IJASST International Journal of Applied Sciences and Smart Technologies
Volume 08 Issue 01
p-ISSN 2655-8564, e-ISSN 2685-943, pp. 81-118, 2026

Using the Six Sigma DMAIC Approach to Improve Maintenance Practices of Ground-Service Mechanical Equipment within a Sub-Saharan African Airport

Olanrewaju Samson Omisakin[1], Sunday Ayoola Oke[1*], Adeyinka Oluwo[1], John Rajan[2], Swaminathan Jose[3]

[1]*Department of Mechanical Engineering, University of Lagos, Akoka-Yaba, Lagos, Nigeria*
[2]*School of Mechanical Engineering, Vellore Institute of Technology, Chennai Campus, Chennai, India*
[3]*School of Mechanical Engineering, Vellore Institute of Technology, Vellore Campus, Vellore, India*
[*]*Corresponding Author: sa_oke@yahoo.com*

(Received 06-09-2025; Revised 25-03-2026; Accepted 09-04-2026)

Abstract

Despite its ambitions for the most effective and world-class standard attainment, the ground-service equipment literature for airports is limited in engagements with the question of how to ascertain the effectiveness of maintenance services for critical ground-service equipment, to improve company goodwill and passenger comfort. By borrowing ideas from the process improvement literature, the DMAIC approach was instituted in a sub-Saharan African airport to capture the five critical ground-services mechanical equipment of package air-conditioner, escalator, travelator, baggage handling equipment and elevator. The methodology deployed to solve the problem is technical action research conducted in a large international airport. The DMAIC improvement framework was designed, installed and regularly managed for outcomes in discussions with the maintenance ground-service team from the delegated department. The cause-and-effect analysis was deployed to establish the frontline reasons for the equipment failures. The results revealed that 80% of the studied ground-service equipment exhibits the Cp/Cpk values above 1.33. Consequently, the maintenance procedure adopted to maintain the equipment is capable of maintaining a large majority of the equipment studied. However, there is scope to improve the performance of the escalator, whose value of the Cp/Cpk ratio falls below the 1.33 benchmark. A DMAIC framework appropriate to analyse the maintenance efficiency of ground-service mechanical equipment in airports is contributed for the first time to the airport setting.

Keywords: Airports, ground-service mechanical equipment, maintenance practices

1 Introduction

Presently, the pressure on ground-service equipment in airports seems unprecedented due to overgrown passenger traffic, particularly in large international airports [1]. Concurrently, to establish the quality of their journeys, passengers require stress-free services, including pre-boarding waiting, check-in services, security checks of passengers, and immigration control [1,2,3,4]. Besides, beyond the passengers' concern about ground-service equipment and pre-flight waiting comfort, the issue of maintenance inefficiency of ground-service equipment triggered agitations among airlines and airport management [1,4,5]. It is argued that to assess and establish the overall airport performance, the conception of a balanced viewpoint of the ground-service equipment performance from various stakeholders and users will strengthen understanding and offer a greater improvement drive. Consequently, in the global airport sector, the International Air Transport Association, known as IATA, and the Airports Council International, ACI, issued calls for level of service enhancement, which greatly validates the importance of the present investigation [6].

At present, the airport ground-service equipment literature lacks insights and motivation on how to ascertain the effectiveness of maintenance services for critical ground-service equipment, using scientific tools of interest. This has caused damage to the airport's goodwill. To commence a goodwill enhancement drive and passenger comfort improvement, the DMAIC approach is introduced for the maintenance process improvement of five critical airport ground-service pieces of equipment in a large international airport within a developing country. Service defects are analysed to enhance maintenance service efficiency. But solving complicated problems such as maintenance inefficiency at airports is challenging, as there are limited manpower constraints and budgets, and the saturation of airports with passengers at most times of the year is compelling. Thus, a unique scientific approach, such as the DMAIC, to create capacity, enhance operations and resolve the complicated problem is the need of the hour in airports.

In an endeavour to apply the DMAIC approach, the challenge of unexpected downtime to the critical equipment, during working hours, is tackled. These pieces of equipment include the elevator, escalator, travelator, baggage handling equipment and air-conditioners. The ground-service equipment failure leads to prolonged waiting time or passenger discomfort as alternative equipment is allocated for service, but the passenger remains dissatisfied, and such instances require control and avoidance. Besides, the present approach of preventive maintenance and reactive maintenance practices appears deficient in controlling the costly and frequently occurring downtime of service equipment.

