



ADDIS ABABA UNIVERSITY ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING INDUSTRIAL ENGINEERING

Operational Productivity of Equipment Maintenance System Enhancement through Total Quality Management: A Case of Ethiopian Construction Works Corporation

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September, 2021

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Quality Management: A Case of Ethiopian Construction Works Corporation

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “Operational Productivity of Equipment Maintenance System Enhancement through Total Quality Management: A Case of Ethiopian Construction Works Corporation” is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been correspondingly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to best of my knowledge

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ABSTRACT

Equipment maintenance system has been given great consideration to any industry to make any equipment available. To avail equipment in productive operation, among the techniques from which are known is that total quality management (TQM) implementation system. Most of the time; equipment or machineries are seen down due to part failure, process failure, improper handling etc. In the case company there are also similar problems that have been detected such as maintenance quality problem, spare part supplying delay, equipment down time, and maintenance reworks. Due to these, the maintenance department faces challenges of quality maintenance and customer satisfaction. In fact, the corporation is actually performing total quality management activities in which it is not in continuous approach. In Ethiopian construction Works Corporation (ECWC) maintenance department is implementing top-down approach in which the TQM linkage with maintenance is weak. Therefore, this study purpose is to improve these problems hindering the operational productivity of equipment maintenance system using the total quality management technique. The objective is met through a research method of qualitative and quantitative data collection and analysis. The data sources were from primary and secondary data. The primary data obtained are from interview, questionnaires, field visit, process mapping and simulation. The secondary data were obtained from ECWC reports, literature review and other data bases. The approaches used was TQM process mapping tool method and arena simulation software to validate the improved process mapping to seek an improvement of equipment maintenance productivity. The study finding indicated that there are long maintenance time, high failure rate, weak process management system, and weak interdepartmental linkage. This study also found that shifting from practice of quality control towards preventive actions into work reduction of Spare part supplying delay, down time, maintenance reworks and increase the level of the commitment of management/leaders. The data are also analyzed using different software mentioned here and model developed by triangulating Business Process Mapping (BPM) and Quality Business mapping Process (QBMP). Operational productivity of equipment maintenance with total quality management (TQM) helped to improve 80% of process path of operational productivity of equipment maintenance system. It has also helped to increase the feeling of empowerment among employees and to involve the people closest to the process mapped and the quality efforts in other departments of the ECWC. This research implication is to improve the maintenance system of the ECWC which also implies to improve any similar industries maintenance system. The research has a contribution to the body of knowledge from

perspective of integrating the maintenance system to TQM which is effective in reducing the maintenance operational time. In general, this research has identified problems and reduced those problems integrating TQM into maintenance system.

Key Words: Equipment maintenance, operational productivity, Total quality management, Process Path, process simulation.

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List of Acronym

SRO= Service Repair Order	TOC= Theory of Constraint
RFS= Request for Service	PDM= Predictive Maintenance
TQM= Total Quality Management	FFM= Failure Finding Maintenance
RCM= Reliability Centred Maintenance	CBM= Condition-Based Maintenance
MGT= Management	RBM= Risk-Based Maintenance
KPI= Key Performance Indicators	BPM= Business Process Mapping
TPM= Total Productive Maintenance	QBMP= Quality Business Mapping Process
GDP= Gross Domestic Product	SWOT= Strength, Weakness, Opportunity, Threat
SWIFT= Specifying, Wainscoting, Integration, Fail-saving, Triangulating	
ECWC= Ethiopian Construction Works Corporation	

CHAPTER ONE

1. INTRODUCTORY PART

1.1. Introduction

What are the operational activities of equipment maintenance system? In the simplest meaning, operational maintenance of equipment care and minor maintenance of equipment using procedures that do not require detailed technical knowledge of the equipment's or system's function and design. This is not the aim of this research. The research aimed at the broad meaning of the operational productivity of equipment maintenance system of linking those departmental operational activities which are related directly or indirectly with the equipment maintenance operations (Zulkipli et al., 2019), in addition to using RCM for equipment productivity improvement and cost minimization.

Industries are facing a lot of challenges such as optimization of operation and maintenance function due to the continual evolving world of technologies, global competitiveness, environmental and safety requirements. The concern towards total quality and profitability of an organization are crucial factors in the business. (Velmurugan & Turan, 2015)

Equipment maintenance, especially in construction organizations needs to maintain, manage, and seek towards continuous improvement strategically the organization to be ahead and profitable. The relation of equipment and construction activities is like a hand and food to a mouth to satisfy hunger. Due to this fact operational productivity of equipment maintenance system requires outlooks for sustainable improvement to be equipment operational at most of working hours to meet the customer's satisfaction- mostly equipment users, the construction sectors.

Operational productivity of equipment maintenance system is the decisions and actions regarding the control and upkeep of property and equipment. These are inclusive, but not limited to actions focused on scheduling, procedures, and work/systems control and optimization; and performance of routine, preventive, predictive, scheduled and unscheduled

maintenances aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

As it is said above, in the competitive environment of today, it is crucial to stay ahead of competition and continuously satisfy customers. Quality management practices have been widely implemented, and while some organizations experience great success, other initiatives have failed (Jinhui et al., 2011). Many studies have started questioning the universal application of quality management in all organizations, and they claim that some of the quality management practices are dependent on the organizational context, such as industry, firm size and country (Sousa & Voss, 2001). Further, Prajogo and McDermott (2005) argue that among several factors, which all have been attributed as key determinants for quality management success, operational productivity of equipment maintenance is among those will be listed.

Thus on actual implementation of the suggestions made to the ECWC, can achieve TQM and compete with the best in the locality.

In capturing increased market share, operational productivity and quality has been the main concern of every manufacturer or service giving organization since old days. Started with the inspection concept, it is moved to the operational productivity and quality control concept, when it was realized that making the inspection department responsible for the operational productivity and quality would be less productive. Concept of operational productivity and quality control emphasizes self-inspection and appropriate systems to assure operational productivity and quality by identifying defectives and eliminating them. Later the concept of quality assurance came in to practice. But the operational productivity and quality movement did not stop with this and the attempt is to continuously improve the quality and assure higher and higher standards of quality, offer better products and services to the customer. It was felt that operational productivity and quality was not only the job of quality control department but also of other departments like sales, procurement, material handling, accounting, industrial relations, design, production, forecasting, marketing, stores and after sales service. The workers should run the system; managers should design and improve the system; while the top management should provide leader ship and team spirit. Total Quality

Management (TQM) is an approach to the art of management that originated in Japanese industry in the 1950's and has become steadily more popular in the west since the early 1980's. TQM is at first glance seen primarily as a change in an organization's technology of doing work. In the human services, this means the way clients are processed the service delivery methods applied to them and ancillary organizational processes such as paperwork, procurement processes, and other procedures.

Effective TQM results in greater customer satisfaction, fewer defects, less waste, reduced costs, improved profitability and increased productivity. [Naor et al. \(2008\)](#) state that quality management is more than tools and techniques and that it has a value system as an underlying foundation. For the effectiveness of TQM program a careful analysis of the customer's needs, and an assessment of the extent to which these needs are currently met, and a suitable plan to fill up the gap between the current level and expectation is necessary. For the success of TQM, top managers must provide vision, mission and reinforce values emphasizing quality, set quality goals, and deploy necessary resources for these quality programs. For this purpose, training and development free flow of information is essential. The top managers must continuously monitor, evaluate, get feedback about TQM program and take necessary steps for its improvement.

TQM is applicable to any organization irrespective of size, and motives, even the public sector organization are fast adopting the ideology in order to make them effective in meeting public demands. However, the adoption of the ideology by most organization has been hampered due to their non-compliance with the procedures and principles of TQM implementation. While some organizations run TQM like a program which they expect to function and perform the magic all by itself, others have used a halfhearted approach to it by using some bits and pieces of the principles. This has accounted for the failure of most organizations in meeting up to their expected target from implementing this ideology. There is a need to continue to buttress the benefits that accrue to organizations from the implementation of TQM especially in developing economies.

There are different views on whether quality management practices are associated with, and therefore supported by only equipment maintenance, or if quality management practices can

be built on different activities. Total quality management could be treated as something that includes operational productivity and quality equipment maintenance system elements.

This research is dedicated to improve the maintenance quality, spare part supplying delay, equipment down time, and maintenance reworks through total quality management using process mapping tool at Kality equipment maintenance center.

1.2. Background of the Study

Many industries and companies have different problem of methodologies to improve their business and to make it continuously improving by measuring the operational productivities by using suitable management improvement tools. This thesis aimed to analyze the operational productivity of equipment maintenance system and how the necessary method-total quality management (TQM) is remarkable for the justification.

According to [Thomas \(2016\)](#); many maintenance departments today 'fight fires' instead of approaching their problems systematically. Due to maintenance problems primarily concerned with four areas namely: maintaining critical systems, fixing the problem quickly and faster than the last time, determining what is causing the breakdown to happen so frequently, and identify the 20% of breakdown that are consuming 80% our resources affects the Operational process. In case of [Wilson et al. \(2017\)](#), the challenge of equipment maintenance summarized as no proper maintenance documentation, no local suppliers for spare parts, and inadequate expertise. The importation of spare parts usually leads to procurement partnerships like in Zimbabwe.

In the study by [Islam et al. \(2018\)](#) their finding; concluded that not using a novel frame work of reliable centered maintenance found not to show corrective maintenance down time decreased and preventive down time decreased by 55.7% and 52.17% respectively in Egypt. In the same manner [\(Rahayu, n.d.\)](#), claim that nowadays, reliability centered maintenance is a solution to perform the assets to in achieving effective and efficient maintenance and arguing implementing only reliable centered maintenance is not enough showing the conclusion reliable centered maintenance implementation improves the plant performance and decreased 33.75% annual maintenance cost of ammonia plant in Indonesia. According to [Ali &](#)

Mohammadreza, (2018), described that applying reliable centered maintenance strategy cannot increase reliability, economic utility, customer satisfaction, and cannot decrease environmental pollution, maintenance cost but argues that almost all research papers conducted only with reducing maintenance costs as a prime goal. In the briefing of Zulaikha et al. (2019), pointed out that reliable centered maintenance is not useful unless in addition to cost minimization, safety and environment, motivation for workers, availability and reliability. However, the researcher argues against one sided cost minimization prospective which is not analyzed the effect of time in operational productivity of equipment maintenance system. In the view of Samuel et al. (2018), elaborated that suggestion for the improved reliability of pusher assembly, implementation of selective run of failure, preventive maintenance and precision maintenance respectively will lead lower down time cost and higher reliability of the pusher assembly. On the other hand, of the study conducted by Zulkipli et al. (2019), claimed that maintenance performance improvement cannot be achieved using fuzzy Delphi method and concluded that the performance improvement through leadership category cannot leads the overall initiatives followed by equipment maintenance management, talent management, working environment and vendor management in Malaysia. Further explained briefly as maintenance operations include scheduling, work order system, materials and tools control. Maintenance management includes organization, training and motivation, and maintenance control. To improve maintenance performance requires a thorough investigation of the management of maintenance activities, maintenance operations, and equipment management. Equipment management covers pm, predictive maintenance, equipment history, equipment management program, and so on. In the belief of Abhisher et al. (2014), implementing total productive maintenance (TPM), cannot be made enhancement equipment availability, performances, quality of product and cannot be reduced maintenance cost, breakdown, and losses in India. But made argument that India SMEs have not given due attention to adopt effective strategy like CI, TPM, TQM and others. By elaborating the fact that, the effective integration of the maintenance function with engineering and other manufacturing functions in an organization can help save large amount of time, money, and other useful resources in dealing with reliability, availability, maintainability, and performance issues. Due to core idea of Teonas

et al. (2014), clearly shown that the improvement of industrial productivity cannot be maintained by implementing total productive maintenance (TPM) and assisting unless improving industrial performance and competitiveness of production line studied, which is useful and suitable for industries. Torbjon et al. (2018), drilled out that operational efficiency losses are not found to have the largest impact on OEE (overall equipment efficiency) unless followed by availability losses..

Kawarpreet & Ahuja, (2012), concluded as quality management, by means of total quality management (TQM), cannot be considered to foster organizational performance characterized by competitiveness and long term profitability. It is argued that however, the benefits of quality management cannot be achieved without the sustainable performance of equipment maintenance and thus, maintenance management has also become important. Total quality management (TQM) is clearly a suitable approach in which the quality the products or services is the major concern. But total productive maintenance (TPM) is on equipment or physical asset in today's manufacturing environment of increased automation and equipment-reliant process, equipment is the major determinant of quality performance. It is recommended the transfusion or paradigms of TPM-TQM for performance enhancement. Mainly most argument is made that starting with both, in a two-front strategy; it is troublesome for this would implicate an overburden and instability owing to swinging short-sighted changes in priority, leading to a loose implementation of both which is not effective.

Esin & Hilal (2014), elaborated that total quality management (TQM) cannot be a firm-wide management philosophy of products/services/process by focusing on the customer needs and expectations to enhance customer satisfaction and firm performance. There are mixed results about the relationship between TQM practices and performance or productivity. The researcher found that TQM is a holistic and ethical approach of the firms to continuously improve their products/services involving all stakeholders in order to satisfy their customers and to improve performance and sustainability. TQM practice also cannot improve all performance measures. Knowledge and process management practices improve inventory management performance, innovation performance, social responsibility, and market and financial performance. Successful training improves operational performance, employee

performance, and customer results. Effective customer focus efforts increase operational performance customer results, and market and financial performance.

But, in case of [Kumari & Rubal \(2016\)](#), described that TQM is will not be an integrated management approach if that not aimed to continuously enhance of products, processes, and services to achieve surplus customer's expectations.

In general, the researcher can conclude from different arguments that TQM is a base and universal methodology for other methodologies to manufacturing and service giving organizations especially, it is suited to continuously improvement needed company like Ethiopian construction Works Corporation (ECWC) with different problems facing. Especially, according to [Saurin & Pratik \(2014\)](#), concluded that Total Quality Management is practiced by many business organizations around the world.

1.3. Statement of the Problem

The construction industry to be globally one of the largest contributors to Gross Domestic Product (GDP), as well as to play an important role in determining a country's economic growth faces different obstacles.

According to [Thomas \(2016\)](#); many maintenance departments today 'fight fires' instead of approaching their problems systematically. Due to maintenance problems primarily concerned with four areas namely: maintaining critical systems, fixing the problem quickly and faster than the last time, determining what is causing the breakdown to happen so frequently, and identify the 20% of breakdown that are consuming 80% our resources affects the Operational process. In case of [Wilson et al. \(2017\)](#), the challenge of equipment maintenance summarized as no proper maintenance documentation, no local suppliers for spare parts, and inadequate expertise. The importation of spare parts usually leads to procurement partnerships like in Zimbabwe.

Ethiopian construction Works Corporation/ECWC/ being one of the known governmental construction corporations; contributing its own parts to Ethiopian GDP, has internal and external problems that are barrier to quality maintenance of operational productivity of equipment maintenance system(16 Project management Reform program).

In the context of competitive economics and business excellence, not having, TQM and operational productivity of equipment maintenance system wouldn't be became core elements in increasing the competitive advantage. Moreover, this led TQM and operational productivity of equipment maintenance system has no vital role in service business success. In addition to this, the importance of the relationship between TQM practices, equipment maintenance from the importance of TQM and operational productivity of equipment maintenance system is hindered in creating and strengthening the competitive advantage of an organization is to be decisive. TQM with no integration of equipment maintenance affects customer satisfaction that top-targeted goal of service organizations' business (Pekovic & Galia, 2009).

To facilitate and perform construction activities, the corporation has different construction equipment at different projects that organized equipment maintenance shops in each projects and Kality equipment maintenance center of construction equipment and machinery management sector to make preventive and corrective maintenance operations. However, the equipment maintenance and management have system and quality problems. For instance, equipment dumped down for a long time at Kality equipment maintenance center and at each project even for 7 and 8 years from information gathered. Because of down equipment, the corporation loses the estimated value of 24,580,000 birr (twenty four million, five hundred eighty thousand birr) per month from internal rental rate (EAD, 2020). Even, those equipment under operational, are sent to the maintenance shops in average 5 times a month which is not normal for PM maintenance at least should not be once before a months.

Although, due to poor disposal strategy, in fact recently there is progress, equipment in ECWC 90% completed their life time-meaning entered from pm to corrective maintenance, those 10% equipment under active life time, visiting the maintenance shops, not small figures as noted above (EAD, 2020). In addition to these drawbacks, there is the problem of management commitment and weak follow-up their workers. This fact is manifested in customer complains handling time in the company. Not only there is the maintenance activities problem seen in the Kality equipment maintenance center and project maintenance shops, but also other operational activities; the delaying of spare part supplying due to purchasing process delaying and not available pm service spare parts in stoke at store

because of unavailability of bulk purchase of service kits for six budget years which led to persistence Performa purchasing process.

1.4. Research Questions

Based on the review of literatures pertaining to operational productivity of equipment maintenance system, the quality management and its implementation continuous improvement in construction projects and central equipment maintenance shops focusing on the issues of practices, management commitment and problems on the subject matters in the context of Ethiopian construction Works Corporation (ECWC) are seriously lacking. Hence, gaps of understanding on the following questions are obvious and require attention:

1. What are the major factors causing maintenance quality problems, spare part supplying delay, and increase maintenance rework and downtime of equipment in equipment maintenance shops?
2. How to improve operational productivity of equipment maintenance system of maintenance quality, spare part supplying delay, equipment downtime, & maintenance reworks?

1.5. Objectives

1.5.1. General Objective

The main objective of this thesis is to improve the operational productivity of equipment maintenance system using TQM in construction equipment and machinery management sector of Ethiopian construction works corporation (ECWC)

1.5.2. Specific objectives

The specific objectives of the study are addressed as:

1. To identify the major factors causing lower maintenance quality, maintenance reworks, equipment downtime, and spare part supplying delay of operational productivity of equipment maintenance system.

2. To minimize equipment downtime, maintenance reworks, and to improve maintenance quality to achieve the improved customer satisfaction level.
3. To shorten the purchasing, supplying, and dispatching time of spare parts to maintenance shops by minimizing the waste operational process time.
4. To develop quality equipment maintenance model and strategy

1.6. Scope and limitation of the study

1.6.1. Scope of the Study

The study finding will address the impact of TQM practices on operational productivity of Equipment maintenance system in Ethiopian construction Works Corporation (ECWC) of construction equipment and machinery management sector which is located at Kality former equipment maintenance center. Since the corporation followed quality management introduction of top-down approach to all sectors and quality management implementation approach is selected to be quality award (business excellence) approach at the head office level, but Japanese model approach in technical sectors, the scope is involved construction equipment and machinery management sector only. This is because, including other project shops, those having the same maintenance trend, same models, and the same maintenance team organization will be redundant and costly research and the result believed to bring insignificant difference.

The study empirically examined the impact of TQM practices that relate to the nature of operational productivity of equipment maintenance system to the area of Management Leadership, People Management, Customer Focus, Information analysis, and Continuous improvement throughout construction equipment and machinery management sector of departments, services, teams and shops at Kality equipment center.

1.6.2. Limitation of the study

When the study is on progress and experiencing in the company, in addition to similarity project shops, there is limitation of covering all projects due to the location of projects; which are very apart from one another: from Kuraz project to Tendaho project; Megech to Gidabo;

from Awash Dulecha to Yabello projects far apart 500-1450km in between them. This was tedious as well as data collection cost was high. Hence, the researcher limited to the sample project construction equipment and machinery management sector which is directly related with equipment maintenance and the company benchmark is taken only Moenco, Nyala Motors, Ethio-Nippon, Addis Ababa City Road authority, Yencomad construction plc, and Sunshine construction plc companies for equipment maintenance system comparison because of the same reason above. The researcher is not intended to make benchmark for equipment maintenance system like Reis Engineering; it is declining from the market that information shows due to the foreign currency and Ethio- Engineering group, it is in the reformation process in which it lacks stability.

The other limitation for the researcher is obtaining fully organized data; which is necessary to the thesis in ECWC. In fact, this problem is not only the case of the corporation. But, it is manifested to be as whole companies in Ethiopia, although, a few organizations can be found having developed data in restricted issues. Beyond this, there is a big challenge of getting clear information in each department because of less encouragement to develop and document to the requesting party/researcher.

Widely known other major challenges during this study now a day is that, due to COVID 19 pandemic there are many restrictions to focal group discussion, data collection, and making interview of those nominated volunteers. Therefore, such a limitation has greater impacts on interpretation of the finding and data analysis. However; the researcher overcome all these limitations by striving day and night and by making close attachment with department, team, and shops to collect data, share idea, and process observations when it is in need for the research.

1.7. Significance of the study

The significance of the study emerges from the significant role of construction sector in economics. The other significance of the study is also to describe from the perspective of construction organizations regarding the relationship between TQM, operational productivity of equipment maintenance system in construction organizations.

The significance of the study also will be drawn from its contribution to the body of knowledge in presenting a new theory in the relationship between TQM and operational productivity of equipment maintenance system. The theory will be characterized by the perspectives of construction organizations compared to the existing theories which will be developed on the relationship mostly in manufacturing organizations context. From methodological perspectives, the study will add to the body of knowledge a holistic construction sector context and construction-related TQM practices study to enhance the operational productivity of equipment maintenance system.

For practitioners and managers of construction organizations the study will present insightful views on the linkage between TQM practices and operational productivity of equipment maintenance system. For example, focusing on customers' satisfaction and supplying spare parts and other resources management are the most useful managerial practices that influence operational productivity of equipment maintenance under TQM implementation.

Improving the maintenance quality, spare part supplying delay, equipment downtime, and maintenance reworks and developing QBMP model led the whole operational productivity of equipment maintenance system by significant value of the operational process of the research.

1.8. Organization of the paper

Chapter One Introduction:

Serves as the introductory chapter to this research and formulates the problem statement and research question of the study. The research objectives and others discussed, followed by an outline of the subsequent chapters in this dissertation.

Chapter Two Literature Review:

In this chapter, many papers reviewed based on operational productivity of equipment maintenance system using the recently published paper on TQM. The other discussed in this chapter is the contribution of TQM to African, Ethiopian and research gap identified.

Chapter Three Research Methodology:

In Chapter three the research design, methods of data collection, data analysis and data validation discussed. The method used for data collection is by means of a questionnaire and individual interviews with those responsible process mapped departments, teams and shops. The basic design and content of the questionnaire discussed as well as the verification and validation of the questionnaire data obtained.

Chapter Four Discussion and interpretation:

Finally, TQM implementation techniques and strategy are discussing. This plan is a comprehensive systematic process for the practical implementation of TQM techniques and practices at the construction equipment & machinery management sector of Kaliti equipment maintenance center.

Chapter Five: Conclusion and recommendations:

The last chapter of this dissertation concludes the study, and gives recommendations for preparation when the TQM implements the recommended maintenance programs for smooth operation and improve operational productivity of equipment maintenance system and future research.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

In construction companies from basic project utilizing resources, construction equipment is the significant one. For the project running without interruption the companies can't afford to engage always new equipment. Equipment maintenance is the discipline and profession of applying engineering concepts for the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment. This chapter has discussed issues related to equipment maintenance, TQM and process mapping.

2.2. Term Definitions

Maintenance is the effort required to undertake for maintaining the equipment performance similar to new ones. Unscheduled downtime due to equipment malfunction is one of the major concerns for industries which call for billions of dollars/birrs of losses each year. Maintenance is an important aspect to increase productivity by reducing such downtimes and improving equipment performance. (Jose, 2016; Anup 2021)

Equipment Maintenance is the discipline and profession of applying engineering concepts for the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment. (Jose, 2016; Anup 2021)

Total quality management (TQM) is a firm-wide management philosophy of continuously improving the quality of the products/services/processes by focusing on the customers' needs and expectations to enhance customer satisfaction and firm performance (Kumari & Rubal, 2016).

Operational Productivity is operational productivity of maintenance of equipment care and minor maintenance of equipment maintenance system using procedures that do not require detailed technical knowledge of the equipment's or system's function and design.

2.3. Equipment Maintenance

Equipment maintenance as it defined earlier is the discipline and profession of applying engineering concepts for the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment (Zulkipli et al. 2019).

2.3.1. Types of maintenance

Broadly, there are two main types of maintenance categories that can further be sub-divided in to various maintenance type groups: proactive maintenance or predictive maintenance and responsive maintenance or corrective maintenance types. (Jose, 2016; Anup, 2021)

2.3.1.1. Proactive maintenance or preventive maintenance

Proactive maintenance or preventive maintenance: is types of maintenance, refers to the fixing of problems before they appear. This type of maintenance includes: time based maintenance (TBM), which is done maintenance at a fixed time, predictive maintenance (PDM), is a type of maintenance refers to the prediction of failure probability of an equipment and schedule maintenance to prevent failure, failure finding maintenance (FFM), is potential hidden failures are searched at regular intervals and if discovered are repaired to prevent major breakdowns, condition-based maintenance (CBM), in this strategy, the actual asset condition is monitored and further maintenance requirement is decided, and lastly, risk-based maintenance (RBM), this type of maintenance considers the philosophy of maintaining the assets carrying the most risk during the failure. (Jose, 2016; Anup, 2021)

2.3.1.2. Responsive or Corrective maintenance

Responsive or Corrective maintenance is any maintenance task that resolves a problem with pieces of equipment and returns it to operational condition. This maintenance type includes: planned or scheduled corrective maintenance, is the corrective action that is not immediate but planned or scheduled depending on the urgency and nature of the deficiency identified, unplanned or unscheduled corrective maintenance, which needs immediate attention due to

some kind of critical failure and must be repaired without delay as it is directly relates to cost. (Jose, 2016; Anup, 2021)

2.4. Total Quality Management

Firms should improve employees' involvement/commitment/awareness to TQM, enhance firm structure, and provide resources to overcome the barriers that prevent effective implementation of TQM practices (Esin & Hilal, 2014). The improvement of total quality management not aimed at a specific area or case, but it stretches, covers, and analyses all process of a system.

2.5. Total Quality Management in ECWC

As it is said earlier in scope part, Ethiopian construction works corporation (ECWC) followed quality management introduction of top-down approach to all sectors and quality management implementation approach is selected to be quality award (business excellence) approach at the head office level, but Japanese model approach in technical sectors. The corporation awarded three ISOs in different scenarios, namely; ISO 45001: 2018, Occupational health and safety management system; ISO 9001: 2015, Quality management system, and ISO 14001:2015, Environmental management system. TQM practice in the corporation can be said in short is that completing first phase kaizen implementation, transferred to start the second phase kaizen implementation of equipment productivity on selected types of equipment (Ebrahim & Mahdie, 2013).

2.6. Fistful Review

The concept of quality management is to ensure efforts to achieve the required level of quality for the product which are well planned and organized (Kumari & Rubal, 2016). From the perspective of a construction company, quality management in construction projects should mean maintaining the quality of construction equipment maintenance at the required standard so as to obtain customers' satisfaction that would bring long term competitiveness and business survival for the companies Tan & Abdul (2005). Quality management is critically required for a construction company to sustain in current

construction market which is highly challenging and competitive. The equipment maintenance strategy program and its positive result is the key and the main component of the construction.

IN this issue **Harris and McCaffer (2001)** explained that quality management has to provide the environment within which related tools, techniques and procedures can be deployed effectively leading to operational success for a company. The role of quality management for a construction company is not an isolated activity, but intertwined with all the operational and managerial processes of the company. Quality management started with simple inspection-based systems. Under such a system, one or more characteristics of a product are examined, measured or tested and compared with specified requirements to assess its conformity. It is undertaken mainly by staff employed specifically for this purpose. Products which do not conform to specification may be scrapped, reworked or sold as lower quality items. In some cases, inspection is used to grade the finished products. The system is an after-the-fact screening process with no prevention content other than, perhaps, the identification of suppliers, operations or workers manufacturing non-conforming products. Simple inspection based systems are usually directly involve suppliers or customers. This elaboration is suited to manufacturing, but, in the same way, can be applied to the service giving organizations, especially to the maintenance department except modifying some points to agree the facts and constraints to be discussed.

Maintenance is increasing in importance due to rising amounts of equipment, systems, machineries and infrastructure. Since the industrial revolution, devices, equipment, machinery and structures have grown increasingly complex, requiring a host of personnel, vocations and related systems needed to maintain them. Under a system of quality control, product testing and documentation control became the ways to ensure greater process control and reduced non-conformance. Typical characteristics of such systems were performance-data collection, feedback to earlier stages in the process, paperwork control, use of basic statistics, basic quality planning, product testing and self-inspection. While screening, inspection was again the main mechanism for preventing products which were outside the specification from being shipped to customers. Quality control measures led to greater process control and a lower incidence of non-conformance.

Total quality management (TQM) is often defined as a complete management philosophy that permeates every aspect of a company and place quality as a strategic issue. It is accomplished through an integrated effort between all levels of a company to increase customers' satisfaction by continuously improving current performance (Biggar, 1990). The adoption of TQM in construction industry has been promoted in some literatures (Low & Teo, 2004; Biggar (1990); Haupt & Whiteman, 2004). ISO certification is nowadays a trend in most industries including construction industry. The ISO 9001 standard is now on its year 2000 revision. The five clauses for its implementation are quality management system, management responsibility, resource management, product realization, and measurement, analysis, and improvement.

