diversity of the survey audience

All together 56 individuals have been participated and completed the questionnaire survey representing 56 different organizations directly related to the construction industry. The selected audience has shown the above illustrated diversification in

terms of type of Organization and CIDA classification. More than 50% of the individuals have represented Private Contractor Organizations and majority of them are among CS2, CS1 and C1 CIDA classification.

4.3.2 The existing FAM approaches

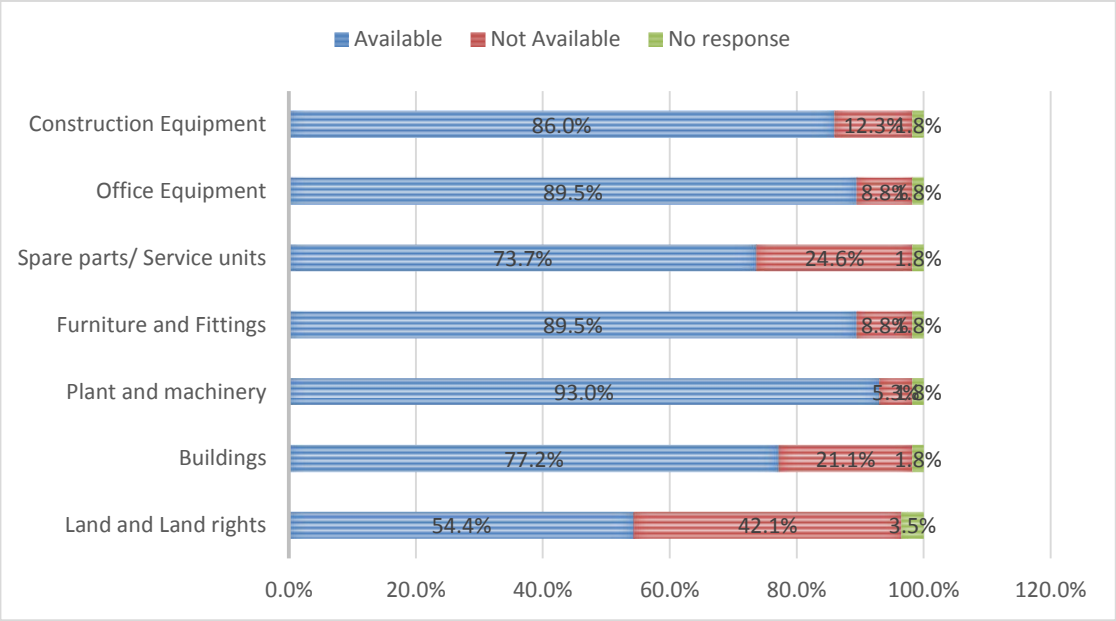


Figure 10 Existing FAM approaches

Classification of fixed assets were researched based on both publications and primary data. Publication have suggested an array of fixed asset categories as shown in the above illustration. The same categorization was found in the "Guidelines for preparation of regulatory accounts" published by Public Utilities Commission in Sri Lanka. It was found that at least 54.4% of the organizations have implemented all those categorizations in their Fixed asset register.

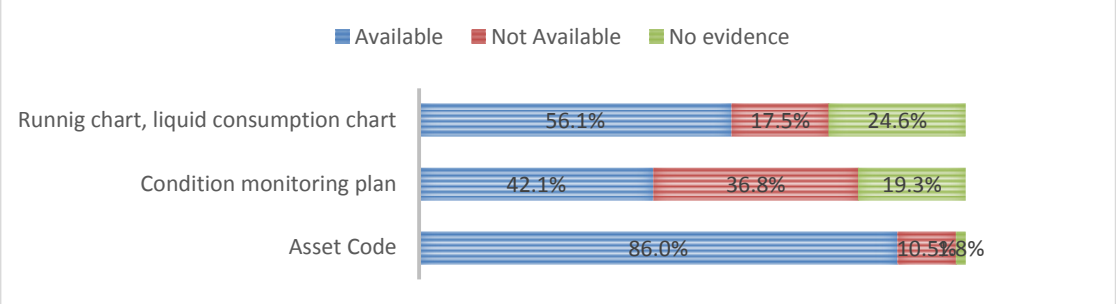


Figure 11 Availability of additional documentation

In addition to fixed asset categorization, vehicle running chart, liquid consumption chart, condition monitoring plan and asset code were identified as key documentation for fixed asset management. 17.5% and 36.8% of organizations have not implemented running charts and condition monitoring plans respectively. 85% of the organizations have assigned a unique Asset code for fixed assets.