The methodology deployed to solve the problem is technical action research conducted in a large international airport in sub-Saharan Africa. In 2019, an equipment condition monitoring scheme was deployed for the five critical pieces of equipment mentioned earlier, and the selection criteria were based on the importance of the equipment due to the high passenger traffic requiring the equipment, the maintenance cost of the equipment and the consequences of equipment failure during operations. The DMAIC improvement framework was designed, installed, and regularly managed for outcomes in discussions with the maintenance service team from the delegated department. The cause and effect analysis was deployed to establish the frontline reasons for the equipment failure. Some technical breakdown data were collected from the third party and in-house maintenance team records to permit proper understanding and the establishment of optimised quality service from equipment while lowering the projected cost from the unanticipated breakdown of the ground-service equipment.

By using the DMAIC approach, this study highlights the value of adopting a scientific approach that encourages the transition from the traditional "run-to-failure" and "preventive maintenance" philosophy to a combination of these approaches and the innovative DMAIC approach that guarantees superior quality maintenance through defect checks and corrections from the cause-and-effect analysis. By following the suggested approach, the maintenance effectiveness was enhanced, and the goodwill decay and damage to passengers' perception regarding the airport services were avoided. Thus, the proposed solution tackles the inherent equipment breakdown needs for superior maintenance quality enhancement. With the solution, the highest quality of service from the ground-service equipment is guaranteed for the crucial equipment studied in an airport that aims at evading the consequences of the ineffectiveness of the current preventive cum reactive maintenance of the ground-service equipment.

The development of a maintenance process enhancement scheme, using the DMAIC approach, for the critical airport ground-service equipment, to detect service defects and eliminate them, is the novel contribution of this paper. More so, the cause-and-effect analysis is deployed to assist the service team in understanding the various causes that stimulate the effects. It links the causes to the effects through pictorial association and pinpoints aspects of maintenance service for enhancement in the airport, regarding the five critical pieces of equipment selected for analysis in this work. Besides, the review of literature conducted discloses the scope for the present work to include the following:

1. Field studies involving activities at the airport in a sub-Saharan African location.
2. Performance analysis of the airport ground-service equipment using a cause and effect diagram and DMAIC approach.
3. The critical ground-service equipment studied includes the elevator, escalator, travelator, baggage handling equipment and air-conditioners.
4. Study to include the process probable capability index as well as the process performance capability index.
5. The use of real-life data for analysis from the perspective of a sub-Saharan African case.
6. To develop ratios for the process probable capability/process performance capability indices.

The rest of the paper includes four sections. Section 2 is the literature review, Section 3 is the methodology, while Section 4 is the results and discussion. Section 5 is the concluding aspect of the research.

1.1 Literature Review

The literature review is approached by first discussing the previous applications of the DMAIC approach to reveal the gap (Section 2.1). Next, the problems commonly discovered in routine inspections regarding the studied ground-service mechanical equipment are discussed (Section 2.2). These pieces of equipment are the package air-conditioner, escalator, elevator, travelator and baggage handling equipment. The problems identified regarding the elevator are first discussed and subsequently elaborated on each of the other equipment in turn. The third sub-section (Section 2.3) discusses the adverse failure events of equipment. These previous reviews reveal the necessity of briefly reviewing accidents and near misses due to these pieces of mechanical equipment. Therefore, the next part (Section 2.4) argues from the available literature on accidents and near misses of the mentioned ground-service mechanical equipment. The concluding part (Section 2.5) summarises the gaps within the service mechanical equipment literature and directs the goal of this article.

1.1.1 Previous literature on the DMAIC approach

Apart from the systematic literature review conducted by Setiawan and Debora [7], several studies have analysed manufacturing processes by deploying the DMAIC approach. Attempts were made in body painting of vehicle [8], amplifier production [9], aluminium profiles manufacturing [10], home appliance [11], vehicle assembly process [12], brake disc products [13], roof tile products[14], O ring products [15], tyre production [16], chair products [17], magazine production[18], drug tablets production [19], cabinet door, jewellery manufacturing[20], pin insertion process [21], food can [22] and motor standard product[23]. Notwithstanding, the application of DMAIC in ground-service systems appears less pronounced compared to its manufacturing counterparts. In these service applications, no reports have been given on the maintenance of ground-service equipment in airports.