The application of ISO standards has received much attention from researchers. Moatazed et al. (1999) argued that the ISO 9000 standards series can form and have formed the basis for an efficient and advantageous quality management system in the construction industry. Love and Faniran (2000) commented that ISO 9000 certification is not an option but rather a reality for construction companies that wish to retain and sustain their competitiveness in today's highly competitive markets. As for the implementation of quality management in project management, the concepts of quality planning (identification of quality standards), quality assurance (evaluation of overall project performance), production systems and quality control (monitoring of specific project results) in the quality management processes were defined by Project Management Institute (2000). Several tools and techniques were identified as part of the implementation process, there are, benefit and cost analysis, benchmarking, flow-charting, design of experiments, cost of quality, quality audits, inspection, control charts, statistical sampling, flow-charting and trend analysis. Mathews and Silva (2001) divided quality tools and techniques that are in support of quality programs into three main types, i.e., hard quality tools, mixing methods and soft methods.

Hard quality tools are formal quality systems, documented quality systems, quality costs, control charts, and statistical sampling standards. Mixing methods are strategy and action plans review, flexibility of organization structure, control charts, quality circles, and quality planning tools. Soft methods are training, customer satisfaction surveys, regular contact with vendors and external organizations, actions to optimize environment impact, empowerment,

self-assessment, and benchmarking. Taylor et al. (2003) concluded that senior managers' involvement, understanding and customer focus are essential antecedents of TQM success. Samson et al. (1999) described that leadership and human resources management are among strong predictors of performance TQM practices.

On construction related research, Low et al. (2004) commented that top management commitment as one of the elements that would reflect TQM performance measures in construction firms. Chin et al. (2003) found that top management commitment is the most critical factor for the successful implementation of ISO 9000. Haupt et al. (2004) argued that high levels of management actions would lead to reduced prevalence of the problems as TQM is deployed on construction sites. Arditi et al. (1997) emphasized that management commitment to quality and to continuous quality improvement is very important in each phase of the building process. Biggar (1990) recommended that management must fully understand and support the TQM process and actively participate in its implementation rather than delegate it.

In addition to the above, ISO 9001:2000 requires the following in relation to management commitment: Communicating about the importance of meeting customer as well as statutory and regulatory requirements; establishing the quality policy; ensuring that quality objectives are established; Conducting management reviews; and ensuring the availability of resources.

Certain problems have been observed in relation to quality management implementation. Haupt et al. (2004) noticed several hindrances for implementing TQM on construction sites, i.e., too much paperwork, transient nature of workforce, field employees regard TQM as irrelevant, difficulty in measuring results, low bid subcontracting, and subcontractors and suppliers not interested in TQM. Tang and Kam (1999) found that the most difficult task in implementing ISO 9001 in engineering consultancies in Hong Kong is to make engineers understand and accept the system, followed by the lack of strong support from the management, and lack of effective communication. Based on interview conducted in Sweden, Landin (2000) argued that in construction process, many of the concepts in ISO 9001 are experienced as being too abstract and too difficult to comprehend. He also argued that it appears difficult for a company to improve its competitiveness and be more efficient

by the use of ISO 9001 alone in view of the many stages of the construction process encompassed and the diverging interests represented. [Moatazed et al. \(1999\)](#) noticed concerns in the areas of bureaucracy, cost, time consumption and interpretation in relation to the implementation of ISO 9000 standards in United Kingdom (UK) construction industry. [Kumaraswamy and Dissanayaka \(2000\)](#) stated that the three most significant negative outcomes encountered by Hong Kong contractors on ISO 9000 certification are, more paperwork, more time spent in management, and increase of bureaucracy. [Low \(1994\)](#) found that most contractors in Singapore consider human-related problems are most critical in implementing quality assurance (QA).

Furthermore; [\(Serpell, 1999\)](#), observed that there are cultural and operational barriers in quality system implementation. In a study of quality management of a large-scale infrastructure construction project in Hong Kong, [Au and Yu \(1999\)](#) found problems in the areas of documentation, control of quality inspection and process procedures. [Lai, Weerakoon and Cheng \(2002\)](#) noticed there are weaknesses in the implementation of quality management for construction industry in Hong Kong in respect of the communication of improvement information, and teamwork structures for quality improvement. [Kubal \(1996\)](#) argued that the construction industry is lacking open communications and mutual support that derived from trust-based relationships among project participants to effect substantive quality improvement.

In the briefing of [Zulaikha Sajaradj et al. \(2019\)](#), pointed out that reliable centered maintenance is useful in addition to cost minimization, safety and environment, motivation for workers, availability and reliability. I argue that the researcher is not analyzed the effect of the time in operational productivity of equipment maintenance system.

In case of [Zulkipli et al. \(2019\)](#), claimed that maintenance performance improvement can be achieved using fuzzy Delphi method and concluded that the performance improvement through leadership category leads the overall initiatives followed by equipment maintenance management, talent management, working environment and vendor management in Malaysia.

Total quality management stage is the highest level, involving the application of quality management principles to all aspects of the business. Total quality management requires that the principles of quality management be applied in every branch and at every level in an organization. Typical of an organization going through a total quality process would be a clear and unambiguous vision, few interdepartmental barriers, time spent on training, excellent supplier and customer relations and the realization that quality is not just product quality but also the quality of the whole organization, including sales, finance, personnel and other none manufacturing and maintenance functions.

The structure for an effective equipment maintenance organization will vary with the size and type of organization. It may also vary with the management philosophy of the company. But one thing must be kept in mind: organizational structure must allow the company to meet its goals and objectives and each unit within the company must be given with sufficient personnel and authority to carry out those objectives and meet those goals.

2.7. Literature Gaps

The gap in general description is about the relationship between TQM practices and equipment maintenance in service organizations regarding the nature of TQM practices in service organizations compared to organizations from other sectors such as manufacturing organizations. The gaps can be described as follows:

First, some of the researches indicated that operational productivity of equipment maintenance department having relation with other departments such as: finance, procurement, equipment & property administration, facility; but they didn't show the impact and the intensity of the results encountered through the work processes.

Second, most of empirical studies on the impact of TQM on equipment maintenance conducted completely or partially in manufacturing industry (The & Ooi, 2009). There is a need for more studies on this field in services industries and the relationship between TQM practices, equipment maintenance addressed a specific type of equipment maintenance works focusing on manufacturing industries.

Third, with respect to the importance of TQM, equipment maintenance in business organizations and based on the literature review, the relationship between TQM, equipment maintenance in service organizations in Ethiopia may need more investigation.

Fourth, results of previous studies concluded different and contradicted results (Kim et al. 2012). Some have found TQM has positive impact on operational productivity of equipment maintenance system (Prajogo & Hong, 2008; Sarkees & Hulland, 2009). Whereas others found TQM has no impact on operational productivity of equipment maintenance system. Therefore, the debate remains because there is no approving regarding that TQM has positive or negative impact on operational productivity of equipment maintenance system.

Fifth, the researcher lacks showing clear direction to solve the impact of other departments on equipment maintenance department directly and indirectly related to the quality and productivity of operational activities.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Research Methodology

In this chapter, the researcher tried to elaborate the overall methodologies of the study along with its approaches for the study, sampling, data collection techniques, strategies for data analysis and validation of the findings. The chapter also describes the ethical consideration of the study.

3.2. Design and Approach of the Study

Numerous types of research design are appropriate for the different types of research projects. Each type of research design has a range of research method that are commonly used to collect and analyses the type of data that generated by the investigations. The research design in this study is used descriptive type of research from preliminary assessment and gaps identified and also the researcher formulated the problems and objectives. More than 500 documents which are related with the title are observed. From these documents only 56 documents are viewed and referenced for literature review. The primary and secondary data which are both qualitative like company's report, magazines cause and effect data and quantitative such as questionnaire, bar graph, Pareto chart research design is proposed for this study and the data are collected and analyzed. After analyzing those data using process mapping tools the researcher evaluated and simulated the existing process. By isolating a store, the so called mini-store which helped to improve the existing process and a model which is called SWIFT is developed. And then the researcher triangulated among the different departments and verified and validated the improved process by simulating the operational process. According to this result the researcher concluded and made recommendation by series back checking until the system is improved 80% of the process time that needed the process from reception up to customer submitting. Thus, qualitative data is collected throughout the data collection process. This approach requires that the researcher

"centers on the attempt to achieve a sense of the meaning that others give to their own situations" (Smith, 2005).

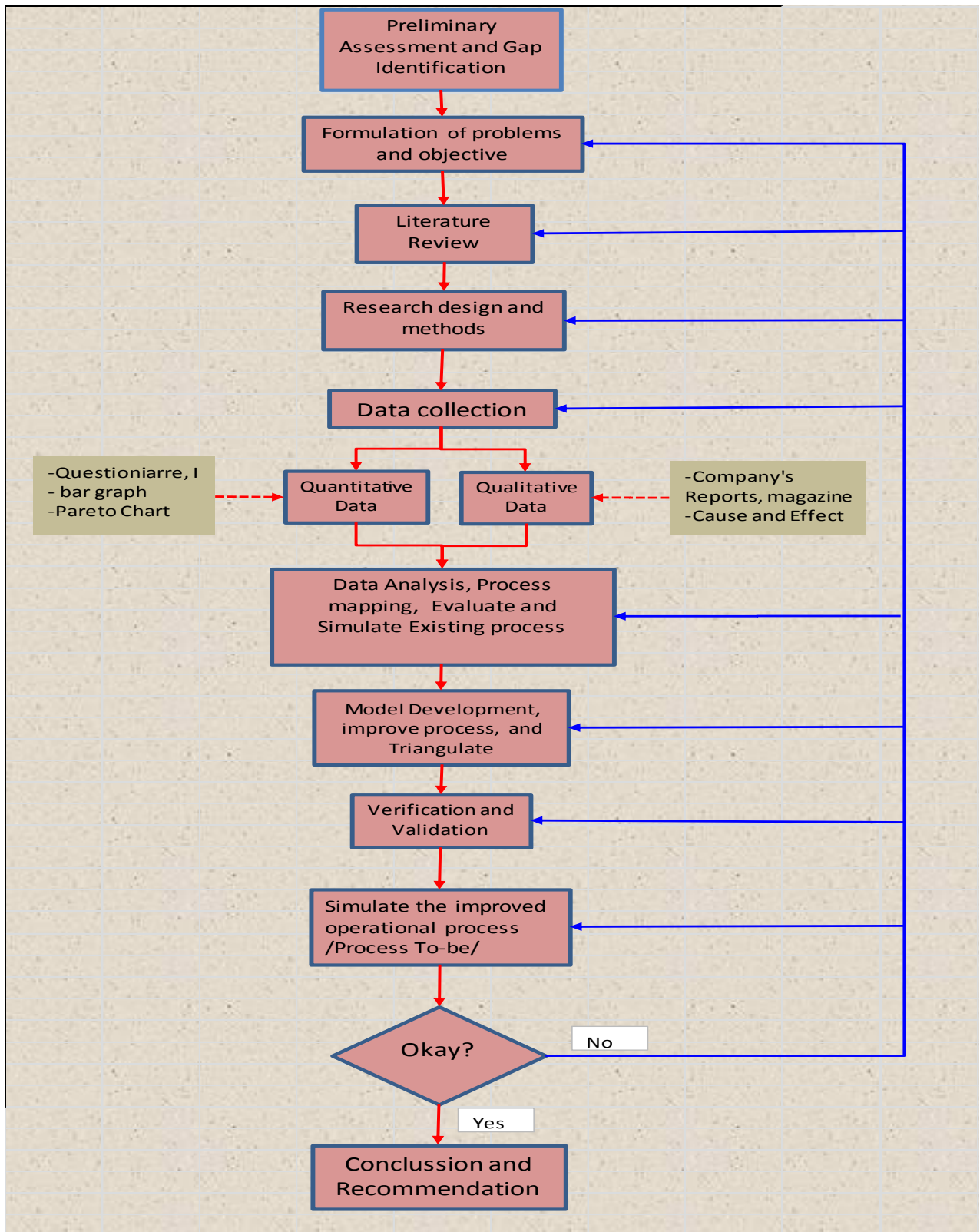


Figure 3.1 Research Methodological Framework

3.3. Sampling Technique

Selection of sample is based on convenience sampling approach where the researcher will obtain the sampling units that are convenience available (Frankfort et al., 2000) from the personal contacts who are capable understand the process because, this process needs technical knowhow broadly. In order to meet the proposed purpose of the study the researcher used purposive sampling methods among the targets. The target of the study made to be those working in the area of equipment maintenance & administration, finance, property administration, procurement, working around supply and warehouse. Like managers, leaders, engineers, mechanics, electricians, so on. The respondents are selected using the aforementioned purposive sampling techniques. The sampling process considered like professions, educational back ground, and service year. In this research, from all construction equipment & machinery management sector; workers who have close relation with the process of 208, it is taken 96 respondents only and the questioner is distributed to all them.

3.4. Data source

Under this study the research is used primary and secondary source of data.

Primary data source

Primary data is collected through questionnaires from employees, leaders, and managers of construction equipment & machinery management sector of human resource department of the organization by using questionnaires invited employees to write what they feel and look appropriate and observation would be used. In the thesis is used close and open ended questionnaires type.

Questionnaire Evaluation assigned values:

I strongly disagree=0, I disagree=1, Neutral=2, I agree=3, I strongly agree=4

Secondary data source

Secondary data from file, weekly, monthly and annually maintenance, purchase, finance, stoke(warehouse), equipment management reports, guide office manuals circular, literature review and policy paper used which provide additional information were appropriate.

3.5. Data Analysis

The researcher analyzed the data using descriptive explanatory approaches. Content and narrative analysis methods employed to analyze the data gathered from the respondents. The basic procedure in reporting the results of this qualitative & quantitative study are to develop descriptions and develop model from the data, to present these descriptions and model that convey multiple perspectives from participants and detailed descriptions of the individuals, using the qualitative & quantitative strategy of inquiry. After collecting the data, a theme is prepared for the analysis and interpretation purpose. Descriptions of terms from the interviews and observation can also be made Graphical presentation; particularly bar graph (both simple and group) is used. Data collected from the participants is also prepared using tables as appropriate as intended. Descriptive statistics like weighted value, percent and cumulative percent is mainly applied for the data analysis. Meanwhile, the process is mapped and through observation, to develop improved process along the flow all decisive departments.

3.6. Model & Data Validation and Verification

In this area, [Cooper and Schindler \(1998\)](#) proposed that in the early stage of an exploratory research, where the researcher is seeking guidance, to test ideas, or even to gain ideas about a subject of interest, such approach might be applicable. So to increase the validity of the study, certain criterion will be set. In order to validate the findings of the results, the researcher will use systematic approaches throughout the data analysis process and will also execute the following techniques:

- Triangulate different data sources of information by examining evidence from the sources and using it to build a coherent justification for themes.
- Using a rich, thick description to convey the findings. By providing detailed descriptions of the setting, offering many perspectives about the themes, then the

results become more realistic and richer. This procedure can add to the validity of the findings.

- Presenting negative or discrepant information that runs counter to the themes. Discussing contrary information helps to add credibility on the findings. Presenting contradictory evidences enable the findings to become more realistic and more valid.
- Peer debriefing which will obtain an individual outside of the study to review and evaluate the report.

3.7. Ethical Considerations

The researcher considered ethical issues at the highest standard during the entire study process and the following procedures are considered.

- **Informed Consent:** - During the data collection phase, it was ensured that participants were fully informed orally about the research procedure and give their consent to participate in the research before data collection takes place.
- **Confidentiality:** - Any information about participants acquired during the research process is kept confidential and is not shared to any party other than the study purpose.
- **Right to Withdraw:** - participants were freed to withdraw from participation in the study without fear at any phase of the interview.
- **Debriefing:** - After and during data collection, participants were informed about the full aims of the research. They should also have access to any publications arising from the study they take part in.

CHAPTER FOUR

4. DATA ANALYSIS, RESULTS AND DISCUSSION

4.1. Introduction

In this chapter, the equipment maintenance activity in the case company is explained in short and by the researcher qualitative and quantitative collected data is analysed. The closed and open type questionnaire distributed and collected from the respondents according to descriptive data sampling which is taken to be 96. From 96 respondents 86 respondents are filled the questionnaire correctly and handed in to the researcher on time that is, almost 95% effective from the questionnaire distributed and collected. From those respondents, 8 respondents were missed to fill some responses and the researcher made them to finish unfilled questionnaire again and collected the questionnaires, whereas 2 respondents were unable to respond due to urgent corporation's assignment and substituted by other similar position holders to make the questionnaire's response 100%.

The data from company report were not summarized well in order to use the data directly for the research purpose. Hence, to maintain the reports according to the research needed all departments of managers, team leaders, and shop Forman were cooperative fully understanding the aim of the research with the researcher to compile the necessary data of process direction, quantity, and time elapsed that of process completed from reports for existing process analysis. For the future or improved process data compiling one store is selected and that located nearest to maintenance shops the so called min-store and the process time of each operation is observed and evaluated for two months relative to this store from weekly reports together with heavy maintenance shop.

From reviewed documents, researchers had done with this similar title used to follow their thesis SPC data analysis. But, since this researcher selected process mapping, total quality management tools, the researcher strictly followed according to the guidance of (Kate, 2017).

4.2. Equipment Maintenance in Ethiopian Construction Works Corporation

Ethiopian construction Works Corporation is the known grade one construction company in Ethiopia. The corporation is organized to construct different irrigation dams, roads, airports, buildings, manage constructed irrigation dams; manage and maintain construction equipment. Construction equipment is the first vital input for construction completion. Nowadays, the equipment maintenance system reaches to be a must task for construction companies especially, in Ethiopia. This is because, the scarcity of foreign currency widely to import equipment.

Ethiopian construction Works Corporation organized equipment maintenance shops at each projects and one main equipment maintenance centre at Kality under the construction and machinery management sector. At each projects simple maintenance task is done and those equipment with heavy maintenance tasks are sent to the central equipment maintenance shop-Kaliy, and also, around Addis Ababa projects and head office equipment are maintained at this centre. In this equipment maintenance centre, many equipment like: light duty vehicles, heavy duty vehicles, and machineries are damped for long time as it is said earlier. The corporation is trying to minimize the down equipment using different mechanism like assigning technical committee and so on. But, still many equipment are down.

The operational productivity of equipment maintenance system at Kality equipment centre starts from inspecting of the equipment; then requesting for spare part; purchasing, modifying, outsourcing, cannibalizing, or dispatching from stoke; and then after fixing the parts and final inspecting the equipment lastly submitting to customers.

4.3. Qualitative Data Analysis

In this sub topic, as it is discussed in the qualitative data analysis part and mentioned in the methodology part of chapter three are company's weekly, monthly, and annually reports, magazine, cause and effect discussion is made as follows.

4.3.1. Cause and Effect Data Analysis/Fish bone diagram/

The researcher did as it is observed from the fish bone diagram, the operational productivity of equipment maintenance system problem is analysed and summarized in **Figure 4.1**.

Almost 80% effect (equipment maintenance quality, spare part supplying delay, and equipment downtime) came from 20% of causes which are responsible for problem or improvement of operational productivity of equipment maintenance system. When we look to the causes of cause /effects/ 80% equipment maintenance quality problems (fire fighting rather than strategy, weak leaders and employee commitment, and weak integration among departments, teams, and shops) caused by 20% of problems, which are very vital that solving these 20% causes or problems, that can have 80% of improved effects or events listed in the parenthesis above.

In the same manner, 80% spare part supplying delay (poor purchasing system, government regulation by themselves, and scarcity of budget) caused by 20% problems. If these 20% problems are solved, the 80% effects are improved.

Doing in the same way, 80% equipment down time (lack of finance for spare parts, lack of trained technicians, jut out cannibalization, and scarcity of spare part in the market, and unnecessary movement waste time) can be improved by solving 20% causes of these.

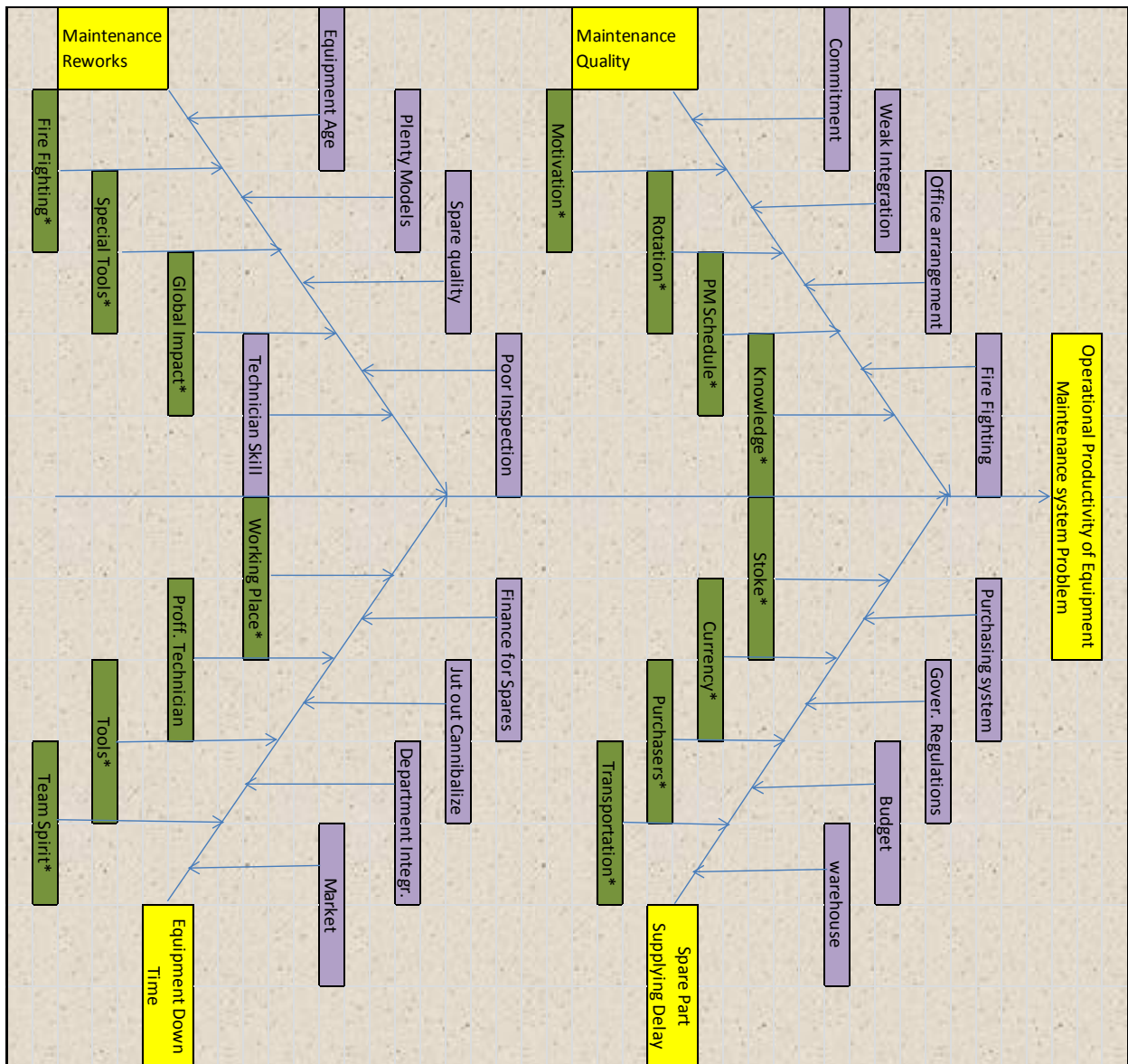


Figure 4.1 Fish-bone Diagram of Cause and Effect

4.3.2. The Root Causes of Cause Effect

The question is what are 20% causes for effect of above problems which are responsible for the main problem of operational productivity of equipment maintenance system?

In the following **Table 4.1** compiled root causes from different shop Forman, team leaders, heads, and department managers interview; in the time of questionnaire dissemination and besides of the background of the researcher is summarized as follows:-

Table 4.1 Summary of root causes of cause effect

Operational Problems	80% Effects	20% Causes
Maintenance Quality Problems	Fire fighting rather than strategy	Poor Planning, resources allocating, leaders and organization problems
	Weak leaders and Employee commitment	Employee encouragement, pro-activeness, and accountability problems
	Weak department, teams, and shops integration	Office and shop location, process flow, responsibility problems
Spare part supplying delay	Poor purchasing system	Absence of Bulk purchase and PM schedule
	Government Regulations	Behavioural, social, higher officials commitment problems
	Scarcity of budget	Weak project planning & execution, personal benefit prioritising, being pushing rather than pulling
Equipment down time	lack of finance for spare parts	Weak project planning & execution, personal benefit prioritising, being pushing rather than pulling
	lack of trained technicians	Strategic employee training and coaching problems
	lack of spare part in the market	Foreign currency & tax regulation problems
	Unnecessary movement	Office and shop location, process flow problems
Maintenance Reworks	poor inspection	Inspector, working place, and organizing problems
	poor quality material & spares	Globalization impact, poor skill and quality control problems
	Equipment age	Cannibalization, technician skill, poor equipment replacement strategy

4.3.3. Data from company Reports

The data that are compiled from weekly, monthly, and annually reports of equipment maintenance department, equipment administration department, financial administration department, procurement team, supply and property administration team, and equipment maintenance administration team is summarized the types of process and the required time for those operations from customer reception to equipment submission to final users or customers in existing process from **Table 4.3** of process mapping.

4.4. Quantitative data Analysis

The quantitative data are those data which are evaluated quantitatively that categorized in the methodology parts are questionnaire, interview, observation, Pareto chart, and bar graph.

4.4.1. Closed questionnaire part

The closed questionnaire part contains and elaborates about causes of operational productivity of equipment maintenance system problems which is shown and discussed in fish bone diagram **Figure 4.1**

4.4.2. Open questionnaire part

In open questionnaire part there are 88 responses filled in dash space and submitted 26, 22, 22, & 18, for down time, maintenance reworks, spare part supplying delay, and maintenance quality problems, respectively. From open questionnaire the following points are raised from different departments. However; which of them important or which are redundant are isolated that crowned the * sign.

For maintenance quality problem taken from respondent are: knowledge, pm schedule, employee motivation system, and rotation of employee. The researcher agreed on the motivation and rotation. Fade up comes from non-motivation system. The other two are indirectly redundant. Those raised for spare part supply delay causes: no spare stock, foreign currency, purchasers' performance, and transportation; only foreign currency is very critical cause of unavailability of spare part in the market. The others are indirectly redundant. On equipment down time noted are: working place, professional technicians, hand tools, and

team spirit unavailability. The researcher agreed on the working place improvement, tools unavailability cause is raised from respondents, which is not critical because many box tools are available in tools shop to be taken out and used rather the problem is the cost of the tools being in dollar. The last cause of maintenance reworks, mentioned are: special tools, global impact, and fire fighting. They all have slight impact on the cause and the researcher agreed on the cases.

4.4.3. Respondent Data Description

The 96 questionnaire distributed and collected; is summarized as the respondent's sex, age, profession, work experience, and department is assigned on X-axis direction whereas, Amounts indicated on Y-axis direction on the top of bars of the bar graph showed the values for sex, age, worker's profession or education, experience, and department of the employee on the bar graphs of **Figure 4.2**.

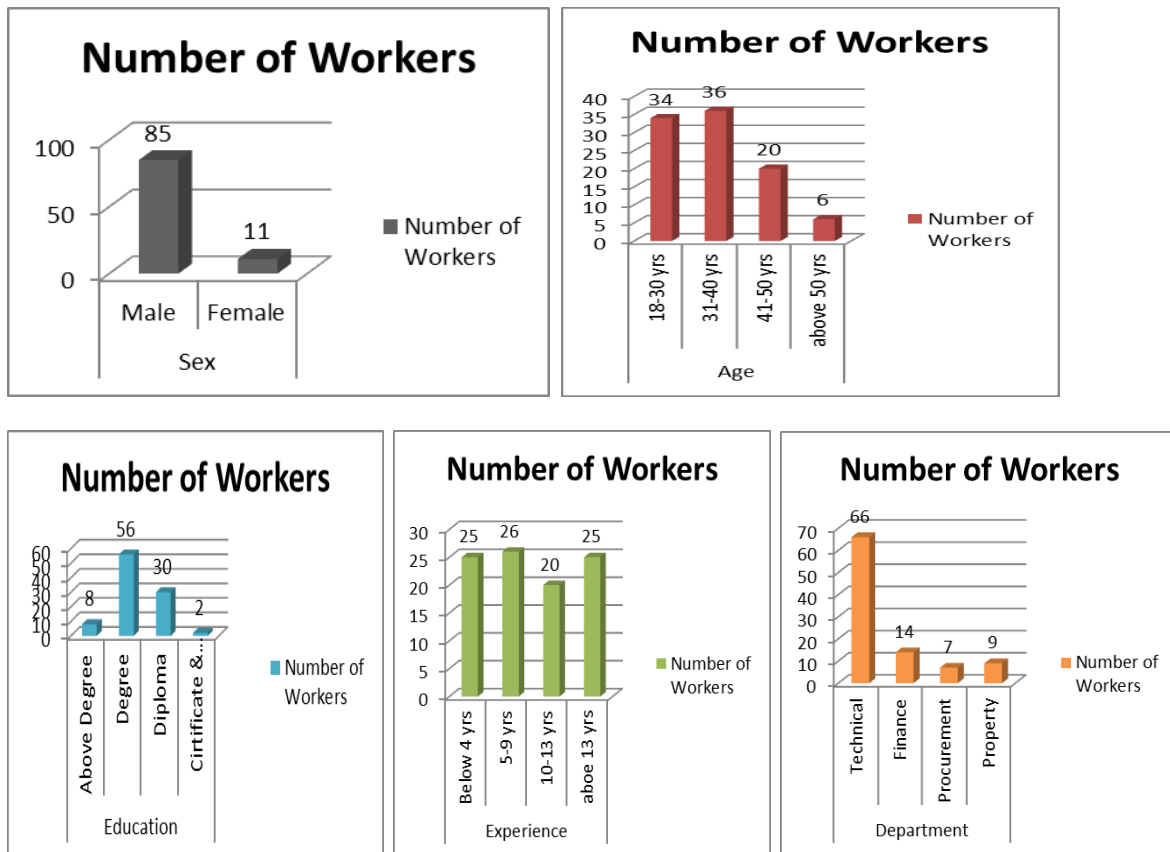


Figure 4.2 Respondent Data of bar graphs

4.4.4. Questionnaire Data Summary

To make the data analysis, first of all the data are grouped and summarized in a suitable manner, hence, the questionnaire collected is grouped according to the strongly disagree, disagree, neutral, agree, and strongly agree groups. After doing this, weighted value and average weighted values are calculated. Then after, using Excels, Edrawmax, and QI Macros trial software summarized data **Table 4.2**, and flow chart, networking diagram, bar and Pareto charts are drawn and explained just before the figures.