4.3.3 The existing ground conditions related to fixed assets

4.3.3.1 Satisfaction level of assets

Table 12 Descriptive statistics of satisfaction level of assets

	Availability of critical assets	The level of service and capacity	The safety of assets	Motivation of staff
N	56	56	56	56
Mean	2.23	2.32	2.45	2.46
Median	2.00	2.00	2.00	2.00
Standard deviation	0.831	0.765	0.971	1.03
Skewness	0.521	0.382	0.342	0.414
Std. error skewness	0.319	0.319	0.319	0.319

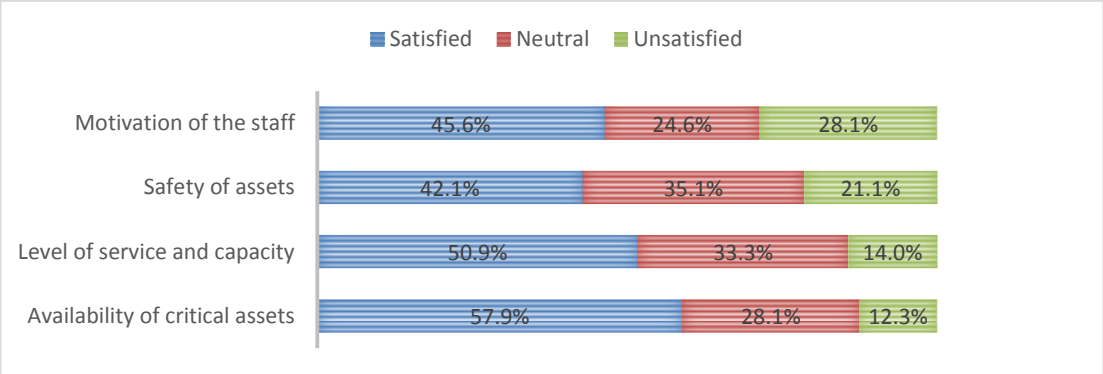


Figure 12 Satisfaction level regarding assets

On a Likert scale where 1 means strongly satisfied and 5 means strongly unsatisfied, based on the recorded 56 responses, organizations have shown satisfaction regarding motivation of the staff to use the fixed assets, how safe the machinery are to be used on daily basis, their level of service and availability on demand. Still a considerable

number of organizations have recorded unsatisfaction about staff motivation and safety as referred to Figure 11.

4.3.3.2 Frequency of happening adverse incidents

Table 13 Descriptive statistics of frequency of happening adverse incidents

	Breakdon of assets	Mobilization delay of assets	Breakdown of accessesories	Incidents and accidents	Environment damage	Fumes smoke	Leakages of toxic liquids
N	56	56	56	56	56	56	56
Mean	3.00	3.02	3.13	2.86	2.89	2.77	2.45
Median	3.00	3.00	3.00	3.00	3.00	3.00	2.00
Standard deviation	0.853	1.02	0.715	0.962	1.02	1.21	1.19
Skewness	-0.730	0.178	-0.498	0.296	0.328	0.209	0.737
Std. error skewness	0.319	0.319	0.319	0.319	0.319	0.319	0.319

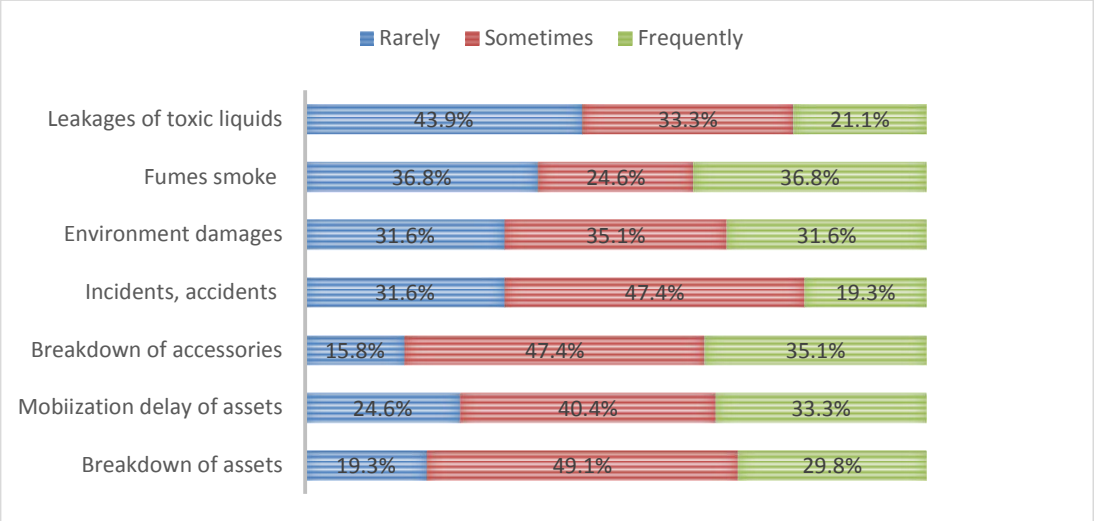


Figure 13 Frequency of happening adverse incidents

On a Likert scale where 1 means strongly satisfied and 5 means strongly unsatisfied, based on the recorded 56 responses, organizations have noted frequent breakdown of accessories with a mean response of 3.13. Similarly, asset breakdowns, mobility delay between sites, accidents and incidents, environment damage has also shown

considerable mean values larger than 2.5. Leakages of toxic liquids have not been a major occurrence in most of the organizations.