1.1.2 Problems common with ground-service equipment

1.1.2.1 Elevators

Though there is no direct information concerning the average usage of elevators in the studied case, the literature, as supported by Kuusinen et al. [24], provided some details on the arrival process of passengers at a lift. The outcome reveals that passengers arrive in the group for lift services in sizes that depend on the time of the day (i.e. morning, afternoon and night) and the floor usage. Given the volume of passengers that utilise escalators in the airport daily, there is a high potential for mechanical failures within the airport escalators. Although a high failure potential of the escalator exists, the rate of failures and the activities causing the failures have not been reported for the airport. Siti et al. [25] presented a list of common defects associated with the elevator in their Figure 3. These problems, with modifications, are adopted in the current article.

1.1.2.2 Escalator

Experience in practice reveals some common challenges faced while maintaining elevators, some of these may include the opening and closing of doors at an inappropriate time, the collapse of the escalator, design flaws, lambs and/or clothing being trapped between moving parts of the escalator and overloading. Jampha et al. [26] analysed maintenance problems in escalators by focusing on three cases in Malaysia. The principal problems relate to the set of motors and brakes. So and Li [27] analysed the performance of escalators regarding energy consumption. By drawing instances from Hong Kong, the authors analysed the energy efficiency control code installed by Hong Kong and discussed the diverse electrical parameters, which include total harmonic distortion and total power factor. Algin et al.[28] studied the escalator-associated injuries on the metro line in Saudi Arabia. It was revealed that the most common means of injury was a fall (97.6%). This resulted in head and extremity injuries of 42% and 33%, respectively. The key type of escalator-associated injuries was related to soft tissues (41.3%), next were laceration, closed lead injuries, fractures and serious injuries, which accounted for 20.7%, 18.5%, 15.2% and 4.4%, respectively. A new protection measure against escalator-associated injuries was advocated for.

1.1.3 Adverse failure events of equipment

The adverse failure activities are definite failures of the ground-service equipment at different levels of failure. For elevators, Siti et al. [25] identified six actual failure instances of elevators. These are norm traction sheave, breakage of suspension ropes, stretch marks on safety gears, elevator and landing door misalignment, missing ropes fibre core and severely corroded suspension ropes.

1.1.4 Near misses and accidents involving ground-service mechanical equipment

Passenger safety experts recommend that accounting for and studying near misses and accidents are important aspects of elevator management and control [29]. Although Khaji and Ghodsi [29] argued that elevator-associated accidents are rare, when they occur, the injuries sustained from them may be significant. They reported instances regarding elevator-associated accidents that spanned from 1999 to 2003 in Tehran, Iran. It was reported that a stable growth of accident cases occurred during the study period. Specifically, a positive rising movement for severe injuries and mortality arising from the accidents was reported. It was concluded that organisations should check the settings, maintain and repair their elevators as essential.

1.1.5 Gaps in the literature

It is evident from the literature review that there is limited literature on how the maintenance effectiveness of the selected service mechanical equipment could be improved. Consequently, observational data regarding the present state of the maintenance effectiveness of the selected service mechanical equipment in the airport are required for the advancement of the aimed maintenance quality enhancement events in the airport setting. Although some studies, including Kuusinen et al. [24] and Siti et al [25] showed some concern and suggested information on the arrival process of passengers and common defects associated with the elevator in the order of the mentioned authors, both suggestions are limited to the elevators alone. Apart, they have not sketched the broad tasks to accomplish the maintenance ineffectiveness correction for each of the selected service mechanical equipment. Consequently, studies have so far failed to establish the details behind the maintenance effectiveness of the service equipment, including the causes and effects, its business impacts (monetary implications of equipment breakdown and economic savings per equipment per month). Thus, research has not suggested the framework for maintenance policymakers and maintenance managers in airports to employ.