Table 4.2 Data Summary (Own)

Causes for Main problems	Operational productivity of Equipment Maintenance System Problems								
	Causes for sub- Problems	Assigned values					6	7	8
Prolonged Equipment down time		1	2	3	4	5			
	Lack of finance for spare part	4	7	7	58	20	2.9688	18.60	18.34
	Lack of trained Technicians	6	23	15	41	11	2.8750	18.02	36.36
	Uncontrolled cannibalization	5	19	15	36	21	2.8646	17.95	54.31
	Lack of spare part in the market	1	26	10	47	12	2.5104	15.73	70.04
	Waste of time due to movement	2	4	10	56	20	2.4479	15.34	85.38
	Lack of integrated mgt system	1	6	10	57	22	2.2917	14.36	99.74
							15.9584		
Maintenance rework	Poor pre and post Inspection	2	11	13	39	31	2.9583	27.90	27.31
	Poor quality of spare and material	2	10	28	45	11	2.8958	27.31	54.62
	Due to old equipment & not replaced	2	5	13	51	25	2.5521	24.07	78.68
	Lack of technicians knowhow	3	28	22	33	10	2.1979	20.73	99.41
							10.6041		
Spare part Supplying delay	Poor purchasing system	2	7	19	48	20	3.0208	28.38	27.67
	Government regulations by themselves	0	12	23	45	16	2.8021	26.32	53.99
	Scarcity of budget for spare parts	1	6	11	50	28	2.6771	25.15	79.14
	Poor arrangement of workplaces	8	22	26	28	12	2.1458	20.16	99.30
							10.6458		

Maintenance quality Problem	More fire fighting rather than strategy	2	10	12	46	26	2.9896	26.31	25.88
	Weak leaders and employee commitment	4	15	18	45	14	2.9375	25.85	51.73
	Weak integration for quality	0	20	15	47	14	2.8750	25.30	77.02
	Poor arrangement of workplaces	6	12	20	38	20	2.5625	22.55	99.57
							11.3646		

Key: Column1= strongly disagree, Column2= Disagree, Column3= Neutral, Column4= Agree, Column5= strongly agree, Column6= Sequential value, column7= Sequential weighted value, Column8= percentage of causes, Column9= Cumulative percentage.

4.4.5. Description of Operational productivity of equipment maintenance System Problems

4.4.5.1. The Description of bar graph

It is so clear to understand and elaborate from the **Figure 4.3** and **Table 4.2** the weighted average value of 2.84 is the largest value from bar graph is the respondent claimed to be maintenance quality problem for the event of the operational productivity of equipment maintenance system problem. The other three causes for the operational productivity of equipment maintenance that are spare supplying delay, equipment down time, and maintenance reworks have almost similar impacts or causes for the main problem.

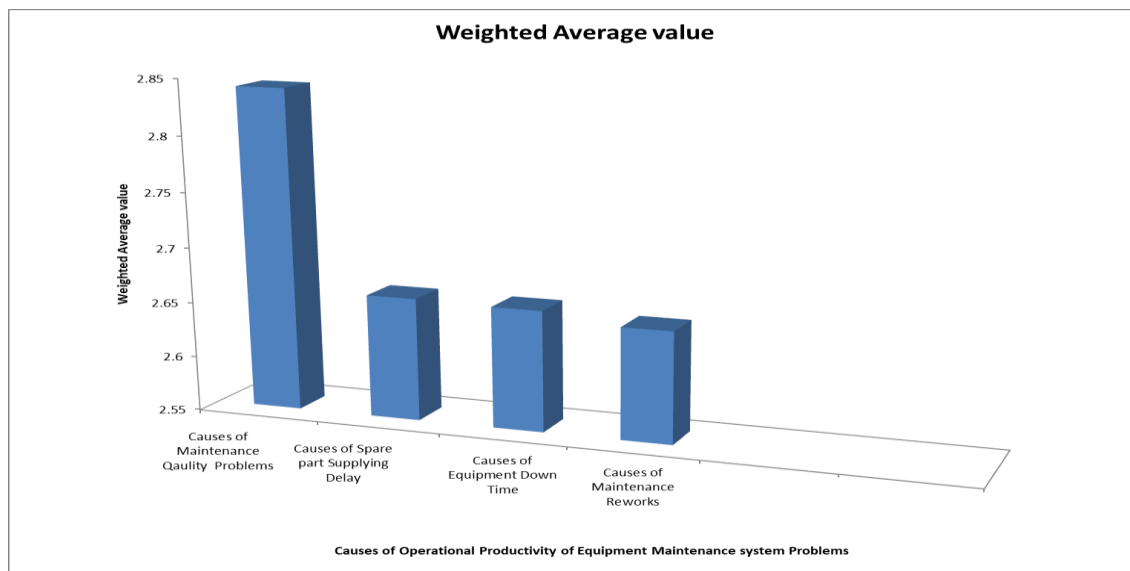


Figure4.3 Bar graph of OPOEMSP

4.4.5.2. The description of Pareto chart

Pareto chart of operational productivity of equipment maintenance system problems **Figure 4.4** shows that except the maintenance quality problems, the others have similar weighted average values that have similar causes for the effect. The Pareto chart looks unique almost straight line. This shows that each cause has similar impact on the effect or result or consumption.

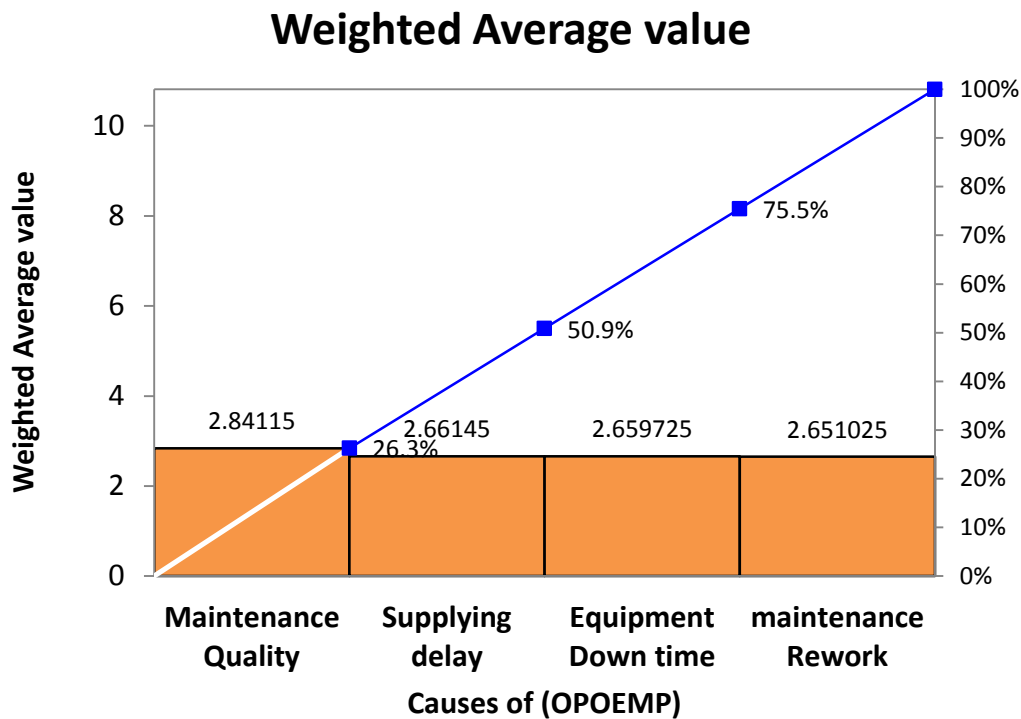


Figure 4.4 Pareto Chart of OPOEMSP

4.4.6. Description of Maintenance Quality problems

4.4.6.1. The description of bar graph

In the same manner described above, the bar graph in **Figure 4.5** of maintenance quality problem observed that the bar graph part constructed with the y-axis direction to be the degree of agreement; strongly disagree, disagree, neutral, agree, and strongly agree bars, whereas the x-axis direction is designated by the causes.

As it is can be observed the longest bar graph in each causes is agree on the causes of maintenance quality problems that are firefighting, weak commitment, weak department

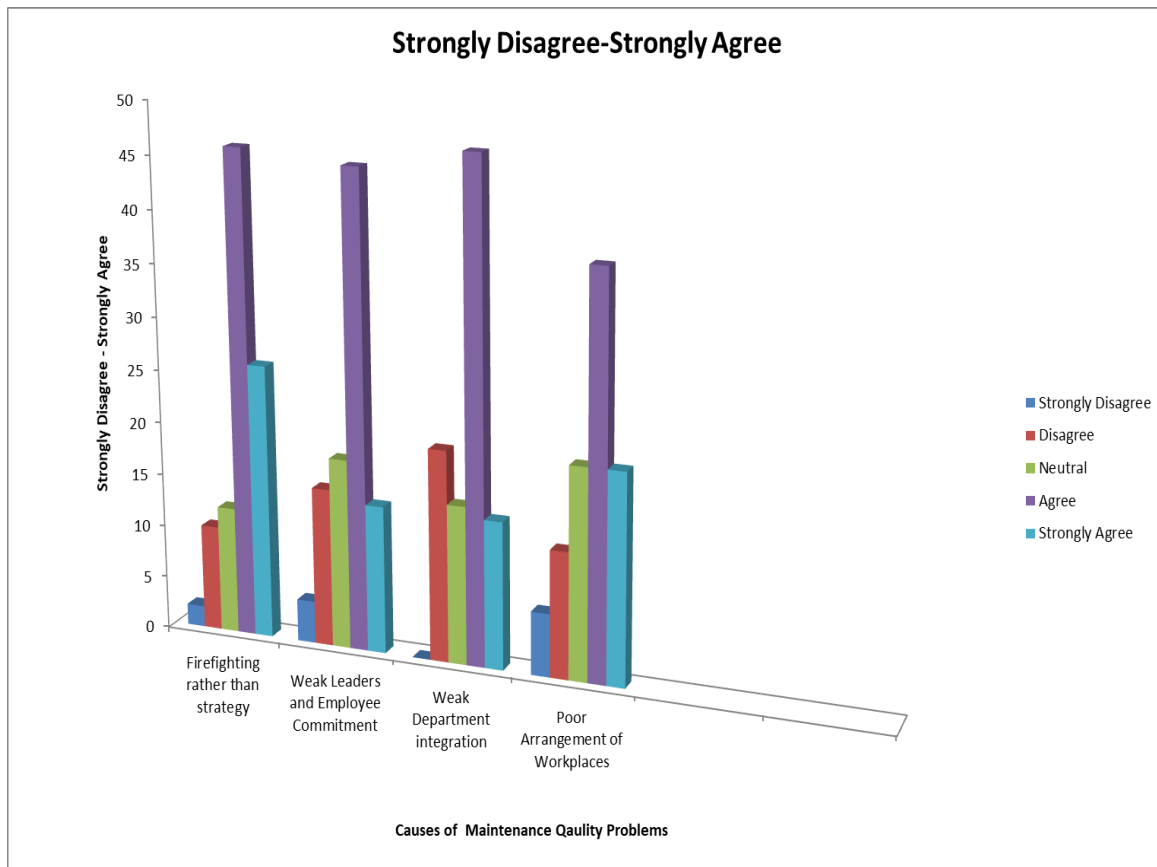


Figure4.5 Bar graph of maintenance quality problems

4.4.6.2. The description of Pareto Chart

For the Pareto chart part y-axis is the weighted value and x-axis assigned causes of the effect still the pattern of the Pareto chart shows that the straight line indicated the causes have almost the same impact distribution in the problem of maintenance quality **Figure 4.6**

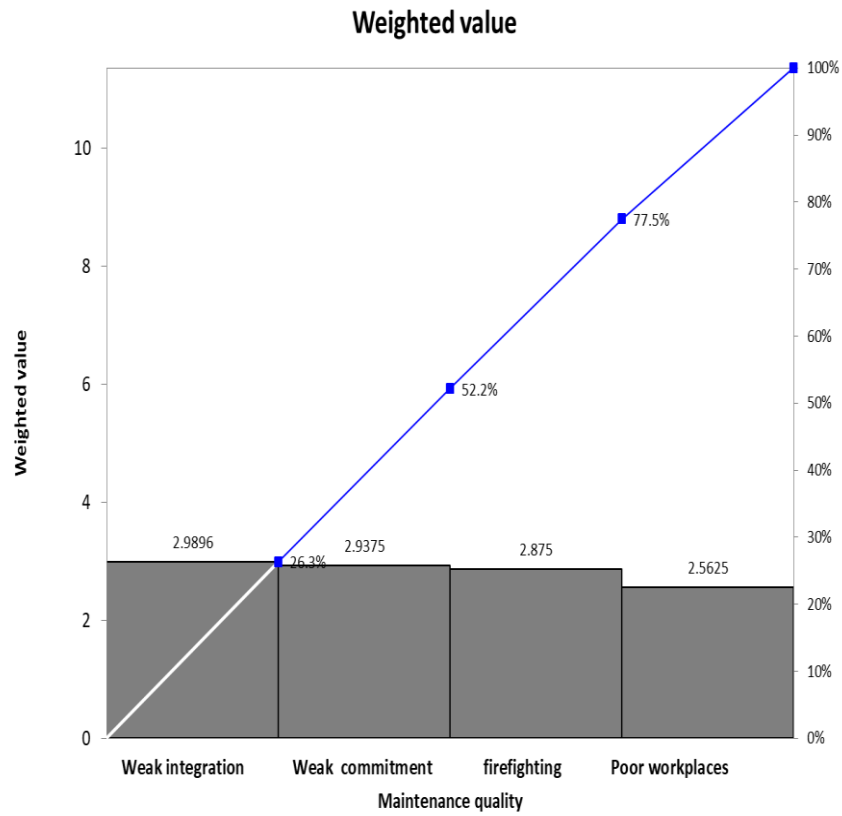


Figure 4.6 Pareto Chart of maintenance quality problems

4.4.7. Description of Spare part supplying delay

4.4.7.1. The description of bar graph

In this case, the bar graph shows the first three causes have longest agree bar. But, the fourth cause slightly the distribution is minimized the cause of poor work place is less than the other causes and shown next **Figure 4.7**.

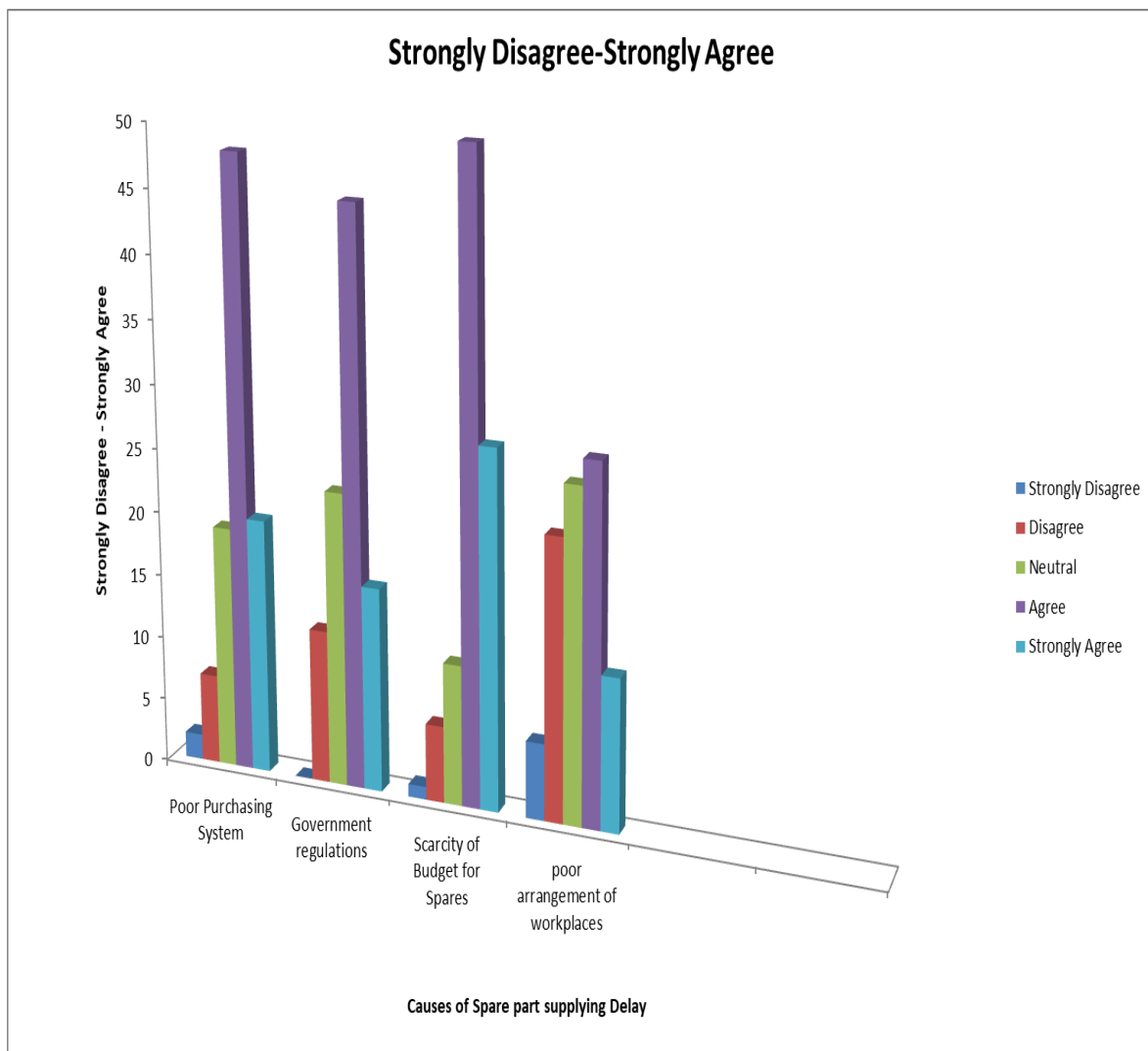


Figure4.7 Bar graph of Spare part supplying delay

4.4.7.2. The description of Pareto Chart

From the Pareto chart, we can derive idea that from all causes of problems, there is no weighted value recorded more than scarcity budget for spare parts which is equal to 3.0208. This is not only the highest weighted value of spare part supplying delay, but also the highest of other. According to the respondent data summary the main causes of spare part supplying delay is scarcity of budget. The researcher strongly agrees on this case. The other lesser weighted value is seen in the data is poor working place, the impact is not as strong as the highest one **Figure4.8**.

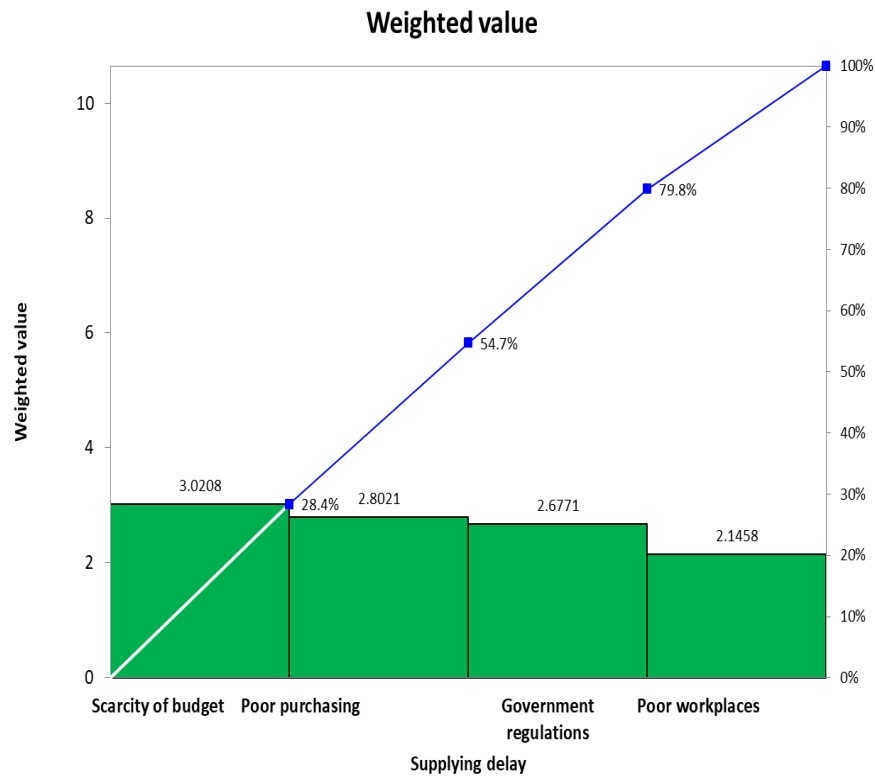


Figure 4.8 Pareto Chart of Spare part supplying delay

4.4.8. Description of Equipment down time

4.4.8.1. The description of bar graph

Bar graph of equipment down time is almost similar with the others that elaborated above in in other causes of main problems. It is the causes denoted in the x-axis from lack of finance for spare part to lack of integrated management system effect by lack of shop integration to lack of trained technician and the Y-axis from strongly disagree to strongly agree have the highest number of agree for lack of finance for spare part. The other 5 causes have different varying number of respondent on the problem of equipment down time the following **Figure 4.9**

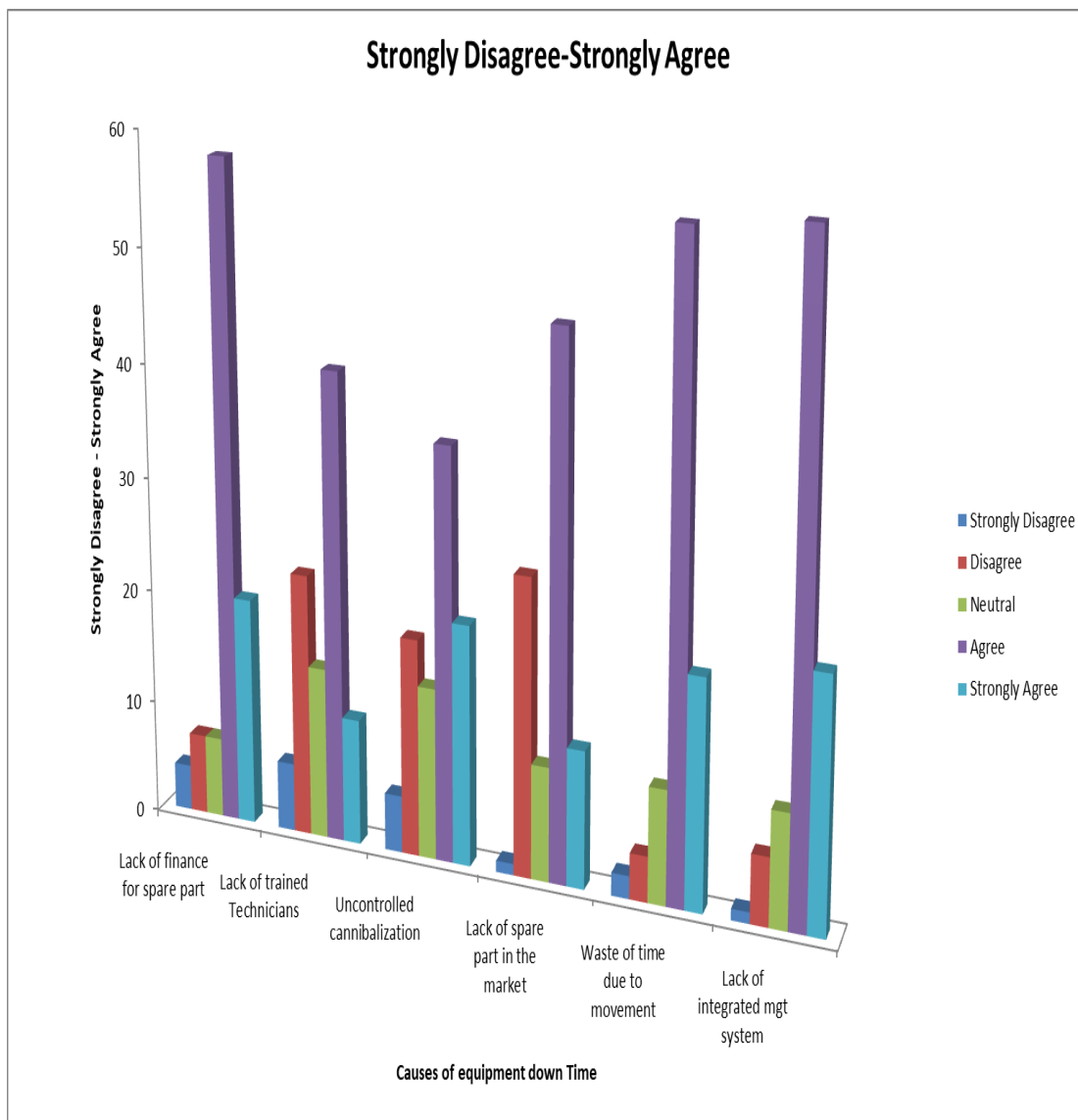


Figure4.9 Bar graph of equipment down time

4.4.8.2. The description of Pareto Chart

The description of Pareto chart of causes of Equipment down time from weighted value clearly seen that the lack of integration depart, shops to be the highest weighted value of 2.9688. Similarly, as it is seen in previous Pareto Charts, this Chart looks like almost straight line is the causes have similar impacts on equipment down time **Figure4.10**

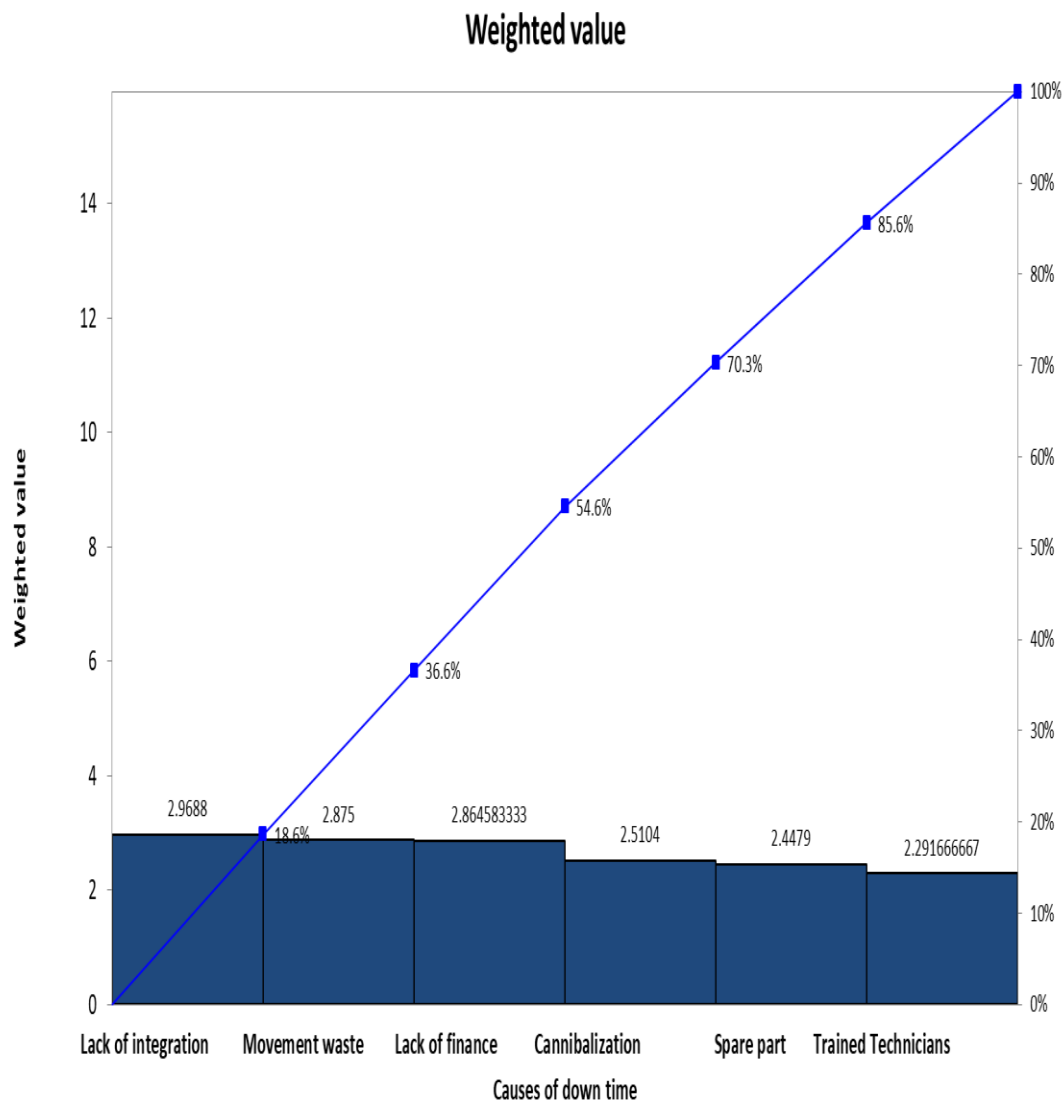


Figure 4.10 Pareto Chart of Equipment down time

4.4.9. Description of Maintenance Reworks

4.4.9.1. The description of bar graph

Finally, the description of bar graph of Causes of maintenance reworks **Figure 4.11** shown below that have the longest bar of agree and observed the longest bar for poor pre and post inspection the equipment age of maintenance reworks.