4.3.4 Classification of FAM Methodology

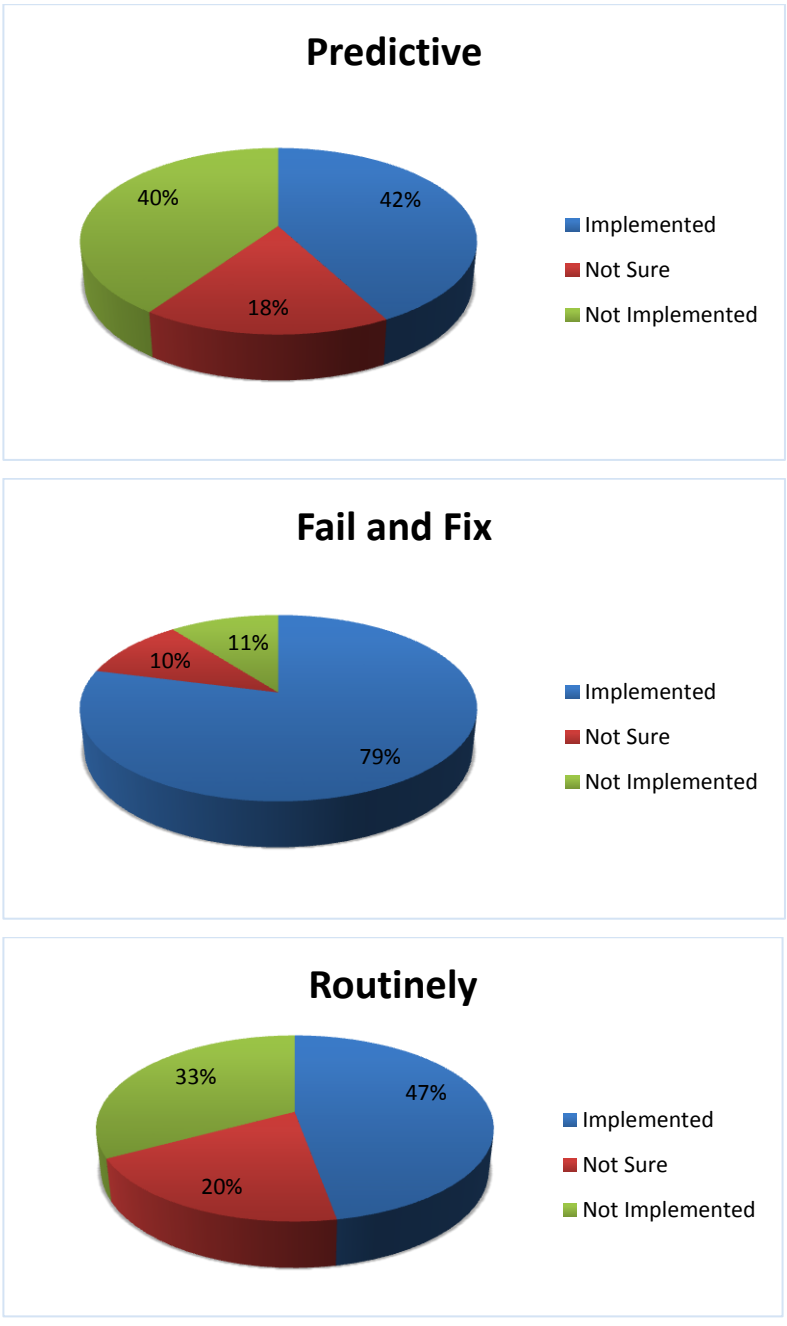


Figure 14 Classification of maintenance approaches

Characteristics of the currently practicing fixed asset maintenance approach was questioned from the audience and based on overall responses, whether fail and fix, routinely or predictive maintenance strategies have been implemented or not was

decided. Figure 14 illustrates the summary of the above analysis. Based on the results it can be concluded that 79% of the respondents believe that they have implemented fail and fix approach. Similarly, 58% and 42% of the respondents believe they have implemented routinely and predictive maintenance approaches in their organizations.

The fact that 40% believe they have not implemented predictive approach should be emphasized since that strongly suggests there is still possibility for them to implement much advanced PBFAM approach. Majority of the Construction Contractor organizations utilize corrective or preventive Fixed Asset maintenance practices.

4.3.5 Technical possibility to prioritize fixed assets maintenance

4.3.5.1 Prioritization based on physical condition (PC)

Table 14 Descriptive statistics of prioritization based on physical condition

	PC - Noice and Vibration	PC - Leakages	PC - Corrosion and body condition	PC - Mechanical defects	PC - Electrical malfunction
N	56	56	56	56	56
Mean	1.82	1.88	2.11	1.68	1.79
Median	2.00	2.00	2.00	2.00	2.00
Standard deviation	0.690	0.992	1.00	0.811	0.825
Skewness	0.250	1.42	0.787	1.30	1.03
Std. error skewness	0.319	0.319	0.319	0.319	0.319