As suggested by experts, accounting for and analysing problems common with service equipment in airports can offer an understanding into equipment failures and related problems, comprising of accidents involving service mechanical equipment. Besides, there is a lack of use of mechanical equipment maintenance process control methods such as the DMAIC (Define, measure, analyse, improve and control), in the maintenance performance analysis perspective of the service equipment in airports. Consequently, research is needed to examine the service mechanical equipment maintenance efficiency within the airport and to establish the degree of process efficiency, equipment turnover of serviceability, economic savings and monetary implications. The maintenance plan, including checking the conformance of maintenance activities to maintenance standards, is a critical process within any airport and contributes greatly to passengers' comfort and airport's goodwill when related to the maintenance of service equipment. As the airport service mechanical equipment has been largely ignored compared with other maintainable equipment, such as manufacturing equipment, and an understanding of the maintenance effectiveness has been downplayed, the researcher aimed to bridge this gap. This research aims to offer an exhaustive understanding of the service mechanical equipment by using the DMAIC approach. The engagement with the DMAIC method will examine how the current equipment deficiencies are tackled and the probable ways to enhance the control of these deficiencies.

2 Material and Methods

2.1 The indicators of capability

The various indicator of capability by Sharma and Sharma [30] will be used in this work. They are numbered as Equations (1) to (4):

$$C_P = \frac{USL - LSL}{6\sigma} \tag{1}$$

$$C_{PKU} = \frac{USL - \mu}{3\sigma} \tag{2}$$

$$C_{PKL} = \frac{\mu - LSL}{3\sigma} \tag{3}$$

$$C_{PK} = \min\left\{\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} \tag{4}$$

where

USL is the upper specification limit, and LSL is the lower specification limit

σ is the standard deviation, and μ is the process mean

C_P signifies the development of the latent capability indicator

C_{PK} signifies the development implementation capability indicator.

Notice that C_P presents a suggestion of distribution of the mechanical equipment components within the precise acceptance region throughout the maintenance procedure. Also, C_{PK} symbolises the concentration of the maintenance procedure regarding the mean of the precise component acceptance region of the equipment. It also provides an impression or indication of whether the maintenance procedure is functioning at the centre of the acceptance region or closer to the upper or lower acceptance boundaries.

Standard deviation **-** Standard deviation reveals how the measurements concerning the maintenance process, for a group outstretch from the expected value. The maintenance parameters are said to have a low standard deviation, with the majority of the numbers near the expected value. Conversely, when the majority of the numbers outstretches, they are known as having high standard deviation. Literature reveals that with the knowledge of two numbers, it is possible to describe the shape of the curve for the data. The term standard normal distribution describes a normal distribution that possesses a mean value of 0 together with a standard deviation of 1.

Latent capability indicator, C_p **-** By adopting the idea of latent, we describe a situation in which the variable cannot be evaluated straightforwardly. A latent value represents an obtainable value, although so far not found. It describes the disparity between certainty and what is likely. As an alternative to the simple linear approach, investigators have, in the recent past, acknowledged the latent character of the maintenance process parametric phenomenon. In this work, the latent idea has been applied to capture maintenance performances. The role of latent performance measures has been made in an airport service equipment context regarding maintenance inefficiency corrections. To illustrate the idea of a latent variable, the global health of the service equipment is regarded as a latent variable. Unfortunately, there is no single evaluation of "health" which can be assessed. This is an abstract idea. However, the performance of the service equipment may be measured using some metrics such as the MTTR, MTBF, and frequency of failures. These individual evaluations may be deployed by maintenance experts to evaluate the health of the service equipment since experience based on observing these values in different healthy and unhealthy machines would count. In this instance, health is regarded as a latent variable. As there is no direct evaluation for the health of the service equipment, other evaluations that play a role in some manner to evaluating the health of service equipment are used.