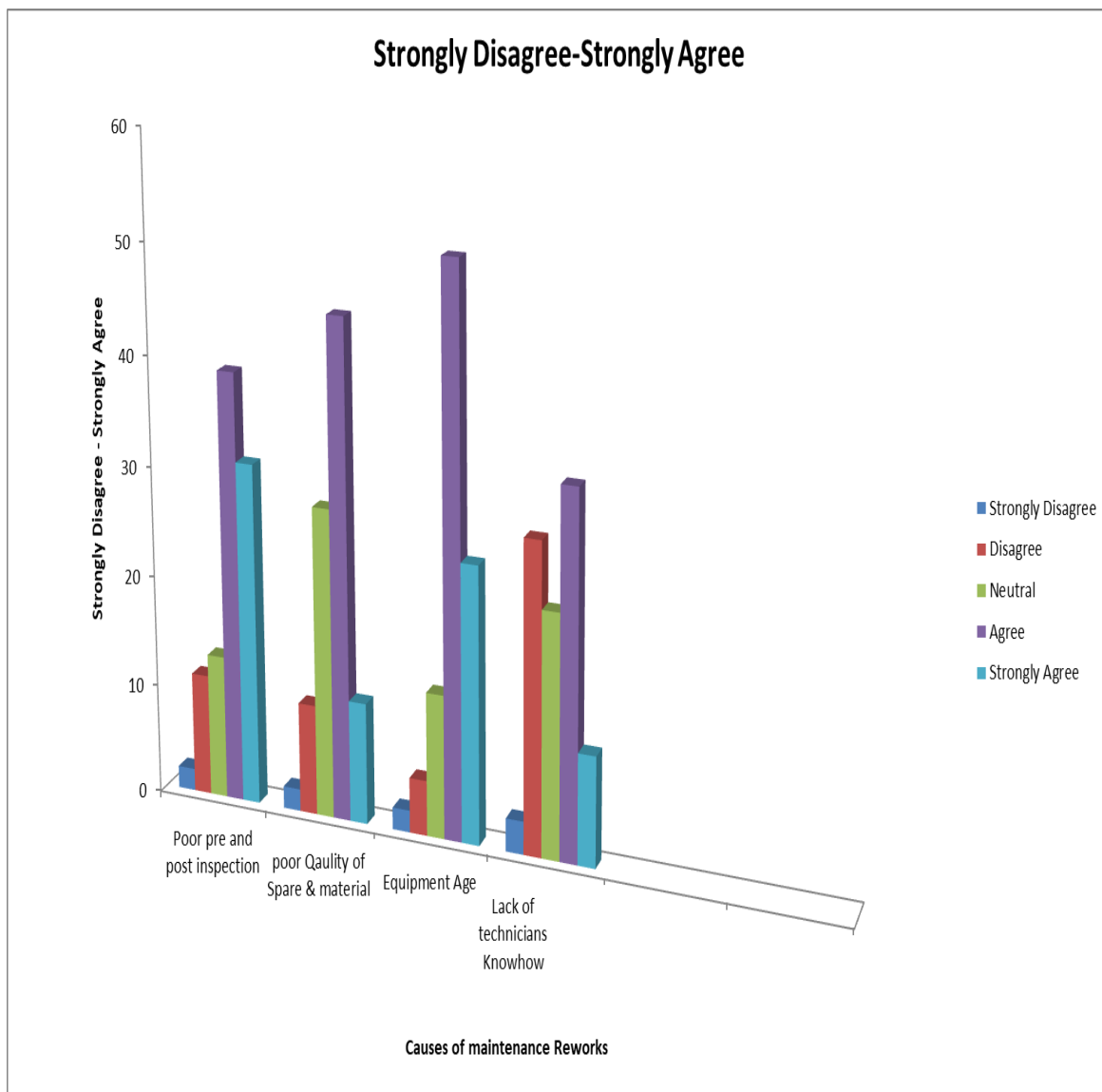


Figure4.11 Bar graph of maintenance reworks

4.4.9.2. The description of Pareto Chart

In order to clarify the Pareto Chart of the causes of equipment maintenance reworks identified from weighted value to be 2.9583 of poor pre and post inspection. The researcher strongly agrees on the result found. As a whole, the Chart shows that have similar impact on equipment maintenance reworks **Figure4.12**

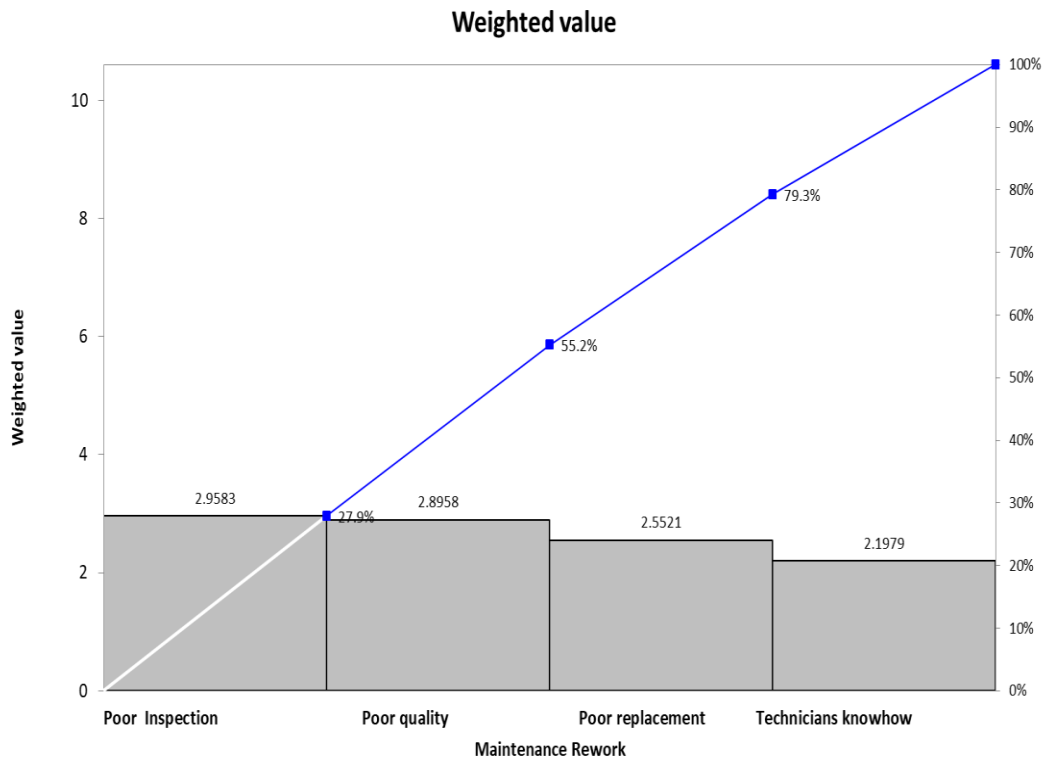


Figure4.12 Pareto Chart of Maintenance reworks

Generally, the point that met the 80% effect can be made by improving the 20% causes of Operational productivity of equipment maintenance system. This result shows that the respondents have knowledge on the causes of the problems and the main problem. Finally, the researcher agrees on the result analysed and found. These are causes of 20% to improve 80% of effects- the so called operational productivity of equipment maintenance problem.

4.5. Process Mapping and Model Development

4.5.1. What is a process?

A process is the transformation of set of inputs, which can include actions, methods and operations, into outputs that satisfy customer needs and expectations, in the form of products, information, services or generally results (John, 1999). In case of this research, the operational productivity of equipment maintenance system also holds input, process and output. To elaborate the constituent of the input, spare parts and tools should be included, in

the same manner, for the process adding, maintaining, purchasing and supplying, warehousing, and financing makes it clear. The output can hold completed equipment and modified parts.

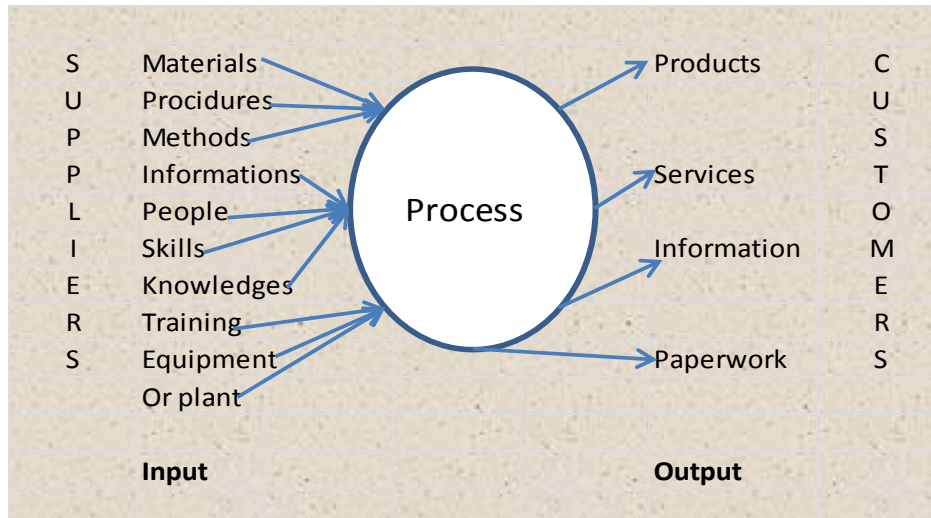


Figure4.13 Process of Operation (John, 1999)

In this sub topic the researcher tried to explain and use the total quality management tool the so called process mapping tool to analyse the whole existing and future operational productivity of equipment maintenance system in the case company-Kality Equipment maintenance centre. Moreover; the researcher developed the new model of process path and quality business mapping process.

4.5.2. Business process mapping

According to [Kate \(2017\)](#), it is a part of business process management (BPM), is a frame work used to create visual representations of work processes shows the relationship between the steps and inputs to produce an end product or service. But, the Purpose of Building Business Process Maps includes: Process standardization, Employee on boarding and training Communication, Compliance with regulating agencies, and Internal auditing.

In doing this mapping process, business process maps: flowchart, state diagram, data flow diagram and value stream mapping are important. The reasons why we map process:

- Enables everyone to see the process in the same way

- Builds understanding between areas that are cross functional
- Decreases errors of procedures
- Helps everyone to see the current state
- Enables development of metrics
- Decreases waste by identifying gaps and excess

4.5.3. The existing state of business process mapping (As-Is)

Businesses today are more focused than ever on suitable improvement. Even with measurable operational improvements, it may be difficult to hold on to the enhancements made. Experts say that technology can certainly help but needs system, this way, business and process improvement sustainability is possible. Steps in business process mapping are: identifying the process, gather the information, develop the process map, analyse the map, develop new, better steps, and manage the press.

Performing the business process mapping:

The Pareto principle, known by 80-20 rule, is an observation states that about 80% of effects come from about 20% of the causes. Therefore, it matters which processes we choose to map and subsequently improve.

How mapping fit in to the process:

Delineate how often those process maps will be improved, and who will be initiating new improvement projects lastly, a big component of process documentation is software documentation encourages users of all levels to use the software for the intended process.

In the design phase it is important to use business process mapping life cycle which includes five phases: Design, Modelling, Execution, Monitoring, and Optimization. A business process mapping exercises falls in to the first step: design **figure 4.14**

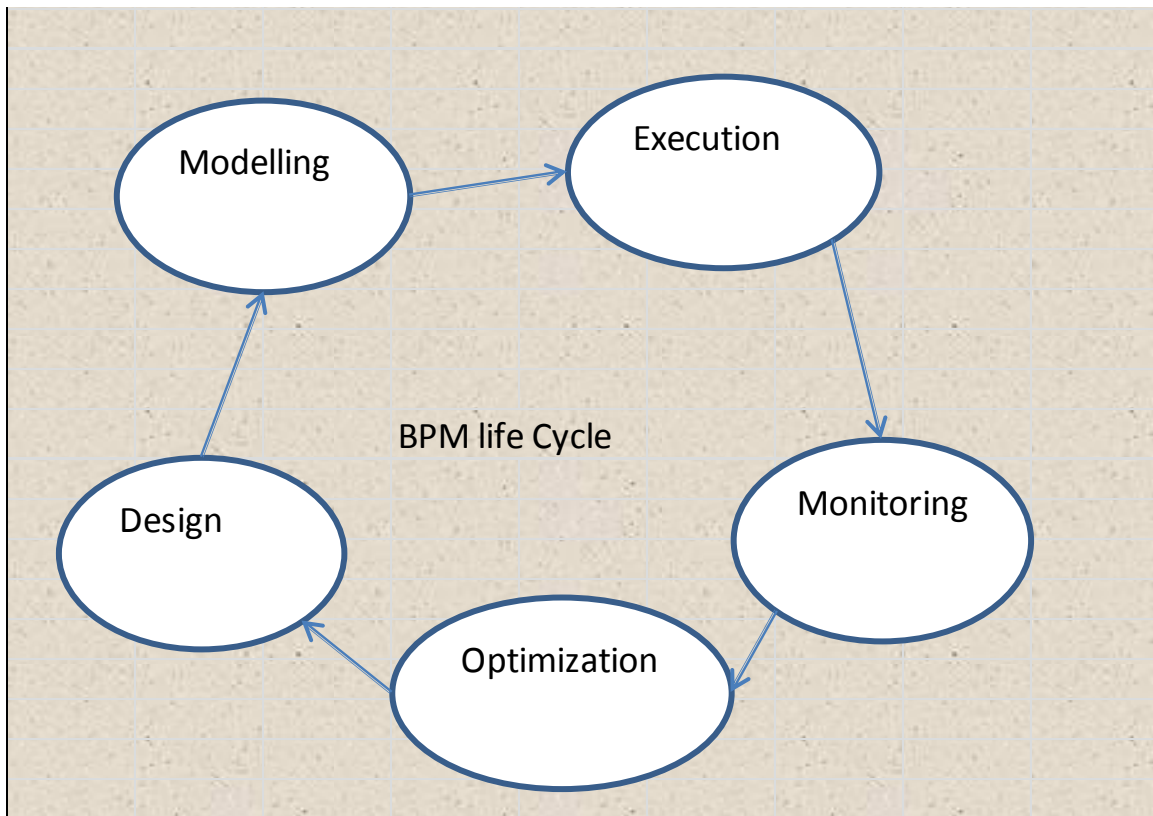


Figure4.14 The diagram of BPM life cycle (Kate, 2017)

4.5.4. The Average operational process Time

According to BPM life cycle, for the optimization of any process the five stages should be designed and analyzed with the KPI, in case of this research directly related to Time, but indirectly related with cost, customer satisfaction, company profit. The focusing area being time is that, time in construction is capital. If any delay in construction is costs, customer complains. Hence, focusing directly on time is improving indirectly improvement of cost; customer complains minimization and making profit.

Therefore, the following operational equipment maintenance process time required compiled from each process of report summarized that required completing one case from equipment reception up to customer submission in the **Table 4.3**

Table 4.3 Calculated and Observed Existing Average operational process Time

Average Current Operational activity processes Time									
NO	Operational Process activities	Responsible department	Objective	Input	Outputs	Customers	Risk and control	KPI	Process Time (min)
1	Customer Reception, RFS	Customers	To make quality maintenance and timely delivery of equipment to customers	Inspection, spare parts, lubricant and oil, materials, documents	Quality maintained equipment, document	Internal and external, with in departments or outside departments	Delay, poor maintenance quality, customer compliance, Reworks, down time, finally project construction delaying. It is important to Seriously follow up and develop a suitable framework of	Time (quality, customer satisfaction, cost minimization, and making profit)	11
2	Making Deep Inspection &SRO	Equipment main/M/ Team							27
3	Equipment Submission to shops	Equipment main/M/ Team							17
4	At shops extra Inspection	Each Maintenance Shops							27
5	Spare Availability checking	Shops, Property Ad/Team							50
6	Spare Available?	Shops, Property Ad/Team							0
7	Modification?	Maintenance Services							0
8	Requesting for modification	Shops							51
9	Modifying Parts	Equip/Mod/Fab/Team							405
10	Outside repair?	Maintenance Services							0
11	Prepare outside repair Order	Maintenance Teams							70
12	Approve Outside Repair Order	Maintenance Services							35
13	Cannibalization?	Maintenance Services							0
14	Requesting for Cannibalization	shops, teams, services							26
15	Authorize and Cannibalize	Shops, EAD, DCEO							125
16	Preparing Requisition	Shops							16

Average Current Operational activity processes Time									
I. N O	Operational Process activities	Responsible department	Objective	Input	Outputs	Customers	Risk and control	KPI	Process Time(min)
17	Approving Requisitions	Maintenance Teams							11
18	Sending Requisition to supply	Shops and related							75
19	Supply Out of stoke	Property Ad/ Team							60
20	Preparing Purchase Req.	Property Ad/ Team							37
21	Approval of Purchase Req.	Property Ad/ Team							40
22	Collecting Performa	Procurement Team							720
23	Opening Performa	Committee							80
24	Preparing Minutes	Procurement Team							55
25	Minutes Authorization	Equipment Ad/ Sector							55
26	Preparing Purchase Order	Procurement Team							55
27	Purchase Order Approval	Department Managers							75
28	Preparing Check	Financial Ad/ Department							45
29	Signing check	Department/Se ctor							35
30	Collecting Spare Part	Procurement Team							360
31	Spare Part Okay?	Shops, Property Ad/Team							0
32	Preparing Requisition	Shops							16
33	Approving Requisitions	Maintenance Teams							11
34	Sending Requisition to supply	Shops and related							75

Average Current Operational activity processes Time									
I. N O	Operational Process activities	Responsible department	Objective	Input	Outputs	Customers	Risk and control	KPI	Process Time(min)
35	Preparing Dispatching Doc.	Property Ad/ Team							50
36	Approve Dispatching Doc.	Property Ad/ Team							45
37	Dispatch Spare parts	Shops							180
38	Fixing Spare Parts	Shops							195
39	Checking Functionality	Shops/Teams							80
40	Submitting to Inspection	Shops/Teams							85
41	Making final Inspection	Equipment main/M/ Team							95
42	Maintenance Okay?	Equipment main/M/ Team							0
43	Submitting to Customers/Users	Equipment main/M/ Team							150
44	Document Redoing	All offices							1120
45	Maintenance Reworks	Shops							1050
46	Inspection Back-shop	Equipment main/M/ Team							17
47	Spare part Return and change	Shops, Property Ad/Team							720

4.5.5. Existing path process and Network Diagram

4.5.5.1. The existing Path Process

The existing path process starts from reception of equipment to be maintained in required type of maintenance and then inspected by inspector at equipment maintenance management team. After completing the inspection, the inspector sends to the shop that identified the type of equipment and related shop to the type of failure. At the shop, further inspection will be done and decided the decision of spare from stokes, modification, cannibalization, or else

request for purchasing to procurement team and Spare part stock will be checked. The documents identified in supply and procurement team whether the requests are to dispatch or purchase request document. If the requisition is to be purchased; Performa is collected by purchaser; opens the assigned committee the Performa and will be prepared Minutes in procurement team and Deputy CEO Authorizes the Minutes. Then, returning the Minutes to Procurement team, the purchase Order document will be prepared and equipment maintenance department manager approves the PO. After recording these documents, the procurement team sends the document to financial management department to prepare Check in order to purchase the requested spare parts. Again, deputy CEO authorizes the Check and returns to financial management department. After recording the Check, will be given to purchaser to collect the spare parts from importers. After the collection of spare parts from importers by the purchasers, the store accepts and will be checked by mechanics, engineers, or Forman. If it is the genuine part, supply and property management team prepares the dispatching document and Forman or mechanic dispatches the spare and the spare part will be fixed to the equipment in the shop by mechanic or electrician. By checking the functionality of the equipment, if the maintenance is okay, the Forman sends the equipment to inspection. At inspection of equipment maintenance management team final inspection work will be done. If it is okay, the inspector submits to final user/customer. Otherwise, if there is any problem the inspector sends back to the shop to be corrected the intended equipment maintenance shown next page **Figure 4.15**

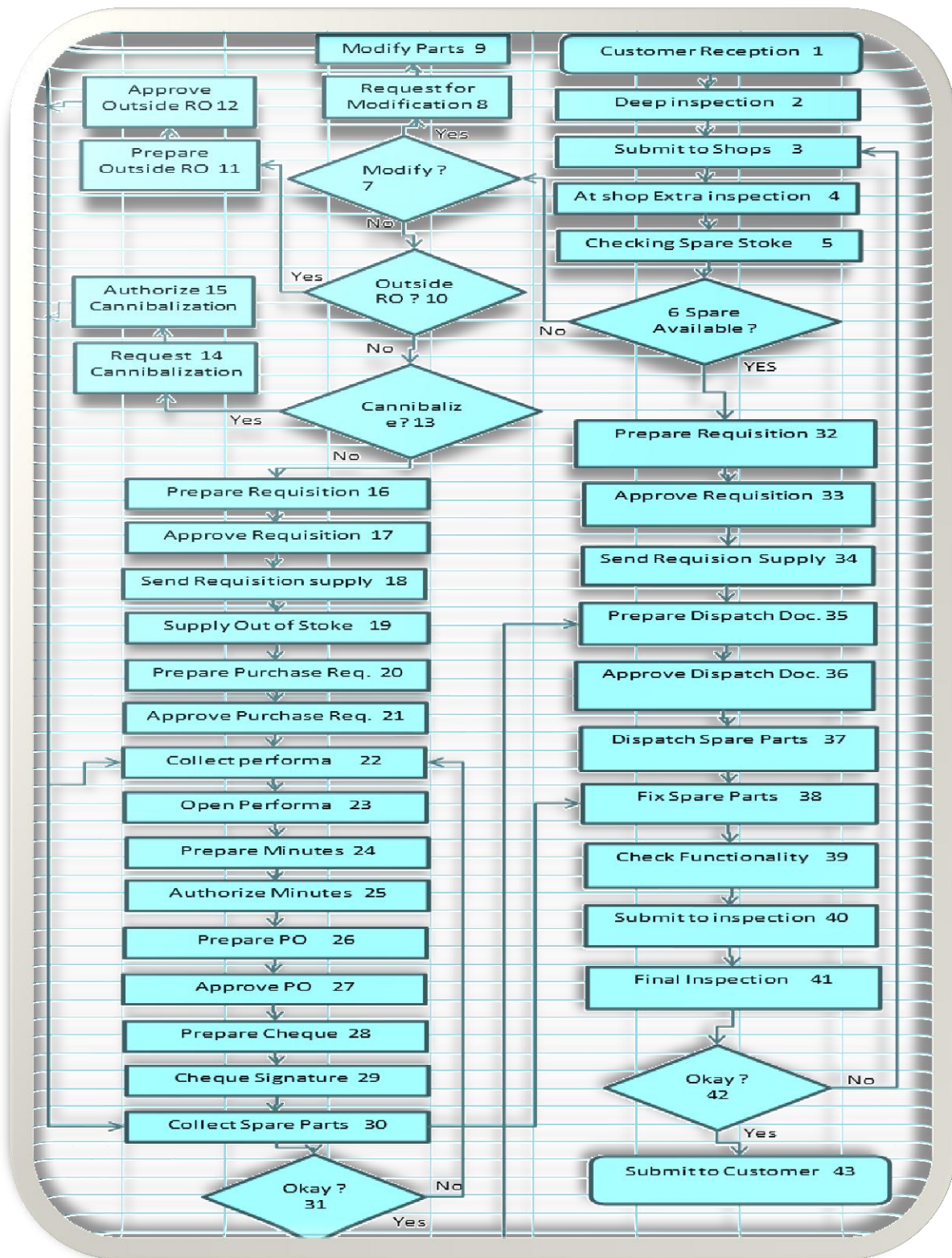


Figure 4.15 Existing Process map design of the case company

4.5.5.2. The existing Process Network Diagram

The network diagram **Figure 4.16** describes the operational process of equipment maintenance starting from equipment reception to equipment summation from inspector to final user as described in existing path process, here the existing process network diagram and on each node designated the node number and the time taken to complete the process.

The collection of Spare part from market, modification, outside repair, and cannibalization are quite different. According to time observation is 360, 360, 45, and 40 minutes for purchased, outside repaired, modified, and cannibalized spare collection respectively. But for node designation it is taken 360 minutes only the largest value of time taken to collect the purchased or outside repaired spare part from market. In fact, the researcher took these values for calculation of path time elapsed.

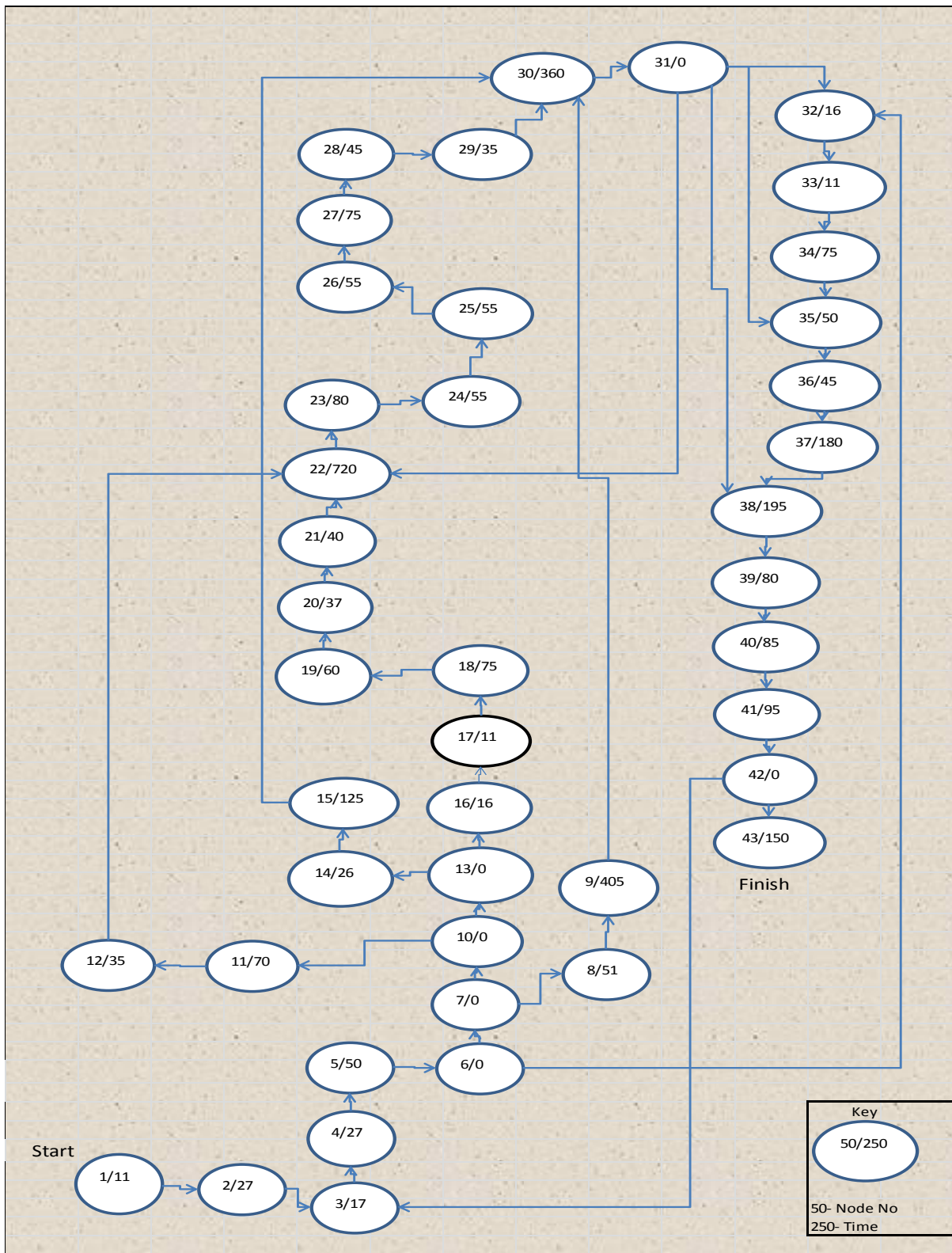


Figure4.16 Network diagram of showing existing operational Process

4.5.6. The path of operational activities of equipment maintenance system

This path identification is not done like of project management in that, each process starting and ending times follow their ways. In fact, the completing time of one equipment maintenance operation is not dependent on the longest path. Rather by all five operational equipment maintenance processes separately to be completed.