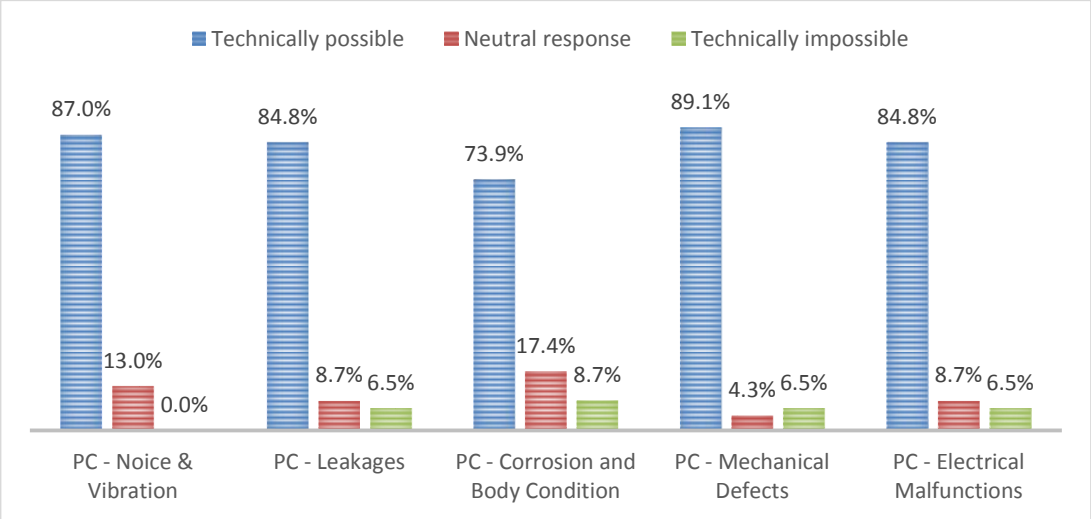


Figure 15 Prioritization based on Physical Condition

On a Likert scale where 1 means strong technical possibility and 5 means strong technical impossibility, based on the recorded 56 responses received, it can be concluded that majority of the originations believe it is technically possible to prioritize maintenance decision based on mechanical defects, noise and vibration, electrical malfunction, leakages, corrosion and body condition.

4.3.5.2 Prioritization based on performance (PE)

Table 15 Descriptive statistics of prioritization based on performance

	PER - Capacity	PER - Downtime	PER - Fuel consumption
N	56	56	56
Mean	2.07	2.13	1.95
Median	2.00	2.00	2.00
Standard deviation	0.970	0.935	0.980
Skewness	0.722	0.434	0.711
Std. error skewness	0.319	0.319	0.319

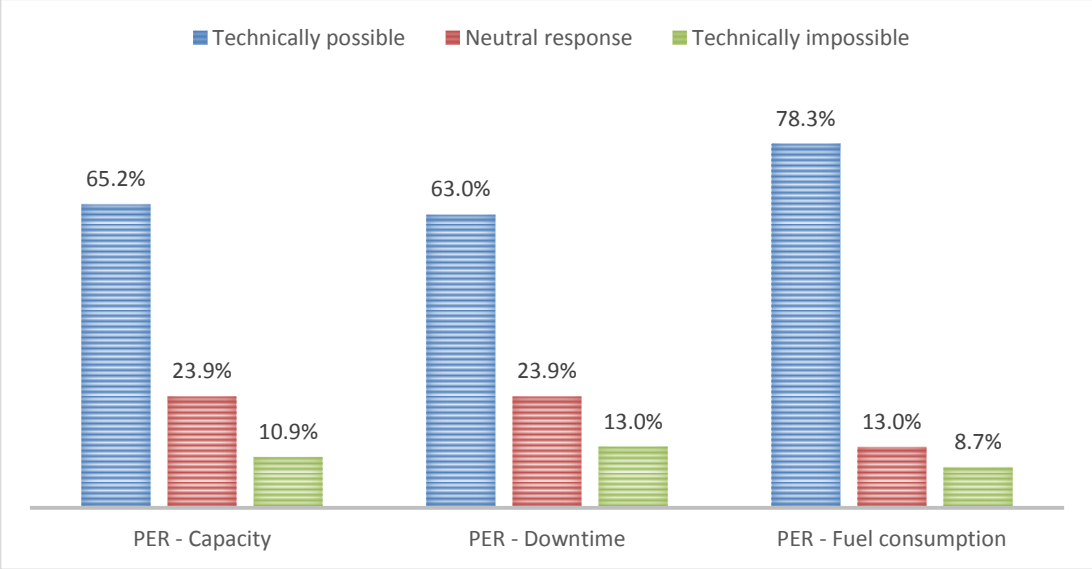


Figure 16 Prioritization based on Performance

On a Likert scale where 1 means strong technical possibility and 5 means strong technical impossibility, based on the recorded 56 responses received, it can be concluded that majority of the originations believe it is technically possible to prioritize maintenance decision based on fuel consumption, downtime and capacity. Overall values suggest it is somewhat complex to prioritize based performance compared to physical condition as it take more time to determine downtime and capacity with the available tools and staff in most of the organizations.

4.3.5.3 Prioritization based on criticality (C)

Table 16 Descriptive statistics of prioritization based on criticality

	C - Service level and frequency of usage	C - HSE impact	C - Quality impact	C - Reliability/age
N	56	56	56	56
Mean	1.86	1.77	2.04	2.02
Median	2.00	2.00	2.00	2.00
Standard deviation	0.923	0.713	0.873	0.924
Skewness	0.869	0.373	1.12	0.824
Std. error skewness	0.319	0.319	0.319	0.319