2.2 Definition of terms

Definition Stage

The define phase of DMAIC project is targeted at explaining the rationale and extent of the maintenance improvement project. At this stage, the fundamental perceptions and expectations of the passengers regarding the quality of service are established. An important feature of this phase is to establish reasonable estimates for timelines and project costs. The advantage of these definitions is to position the passengers of the airport and the maintenance team at the same level concerning what to be done and how the evolution and achievement of the project could be assessed. Often in many organizations, substantial work is conducted before installing a DMAIC project, which prepares the entire employee team to receive the project as everyone will be involved in these preparations. In summary, the DMAIC involves identifying the maintenance problem to be tackled. This also involves recognising the need for regular and periodic maintenance of equipment, understanding the requirements for preventive task planning and the impact of equipment breakdown on the overall performance and deliveries of operational equipment. In this paper, some of the concerns to validate the need to implement a DMAIC project in the service equipment aspect of the airport are as follows:

- Is the maintenance data available? There are two aspects of maintenance engaged in the plant. The first concerns the tasks handled by the in-house personnel, while the second are those regarding jobs contracted out to third parties. The later is where the expertise in-house is not sufficient to maintain the service equipment or it may be too expensive to deploy in-house staff to do. An example is the maintenance of the escalators, which is handled by third-party contractors. In this case, interactions with them are made to assess how easy it is to obtain data.
- The second issue is the top management commitment to support the improvement project. At this definition stage, an assessment and solicitation of the top management were sought.

- A third issue was to assess whether the scope of the defined work is reasonable bearing in mind that scope outside the capability of the team may be unattainable.
- A fourth issue is to determine if the DMAIC process to be installed has direct linkage with a principal outcome, for example, the passenger's satisfaction.

Measurement Stage

The measuring stage of DMAIC elaborates on the numerical and data analysis aspects of the process, involving the scheme's validation and the collection of the root causes of the maintenance problem. In the DMAIC measurement phase, data collection takes an important position. Before embarking on the collection of data, information on when, who and where the service data will be collected and the analysis to perform on these data were considered. In the airport studied, there is a service agreement with a contractor company to service the elevators, travellators and escalators of the airport. However, their services are complemented with the monitoring of the in-house personal. The same applies to air conditioners and the baggage handling equipment in the plant. For the baggage handling equipment, the maintenance activities logbook was consulted. It gives information on the baggage handling equipment concerning the downtime span. In a data item, for instance, the downtime was recorded to start with the data and the actual time the crew was notified of the failure of the equipment.

What follows is the nature of the fault(s). For the data item considered, "Broken 2No. carriers on conveyor line" was recorded, which means that two units of carriers broke down in the conveyor labelled as "9". This is followed by the uptime, where the data of repairs and the time the baggage equipment was restored is recorded. Next is the item interval, which shows the range of time from downtime to uptime. In this instance, 20 mins were recorded as the downtime to uptime interval. The last item of information is "remarks". For the data item, a typical remark is "Broken carriers replaced with good ones from conveyor line 11". In this instance, the downtime to uptime interval is the process and imprint variable, which influences the cuticle-to-quality (CTQ) as well as critical-to-process (CTP) parameters but when this interval is considered for the whole year, an average may be obtained, which is defined as interval time average, and this influences the critical-to-satisfaction parameters. The interval time and the interval time average are collected in tandem to establish the association between these two issues and apply the analyse stage of the DMAIC process. The interval time average is essential to demonstrate a baseline for the performance of the service equipment regarding breakdown, which should be enhanced.

In the preceding paragraph, the CTQ is mentioned but its meaning is that it defines the interval quality parameters that associate with the need of the customer as well as his/her wants. In the literature, two variants of CTQs are possible. These are the KPIV and KPOV, respectively, indicating the key process input variable as well as the key process output variable. The CTP and CTS are mapped to the KPIV and KPOV, respectively.

Analysis Stage

As the name suggests, the analysis phase of the DMAIC process, which proceeds with the output of the "measure" phase to analyse the data collected, attempts to search for the answer to the "why" question. The present researchers attempt to establish the root cause of the performance concern through the application of statistical tools and procedures, validate it and ascertain that the enhancement drive focuses on the foundation instead of the symptoms. The Literature warns that problem-solving teams globally frequently instigate improvement projects while assuming that the causes of the process concerns are known. However, the literature reports that such preconceived ideas often lead to solutions which fail to settle the maintenance problem. Here, the team proffers solution ahead of confirming the exact root causes. The weakness of this approach is the huge wastage of time involved and resources consumed, as more variations are created and new problems emerge. The standard practice would be to examine the maintenance process as well as the supporting data to obtain evidence of the probable root causes of the maintenance problem.