Path one 1-2-3-4-5-6-7-10-13-16-17-18-19-20-21-22-23-24-25-26-27-28-29-30-31-35-36-37-38-39-40-41-42-43

Path two 1-2-3-4-5-6-7-10-22-23-24-25-26-27-28-29-30-31-34-35-36-37-38-39-40-41-42-43

Path three 1-2-3-4-5-7-10-13-14-15-30-38-39-40-41-42-43

Path four 1-2-3-4-5-6-7-8-9-30-38-39-40-41-42-43

Path five 1-2-3-4-5-6-32-33-34-35-36-37-38-39-40-41-42-43

Path six 31-22-23-24-25-26-27-28-29

Path seven 42-3-4-5-6-7-8-9-30-38-39-40-41-42-43

Path eight 42-3; Path nine 31-22

Path 1:- This Operational activity of equipment maintenance system path is called spare part purchasing or part unavailable path. It is responsible for spare part is requested, purchased, collected, dispatched from store, fixed, and finally submitted to the end user. This path is the longest time consuming path that brings frequent customers complains. This path is observed to take the time:-

2741min=45.683hrs=5.71 days in the average maintenance condition.

Path 2:- It is the path of allowing outside repair order of equipment which is beyond the capacity of the technician or the spare parts are not available in ware house and in the market or if the case is top urgent and to make it avail on time. The path consumed time in the report is:-

2217min=36.95hrs=4.61875 days in the average maintenance condition.

Path 3:- This path also said to be forced situation path is called cannibalization path, this operational activity is done when the spare parts unavailable in the market, or if there is an equipment total loss recommendation is given by insurance, or if the equipment is decided to be scrap then shops request for cannibalization and authorized by DCEO, by taking the spare from one equipment fixing on the other machine then submit to customer.

928min=15.47hrs=1.93 days in average maintenance condition.

Path 4:- This is called modification path which is known by the necessary components are modified and fixed to the equipment, and then the equipment are submitted to the users. By the time of all over observation to this research it was recorded time to be:-

1200min=20hrs=2.5 days in average maintenance condition

Path 5:- The so called spare part available path which is the process is responsible for spare parts dispatched from store, fixed to the equipment, and finally the equipment is submitted to customers. According to the observation time taken in existing case is equal to: -

965min=16.083hrs= 2.01 days in average maintenance condition.

Path 6:- This path is called document redoing path, by neglecting document redoing in all departments except finance and procurement department and team respectively. The impact of document redoing especially in procurement team is significant. Taking the longest path that affects the process and considering most likely happen.

1120min=18.67hrs=2.33 days in average maintenance condition.

Path 7:- Is called maintenance rework path. It is expected not to be returned twice by the inspectors, because once it is returned and completely resolved the problem found at once.

1050min=17.5hrs=2.1875 days in average maintenance condition.

Path 8:- The path is said to be inspection back-shop for further correction. Taking the path node values:

17min=0.283hrs=0.0354 days in average maintenance condition.

Path 9:- lastly, this path named as spare part return and change path, which is affecting more time the operational activity of equipment maintenance in Kality maintenance centre.

720min=12hrs=1.5 days in average maintenance condition.

These paths are used separately, or two of them, or three of them all, or four of them all, or five of them all, and so on. Because, all requested spare part line items may not be found at once in the market or warehouse. From the report found one equipment passing through more than one path is very small number of equipment and the effect is neglected.

4.5.7. Causes of Time wastes in operational maintenance processes

Time is a huge capital for construction companies in any developed, developing, or under developed countries. However, the level of utilizing time differs from one country to other as well as time wastage. These causes of time wastage are likely to be sought in Ethiopian construction Works Corporation, especially at Kality equipment maintenance centre are:

- 1- Document Redoing
- 2- Maintenance Reworks
- 3- Inspection back shop
- 4- Purchased part Return
- 5- Waiting maintenance in each shops and unnecessary movement

From 1-4 all are considered to be task redoing and the fifth one is wasting surplus time which is unnecessary for intended job.

1) Document Redoing

This could be found because of personnel error and/or lack of information or wrongly disseminated document information. This research is not aimed on document reworking of in each office. Because, as such not a big problem for operational equipment maintenance productivity. But, the document redoing in procurement team, financial administration department, and property administration teams is matters. These includes, requisition for purchase, dispatching from store, and redoing cheques, minutes, PO, and PR.

2) Maintenance Reworks

This would happen through maintenance process by the fault of technicians, operators or functionality testing supervisors or Forman before the total inspection and quality assurance.

This rework should be improved enormously or if it is possible, not possible should be eliminated.

3) Inspection back-shop

It is just equipment are returned to maintenance shops for further correction that are errors found by the inspector at the time of final inspection.

4) Purchased spare part return to importers

Today in ECWC almost 90 variety models of equipment, machinery, and vehicles found in different projects and equipment centre; since it is found from the experience some model equipment share similar spare parts and part numbers. In the contrary, most models do not share spare parts and part numbers. This is the interest of the manufacturers to make additional business from after sell by making slight differences up on the spares. Due to this fact, and frequently part number changing errors happen. In addition to this, due to weak attention of purchasers and leaders, technicians; spare parts are returned to the suppliers and these brings about maintenance completing time delaying and increase of downtime and then decreases the project profitability and customer satisfaction.

5) Waiting and movement time

Waiting time can be divided in to forced waiting and relaxed time. Forced waiting time is happens a must wait due to system capacity unless the process is changed and system interruption. Whereas, relaxed waiting time elapsed additionally due to process performing under capacity. From report and observation, it is seen that, equipment enters different shops, for mechanical, electrical, body, engine, welding maintenance works, and these disintegrated shops caused much waste time of equipment down time.

But, movement waste time is one of the seven wastes of kaizen principle recognized, which is seen in the case company there are many movements practiced by the employees in Kality equipment maintenance centre from shops to store, supply, finance, procurement, and different offices and back to shops. These movements take most of active time of quality equipment maintenance in the maintenance shops.

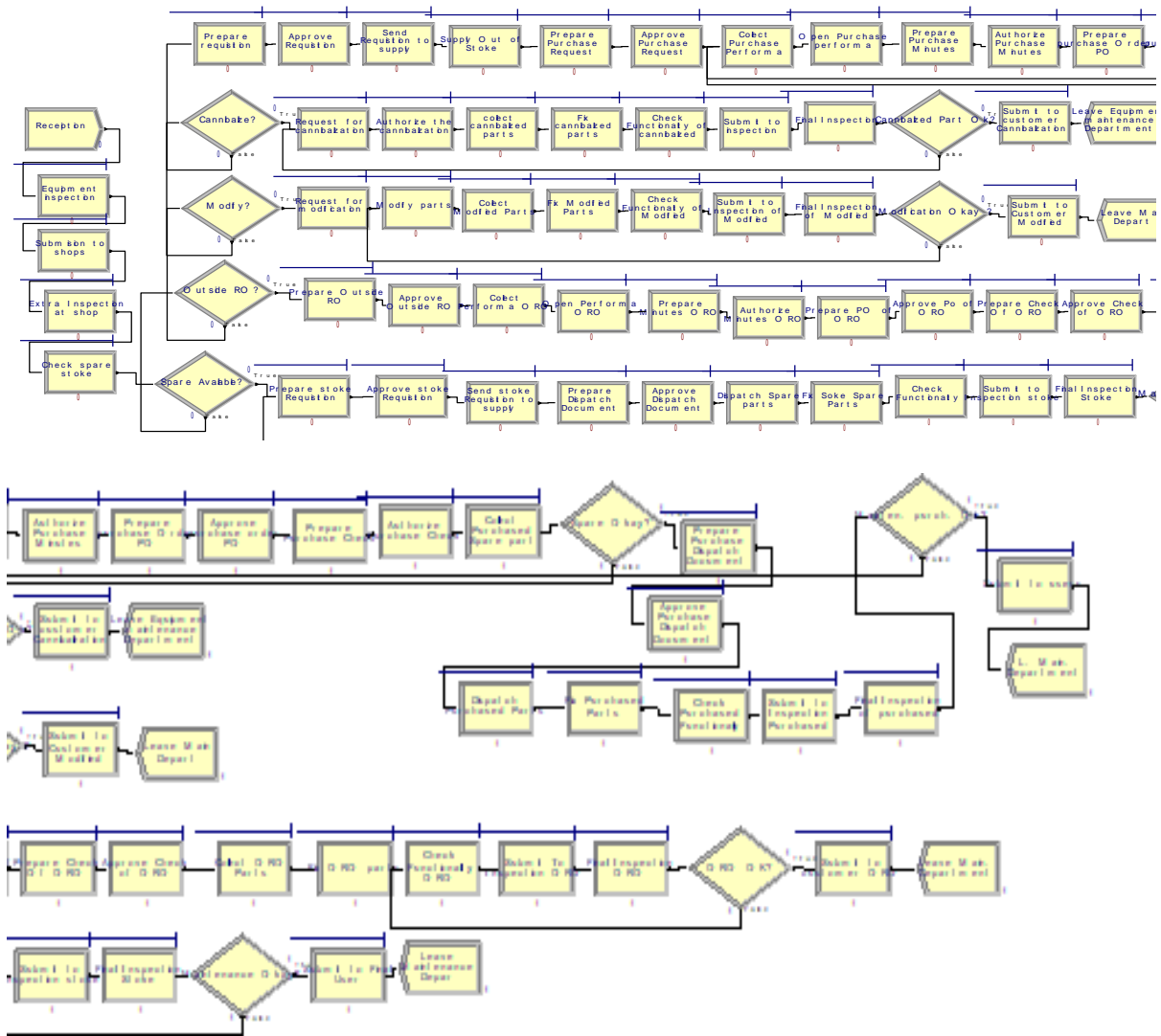
In general, improving these reworks, waste and non-value added movement means improving the total process of operational productivity of equipment maintenance system of time, cost, customer complaints, and working place atmosphere in addition to the improvement of paths from path1 up to path 5.

4.5.8. Existing Process Path simulation

Anyone can understand from the **Table 4.4** is that, the operational productivity of equipment maintenance system to complete 3,018 equipment maintenance operations passed different paths in a distinguished rate, which is the probability of the process of activities passing the paths. The data is compiled from report from July 01, 2020 up to May 31, 2021 GC. The researcher forced to use only 11 month data. Because, the equipment maintenance centers namely: Orma equipment maintenance center and Kality equipment maintenance centers merged to one equipment maintenance center at Kality equipment maintenance center and fully started the operation and compiling the reports. Using data beyond these months; the researcher recognized there would be wrongly perceived research result. The following data is calculated for the process path simulation.

Table 4.4 Existing Process Simulation Data

I.NO	Operation completed path	Quantity of Operation completed	Time required for the path/min/	path probability
1	Spare part purchase path performance	1450	2741	42.90
2	Outside repair performance	108	2217	3.20
3	part cannibalization performance	360	928	10.65
4	part modification performance	680	1200	20.12
5	Spare part from stoke performance	420	965	12.43
6	Document redoing	118	1120	3.49
7	Maintenance rework	116	1365	3.43
8	Inspection back-shop	76	17	2.25
9	Spare part return	52	720	1.54
	Total	3380	11273	100.00



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Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	589

Figure 4.17 Half Trimmed Arena Simulation and existing process number out

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Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	739.81	19.79082	273.42	1873.89
NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	498.41	20.18907	250.59	2127.32
Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	13504.18	(Correlated)	163.15	134803.17
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	14742.39	(Correlated)	1269.55	137528.50
Other				
Number In	Value			
Entity 1	1832.00			
Number Out	Value			
Entity 1	589.00			
WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	629.44	(Correlated)	0.00	1243.00

Figure4.18 Sample Arena Simulation result showing Time

4.5.9. The Future state of business process mapping (To- Be)

The future process to design and make improvement in a new era, document the process, emphasize any problem areas by identifying company organization best practices in the existing and new process. Using a root cause analysis to ferret out potential problems is essential.

Newly developed and Recommended Quality analysing model for process mapping: SWIFT Analysis.

S-Specifying

W-Wainscoting

I-Integrating

F-Fail-Saving

T- Triangulating

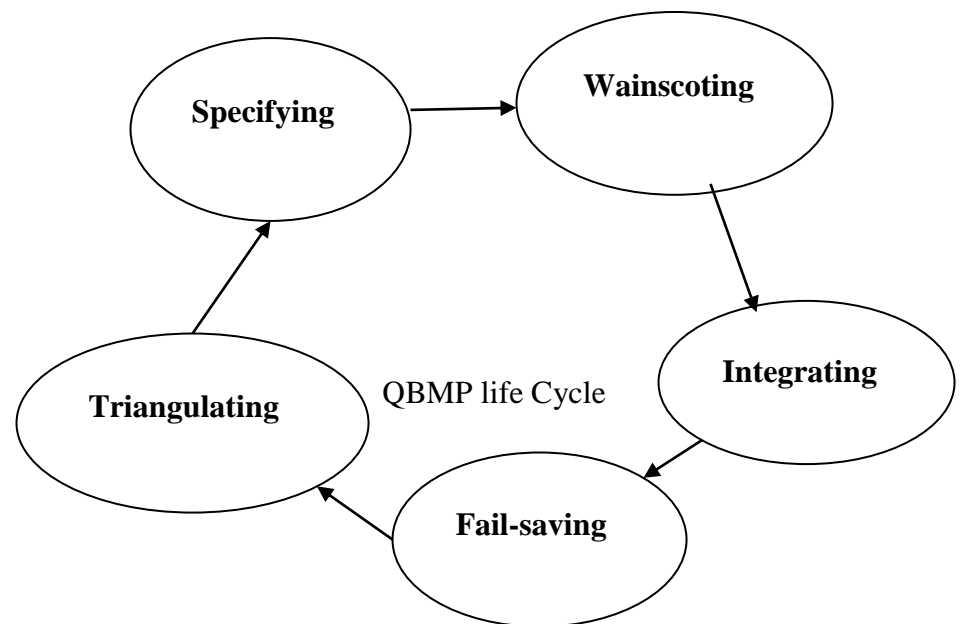


Figure4.19 The diagram of QBMP life cycle (own)

- 1- **Specifying**: - is the first step of quality business mapping process that is used to identifying those are initially to be considered operational activities that lead to the goal of quality improvement. These are: work place/ location identification, resource allocation, capacity, mandates, scope, and objectives. In the specifying stage there will be identified operations exactly necessary to do the process, lead to the goal of the company.
- 2- **Wainscoting**:- This is the main part of the new model which is useful to bring beauty, shines or quality to implement continuously in the process or company as whole. The simple vocabulary meaning of wainscoting is just to cover something with wood to bring beauty looking. But in the broad meaning for this research and

- recommendation, it is intended to focus quality improvements at each department, teams, and shops separately and then work to link for the whole company continuously. The aim of this process mapping phase is to improve quality issue in the grouped manner. Here, 5s benchmarking and sharing, standardizing, implementing, and controlling tasks in each departments are performed.
- 3- **Integrating**:- After wainscoted each department, teams, or shops, should be interlocked in the way of smooth-displacement thinking to have most of the result expected of smooth communication, software application, series feedback, process evaluation and test errors found at the system.
 - 4- **Fail-Saving**:- The act of immediately making compensation during failure. This phase is making confidential for the system at most failure minimized process which is related with the process evaluated and tested those drawbacks found internal and external impacts. The main task to be done seriously and without interruption is implementing technology not sophisticated that reporting timely and to act immediately. For example, where the standard time is not utilized in the process or working station.
 - 5- **Triangulating**:- Different department have their own strength and weakness due to the nature of their task process. They need systematically hand in the end process of one department to others without jerking that affects the standard time of each task or process completion. What makes and needs triangulating is two and more department issues end process may be the starting of one department.

Generally SWIFT analysis of quality business mapping process (QBMP) is the extension of business process mapping (BPM) which is developed as follows:

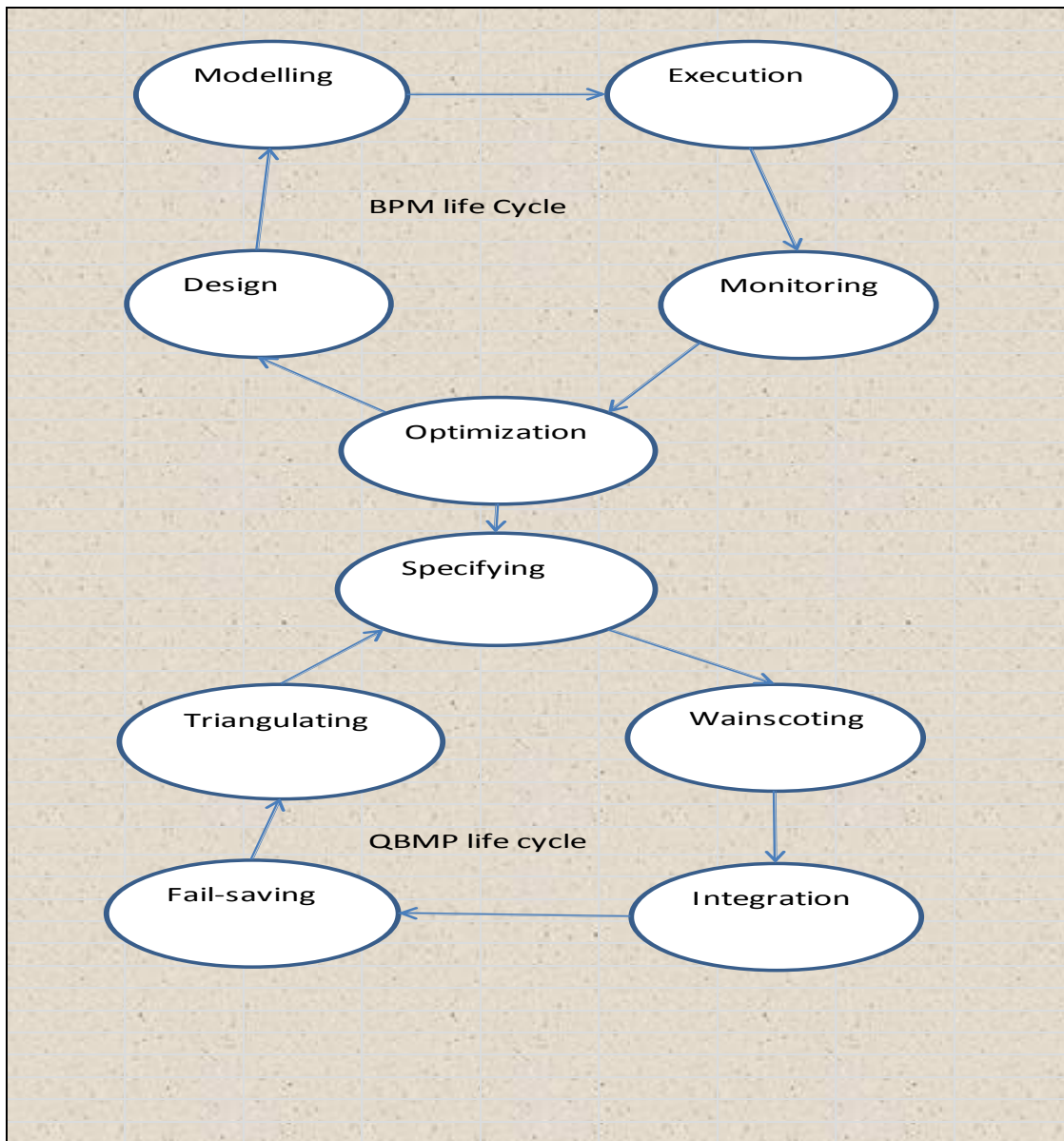


Figure4.20 The diagram of BPM & QBMP life cycle relationship

4.5.9.1. The link between BPM and QBMP

According to newly developed mapping system and model, which is very essential for enhancement of operational productivity of equipment maintenance system with the quality essence is clarified as follows, especially, the link between BPM life cycle and QBMP life cycle.

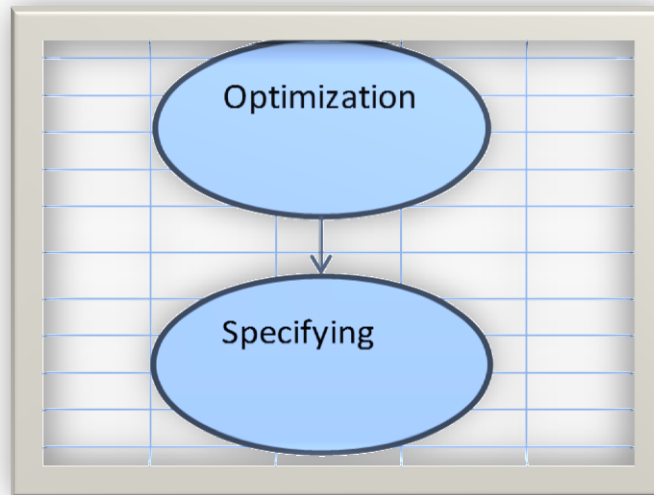


Figure4.21The Linked part of BPM and QBMP (own)

Since the optimization of any process cannot reach 100% at once, the newly developed model is intended additionally to improve beyond its QBMP life cycle that the residual per cent dropped from BPM cycle and re-filtered to accelerate the improvement of total quality management through departments of the company. But, what the difference between BPM (business process mapping) and QBMP (quality business mapping process) is that , they have more of common idea, BPM focuses on the system of any type that how the process should be mapped, but, QBMP cares about how quality business mapping should be processed to reach to the optimized total quality management level expected. The residual from the optimization of BPM observed or uncovered pass to QBMP cycle enter to the specifying phase and reach to the triangulating phase according to the case encountered.

4.5.9.2. Description of QBMP life cycle and Schedule

QBMP life cycle of quality improvement stages are defined and described what specifying, wainscoting, integration, fail-saving, and triangulating stages mean. This life cycle will be alive through continuously improving quality. To make this task done, there should be assignment of ceilings. What are the ceilings of these stages to be continues and effective? According to the observation and experience gathered from total quality management implementation in the case company, without the following five ceilings, the QBMP life

cycle will not be practicable anymore in the case company. These five Ceilings are 1- higher officials and employee serious commitment assurance for implementation, 2- clear schedule at each stages, 3- controlling and reporting 4-improvement audit by quality control, safety, health, and environmental management department shown in recommended organization in appendix C and implement accountability, and 5- making re-audit by external quality assurances according to the schedule declared. These ceilings are nothing, but, that are dragged from cause and effect analysis and experience of the researcher. These five ceilings believed to be fit for the case company; for other companies, other researchers can widen it/them. The following schedule **Table 4.5** shown by specifying the area of continuous quality maintenance works should be started and made improved according to the newly developed model.

Table 4.5 QBMP life cycle Schedule (own)

IN O	Name of Stage	Duties to be Performe d	Time Tabl e	Respons ible Departm ent	Selected Area	Auditing body	Result Found	Optimiz ation linking	Remar k
1	Specifying	identifica tion, resource allocatio n, capacity, mandate, scope, and objective	one week	all Departm ents	Machin e shops, equipme nt main tenan ce shop, all stores, cafeteria , Equipm ent main tenan ce office, shops showers and rest rooms	Quality control, safety, health, and environm ental mgt departme nt and recomme nded external audit	To be identif ied	Level the stage of linkage	Share if any new findings recogni zed
2	wainscoting	identifica tion, resource allocatio n, capacity, mandate, scope, and objective	two week s	all Departm ents	Machin e shops, equipme nt main tenan ce shop, all stores, cafeteria , Equipm ent main tenan ce office, shops showers and rest rooms	Quality control, safety, health, and environm ental mgt departme nt and recomme nded external audit	To be identif ied	None	Share if any new findings recogni zed

3	Integration	identification, resource allocation, capacity, mandate, scope, and objective	two weeks	all Departments	Machine shops, equipment maintenance shop, all stores, cafeteria, Equipment maintenance office, shop's showers and rest rooms	Quality control, safety, health, and environmental mgt department and recommended external audit	To be identified	None	Share if any new findings recognized
4	Fail-saving	identification, resource allocation, capacity, mandate, scope, and objective	through 1-3 stage weeks	all Departments	Machine shops, equipment maintenance shop, all stores, cafeteria, Equipment maintenance office, shops showers and rest rooms	Quality control, safety, health, and environmental mgt department and recommended external audit	To be identified	None	Share if any new findings recognized

5	Triangulating	identification, resource allocation, capacity, mandate, scope, and objective	two weeks	all Departments	Machine shops, equipment maintenance shop, all stores, cafeteria, Equipment maintenance office, shops showers and rest rooms	Quality control, safety, health, and environmental mgt department and recommended external audit	To be identified	None	Share if any new findings recognized
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4.5.10. The Improvement of Operational process

The improvement of operational process is nothing, but the operational productivity of equipment maintenance system of those paths mapped in the assessments, especially specified, wainscoted, integrated, fail-saved, and triangulated processes.

4.5.10.1. Improvement of Procurement Path

To improve the operational process times by lowering the time required to maintain equipment using the selected process mapping is to be discussed.

- Currently in the case company, after Performa collection and opening, Minutes preparation up to authorization process passes alone up to PO preparation.
- PO preparation also up to approval processed separately, till cheque preparation.
- The cheque preparation waits until the completion of Minutes and PO submission to financial management department.

The aim of these documents is just to purchase spare part from market. Hence, documents can be done simultaneously and decreases the time of preparation by 60%, which decrease directly the equipment down time, and indirectly the maintenance cost and customer complaints that improve the satisfaction of customers or end users.

In addition to this, using software that helps shop foreman, leaders, and store man for stoke balance checking. Due to this software implementation the time of making out of stoke process eliminated and stoke balance checking time decreases by 85%.

The main and very important part improvement of this path is that strictly implementing PM program by solving the scarcity of budget and finance, which is critical to spare part supplying delay, as it is shown in the cause and effect analysis and the researcher agreed on the case, almost 60% of equipment maintenance delay eliminated. When we observe the path time difference between the spare part availability in the ware house and supplying by purchasing is $2741-965=1776$, it is above 60% of the time of equipment maintenance process is lagging by purchasing and co-processes.

The other way of improvement can be made is exercising of accountability and commitment of employee and leaders in spare part returning to the importer can be made to zero. This is can be done by assigning special technician and engineer which are expertise on the case. A better not least is the document preparation using the software requested by shops foreman will be prepared but the process continues to the next level. The other improvement practically observed is sending the requisitions to importer of spare part by purchasers or responsible party using electronic media could decrease the process of Performa by 40% time consumed.

Generally, this operational process path observed that can be improved by 85% which is a great improvement without any miracles. As to researcher, it is known a 40/60 program is in progress to be implemented. This program is vital to the operational productivity of equipment maintenance system implementing and continuously to improve by solving the financial problems.

4.5.10.2. Improvement of outside repair order Path

This operational process path can be improved by not only mentioned above document preparation, but also highly decreases outside repair orders entering the machine shop fully engagement of all installed machines to perform soon. So, increasing employee motivation and starting the machines to the operation decreases outside repair order by 40%. This also decreases the maintenance cost, and improve customer satisfaction.

4.5.10.3. Improvement of Part Cannibalization Path

This path is directly or indirectly affected by path1, which is spare part procurement path. If the procurement path is improved, the jut out cannibalization will be minimized and additional cannibalized part mounting dismounting work process will be enormously decreased. This operational process has very negative impact on equipment maintenance and leads to forced equipment disposing. This choice is bad choice. But, it is better -bad recommendation, when it is decided up on the spare part waiting –equipment. Whereas, the cannibalization decision made up on the equipment of isolated to scrap and found from insurance total loss has positive impact on the operational productivity of equipment

maintenance system. In doing this and improving path1, this path will be improved significantly. Further decreasing cannibalization improves the quality of operational productivity of equipment maintenance system, which is not greater than as much as the procurement path and not less than as much as the outside repair order.

4.5.10.4. Improvement of Modification Path

This path is directly or indirectly affected by outside repair order. More or less decreasing the outside repair order is increasing the modification of parts in machine shop. Besides to this, using the developed software decreases requisition of document and receiving modification orders by minimizing unnecessary movements from shop to shop. Since the machine shops wainscoted and fully going to start the operation, expected to improve by significant figure

4.5.10.5. Improvement of Spare part Availability Path

Spare part availability or part from stoke path is the easiest, shortest, safest, and charm full path for maintenance shops. However, it should be improved and needs the commitment of leaders and higher officials of the corporation. This is because; the process of the path needs capital, strategy, and strict follow up. The improvement can be in such a way that:-

- Checking the availability of spare part in stoke, was time consuming and tedious operational activity. Using the implemented software minimized the operation time to only 15 minute, not by supply but in each shop taken average value. Only by this process it is improved about $(60-15)/60*100=75\%$.
- The other strategy to improve this process path is, no need of waiting for the documents to be completed preparing, approving, and sending them to store, rather due to the software implementation, the spare part will be dispatched but hard copy process will be continue and finished giving responsibility and accountability to the employee. This process practiced online or electronic media.