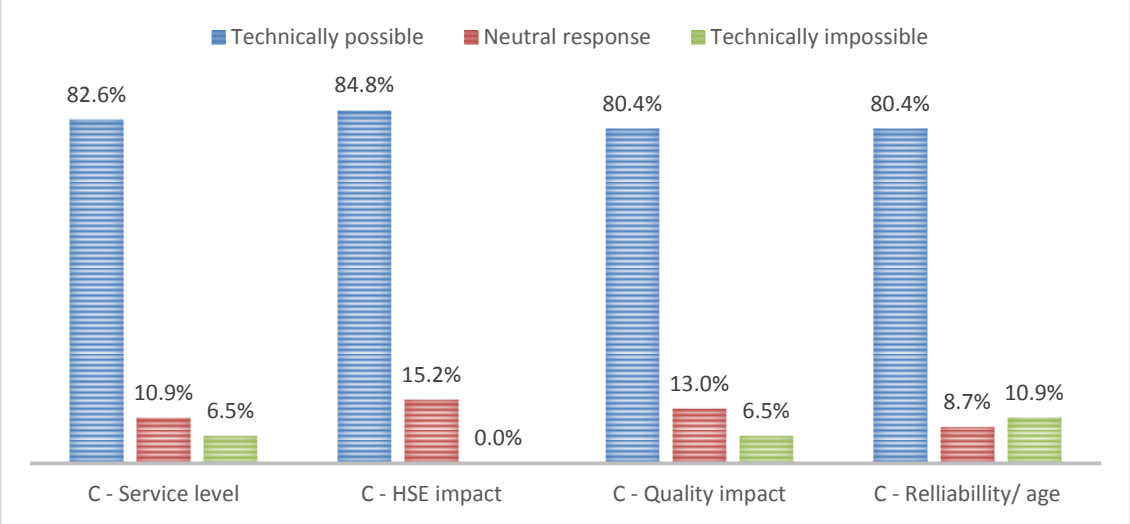


Figure 17 Prioritization based on Criticality

On a Likert scale where 1 means strong technical possibility and 5 means strong technical impossibility, based on the recorded 56 responses received, it can be concluded that majority of the originations believe it is technically possible to prioritize maintenance decision based on HSE impact, service level, quality impact and reliability/age.

4.4 Analysis of priority scores of field data collected – The case study analysis

Table 17 Analysis of field data - framework validation

No	Asset Category	Registration/Code	Asset Description	Model	PC % score	PER % score	C % score	Final % score
1	Vehicle	HR-45542	Three-Wheeler	Bajaj 4 stroke	55%	58%	25%	46%
2	Vehicle	253-1588	Crew Cab	Isuzu	75%	75%	50%	67%
3	Vehicle	PB-0568	Crew Cab	Mitsubishi	75%	92%	50%	72%
4	Vehicle	GZ-8349	Double Cab	Isuzu	20%	33%	56%	37%
5	Vehicle	252-1272	Double Cab	Isuzu	30%	42%	50%	41%
6	Vehicle	LJ-5847	Dumper Truck	Leyland	20%	25%	75%	40%
7	Vehicle	LI-8501	Dumper Truck	Leyland Cargo	10%	25%	75%	37%
8	Vehicle	LJ-5847	Dumper Truck	Leyland Cargo	30%	42%	75%	49%
9	Vehicle	LY-4541	Low Bed Truck	Tata LB	0%	25%	44%	23%
10	Vehicle	BBT-0819	Motor Bike	CT100	30%	17%	19%	22%
11	Vehicle	MN-7691	Motor Bike	Platina	30%	17%	19%	22%
12	Construction Equipment	R139	Skid Loader	GEHL	0%	0%	81%	27%
13	Construction Equipment	ZA-8292	Truck Mixer	Tata	30%	17%	75%	41%
14	Construction Equipment	DB 460	Self-Loading Mixer	Fiori	45%	42%	88%	58%
15	Construction Equipment	RS-1436	Wheel Loader	LX50	90%	92%	88%	90%
16	Construction Equipment	-	Asphalt Paver	RP600	85%	92%	81%	86%
17	Construction Equipment	5550	Asphalt Paver	RP600	95%	92%	88%	91%
18	Construction	GC/CM/03	Concrete Mixer	Vibromix	95%	92%	63%	83%

	Equipment							
19	Construction Equipment	PC-30	Excavator	PC30	85%	25%	88%	66%
20	Construction Equipment	ZA-8293	Truck Mixer	XCMG	40%	17%	100%	52%
21	Construction Equipment	RB-8235	Tractor	Mahindra	95%	75%	88%	86%
22	Construction Equipment	-	Backhoe Loader	3CX	20%	33%	81%	45%
23	Construction Equipment	28 Sri 2063	Water Bowser	Tata	85%	58%	38%	60%
24	Construction Equipment	LK-2133	Truck Mixer	Fuzo	30%	33%	69%	44%
25	Construction Equipment	GC/CM/04	Concrete Mixer	Mini Vibromax	50%	42%	63%	51%
26	Construction Equipment	GC/EX/02	Excavator	Mark 5	55%	33%	75%	54%
27	Construction Equipment	GC/PTR/02	Pneumatic Tire Roller	Sakai	25%	33%	88%	49%
28	Construction Equipment	GC/HR/02	Roller	BWR 650	45%	33%	81%	53%
29	Construction Equipment	GC/HR/01	Roller	-	40%	50%	81%	57%
30	Construction Equipment	GC/RM/12	Rammer	-	30%	50%	81%	54%
31	Plant and Machinery	GC/GE/02	Generator	CAT 5GF-LDE3	25%	25%	69%	40%
32	Plant and Machinery	GC/LT/04	Light Tower	-	30%	25%	69%	41%
33	Plant and Machinery	GC/GE/06	Generator mini	5GF-LDE3	30%	17%	44%	30%

5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%

The level of priority assigned to the particular fixed asset is shown in percentages and colors, where green indicates the least and red indicates the highest priorities.