To proceed, hypotheses may be created regarding why the problems occur and then detail explanations to support or dispose of the formulated hypotheses. The word verification used earlier in this discussion involves observing the process, analysing the data and testing the potential causes, thereby obtaining a clear understanding of the sources of the maintenance problems before examining the solutions. Furthermore, a thorough approach to the "analyse" phase digs into the data to observe patterns that aid to establish the root cause and the issues to tackle to correct the problem. The literature shows the procedure to implement the analysis phase of the DMAIC process commences with the establishment of the datasets to analyse. The important question to answer concerns what variables of the process that produces the defects. Associations between these variables are sought. On a wide scope, if the downtime rate for the airport equipment is sought, correlations between inputs such as equipment regulation, spare parts 'quality, equipment operators, and the cooling capacity for the package air conditioner, for instance. This step leads the researcher in carrying out different approaches of statistical analysis in an attempt to compute the degree of correlation between the variables. Notice that this action will assist the researcher to evaluate how likely that the variable is responsible for the problem.

The degree of analysis is aided by using the fishbone diagrams, hypotheses testing, root cause analysis and linear regression. The last procedure of analyse phase is to list the causes. In establishing the variables that possess a superior degree of correlation with the problem, the researcher creates a list of "causes" of variations in the maintenance process, which are supported with practical data.

Improvement Stage

This is the fourth of the fifth stages and the most creative aspect in the DMAIC method, where stakeholders of the maintenance process are asked to propose suggestions for the solution to the problem. It has an experimental side also like the suggestions by the stakeholders are examined using a pilot study before execution by the continuous improvement team, to solve the problem. At this phase, the team advances the solution, leads the process modifications, applies their suggestions and obtains data to verify that they create a quantifiable change. The improve phase needs insight into the KPIVs, which is basic for the effect. At this stage, the association of the principal variables with the project "Y" is established, while the modification suggestions are guided. It is acknowledged that without implementing the ideas, all the work done at the earlier stages would be fruitless. The key tools used for the improve stage include the failure mode and effect analysis, hypothesis testing, fishbone diagram and 5 whys. There are three principal steps associated with the improve phase of the DMAIC process.

First, the idea-generating workers are invited again into the discussion room. Here, the operator or the staffs involved in everyday activities is central to this discussion and brainstorming process. The brainstorming exercise is commenced for the probable result. A good approach is to recast the established problem at the Define haze, open up the root causes to the problem established at the Measure and Analyse phase. Then let them propose the solution. For progress, it is essential to set a deadline for the solution. It means that the operators are permitted to leave the discussion room and think solely while they are carrying out their jobs or during their relaxation periods. The ideas are then collated there.

Second, based on the team leader's knowledge and understanding, the ideas are weighed up, and those acknowledged as superior are further pursued. To pursue the ideas means piloting them, a task that is crucial to verify the idea. Experts acknowledge that a screamingly sound idea in the discussion room may not be wonderful in practice on the factory floor. This brings out the benefits of piloting the ideas while including monetary savings, avoidance of frustration and time savings. As the idea is being tested on a pilot scale, the failed ones are noted, thereby preventing their implementation on a wide scale before they are known. Third, the task is to select an acceptable idea. After considering the improve phase of the DMAIC process, several suggestions that have been pilot-tested may have been ruled out while picking the best suggestion to implement on an extensive scale.

Control Stage

This is the last of five phases in the DMAIC method aimed at ascertaining that actions to execute from the ideas generated during the improve phase are properly executed and regulated. Numerous control tools assist to regulate the variables within the specified limits. These include control charts, and failure modes and effect analysis. At the control phase, the team leader ought to have established the process requiring improvement, obtained the essential data, analyse it for the establishment of the cause and effects of the problem and must have established a practical suggestion from the pilot testing. At this stage, the final implementation of the solution is made. However, experts suggest that this phase is very uninteresting due to the multiple tasks and cycles of repeating the same set of procedures to ascertain that the desired systems are properly installed.