Generally, the Improvement of path 6, 7, 8, & 9 redoing works improvement made on these paths is related to the time improvement of total process times required to complete the redoing operations. Refer Table 4.6

4.5.10.6. Improvement of Operational process Average Time

The operational process average time shown in Table 4.8 taken after trial the software using and a spare part store moved from main store to mini store nearest to maintenance shops; especially, to the heavy vehicle maintenance shop for Nissan vehicles and found it to be very important to check and take out the spare parts without any delay and wasting time as shown in (**Appendix D**). Data are recorded for two months (April 1 to May 30) operational process and projected to make the data analyse.

Table 4.6 Improved operational process average time (Owen)

LN O	Operational Process activities	Responsible department	Objective	Input	Outputs	Customers	Risk and control	K PI	Time (min)
1	Customer Request by RFS	Customers	To make quality maintenance and timely delivery of equipment to customers	Inspection, spare parts, lubricant and oil, materials, documents	Quality maintained equipment, document	Internal and external with in departments or outside departments	Delay, poor equipment maintenance quality, more customer compliance, Reworks, prolonged down time, finally project construction delaying. It is important to Seriously follow up and develop a suitable framework	Time (quality, customer satisfaction, cost minimization, and making profit)	6
2	Making Deep Inspection &SRO	Inspection team							20
3	Equipment Submission to shops	Inspection team							10
4	Extra Identification at shops	Maintenance Shops							15
5	Spare Available?	Shops, Property Ad/Team							0
6	Modify?	Maintenance Services							0
7	Requesting for modification	Shops							10
8	Modifying Parts	electrical and manufac. team							80
9	Outside repair Order?	Maintenance Services							0
10	Request And Approve ORO	Maintenance Teams							15
11	Cannibalize?	Shops							0
12	Requesting for Cannibalization	Shops, teams, services							15
13	Authorize and Cannibalize	shops, EAD, DCEO							45
14	Preparing & Approve Requisition	Shops							10
15	Prepare Purchase Req.	Property Ad/ Team							15
16	Collect Performa	Procurement Team							180
17	Opening Performa	Procurement							20

		t Team							
18	Preparing minutes, PO, Approve	Procurement Team							20
19	Preparing Check	Financial Ad/ Department							20
20	Authorize minutes, PO, & Check	Department/ Sector							25
21	Collecting Spare Part	Procurement Team							150
22	Preparing & Approve Requisition	Shops							10
23	Prepare Dispatch Document	Property Ad/ Team							20
24	Dispatch Spare parts	Shops							30
25	Fixing Spare Parts and checking	Shops							40
26	Submitting to Inspection	Shops/Teams							20
27	Making final Inspection	Inspection team							25
28	Equipment Working Confirmation	Inspection team							0
29	Submitting to Customers/Users	Inspection team							15
30	Document Redoing	Finance, procurement, Property							0
31	Maintenance Reworks	Shops							225
32	Inspection Backshop	Inspection team							10
33	Spare part Return and change	Shops, Property Ad/Team							0

4.5.10.7. Improved Operational process path and Network Diagram

4.5.10.7.1. The improved Operational Path Process

The improved operational process path **Figure 4.20** and improved next page showed is clarifies that the improved operational process path from 43 operations and decisions minimized to 29 operation and decision. In doing this task as it is explained in process improvement sub title 4.6.10.1, the redundant operations are eliminated; the spare part returning task completed at the company. Removing this unnecessary and time waste operational activity means further eliminates the document redoing of minutes, checks and Performa collection operations can be omitted due to the assignment of professional engineer and give accountability.

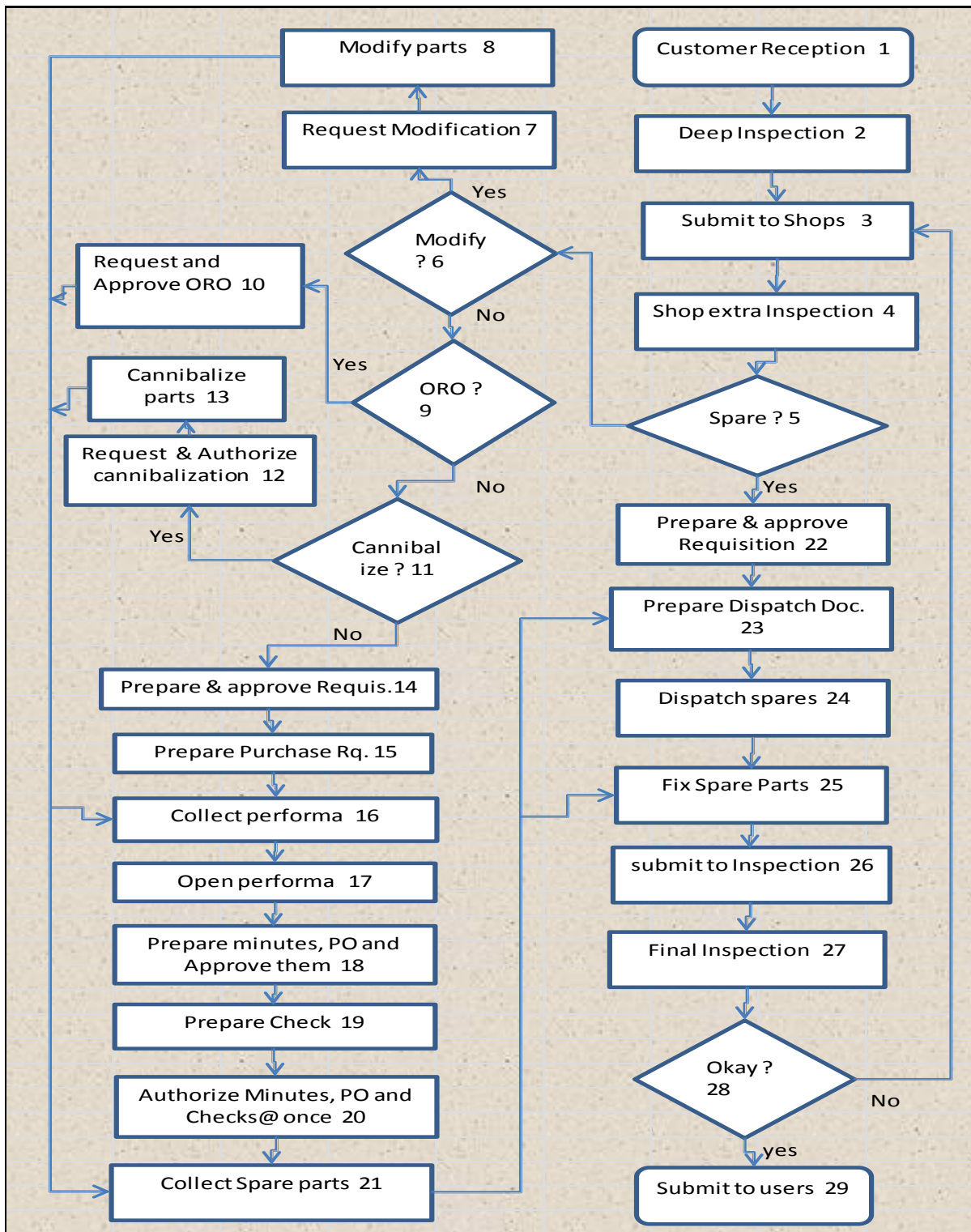


Figure4.20 Recommended Operation Process (Owen)

4.5.10.7.2. The improved Operational Process Network Diagram

According to the improved operational process network diagram **Figure4.21**, the researcher of this thesis can say that the complicated paths are corrected and total time taken to complete equipment maintenance and submit to the customer is not done only by removing the redundant operation, reassigning of shops, working place, and smooth the continuity of operations but also, the usage of online checking of spare stoke, send requisition of spare to procurement team, make know the importers spare needs, and follow up each requests and claim the urgency of the cases.

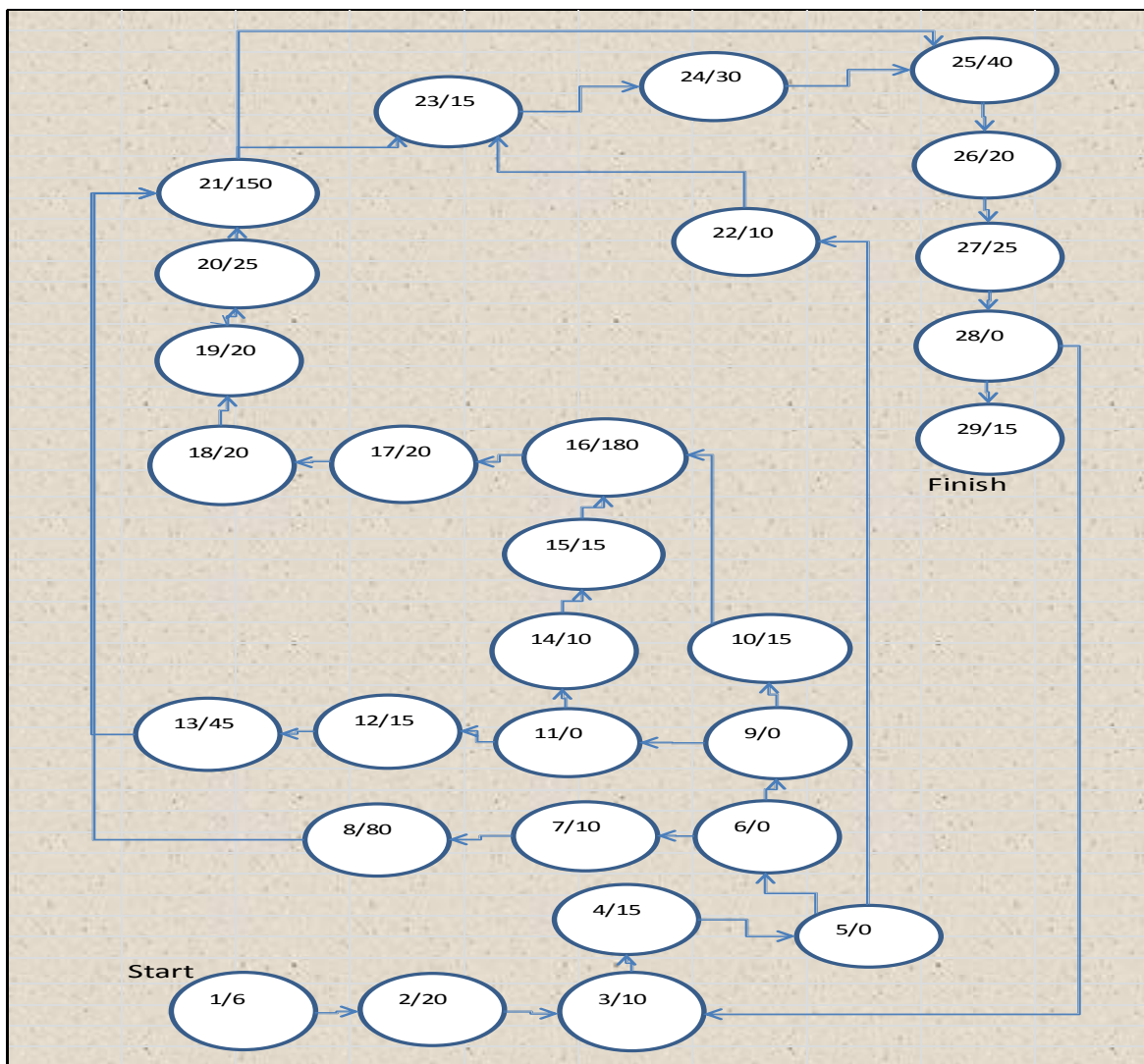


Figure4.21 Improved Operational Network diagram

4.5.10.8. Path Supportiveness and Dependency of operation of Equipment Maintenance

The aim of this sub topic is not to evaluate the advantage, method, or efficiency of queuing, but, it is just to check and evaluate the quantity of operational productivity of equipment maintenance to be performed in improved equipment maintenance supportive process that the right amount of equipment depending on the improved path, time, and annual plan. According to this analysis, the following table is summarized for the calculation of the improved path and quantity of operational activities.

Table 4.7 Path supportiveness and dependency sign

	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	+, -%	0	0	0	+, -%	0	0	0	0
P2	0	+, -%	0	0	+, -%	0	0	0	0
P3	0	0	+, -%	0	+, -%	0	0	0	0
P4	0	0	-, -%	+, +%	0	0	-, -%	0	0
P5	+, -%	+, -%	+, -%	+, -%	+, +%	0	0	0	0
P6	0	0	0	0	0	+, -%	0	0	0
P7	0	0	0	0	0	0	+, -%	0	0
P8	0	0	0	0	0	0	0	+, -%	0
P9	0	0	0	0	0	0	0	0	+, -%

P1-P9= Path1 up to Path9

+, -%= Supportive but, on unperformed rate

+, +% = supportive on performed rate

-, -%= Supportive on contrary; 0= Means insupportable or supportiveness is negligible

This supportiveness is path process that supports the maintenance of equipment positively.

4.5.10.9. Path Performance improvement for quantity evaluation

Since, we observed that the spare part availability/stoke/ path is very important for operational productivity of equipment maintenance system; the path performance improvement should be evaluated from the effect of the other operational process improvement and also the same way for other operational processes. The operational productivity of equipment maintenance system is improved almost by 80% as it is shown in

the **Table 4.8**. This is the total quality management improvement in the case company- Ethiopian construction works corporation. But, to show the process simulation the data planned for 2014 EC budget year total number of equipment operations to be maintained is 3,018. This quantity shows only the quantity, it doesn't show how many equipment maintenance operations should pass through each path. Hence, the data collected from report of 11 months is projected for the next forecast data of 2014EC through improved path process simulation that having the effect of one path on the others is calculated as follows using the value from **Table 4.4 and Table 4.7** shown:-

$$\text{Path1} = 1450(1-0.7607) + 420(1-0.7865) = 437; \text{Path2} = 108(1-0.7379) + 420(1-0.8046) - 360(1-0.7565) = 30$$

$$\text{Path3} = 360(1-0.7565) + 420(1-0.7865) = 177; \text{Path4} = 680(1+0.7908) - 360(1-0.7565) - 116(1-0.7857) = 1105$$

$$\text{Path5} = 420(1+0.7865) + 1450(1-0.7607) + 108(1-0.7379) + 360(1-0.7565) + 680(1-0.7908) = 1356$$

$$\text{Path6} = 118(1-1) = 0; \text{Path7} = 116(1-0.7857) = 25; \text{Path8} = 76(1-0.4118) = 45; \text{Path9} = 52(1-1) = 0$$

From the calculation, for instance, for path1, the path is affected by the path of itself and those paths affecting path1 by decreasing or increasing is a matter of adding and subtracting using **Table 4.7**. The main causes of effect are from path1-path5, the other paths are wastes, redone operations, and quality lowering processes. They are not supportive and constructive to improvement. But improving them is additional climax for the first five paths of improvement.

80% improvement means, 20% lagging from improvement. Therefore, the encouraging paths for maintenance, is added the improved value, whereas, discouraging paths, evaluated by the lagging value. Only path 4 and path 5 are encouraging paths, the others are discouraging paths of maintenance quality time, cost, and customer satisfaction. In fact, path 2 is a vague path, if one vehicle is outsourced to company and delivered to user, the customer will be satisfied; but, the performance of the maintenance shop decreases.

Table 4.8 Evaluated Path performance Improvement

I.NO	Identified Operational path	Existing Time Consumed (Min)	Improved Time (Min)	Performance Improvement %
1	Spare part purchase path performance	2741	656	76.07
2	outside repair performance	2217	581	73.79
3	Part cannibalization performance	928	226	75.65
4	Part modification performance	1200	251	79.08
5	Spare part from stoke performance	965	211	78.65
6	Document redoing	1120	0	100.00
7	maintenance rework	1050	225	78.57
8	Inspection back-shop	17	10	41.18
9	Spare part return	720	0	100.00
	Total	10958	2155	80.33

4.5.11. Improved Process simulation Data

Due to the path improvement and suitable quantity of maintenance operation is calculated depending on the average time that each process path needed to be completed the process. Because of the improvement made depending up on the data compiled from report from July 01, 2020 up to May 31, 2021 GC; the improved number of maintenance operation is changed to 3105. This also enables the shop to perform additional 87 equipment maintenance operations completed with time improvement. Therefore; the following improved simulation data is compiled in **Table 4.9**.

Table 4.9 Operational process simulation path data

I.NO	Operation completed path	Quantity of operation Improved	Time required for the path/min/	path probability %
1	Spare part purchase path performance	437	656	13.76
2	Outside repair performance	30	356	0.94
3	part cannibalization performance	177	436	5.57
4	part modification performance	1105	421	34.80
5	Spare part from stoke performance	1356	211	42.71
6	Document redoing	0	0	0
7	Maintenance rework	25	385	0.79
8	Inspection back-shop	45	25	1.42

9	Spare part return	0	0	0.00
10	Total	3175	2155	100.00

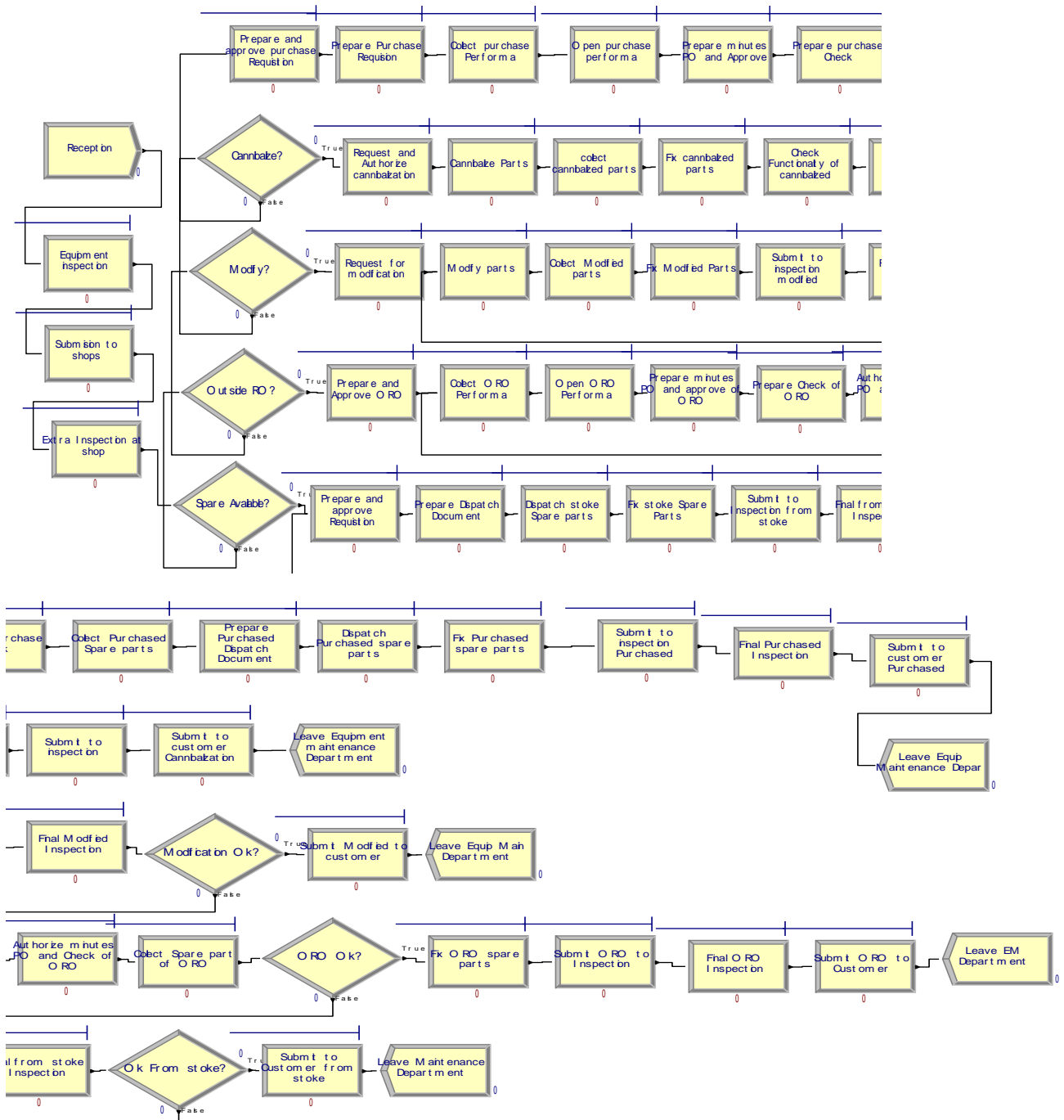


Figure4.22 Half Trimmed Improved Arena Process Simulation

6:42:11PM

Category Overview

August 18, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	1,558

6:42:11PM

Category Overview

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	82.5280	2.48037	37.2478	293.96
NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	205.36	4.81047	81.7004	584.95
Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	25095.48	(Correlated)	46.1536	102886.26
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	25383.37	(Correlated)	251.35	103508.47
Other				
Number In	Value			
Entity 1	2774.00			
Number Out	Value			
Entity 1	1558.00			
WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	620.68	(Correlated)	0.00	1216.00

Figure4.23 Sample Arena Improved Process Simulation Result

4.6. Result Discussion

The researcher already made discussion in the parts of qualitative and quantitative data analysis and process mapping discussion sub units. However; the researcher is very interested to elaborate the result that found to be focussed shortly in this sub topic. The main problem of the case company is found that there is no strategic equipment maintenance experiencing schedule due to lack of bulk purchase of PM Service kits. The following points are raised for the result discussion.

1- PM Schedule Strategy

The main problem of case company is identified that there is no PM scheduled strategy of equipment maintenance program implementation due to unavailability of bulk service kit readiness. This is, because of scarcity of finance/budget for spare parts. If the corporation implements seriously the PM schedule strategy, without any miracles, the operational process path improvement made by average value of:-

$((2741-965)/2741 + (656-211)/656) * 1/2 * 100 = 66.5\%$ (refer to Table 4.9).

2- Operations omitting or re-organizing

No need of going to store or supply to check spare part availability in stoke; because, it is done direct on line at the shop. Preparing and approving requisitions to be completed in one team and in the same desk of the supply and property administration team. And also preparing and approving of dispatch documents to be finished at one desk of supply and property administration team. Sending purchase requisition or form to store stoke requisition is omitted. Because, the required spare parts is to be requested on line.

- Currently, Minutes and PO documents are preparing separately, that is, PO document is prepared after Minutes authorization. But, it is time saving to prepare the two documents simultaneously. Authorization of Minutes, PO, and Check in existing condition passing separately and finally all documents taken to be authorized. However, after preparing PO and Minutes at Procurement and Check at Financial management department, then the authorization can be made at once.

- In existing condition, the purchased spare parts from company or importers, purchaser brings the parts and Engineers or Forman or mechanics check whether the parts are genuine. If the parts are decided to be returned, it is wastage of time, cost incurring. Therefore, the genuine spare parts to be checked and approved at the company or importers store and eliminate the spare part returning document redoing.
- Requesting and Approving Outside repair order (ORO) document to be completed at one team of the required shops. Preparing and approving purchase requisition to be finished at one desk. The time of going and coming from supply to team leader should be cut off. Checking functionality of maintained equipment to be done after the professionals are assigned and checked in the same shops and also implement accountability.

Making this process mapping, omitting and/or re-organizing the operations to improve the process paths **43-29=14** operational processes are improved.

3- Electronics software usage

The researcher recommended fantastic task to the case company to do is electronic software, that is, important to check spare part stock in store, purchase requisition of company, importers, or supply, maintenance completion report, equipment status, and so on. Fortunately, we are lucky Ethiopia electronics purchasing regulation is implementing soon.

4- Over all Process time improvement

The existing operational process path had 43 operations and this path reduced to be 29 operational paths without rework, redo, return and inspection back shops. Due to this process path time improvement made, totally **80%** improvement and **87** additional equipment enable us to submit to customers.

5- Total quality improvement due to commitment and QBMP model

Quality improvement due to commitment of leaders and employee and implementing quality business mapping process (QBMP) model is not evaluated but recommended. The researcher believed that the total quality management will be enhanced by some essential figures.

6- Process Simulation interpretation.

In existing condition, the department, teams, and shops arrangement need to be synchronized to make the process smooth and the operational activities to be productive. In existing situation, due to dis-organization of shops of electric, body repair, engine overhauling, and mechanical maintenances, seems there is mixed mandate of one team to other team of light duty vehicles, heavy duty vehicles, and machinery. Because of this, many times, there is blaming of one team for the other. This brought more down time, customer complaints, and extended waiting time in each shop. To tackle this problem, according to the recommended organization of the case company (Appendix C), the shops of similar purposes are reorganized in their own shops. Light duty vehicle maintenance team is organized electric and mechanical, body repair, and engine overhauling of three shops; similarly, heavy duty and machinery.

A) Existing process arena simulation interpretation

The existing process simulation result shows that only 589 Equipment were maintained and out from the equipment maintenance department using single line process from 1832 Equipment entered/in the reception. All 1243 Equipment were on process and waiting for maintenance. Maintained equipment in two parallel lines is 1178, three parallel is 1767, four parallel is 2356, five parallel 2945, and six parallel 3534. In order to fulfil the annual plan of 3,018 case company equipment maintenance need six parallel process lines that has been justified from simulation result. Therefore, that is why there are prolonged down time of equipment, more fire fighting activities, intensive support have been requested from one team to the other, unnecessary continuous follow up of each operational activities, and extended over time cost paid more than 6.7 million birr in the budget year only for Kality equipment maintenance centre only per year (IPD, 2020/21).

B) Improved Process simulation interpretation

The improved process simulation result shows that 1,558 Equipment are left the Equipment maintenance department using single process from 2771 Equipment entered the reception. In fact all 1213 Equipment are on process and waiting. But only two parallel processes are enough to complete the annual plan of 3105 Equipment to leave the equipment maintenance

department. In doing this, or implementing the recommended process, the corporation can save the overtime cost and over manpower can shift to the projects like Yabello airport construction site.

4.7. Existing and Improved Arena Result Comparison

The comparison of the result of the existing process path arena simulation and the improved process path arena simulation compiled the following Table 4.10 & Figure4.26; As it is can be seen, the negative values show time improvement and the positive values show that the improvement of operational process in difference and efficiency columns. Sp indicated is as a whole process.

Table4.10 Existing and Improved Arena Result Comparison

I.No	Arena Result Target Area	Sample	Existing	Improved	Difference	Efficiency
1	VA Time	sp	739.81	82.53	-657.28	-796.413
2	NVA Time	sp	498.41	205.36	-293.05	-142.700
3	Average number in	sp	1832	2774	942	33.958
4	Average number Out	sp	589	1558	969	62.195
5	Average waiting time	sp	13504.18	25095.48	11591.3	46.189
6	Average number of waiting	sp	1243	1216	-27	-2.220
7	Average Number busy	Committee	10.22	7.37	-2.85	-38.670
		Mechanic	48.05	27.07	-20.98	-77.503
		Purchaser	99.75	99.9	0.15	0.150
		Inspector	99.75	99.9	0.15	0.150
8	Schedule Utilization	Committee	10.22	7.37	-2.85	-38.670
		Mechanic	48.05	27.07	-20.98	-77.503
		Purchaser	99.75	99.9	0.15	0.150
		Inspector	99.75	99.9	0.15	0.150

The bar graph displayed next page shows that the average time of sample comparison of existing and improved arena process simulation result. The average waiting time for improved arena simulation is bigger due to the amount of equipment out is almost three times that of existing.

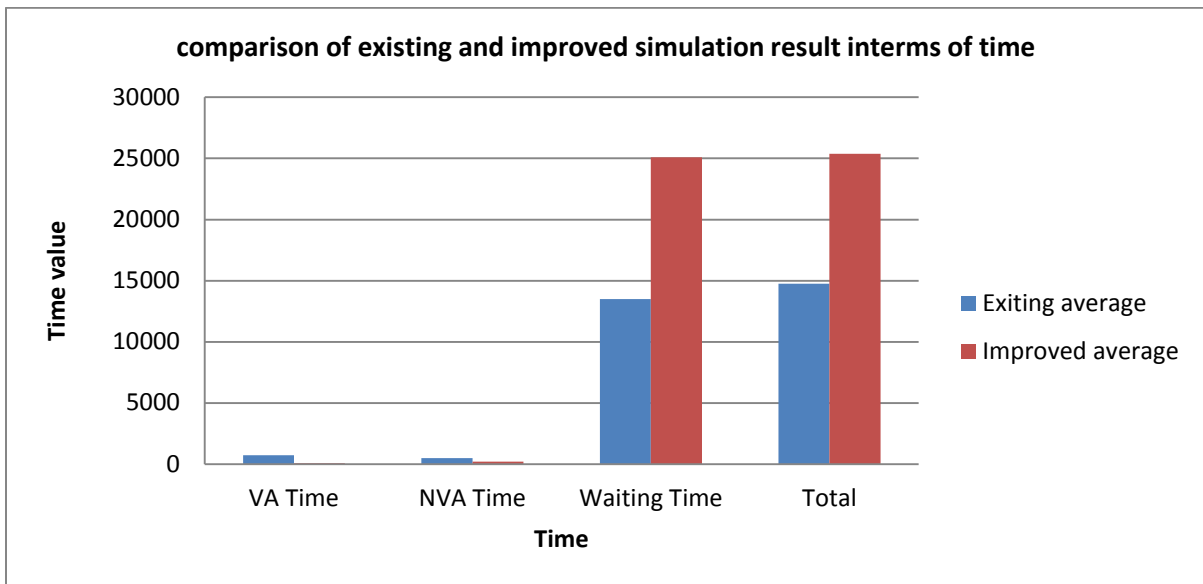


Figure4.24 Bar graph of Existing and Improved Comparison of Time

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This research is being conducted and written in relation of operational productivity of equipment maintenance system and total quality management a case of Ethiopian construction works corporation of Kality equipment maintenance centre. The problem in the research included lack of quality maintenance model framework, equipment down time, spare part supplying delay, and maintenance reworks. To solve the above listed problems, the data collected were analysed using excel, Edrawmax, and Qi Macros software.