Based on the generated priority list fixed assets were divided in to four categories based on 25%, 50% and 75% percentiles and each group was asked to be given feedback by the mechanical engineer in charge of the warehouse. The following comments were received.

Table 18 Prioritized fixed asset list - Road Construction Company

Cat	No	Registration	Asset Description	Picture	Final % score	ME's feedback
A	10	BBT-0819	Motor Bike		22%	Routinely maintained and currently there are no failures reported.
	11	MN-7691	Motor Bike		22%	
	9	LY-4541	Low Bed Truck		23%	Low bed truck and skid loader are brand new and in show room conditions.
	12	R139	Skid Loader		27%	
	33	GC/GE/06	Generator mini		30%	-
	4	GZ-8349	Double Cab		37%	-
	7	LI-8501	Dumper Truck		37%	Routinely maintained and currently there are no failures reported.
	31	GC/GE/02	Generator		40%	

	6	LJ-5847	Dumper Truck		40%	
B	5	252-1272	Double Cab		41%	Frequent electric system failures reported by the technician.
	13	ZA-8292	Truck Mixer		41%	-
	32	GC/LT/04	Light Tower		41%	Very frequently used and maintained.
	24	LK-2133	Truck Mixer		44%	-
	22	-	Backhoe Loader		45%	-
	1	HR-45542	Three-Wheeler		46%	Very less reliable and fuel consuming.
	8	LJ-5847	Dumper Truck		49%	-
	27	GC/PTR/02	Pneumatic Tire Roller		49%	Pneumatic system repaired in September - 2020
C	25	GC/CM/04	Concrete Mixer		51%	Very frequently used.
	20	ZA-8293	Truck Mixer		52%	Very frequently used.
	28	GC/HR/02	Roller		53%	Very frequently used.

	30	GC/RM/12	Rammer		54%	Very frequently used.
	26	GC/EX/02	Excavator		54%	Currently undergoing in house electrical system restoration work.
	29	GC/HR/01	Roller		57%	-
	14	DB 460	Self-Loading Mixer		58%	Less fuel efficient, less reliable and old machinery.
	23	28 Sri 2063	Water Bowser		60%	Bowser leakages recorded and very high demanded vehicle.
D	19	PC-30	Excavator		66%	Extreme repairing frequency is observed.
	2	253-1588	Crew Cab		67%	Less reliable, high demand vehicle.
	3	PB-0568	Crew Cab		72%	High demanded but unable to cater the weekly demand due to malfunctions
	18	GC/CM/03	Concrete Mixer		83%	Bucked replaced and disposable.
	21	RB-8235	Tractor		86%	In disposable conditions.

	16	-	Asphalt Paver		86%	Time and staff consuming repair undergoing.
	15	RS-1436	Wheel Loader		90%	Disposable.
	17	5550	Asphalt Paver		91%	Extremely low level of service and costly repairs undergoing.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Practical Implications of the study

Being a developing economy Sri Lanka has a lot of areas which can be improved in terms of key infrastructure. This modern trend of infrastructure development has led to substantial growth of utilization of resources and assets. It is high time that government and private contractors adhere to best practices of utility of resources and assets. The presented research has a scope to deliver on gained knowledge about fixed asset management. This study's literature review can be identified as a collection of resources about best practices on fixed asset management. Specifically for construction contractor organizations to think of ways to improve repairing process of their owned property plant and equipment, this work is a valuable guide.

Most of the construction contractor's own construction machinery yards which take care of in house maintenance and repair of these valuable fixed assets. Management, engineers and technical officers search for best practices to improve their overall yard performance to deliver fixed assets which can successfully cater the required level of service to the construction sites. Priority based fixed asset maintenance approach can be a feasible way for key technical staff to decide on which machinery to be given more focus first. Other than contractors, software service providers who can design and build asset management systems can also gain ideas to produce platforms by which warehouses and yards might be automated. Researchers, academics and undergraduates are also benefitted with the gained new knowledge.

5.2 Further research areas

Within the same research scope 'fixed assets management', 'fixed asset maintenance' there is a whole lot of grey areas which can be further researched. While doing this study it was understood that even though it is considered under the same industry still government and private owned organization behave at a level considerably different when it comes to asset management. Suitability of the suggested approach on government organizations should be separately researched. Substantial amount of human workflow that will be consumed while prioritizing the fixed asset maintenance can be alternatively replaced by computers. The possibility to automate a priority-

based maintenance strategy is another suggested research area. Coordination between PAS55 asset management standard and the suggested approach is also researchable as PBFAM strongly adopts PAS55 concepts.