The main causes of quality maintenance problems are found from the cause and effect tool, to be no strategic plan of maintaining, purchasing, supplying, warehousing, and weak commitment of employee and leaders, weak integration of departments, teams, and shops. Similarly, the main causes of spare part supplying delay, also known poor purchasing system, Governmental regulation by themselves retarding, and scarcity of budget/finance for spare part to PM schedule of equipment maintenance.

The main causes of prolonged equipment down time is lack of finance for spare part, lack of trained technician especially, in electro mechanical problem of equipment maintenance, jut out cannibalization of parts from one equipment to other, and lack of spare part from market due to foreign currency. The main causes of maintenance reworks are poor pre and post inspection due to technician skill, poor work place, and unavailability of special tools for inspection; poor quality of material and spare parts due to skill and globalization impact; equipment being old due to poor new equipment replacement strategy and weak top management commitment due to no accountability.

Based on the data analysed tools of cause and effect, bar graph, Pareto chart, the critical causes are identified and based on the report data the process paths is designed and QBMP model developed, and then sample store is isolated for observation data. The researcher

triangulated and simulated before and after improvement the process paths. In doing this, the researcher found that the system path improved by 80% of the total process path time.

Generally, isolating mini store and shop in heavy vehicles maintenance team and using electronic media, observed that, the improvement of employee and leaders' commitment, operation process time, customer satisfaction, smoothness of operational process, and finally total quality management is improved.

5.2. Recommendation

The improved process path, the QBMP model, 20% root causes that is responsible for the improvement of 80% effect **Table 4.1** and organizational structure which helps for continuous total quality management improvement are proposed.

- ❖ To improve quality equipment maintenance, the corporation needs strategically plan and execute PM program, right budget, commitment of employee and top management, and integrate the departments, teams, and shops with suitable process linkage recommended.
- ❖ To improve spare part supplying delay, the case company needs the system purchasing of spare part with Performa should shift to bulk purchase; government regulations like in case of private enterprises should be freed with accountability; the scarcity of budget, it is suitable to implement 40/60 which enables the sectors not to wait for corporation budget release that 60% their income directly use for their intended plan. In addition to this, improving project completing time increases the corporation income because, as earlier said the time is cost or income for construction companies.
- ❖ To improve the equipment down time, allocating finance as it is said above, training technicians on the electro-mechanical problems of nowadays equipment; strictly avoid jut out cannibalization by availing spare part and develop new equipment replacement strategy, and spare part importing with new machine and manufacture spare part in our premises or directly importing from company of equipment sellers.
- ❖ To improve maintenance reworks, assign the professional inspectors, upgrading inspecting workplace, equip the inspectors with special modern tools; assign

qualified engineers for on spare part quality control, direct manufacturing or importing genuine parts and older equipment replacing needs the top management commitment.

- ❖ To improve the whole system and to be competitive in the business, electronically supporting the process/system with software is a must. Hence, the initially developed software and taken for further development, to request maintenance and document for spare, checking spare availability in store by supply and all shops; reporting equipment and document completed, staff data, list of spare part to request company, so on, implementing in all departments is recommended.
- ❖ Finally, the total quality management (TQM), implemented in the case company, should be synchronized with operational productivity of equipment maintenance system to continuously improve the operational productivity of equipment maintenance system.

5.3. Future scope of the Research

- ❖ The researcher analysed the process path from spare part supplying from market to maintenance completion and submission to the end user/customer using total quality management (TQM). But the research is open to be done using supply chain management (SCM) starting from producer or manufacturer of spare part to consumers/end users of the equipment can be analysed to get even stronger result.
- ❖ In process mapping and networking evaluation there are bottleneck processes to be solved for process improvement, in this research, the bottleneck effects neglected for simplicity interest, using heuristic bottle neck process evaluation will increase the improvement of the process of path.
- ❖ The developed model QBMP life cycle of improvement of total quality management (TQM), is just clarified and not done thoroughly, the researchers tomorrow can widen and approve the effectiveness of the model. For today it is important for triangulating with other data analysis- cause and effect and process mapping.

- ❖ The improvement is done by process mapping tool of total quality management (TQM) technique, this research can be analysed using statistical data and use of SPSS software to compare the result found using process mapping of the process.

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APPENDIX A

Questionnaire

This questionnaire is prepared by the researcher in the field of Industrial Engineering Addis Ababa University, AA Institute of Technology for the partial fulfillment of MSC degree, **Enhancement of Operational productivity of Equipment Maintenance system using total quality management (TQM): in case of ECWC of kality Equipment Maintenance Centre.** Please fill the following data carefully and honestly in order to identify the main problems and search suitable system for necessary improvement in maintenance and making spare parts available in shortest time.

A. Background of the Respondents

- 1) Gender: Male Female
- 2) Age: 18-30 31-40 41-50 Above 50
- 3) Educational level: Under certificate Certificate Diploma
Degree Masters & Above
- 4) Working Experience in ECWC: Below 4 years 5-9 years
10-13 years above 13 years
- 5) Profession stream: Technical Finance purchase Administrative

D) what is equipment downtime in maintenance shops?

1- Lack of finance for spare parts supplying:

I strongly agree I agree Neutral I disagree I strongly disagree

2- Lack of trained technicians:

I strongly agree I agree Neutral I disagree I strongly disagree

cause of prolonged

3- Jut out/Uncontrolled/ cannibalization parts from one equipment to others:

I strongly agree I agree Neutral I disagree I strongly disagree

4- Lack of necessary spare parts in the market:

I strongly agree I agree Neutral I disagree I strongly disagree

5- Waste of time due to movement from shop to store, office, and vice versa:

I strongly agree I agree Neutral I disagree I strongly disagree

6- Lack of integrated management system:

I strongly agree I agree Neutral I disagree I strongly disagree

7- Other Problems

.....

II) What is the cause of maintenance reworks in quality equipment maintenance center?

1- Poor Pre and post inspection by inspectors:

I strongly agree I agree Neutral I disagree I strongly disagree

2- Poor quality of material and spare parts in the maintenance process:

I strongly agree I agree Neutral I disagree I strongly disagree

3- Because our equipment are old and did not replaced timely:

I strongly agree I agree Neutral I disagree I strongly disagree

4- Lack of technician's knowhow:

I strongly agree I agree Neutral I disagree I strongly disagree

5- Other problems

.....

III) What are the causes of delaying of spare part supplying?

1- Poor purchasing system:

I strongly agree I agree Neutral I disagree I strongly disagree

2- Government regulations delays today's purchasing, it should be changed:

I strongly agree I agree Neutral I disagree I strongly disagree

3- Scarcity of budget for spare parts:

I strongly agree I agree Neutral I disagree I strongly disagree

4- The arrangement of office, store, and shops are far apart each other:

I strongly agree I agree Neutral I disagree I strongly disagree

5- Other problems

.....
.....

IV) Why expected quality level is not achieved in machinery sector?

1- There is more firefighting works rather than maintenance strategy:

I strongly agree I agree Neutral I disagree I strongly disagree

2- There is weak leader’s and employee’s commitment:

I strongly agree I agree Neutral I disagree I strongly disagree

3- Weak department integration in continuous quality works:

I strongly agree I agree Neutral I disagree I strongly disagree

4- The arrangement of office, store, and shops are far apart each other:

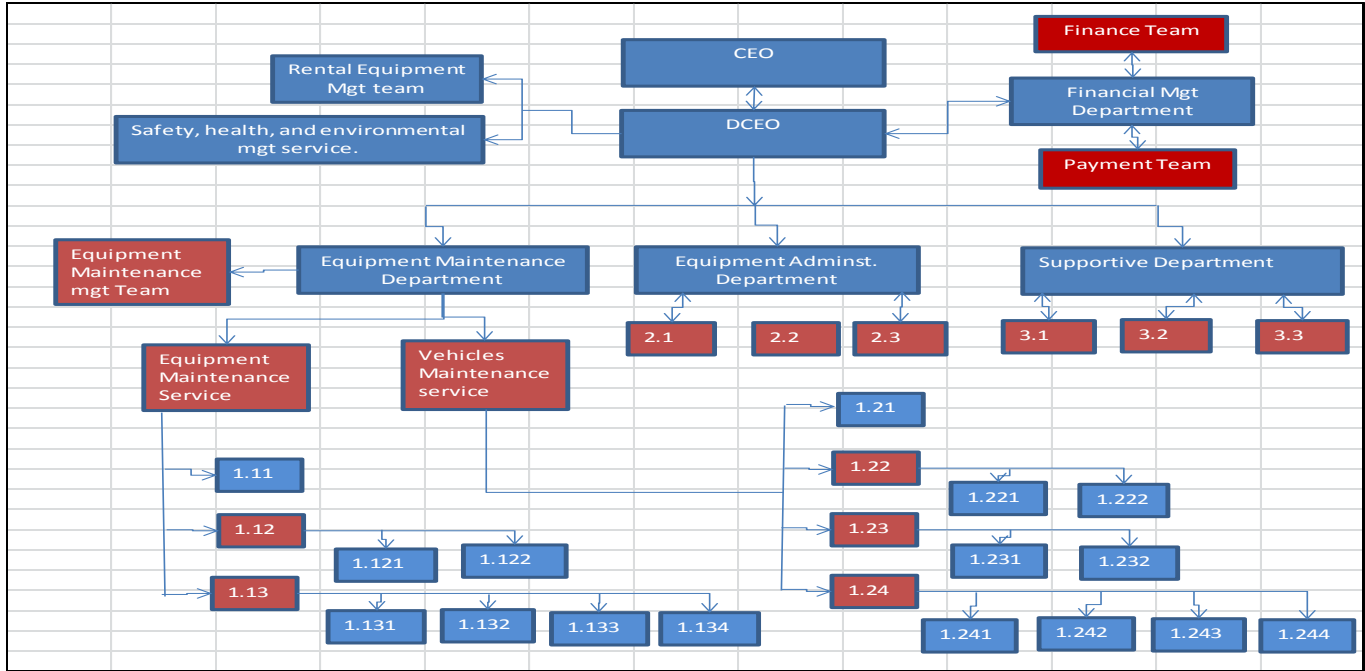
I strongly agree I agree Neutral I disagree I strongly disagree

5- Other problems

.....
.....

APPENDIX B

Organization Chart of ECWC of Con/Equip/Mach./Man/Sector



Key

- | | |
|---|---|
| 2.1 Equipment administration Team 1 | 1.134 Equipment Power Train main. Shop |
| 2.2 Equipment administration Team 2 | 1.21 Tyre Repair and service Shop |
| 2.3 Inspection & Specification Team | 1.22 Light Vehicles Maintenance Team |
| 3.1 Human resource Management Team | 1.23 Heavy Vehicles Maintenance Team |
| 3.2 Procurement Team | 1.24 Vehicles modification & Fab. Team |
| 3.3 Supply & Property Management Team | 1.221 Light Vehicles Maintenance Shop 1 |
| 1.11 Electrical Electro. Maintenance Shop | 1.222 Light Vehicles maintenance Shop 2 |
| 1.12 Equipment Maintenance Team | 1.231 Heavy Vehicles Maintenance Shop |
| 1 | 1.232 Heavy Vehicles Maintenance Shop |
| 1.13 Equipment Modification & Fab. Team | 1.241 Light Vehicles Body Repair Shop |
| 2 | 1.242 Heavy Vehicles Body Repair Shop |
| 1.121 Equipment maintenance Shop 1 | |
| 1.122 Equipment Maintenance Shop 2 | |

1.131 Metal & Welding Shop
Main. Shop

1.243 Vehicles Engine & Inj. Pump

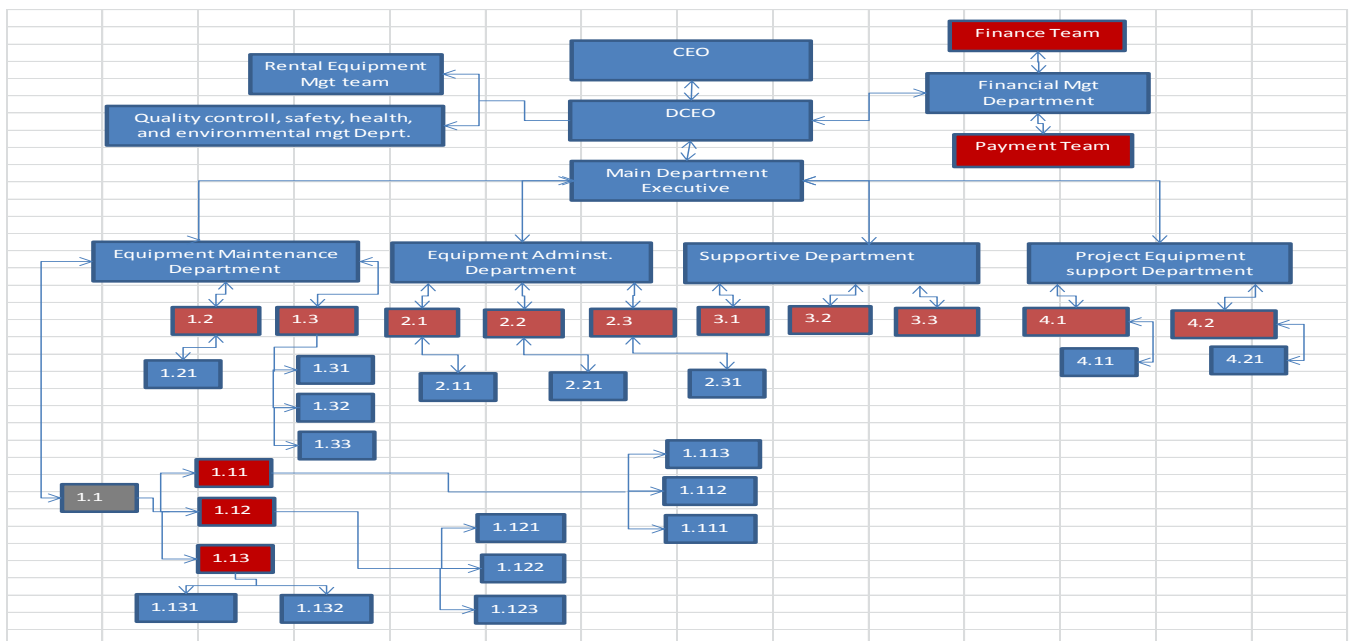
1.132 Machine (part Manufacturing) shop
Shop

1.244 Vehicles power Train Maintenance

1.133 Engine & Inj. Pump Maint. Shop

APPENDIX C

Recommended Organization of the case Company



1.1 Equipment maintenance center 1.2 Spare part Adm. Team 1.3 Electrical and mnftrg Team

2.1 Equipment Adm. Team 1 2.2 Equipment Adm. Team 2 2.3 Specific. & insp. Team

3.1 Procurement team 3.2 Supply & prop. Adm. Team 3.3 Human Res. & facil. Mgt Team

1.11 Light vehicle main. Team 1.12 heavy vehicles main. Team 1.13 Equipment main. Team

1.111 Light body Rep. shop 1.112 Light Engine main. Shop 1.113. Light mech. & elec. Shop

1.121 Heavy body Rep. shop 1.122 heavy engine main. Shop 1.123 Heavy mech. & elec. Shop

1.131 Equipment Mechan. Elect.main. Shop 1.132. Equipment engine maintenance Shop

4.1 Inspection and Main. Mgt. Team 4.2 Project Support Team

1.21 Spare part request prep. Unit 4.11 Inspection and main. Mgt. unit 4.21 Project Support Unit

1.31 Elec. Electro. Main. Shop 1.32 Metal & mnfctrg Shop 1.33 Machine & Modific. Shop

2.11 Engineering Unit 1 2.21 Engineering Unit 2 2.31 Specification Unit

APPENDIX D

Observed Operational Equipment Maintenance Time Elapsed at sample store of heavy Vehicle Maintenance Team’s Shop (April 1/21-May 30/21)

I.No	Equipment Type	Make	Plate No	Date	Requisition No	Path	Process and Time Elapsed (Min)																									
							p1	p2	p3	p4	p7	p8	p10	p12	p13	p14	p15	p16	p17	p18	p19	p20	p21	p22	p23	p24	p25	p26	p27	p29		
1	Truck, Crane	Nissan	3-24074	1/4/2021	0574964	1	5	20	9	15	10	0	0	0	8	17	185	22	20	19	28	156	0	18	33	36	17	29	14			
2	Truck, Cargo	Nissan	3-30365	5/4/2021	0574966	2	5	23	11	12	0	0	19	0	0	0	175	18	21	19	25	160	0	21	27	42	21	21	18			
3	Truck, Crane	Nissan	4-12812	5/4/2021	0574970	5	8	17	8	18	0	0	0	0	0	0	0	0	0	0	0	0	11	25	30	39	19	23	12			
4	Truck, Fuel	Nissan	4-12807	11/4/2021	0574986	4	5	19	12	13	9	84	0	0	0	0	0	0	0	0	0	11	0	0	31	41	18	27	13			
5	Truck, Dumping	Nissan	3-26950	12/4/2021	0574974	5	7	23	13	17	0	0	0	0	0	0	0	0	0	0	0	0	8	18	28	40	24	25	17			
6	Truck, Crane	Nissan	3-34075	12/4/2021	0574975	1	6	18	9	20	10	0	0	0	10	15	184	17	19	21	25	141	0	20	25	45	22	24	15			
7	Truck, water	Nissan	3-30572	14/4/2021	0574979	5	5	20	9	10	0	0	0	0	0	0	0	0	0	0	0	0	11	20	35	41	20	28	14			
8	Bus, Coaster	Nissan	4-12383	19/4/2021	0574987	3	7	21	10	11	0	0	17	48	0	0	0	0	0	0	0	9	0	20	0	37	23	24	16			
9	Truck, Cargo	Nissan	3-30363	24/4/2021	0574986	2	5	19	8	16	0	11	0	0	0	0	174	24	18	20	24	148	0	18	26	39	18	27	12			
10	Truck, Fuel	Nissan	3-30571	6/5/2021	0574906	4	7	17	11	17	11	76	0	0	0	0	0	0	0	0	0	16	0	0	31	42	20	26	15			
11	Bus, Coaster	Nissan	4-12395	14/5/2021	0574913	5	8	23	9	15	0	0	0	0	0	0	0	0	0	0	0	0	9	24	30	37	21	25	17			
12	Bus, Coaster	Nissan	3-28845	14/5/2021	0574914	1	6	21	10	14	8	0	0	0	12	13	182	19	22	21	23	145	0	21	32	38	18	26	18			
13	Truck, Cargo	Nissan	3-30366	18/5/2021	0574918	4	6	22	11	16	10	80	0	0	0	0	0	0	0	0	0	18	0	0	34	44	19	21	14			
14	Truck, Cargo	Nissan	3-30364	19/5/2021	0574919	5	7	20	9	18	0	0	0	0	0	0	0	0	0	0	0	0	12	16	27	43	20	22	13			
15	Truck, Cargo	Nissan	3-30365	20/5/2021	0574920	3	5	19	9	14	0	0	13	42	0	0	0	0	0	0	0	11	0	17	0	39	17	28	16			
16	Cargo Truck	Nissan	3-30366	21/5/2021	0574925	5	5	18	10	12	0	0	0	0	0	0	0	0	0	0	0	0	9	26	29	40	23	27	15			
17	Cargo Truck	Nissan	3-30364	24/5/2021	0574927	4	5	20	12	18	11	81	0	0	0	0	0	0	0	0	0	15	0	0	32	37	20	22	16			
Average Time Elapsed							6	20	10	15	12	80	15	15	45	10	15	180	20	20	25	150/10	10	20	30	40	20	25	15			
Path1= 1,2,3,4,7,14,15,16,17,18,19,20,21,23,24,25,26,27,29																																
Path2= 1,2,3,4,10,16,17,18,19,20,21,23,24,25,26,27,29																																
Path3= 1,2,3,4,12,13,21,25,26,27,29																																
Path4= 1,2,3,4,7,8,21,25,26,27,29																																
Path5= 1,2,3,4,22,23,24,25,26,27,29																																

APPENDIX E

Existing Process Arena Simulation Result

6:06:48PM

Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	739.81	19.79082	273.42	1873.89
NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	498.41	20.18907	250.59	2127.32
Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	13504.18	(Correlated)	163.15	134803.17
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	14742.39	(Correlated)	1269.55	137528.50

Other

Number In	Value			
Entity 1	1832.00			
Number Out	Value			
Entity 1	589.00			
WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	629.44	(Correlated)	0.00	1243.00

6:06:48PM

Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Approve Check of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Approve Dispatch Document.Queue	9.7939	(Insufficient)	0.00	87.8909
Approve Outside RO.Queue	11.0511	(Insufficient)	0.00	59.0157
Approve Po of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Approve Purchase Dispatch Document.Queue	5.9592	(Insufficient)	0.00	43.8783
Approve purchase order PO.Queue	0.00	(Insufficient)	0.00	0.00
Approve Purchase Request.Queue	5.7281	(Correlated)	0.00	89.4234
Approve Requisition.Queue	14.9572	2.31486	0.00	116.18
Approve stoke Requisition.Queue	13.5969	(Insufficient)	0.00	67.6486
Authorize Minutes ORO.Queue	0.00	(Insufficient)	0.00	0.00
Authorize Purchase Check.Queue	0.00	(Insufficient)	0.00	0.00
Authorize Purchase Minutes.Queue	0.00	(Insufficient)	0.00	0.00
Authorize the cannibalization.Queue	7.3913	(Insufficient)	0.00	81.4153
Check Functionality of cannibalized.Queue	16.1245	(Insufficient)	0.00	165.26
Check Functionality of Modified.Queue	1643.77	(Insufficient)	0.00	3542.08
Check Functionality ORO.Queue	0.00	(Insufficient)	0.00	0.00
Check Functionality.Queue	0.5469	(Insufficient)	0.00	24.8428
Check Purchased Functionality.Queue	1405.25	(Insufficient)	135.30	2651.76
Check spare stoke.Queue	42.4538	7.71876	0.00	328.29
collect cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Modified Parts.Queue	7.2587	(Insufficient)	0.00	135.95
Collect ORO Parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Performa ORO.Queue	46939.54	(Insufficient)	4201.01	112988.70
Collect Purchase Performa.Queue	58630.74	(Insufficient)	0.00	116771.64
Collect Purchased Spare part.Queue	59193.96	(Insufficient)	6436.22	116608.60
Dispatch Purchased Parts.Queue	1460.41	(Insufficient)	0.2767	3299.01
Dispatch Spare parts.Queue	1629.13	(Insufficient)	0.00	3521.38
Equipment inspection.Queue	2784.13	(Correlated)	0.00	5050.35
Extra Inspection at shop.Queue	7.5179	0.833718751	0.00	66.5739
Final Inspection of Modified.Queue	13.7146	(Insufficient)	0.00	166.14

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Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Final Inspection of purchased.Queue	2725.81	(Insufficient)	818.08	4787.70
Final Inspection ORO.Queue	882.24	(Insufficient)	882.24	882.24
Final Inspection Stoke.Queue	2723.09	(Insufficient)	12.8129	4981.72
Final Inspection.Queue	2761.81	(Insufficient)	55.7886	4961.64
Fix cannibalized parts.Queue	21.3416	(Insufficient)	0.00	207.02
Fix Modified Parts.Queue	0.5863	(Insufficient)	0.00	14.6996
Fix ORO parts.Queue	0.00	(Insufficient)	0.00	0.00
Fix Purchased Parts.Queue	3.9969	(Insufficient)	0.00	47.5075
Fix Stoke Spare Parts.Queue	3.4797	(Insufficient)	0.00	62.3821
Modify parts.Queue	499.86	(Insufficient)	0.00	2037.31
Open Performa ORO.Queue	0.00	(Insufficient)	0.00	0.00
Open Purchase performa.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Check Of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Dispatch Document.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Minutes ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Outside RO.Queue	58.0870	(Insufficient)	0.00	229.30
Prepare PO of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Check.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Dispatch Document.Queue	49.3121	(Insufficient)	0.00	229.39
Prepare Purchase Minutes.Queue	0.00	(Insufficient)	0.00	0.00
Prepare purchase Order PO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Request.Queue	53.7066	9.94973	0.00	293.34
Prepare requisition.Queue	42.7468	4.97319	0.00	194.59
Prepare stoke Requisition.Queue	35.5331	(Insufficient)	0.00	198.41
Request for cannibalization.Queue	11.9662	(Insufficient)	0.00	87.9312
Request for modification.Queue	0.1662	(Insufficient)	0.00	3.8304
Send Requisition to supply.Queue	58.6870	8.58217	0.00	342.69
Send stoke Requisition to supply.Queue	15.4755	(Insufficient)	0.00	146.57
Submission to shops.Queue	2796.60	(Correlated)	0.00	5036.93
Submit to customer Cannibalization.Queue	18.7566	(Insufficient)	0.00	147.15
Submit to Customer Modified.Queue	1637.03	(Insufficient)	0.00	3460.38

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Submit to customer ORO.Queue	847.68	(Insufficient)	847.68	847.68
Submit to Final User.Queue	2777.07	(Insufficient)	16.6867	4904.20
Submit to Inspection of Modified.Queue	1627.87	(Insufficient)	0.00	3622.34
Submit To Inspection ORO.Queue	177.55	(Insufficient)	177.55	177.55
Submit to Inspection Purchased.Queue	1464.14	(Insufficient)	0.00	3011.16
Submit to Inspection stoke.Queue	2.0408	(Insufficient)	0.00	27.7779
Submit to inspection.Queue	1628.79	(Insufficient)	0.00	3495.95
Submit to users.Queue	2708.41	(Insufficient)	917.10	4803.92
Supply Out of Stoke.Queue	44.5258	8.26283	0.00	322.28

Other

Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Approve Check of ORO.Queue	4.9072	(Insufficient)	0.00	9.0000
Approve Dispatch Document.Queue	0.01523492	(Insufficient)	0.00	1.0000
Approve Outside RO.Queue	0.00291627	(Insufficient)	0.00	1.0000
Approve Po of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Approve Purchase Dispatch Document.Queue	0.00124151	(Insufficient)	0.00	1.0000
Approve purchase order PO.Queue	0.00	(Insufficient)	0.00	0.00
Approve Purchase Request.Queue	0.04196649	0.007413473	0.00	2.0000
Approve Requisition.Queue	0.1102	0.019696202	0.00	4.0000
Approve stoke Requisition.Queue	0.02115073	(Insufficient)	0.00	2.0000
Authorize Minutes ORO.Queue	0.00	(Insufficient)	0.00	0.00
Authorize Purchase Check.Queue	0.00	(Insufficient)	0.00	0.00
Authorize Purchase Minutes.Queue	0.00	(Insufficient)	0.00	0.00
Authorize the cannibalization.Queue	0.00687805	(Insufficient)	0.00	1.0000
Check Functionality of cannibalized.Queue	0.01500472	(Insufficient)	0.00	1.0000
Check Functionality of Modified.Queue	3.0340	(Correlated)	0.00	8.0000
Check Functionality ORO.Queue	0.00	(Insufficient)	0.00	0.00
Check Functionality.Queue	0.00082409	(Insufficient)	0.00	1.0000
Check Purchased Functionaliy.Queue	0.2806	(Insufficient)	0.00	1.0000
Check spare stoke.Queue	0.5044	0.108689794	0.00	7.0000
collect cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Modified Parts.Queue	0.01350932	(Insufficient)	0.00	1.0000
Collect ORO Parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Performa ORO.Queue	14.9525	(Insufficient)	0.00	28.0000
Collect Purchase Performa.Queue	431.40	(Correlated)	0.00	880.00
Collect Purchased Spare part.Queue	70.5888	(Insufficient)	0.00	144.00
Dispatch Purchased Parts.Queue	0.2943	(Insufficient)	0.00	1.0000
Dispatch Spare parts.Queue	2.5242	(Correlated)	0.00	9.0000
Equipment inspection.Queue	35.2498	(Correlated)	0.00	73.0000
Extra Inspection at shop.Queue	0.08932691	0.013325006	0.00	3.0000
Final Inspection of Modified.Queue	0.02447682	(Insufficient)	0.00	1.0000