5.3 Limitations of the study

A total of 56 organizations represents the population which can be considered as a limitation regarding accuracy of final conclusions. Majority of organizations responded were private entities, hence there might be a biasness to cultural behavior of such organization. The respondent's level of understanding about the subject matters relevant to predictive maintenance is expected to be substantially low, therefore it might have caused some error associated with questionnaire survey output statistics. Validation of the data was done based on three sites governed by one contractor organization. A total of 33 fixed assets were surveyed to validate the framework. Success of the approved framework depends only on one organization. Since the research work was conducted within the COVID-19 outbreak time in Sri Lanka, most of organizations might have responded with a biasness to the socio-environmental changed that had occurred within that time period.

5.4 Research assumptions

Responses received from the audience are assumed to be a one-to-one map of the exact situation in each organization. Any biasness that might have occurred because of level of education, experience was assumed to be minimum and negligible.

5.5 Conclusion

5.5.1 Fixed asset management approaches

It can be concluded that 54.4% of all the contractor organizations have classified their fixed asset register including construction equipment, office equipment, spare parts or service units, furniture and fittings, plant and machinery, Vehicle, building and land and building fixed asset categories which are stated by IAS 16 global standard and LKAS 15 local standard. Even though it is considered as a key documentation to be implemented in a contractor organization, 17.5% and 36.8% of organizations have not

implemented running charts and condition monitoring plans respectively. 85% of the organizations have assigned a unique Asset code for fixed assets.

Based on statistics of 56 organizations it can be concluded that 79% of the respondents believe that they have implemented fail and fix approach. Similarly, 58% and 42% of the respondents believe they have implemented routinely and predictive maintenance approaches in their organizations. Majority of the Construction Contractor organizations utilize corrective or preventive Fixed Asset maintenance practices.

5.5.2 Existing conditions related to fixed assets

Warehouse managers, mechanical engineers and other technical staff experiences adverse incidents like breakdown of assets and accessories, environmental damage, fumes, site accidents and mobilization delays regarding their owned fixed assets. But the level of satisfaction in terms of staff motivation, safety of assets to use, level of service and availability on demand are maintained up to the required levels.

5.5.3 Technical possibility to prioritize fixed assets maintenance

The possibility to prioritize maintenance of fixed assets based on priority main categories, Physical Condition, Performance and Criticality were found in previously published literature and were also accepted by majority of respondents. The following sub factors were tested with experts and survey audience under which was accepted with significant confidence.

Table 19 Finalized priority categories and factors

Main category	**Sub factor**
Physical Condition (PC)	Noise and Vibration
	Leakages
	Corrosion and Body Condition
	Mechanical defects
	Electrical Malfunctions

Performance (PE)	Capacity
	Downtime
	Fuel/Liquid/Power Consumption
Criticality (C)	Service Level and frequency of usage
	Environmental, Health and Safety impact
	Quality Impact
	Reliability/Age

5.5.4 Validity of priority based fixed asset maintenance methodology

The warehouse manager of the selected road construction company gave positive comments about prioritized maintenance list of their company owned fixed assets. Category D high prioritized fixed assets received comments including words ‘disposability’, ‘requiring extreme repairs’, ‘high level of service demand’ which was correctly predicted by the priority score. And Category A least prioritized fixed assets received comments including words ‘brand new’, ‘least repair requirement’. With the feedback received it can be concluded that suggested score has predicted maintenance requirement successfully which enables researcher to validate the applicability of PBFAM in Sri Lankan contractors

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Appendix A: Questionnaire survey – lime survey platform

APPLICABILITY OF PRIORITY BASED FIXED ASSET MAINTENANCE FOR SRI LANKAN CONSTRUCTION CONTRACTORS

Dear sir/madam/participant,

You have been invited to participate for the following survey on "CHALLENGES OF IMPLEMENTING ASSET MANAGEMENT SYSTEMS FOR SRI LANKAN CONTRACTORS". I am a Postgraduate student of Faculty of Engineering, University of Moratuwa, reading for a research as a partial fulfillment of the Masters Degree of Construction Project Management.

This survey is a part of the research study and please be informed that your participation is completely voluntary.

Information collected will remain completely confidential and be used solely for the academic purposes. Further, I am not requesting you to provide your name, company name etc, as I want to assure your anonymity. I would really appreciate if you could spend few minutes of your precious time to fill the table provided.

It will take 2-5 minutes to fully complete the questionnaire.

Thanking you

Eng. Geethike Ranga Vidana Arachchi

There are 16 questions in this survey

User and Organization Details

In the section yours and your organization's details will be requested for you to fill.

[]1. Please fill your full name. (Not Compulsory)

Please write your answer here:

[]2. Please fill your age.

Only numbers may be entered in this field.

Please write your answer here:

-

[]3. Please select your gender. *

Please choose **only one** of the following:

- ◯ Female
- ◯ Male

[]4. Please select the type of organization that you are part of. *

Please choose **only one** of the following:

- ◯ Government Consultant/Authority Organization
- ◯ Semi Government Contractor Organization
- ◯ Semi Government Consultant Organization
- ◯ Private Contractor Organization
- ◯ Private Consultant Organization
- ◯ Other

[]5. Mention number of professional years that you have been a part of this organization *

Only numbers may be entered in this field.

Please write your answer here:

-

[]6. Please fill your designation. (Not Compulsory)

Please write your answer here:

[]7. Please select your CIDA Company Registration Grading from the given list.

Please choose **only one** of the following:

- ◯ CS2
- ◯ CS1
- ◯ C1
- ◯ C2
- ◯ C3
- ◯ C4
- ◯ C5
- ◯ EM

- ◯ SP-C
- ◯ GP
- ◯ Not applicable

Existing FAM practices

In this section, your organizations existing Fixed Asset Management practices will be questioned

[]8. Do you keep separate records/spread sheets of Consumables and Fixed Assets in your organization? *

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

[]9. Do you use following categories in your company Fixed Asset Register? *

Please choose the appropriate response for each item:

	Yes	Uncertain	No
Land and Land Rights	◯	◯	◯
Buildings	◯	◯	◯
Plant and Machinery	◯	◯	◯
Furniture and Fittings/Fixtures	◯	◯	◯
Spare Units/ Service Units	◯	◯	◯
Office Equipment	◯	◯	◯
Construction Equipment	◯	◯	◯

[]10. If you use categories other than mentioned in the previous question please state them.

Please write your answer here:

[]

11. How do you personally evaluate the following aspects related to Fixed Asset on the following scale?

1 - Very Satisfied

2 - Somewhat Satisfied

3 - Neither Satisfied not unsatisfied

4 - Unsatisfied

5 - Very Unsatisfied

*

Please choose the appropriate response for each item:

	1	2	3	4	5
The availability of critical machinery, construction equipment and tools for your construction works	○	○	○	○	○
The level of service and capacity of the most important machinery	○	○	○	○	○
The safety aspect of machinery, equipments and their users	○	○	○	○	○
Motivation of the site staff, drivers, helpers and supervisors to use the fixed assets on daily basis	○	○	○	○	○

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12. On the given scale, how do you personally evaluate the frequency of occurring of following Fixed Asset related issues?

1 - Never

2 - Rarely

3 - Sometimes

4 - Often

5 - Always

*

Please choose the appropriate response for each item:

	1	2	3	4	5
Breakdown of critical fixed assets Delay of mobilization of assets to the site	○	○	○	○	○
Breakdown of accessosories of machinery and equipment	○	○	○	○	○
Incidents, Near misses and Accidents related to fixed assets	○	○	○	○	○
Considerable amount of environmental damages due to machinery and vehicles	○	○	○	○	○
Generation of fumes, smoke and toxic gases from machinery and vehicle	○	○	○	○	○
Leakage of toxic liquids and fuel	○	○	○	○	○

[]

13. How do you personally evaluate the following statements regarding your organization's Fixed Asset Management practices on the following scale.

1 - Strongly Agree

2 - Agree

3 - Neither agree nor disagree

4 - Disagree

5 - Strongly Disagree

*

Please choose the appropriate response for each item:

	1	2	3	4	5
All the fixed assets are given a Company Registration Code to account	○	○	○	○	○
Fixed assets a routinely monitored regarding their performance and capacity	○	○	○	○	○
Every vehicle owened is maintaned a running chart, Liquid Consumpsion charts and Maintenance records	○	○	○	○	○

	1	2	3	4	5
Atleast important assets are maintained routinely	○	○	○	○	○
Most of the repairs you undertake are done upon breakdowns	○	○	○	○	○
Equipment, Machinery and Vehicle maintenances are done based on pre-asigned priorities	○	○	○	○	○

Priority based FAM

In this section, your valuable input will be recorded on applicability of Priority Based Fixed Asset Management practice

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14. To prioritize the maintenance decisions, below mentioned factors are suggested to be considered. How would you agree with these each factor on the following scale?

1 - Strongly Agree

2 - Agree

3 - Neither agree nor disagree

4 - Disagree

5 - Strongly Disagree

*

Please choose the appropriate response for each item:

	1	2	3	4	5
Physical Condition (PC) of the Fixed Asset Performance (PER) of the Fixed Asset	○ ○	○ ○	○ ○	○ ○	○ ○
Criticallity (C) of the Fixed Asset	○	○	○	○	○

Physical Condition - Mechanical, Electrical and Structural status of the Asset which can be physically observed

Performance - Output capacity of the Asset

Criticality - Impact, Reliability and frequency of the usage of the Asset

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15. State how relevant are the following key factors to measure the Physical Condition(PC), Performance(PER) and Criticality(C) of Fixed Assets that are used in your sites based on the following scale? Consider a Road Roller as an example.

1 - Strongly Relevant

2 - Somewhat relevant

3 - Neither relevant not irrelevant

4 - Somewhat irrelevant

5 - Strongly irrelevant

*

Please choose the appropriate response for each item:

	1	2	3	4	5
PC - Noice and Vibration	○	○	○	○	○
PC - Leakages	○	○	○	○	○
PC - Corrosion and Body Condition	○	○	○	○	○
PC - Mechanical defects	○	○	○	○	○
PC - Electrical Malfunctions	○	○	○	○	○
PER - Capacity	○	○	○	○	○
PER - Downtime	○	○	○	○	○
PER - Fuel Consuption	○	○	○	○	○
C - Service Level and frequency of usage	○	○	○	○	○
C - Environmental, Health and Safety impact	○	○	○	○	○
C - Quality Impact	○	○	○	○	○
C - Reliability/Age	○	○	○	○	○

Thank you for spending your valuable time.

Submit your survey.
Thank you for completing this survey.