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Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Final Inspection of purchased.Queue	0.5092	(Insufficient)	0.00	2.0000
Final Inspection ORO.Queue	0.00612666	(Insufficient)	0.00	1.0000
Final Inspection Stoke.Queue	4.0614	(Correlated)	0.00	10.0000
Final Inspection.Queue	2.5795	(Insufficient)	0.00	11.0000
Fix cannibalized parts.Queue	0.01985958	(Insufficient)	0.00	2.0000
Fix Modified Parts.Queue	0.00109110	(Insufficient)	0.00	1.0000
Fix ORO parts.Queue	0.00	(Insufficient)	0.00	0.00
Fix Purchased Parts.Queue	0.00080494	(Insufficient)	0.00	1.0000
Fix Soke Spare Parts.Queue	0.00526790	(Insufficient)	0.00	1.0000
Modify parts.Queue	0.9586	(Correlated)	0.00	6.0000
Open Performa ORO.Queue	0.00	(Insufficient)	0.00	0.00
Open Purchase performa.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Check Of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Dispatch Document.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Minutes ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Outside RO.Queue	0.01532852	(Insufficient)	0.00	2.0000
Prepare PO of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Check.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Dispatch Document.Queue	0.01027334	(Insufficient)	0.00	1.0000
Prepare Purchase Minutes.Queue	0.00	(Insufficient)	0.00	0.00
Prepare purchase Order PO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Request.Queue	0.3951	0.094787445	0.00	3.0000
Prepare requisition.Queue	0.3150	0.047868390	0.00	4.0000
Prepare stoke Requisition.Queue	0.05527378	(Insufficient)	0.00	2.0000
Request for cannibalization.Queue	0.01113523	(Insufficient)	0.00	1.0000
Request for modification.Queue	0.00030353	(Insufficient)	0.00	1.0000
Send Requisition to supply.Queue	0.4324	0.079056631	0.00	5.0000
Send stoke Requisition to supply.Queue	0.02407295	(Insufficient)	0.00	2.0000
Submission to shops.Queue	34.4490	(Correlated)	0.00	72.0000
Submit to customer Cannibalization.Queue	0.01641199	(Insufficient)	0.00	1.0000
Submit to Customer Modified.Queue	2.7746	(Correlated)	0.00	8.0000

Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Submit to customer ORO.Queue	0.00588668	(Insufficient)	0.00	1.0000
Submit to Final User.Queue	3.9068	(Correlated)	0.00	10.0000
Submit to Inspection of Modified.Queue	2.9432	(Correlated)	0.00	8.0000
Submit To Inspection ORO.Queue	0.00123298	(Insufficient)	0.00	1.0000
Submit to Inspection Purchased.Queue	0.2855	(Insufficient)	0.00	1.0000
Submit to Inspection stoke.Queue	0.00307541	(Insufficient)	0.00	1.0000
Submit to inspection.Queue	1.5121	(Insufficient)	0.00	8.0000
Submit to users.Queue	0.4777	(Insufficient)	0.00	2.0000
Supply Out of Stoke.Queue	0.3295	0.086657818	0.00	4.0000

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Committee	0.1022	0.002933243	0.00	1.0000
DCEO	0.07022852	(Correlated)	0.00	1.0000
DCEO and Manager	0.04239158	0.001874359	0.00	1.0000
DCEO and managers	0.1162	(Insufficient)	0.00	1.0000
foreman	0.0930	0.010762830	0.00	1.0000
foreman mechanic electrician	0.3211	0.019736408	0.00	1.0000
Forman	0.3752	0.033057828	0.00	1.0000
Forman or Mechanic	0.9703	(Insufficient)	0.00	1.0000
forman or mechanic or electrician	0.2729	0.031272070	0.00	1.0000
Inspector	0.9975	(Insufficient)	0.00	1.0000
machinist	0.7560	(Insufficient)	0.00	1.0000
Manager	0.00521644	(Insufficient)	0.00	1.0000
Managers	0.9550	(Insufficient)	0.00	1.0000
Mechanic	0.4805	(Correlated)	0.00	1.0000
Mechanic or forman and officer	0.5944	0.037048338	0.00	1.0000
Mechanics	0.3586	0.036507513	0.00	1.0000
Mechanics or electrician	0.1815	(Insufficient)	0.00	1.0000
Mechanics or electricians	0.0977	(Insufficient)	0.00	1.0000
Mecnanics Or Electricians	0.00135473	(Insufficient)	0.00	1.0000
Officer	0.07017921	0.002487358	0.00	1.0000
Purchaser	0.9975	(Insufficient)	0.00	1.0000
Purchasers	0.00249151	(Insufficient)	0.00	1.0000
Senior finance officer	0.05757221	0.002206816	0.00	1.0000
Senior Officer	0.07024991	(Correlated)	0.00	1.0000
Supply Officer	0.7224	0.048759803	0.00	1.0000
Supply Officers	0.07759861	0.011950340	0.00	1.0000
Team Leader	0.4804	0.031389892	0.00	1.0000
Team Leader and Manager	0.0907	0.003606674	0.00	1.0000
Technician	0.5706	0.040384630	0.00	1.0000
Technicians	0.2750	0.024902968	0.00	1.0000

Resource

Usage

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Committee	0.1022	0.002933243	0.00	1.0000
DCEO	0.07022852	(Correlated)	0.00	1.0000
DCEO and Manager	0.04239158	0.001874359	0.00	1.0000
DCEO and managers	0.1162	(Insufficient)	0.00	1.0000
foreman	0.0930	0.010762830	0.00	1.0000
foreman mechanic electrician	0.3211	0.019736408	0.00	1.0000
Forman	0.3752	0.033057828	0.00	1.0000
Forman or Mechanic	0.9703	(Insufficient)	0.00	1.0000
forman or mechanic or electrician	0.2729	0.031272070	0.00	1.0000
Inspector	0.9975	(Insufficient)	0.00	1.0000
machinist	0.7560	(Insufficient)	0.00	1.0000
Manager	0.00521644	(Insufficient)	0.00	1.0000
Managers	0.9550	(Insufficient)	0.00	1.0000
Mechanic	0.4805	(Correlated)	0.00	1.0000
Mechanic or forman and officer	0.5944	0.037048338	0.00	1.0000
Mechanics	0.3586	0.036507513	0.00	1.0000
Mechanics or electrician	0.1815	(Insufficient)	0.00	1.0000
Mechanics or electricians	0.0977	(Insufficient)	0.00	1.0000
Mecnanics Or Electricians	0.00135473	(Insufficient)	0.00	1.0000
Officer	0.07017921	0.002487358	0.00	1.0000
Purchaser	0.9975	(Insufficient)	0.00	1.0000
Purchasers	0.00249151	(Insufficient)	0.00	1.0000
Senior finance officer	0.05757221	0.002206816	0.00	1.0000
Senior Officer	0.07024991	(Correlated)	0.00	1.0000
Supply Officer	0.7224	0.048759803	0.00	1.0000
Supply Officers	0.07759861	0.011950340	0.00	1.0000
Team Leader	0.4804	0.031389892	0.00	1.0000
Team Leader and Manager	0.0907	0.003606674	0.00	1.0000
Technician	0.5706	0.040384630	0.00	1.0000
Technicians	0.2750	0.024902968	0.00	1.0000

Resource

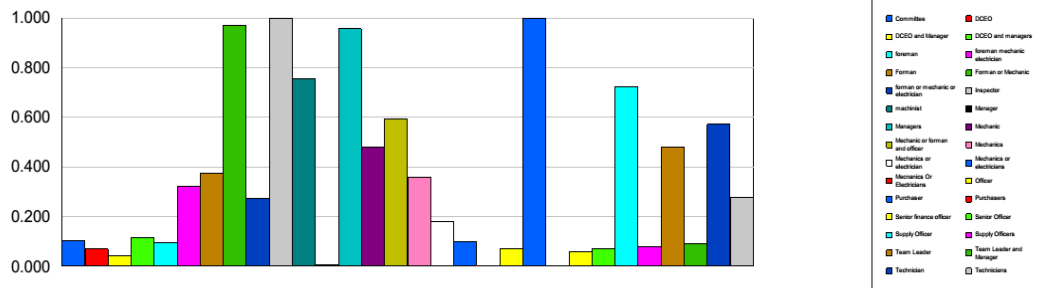
Usage

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Committee	1.0000	(Insufficient)	1.0000	1.0000
DCEO	1.0000	(Insufficient)	1.0000	1.0000
DCEO and Manager	1.0000	(Insufficient)	1.0000	1.0000
DCEO and managers	1.0000	(Insufficient)	1.0000	1.0000
foreman	1.0000	(Insufficient)	1.0000	1.0000
foreman mechanic electrician	1.0000	(Insufficient)	1.0000	1.0000
Forman	1.0000	(Insufficient)	1.0000	1.0000
Forman or Mechanic	1.0000	(Insufficient)	1.0000	1.0000
forman or mechanic or electrician	1.0000	(Insufficient)	1.0000	1.0000
Inspector	1.0000	(Insufficient)	1.0000	1.0000
machinist	1.0000	(Insufficient)	1.0000	1.0000
Manager	1.0000	(Insufficient)	1.0000	1.0000
Managers	1.0000	(Insufficient)	1.0000	1.0000
Mechanic	1.0000	(Insufficient)	1.0000	1.0000
Mechanic or forman and officer	1.0000	(Insufficient)	1.0000	1.0000
Mechanics	1.0000	(Insufficient)	1.0000	1.0000
Mechanics or electrician	1.0000	(Insufficient)	1.0000	1.0000
Mechanics or electricians	1.0000	(Insufficient)	1.0000	1.0000
Mecnanics Or Electricians	1.0000	(Insufficient)	1.0000	1.0000
Officer	1.0000	(Insufficient)	1.0000	1.0000
Purchaser	1.0000	(Insufficient)	1.0000	1.0000
Purchasers	1.0000	(Insufficient)	1.0000	1.0000
Senior finance officer	1.0000	(Insufficient)	1.0000	1.0000
Senior Officer	1.0000	(Insufficient)	1.0000	1.0000
Supply Officer	1.0000	(Insufficient)	1.0000	1.0000
Supply Officers	1.0000	(Insufficient)	1.0000	1.0000
Team Leader	1.0000	(Insufficient)	1.0000	1.0000
Team Leader and Manager	1.0000	(Insufficient)	1.0000	1.0000
Technician	1.0000	(Insufficient)	1.0000	1.0000
Technicians	1.0000	(Insufficient)	1.0000	1.0000

Resource

Usage

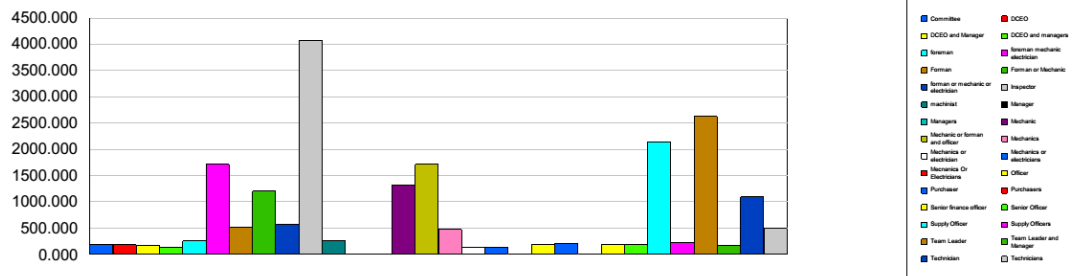
Scheduled Utilization	Value
Committee	0.1022
DCEO	0.07022852
DCEO and Manager	0.04239158
DCEO and managers	0.1162
foreman	0.0930
foreman mechanic electrician	0.3211
Forman	0.3752
Forman or Mechanic	0.9703
forman or mechanic or electrician	0.2729
Inspector	0.9975
machinist	0.7560
Manager	0.00521644
Managers	0.9550
Mechanic	0.4805
Mechanic or forman and officer	0.5944
Mechanics	0.3586
Mechanics or electrician	0.1815
Mechanics or electricians	0.0977
Mecanics Or Electricians	0.00135473
Officer	0.07017921
Purchaser	0.9975
Purchasers	0.00249151
Senior finance officer	0.05757221
Senior Officer	0.07024991
Supply Officer	0.7224
Supply Officers	0.07759861
Team Leader	0.4804
Team Leader and Manager	0.0907
Technician	0.5706
Technicians	0.2750



Resource

Usage

Total Number Seized	Value
Committee	184.00
DCEO	184.00
DCEO and Manager	174.00
DCEO and managers	134.00
foreman	263.00
foreman mechanic electrician	1711.00
Forman	517.00
Forman or Mechanic	1199.00
forman or mechanic or electrician	568.00
Inspector	4073.00
machinist	269.00
Manager	10.0000
Managers	1.0000
Mechanic	1329.00
Mechanic or forman and officer	1711.00
Mechanics	471.00
Mechanics or electrician	134.00
Mechanics or electricians	134.00
Mecanics Or Electricians	1.0000
Officer	184.00
Purchaser	215.00
Purchasers	1.0000
Senior finance officer	184.00
Senior Officer	184.00
Supply Officer	2144.00
Supply Officers	224.00
Team Leader	2632.00
Team Leader and Manager	174.00
Technician	1099.00
Technicians	492.00



APPENDIX F

Improved Process Arena Simulation Data

5:40:50PM

Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	82.5280	2.48037	37.2478	293.96
NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	205.36	4.81047	81.7004	584.95
Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	25095.48	(Correlated)	46.1536	102886.26
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	25383.37	(Correlated)	251.35	103508.47
Other				
Number In	Value			
Entity 1	2774.00			
Number Out	Value			
Entity 1	1558.00			
WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	620.68	(Correlated)	0.00	1216.00

5:40:50PM

Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Authorize minutes PO and Check of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Cannibalize Parts.Queue	2.6789	(Insufficient)	0.00	30.8599
Check Functionality of cannibalized.Queue	14.6738	(Insufficient)	0.00	133.10
collect cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Modified parts.Queue	0.9807	0.284600825	0.00	19.7613
Collect ORO Performa.Queue	12877.97	(Insufficient)	1127.44	24628.50
Collect purchase Performa.Queue	28066.93	(Correlated)	0.00	55259.80
Collect Purchased Spare parts.Queue	28903.77	(Insufficient)	113.49	55270.83
Collect Spare part of ORO.Queue	22248.40	(Insufficient)	2439.72	42057.08
Dispatch Purchased spare parts.Queue	10.1074	(Insufficient)	0.00	79.0831
Dispatch stoke Spare parts.Queue	11.0023	2.08807	0.00	113.95
Equipment inspection.Queue	5467.84	(Correlated)	0.00	10465.73
Extra Inspection at shop.Queue	1.9400	0.441460807	0.00	52.7924
Final from stoke Inspection.Queue	5593.36	(Correlated)	0.00	10477.62
Final Modified Inspection.Queue	5467.74	(Correlated)	0.00	10432.71
Final ORO Inspection.Queue	4698.62	(Insufficient)	676.42	8720.83
Final Purchased Inspection.Queue	5654.82	(Insufficient)	22.1681	10417.75
Fix cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Fix Modified Parts.Queue	9.7029	(Correlated)	0.00	74.6252
Fix ORO spare parts.Queue	14.9967	(Insufficient)	9.7670	20.2265
Fix Purchased spare parts.Queue	7.7226	(Insufficient)	0.00	67.2166
Fix stoke Spare Parts.Queue	8.3955	1.50280	0.00	97.5510
Modify parts.Queue	11.4583	2.80663	0.00	132.71
Open ORO Performa.Queue	0.00	(Insufficient)	0.00	0.00
Open purchase performa.Queue	0.00	0.000000000	0.00	0.00
Prepare and Approve ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare and approve purchase Requisition.Queue	0.9345	0.246421049	0.00	30.2039
Prepare and approve Requisition.Queue	0.00661412	0.010848955	0.00	5.2737
Prepare Check of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Dispatch Document.Queue	0.5122	0.133815083	0.00	14.5298

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5:40:50PM

Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Prepare minutes PO and approve of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare minutes PO and Approve.Queue	0.00	0.000000000	0.00	0.00
Prepare purchase Check.Queue	0.00	0.000000000	0.00	0.00
Prepare Purchase Requisition.Queue	0.5688	0.292775072	0.00	25.4540
Prepare Purchased Dispatch Document.Queue	0.00	(Insufficient)	0.00	0.00
Request and Authorize cannibalization.Queue	0.00	(Insufficient)	0.00	0.00
Request for modification.Queue	0.00	0.000000000	0.00	0.00
Submission to shops.Queue	5500.85	(Correlated)	18.1144	10479.53
Submit Modified to customer.Queue	5451.10	(Correlated)	21.3174	10405.65
Submit ORO to Customer.Queue	5225.16	(Insufficient)	792.87	9657.45
Submit ORO to Inspection.Queue	41.0599	(Insufficient)	0.00	82.1199
Submit to customer Cannibalization.Queue	0.00	(Insufficient)	0.00	0.00
Submit to Customer from stoke.Queue	5682.11	(Correlated)	0.00	10419.38
Submit to customer Purchased.Queue	5568.88	(Insufficient)	35.6406	10385.54
Submit to Inspection from stoke.Queue	12.6900	2.26789	0.00	119.77
Submit to inspection modified.Queue	7.7955	1.33063	0.00	110.99
Submit to inspection Purchased.Queue	10.0870	(Insufficient)	0.00	100.96
Submit to inspection.Queue	14.1632	(Insufficient)	0.00	65.3749

Other

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Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Authorize minutes PO and Check of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Cannibalize Parts.Queue	0.00094955	(Insufficient)	0.00	1.0000
Check Functionality of cannibalized.Queue	0.00520123	(Insufficient)	0.00	1.0000
collect cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Collect Modified parts.Queue	0.00329871	(Insufficient)	0.00	1.0000
Collect ORO Performa.Queue	0.9979	(Insufficient)	0.00	5.0000
Collect purchase Performa.Queue	161.30	(Correlated)	0.00	306.00
Collect Purchased Spare parts.Queue	104.84	(Correlated)	0.00	200.00
Collect Spare part of ORO.Queue	0.3219	(Insufficient)	0.00	1.0000
Dispatch Purchased spare parts.Queue	0.02244629	(Insufficient)	0.00	1.0000
Dispatch stoke Spare parts.Queue	0.08197607	0.018544771	0.00	3.0000
Equipment inspection.Queue	109.42	(Correlated)	0.00	241.00
Extra Inspection at shop.Queue	0.03292196	0.007262694	0.00	4.0000
Final from stoke Inspection.Queue	41.5669	(Correlated)	0.00	86.0000
Final Modified Inspection.Queue	18.4170	(Correlated)	0.00	48.0000
Final ORO Inspection.Queue	0.06797778	(Insufficient)	0.00	1.0000
Final Purchased Inspection.Queue	12.5244	(Correlated)	0.00	29.0000
Fix cannibalized parts.Queue	0.00	(Insufficient)	0.00	0.00
Fix Modified Parts.Queue	0.03263789	(Correlated)	0.00	1.0000
Fix ORO spare parts.Queue	0.00021697	(Insufficient)	0.00	1.0000
Fix Purchased spare parts.Queue	0.01715010	(Insufficient)	0.00	1.0000
Fix stoke Spare Parts.Queue	0.06265133	0.012784313	0.00	2.0000
Modify parts.Queue	0.03870920	(Insufficient)	0.00	2.0000
Open ORO Performa.Queue	0.00	(Insufficient)	0.00	0.00
Open purchase performa.Queue	0.00	(Insufficient)	0.00	0.00
Prepare and Approve ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare and approve purchase Requisition.Queue	0.00546907	(Insufficient)	0.00	2.0000
Prepare and approve Requisition.Queue	0.00004928	(Insufficient)	0.00	1.0000
Prepare Check of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Dispatch Document.Queue	0.00381618	(Insufficient)	0.00	1.0000

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Category Overview

August 20, 2021

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Prepare minutes PO and approve of ORO.Queue	0.00	(Insufficient)	0.00	0.00
Prepare minutes PO and Approve.Queue	0.00	(Insufficient)	0.00	0.00
Prepare purchase Check.Queue	0.00	(Insufficient)	0.00	0.00
Prepare Purchase Requisition.Queue	0.00332883	(Insufficient)	0.00	1.0000
Prepare Purchased Dispatch Document.Queue	0.00	(Insufficient)	0.00	0.00
Request and Authorize cannibalization.Queue	0.00	(Insufficient)	0.00	0.00
Request for modification.Queue	0.00	(Insufficient)	0.00	0.00
Submission to shops.Queue	100.53	(Correlated)	0.00	200.00
Submit Modified to customer.Queue	16.3804	(Correlated)	0.00	36.0000
Submit ORO to Customer.Queue	0.07559544	(Insufficient)	0.00	1.0000
Submit ORO to Inspection.Queue	0.00059404	(Insufficient)	0.00	1.0000
Submit to customer Cannibalization.Queue	0.00	(Insufficient)	0.00	0.00
Submit to Customer from stoke.Queue	38.0083	(Correlated)	0.00	77.0000
Submit to customer Purchased.Queue	11.3350	(Correlated)	0.00	28.0000
Submit to Inspection from stoke.Queue	0.0945	0.020721947	0.00	3.0000
Submit to inspection modified.Queue	0.02616556	0.005306256	0.00	1.0000
Submit to inspection Purchased.Queue	0.02240088	(Insufficient)	0.00	1.0000
Submit to inspection.Queue	0.00502023	(Insufficient)	0.00	1.0000

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Category Overview

August 20, 2

Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Committee	0.07373279	0.002713824	0.00	1.0000
foreman	0.03359235	0.003013218	0.00	1.0000
Forman	0.06018154	(Insufficient)	0.00	1.0000
Forman or Mechanic	0.5595	0.022420736	0.00	1.0000
Inspector	0.9995	(Insufficient)	0.00	1.0000
machinist	0.2693	0.025101570	0.00	1.0000
Manager and DCEO	0.00038381	(Insufficient)	0.00	1.0000
Mechanic or electrician	0.5218	0.021671304	0.00	1.0000
Mechanics	0.2707	0.009724511	0.00	1.0000
Mechanics or electrician	0.01417753	(Insufficient)	0.00	1.0000
Mechanics or electricians	0.00532771	(Insufficient)	0.00	1.0000
Officer and team Leader	0.07336009	0.002666599	0.00	1.0000
Officers	0.1492	0.008300317	0.00	1.0000
Officers and Team leader	0.00028555	(Insufficient)	0.00	1.0000
Purchaser	0.9990	(Insufficient)	0.00	1.0000
Senior finance officer	0.0921	0.003158716	0.00	1.0000
Service Head and DCEO	0.00542327	(Insufficient)	0.00	1.0000
Supply Officers	0.04440688	0.002915735	0.00	1.0000
Technician	0.1806	0.010043737	0.00	1.0000
Technician and Team leader	0.00079674	(Insufficient)	0.00	1.0000
Technicians	0.07454266	0.004105012	0.00	1.0000

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Category Overview

August 20, 21

Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Committee	1.0000	(Insufficient)	1.0000	1.0000
foreman	1.0000	(Insufficient)	1.0000	1.0000
Forman	1.0000	(Insufficient)	1.0000	1.0000
Forman or Mechanic	1.0000	(Insufficient)	1.0000	1.0000
Inspector	1.0000	(Insufficient)	1.0000	1.0000
machinist	1.0000	(Insufficient)	1.0000	1.0000
Manager and DCEO	1.0000	(Insufficient)	1.0000	1.0000
Mechanic or electrician	1.0000	(Insufficient)	1.0000	1.0000
Mechanics	1.0000	(Insufficient)	1.0000	1.0000
Mechanics or electrician	1.0000	(Insufficient)	1.0000	1.0000
Mechanics or electricians	1.0000	(Insufficient)	1.0000	1.0000
Officer and team Leader	1.0000	(Insufficient)	1.0000	1.0000
Officers	1.0000	(Insufficient)	1.0000	1.0000
Officers and Team leader	1.0000	(Insufficient)	1.0000	1.0000
Purchaser	1.0000	(Insufficient)	1.0000	1.0000
Senior finance officer	1.0000	(Insufficient)	1.0000	1.0000
Service Head and DCEO	1.0000	(Insufficient)	1.0000	1.0000
Supply Officers	1.0000	(Insufficient)	1.0000	1.0000
Technician	1.0000	(Insufficient)	1.0000	1.0000
Technician and Team leader	1.0000	(Insufficient)	1.0000	1.0000
Technicians	1.0000	(Insufficient)	1.0000	1.0000

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Category Overview

August 20, 2021

Unnamed Project

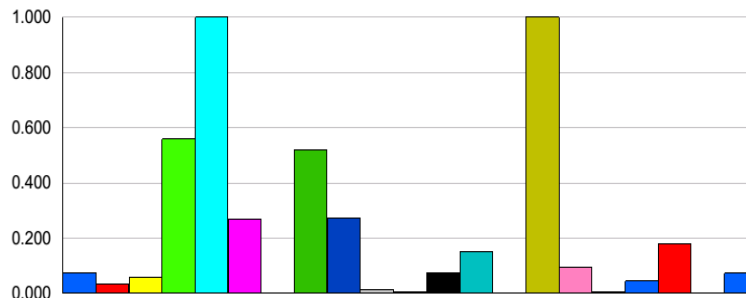
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Committee	0.07373279
foreman	0.03359235
Forman	0.06018154
Forman or Mechanic	0.5595
Inspector	0.9995
machinist	0.2693
Manager and DCEO	0.00038381
Mechanic or electrician	0.5218
Mechanics	0.2707
Mechanics or electrician	0.01417753
Mechanics or electricians	0.00532771
Officer and team Leader	0.07336009
Officers	0.1492
Officers and Team leader	0.00028555
Purchaser	0.9990
Senior finance officer	0.0921
Service Head and DCEO	0.00542327
Supply Officers	0.04440688
Technician	0.1806
Technician and Team leader	0.00079674
Technicians	0.07454266



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Category Overview

August 20, 2021

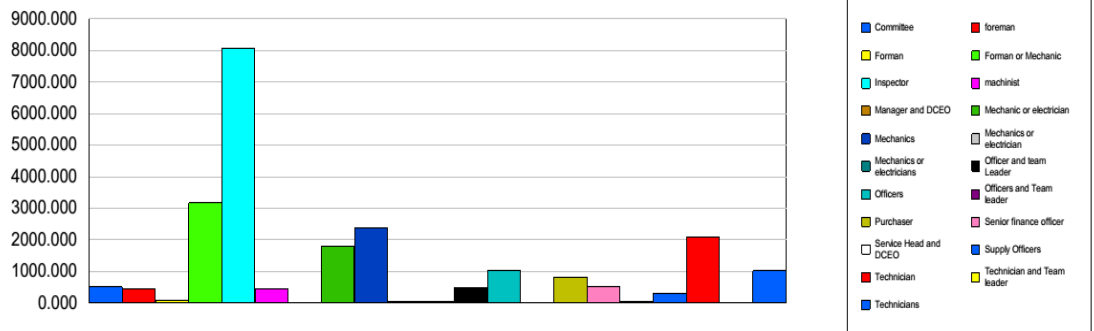
Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized	Value
Committee	509.00
foreman	465.00
Forman	98.0000
Forman or Mechanic	3188.00
Inspector	8041.00
machinist	466.00
Manager and DCEO	2.0000
Mechanic or electrician	1803.00
Mechanics	2395.00
Mechanics or electrician	49.0000
Mechanics or electricians	49.0000
Officer and team Leader	507.00
Officers	1030.00
Officers and Team leader	2.0000
Purchaser	819.00
Senior finance officer	509.00
Service Head and DCEO	49.0000
Supply Officers	307.00
Technician	2083.00
Technician and Team leader	7.0000
Technicians	1030.00



APPENDIX G

Preventive and Protective Maintenance schedule

PM Schedule											
I.No	Types of Equipment	PM1		PM2		PM3		PM4		Pm5	
1	Automobile	Km	2000/3000	Km	5000/10000	Km	10000/20000	Km	15000/30000	Km	20000/40000
		Operational Activities	Co	Operational Activities	Co, L,C1	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2,C3,C5
2	Field pick up & Station	Km	1000/2000	Km	2500/5000	Km	5000/10000	Km	10000/20000	Km	2000/40000
		Operational Activities	Co	Operational Activities	Co, L,C1	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2,C3,C5
3	Heavy Duty Vehicles	Km	1000	Km	5000	Km	10000	Km	15000	Km	20000
		Operational Activities	Co	Operational Activities	Co, L,C1	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2	Operational Activities	Co,L,C1,C2,C3,C5
4	Machinery	Hr	10 & 50 & 100	Hr	250	Hr	500	Hr	1000	Hr	2000
		Operational Activities	Co	Operational Activities	Co, L,C1	Operational Activities	Co,L,C1,C2,C4,C5,C6	Operational Activities	Co,L,C1,C2,C4,C5,C6	Operational Activities	Co,L,C1,C2,C3,C4,C5,C6

Key

Co= Check and/or adjust as necessary parts

L= Change lubricant

C1= Replace oil filter

C2= Replace fuel filter

C3= Replace air cleaner

C4= Replace transmission oil filter

C5= Replace corrosion resister

C6= Replace hydraulic oil filter