It is worthwhile to note that such changes may be organisation-wide in their implementation and all staff is expected to comply with the procedure. Four important steps are associated with the control phase of the DMAIC method regarding the maintenance process. These are the measurement planning, tools for the control and success level evaluation, the action plan and the time frame. For the measurement planning aspect, some interesting questions to guide the team are: How shall we evaluate the new process performance? How do we ascertain that the defect rate established is enhancing? Could the team state the reliability of the data? Is it necessary to develop data collection approaches in the process? Will it require staff training, or may it have an automatic implementation? The control chart is the widely adopted tool for the second step. They assist to know the stability as well as process control, establish variant and their causes. The next step is the action plan, which is to tackle the deviations. The last step is the time frame that acknowledges that the control phase is time-bound.

2.3 Identifying KQCs

The satisfactory procedure of maintenance through the identification of key performance components of any equipment was considered in support of the related account of maintenance activities. Consequently, the objective of this analysis is to enhance the operational effectiveness of mechanical equipment by reducing any appearance of fault or breakdown in the course of operation so that damages do not render the equipment inoperative and deliveries unachievable.

2.4 Cause and Effect Diagram

The cause-and-effect diagram analyses the reason why something happened or might happen by arranging probable cause into smaller groups.

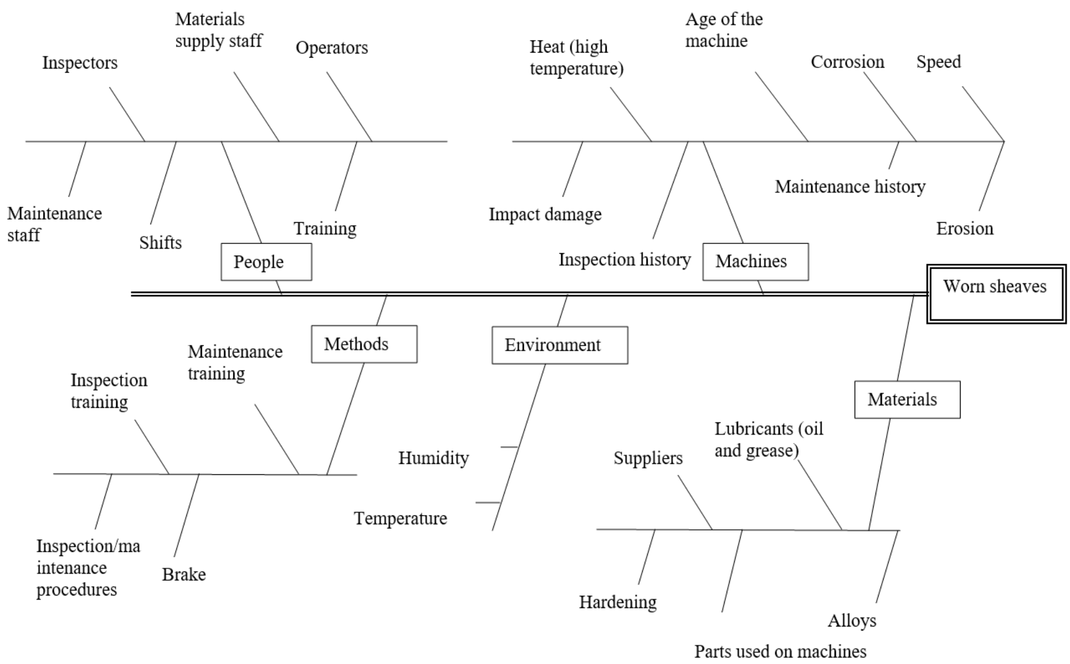

Figure 1. Cause-and-effect diagram illustrating the variables effecting Worn sheaves of elevators

Also, it is a picture or an image that means for organising the possible roots of challenge to recognize its main basis. Fig. 1 provides an illustration of the cause-and-effect diagram for the variables effecting worn sheaves of elevators. This is an example and other aspects of the study could be analysed through the cause-and-effect diagram.

2.5 Project Charter of the DMAIC Project Relating to the Maintenance of Mechanical Equipment in the Airport

Objectives

1. To maintain equipment in tough operating conditions.
2. To maintain equipment in acceptable conditions.
3. To ensure maximum availability of plant and equipment at a reasonable cost.
4. To provide service that will avert breakdowns at all times and at any cost.
5. To extend plant life to the last limit.
6. To maintain plant and equipment with maximum economy and to replace at predetermined periods.
7. To ensure high-quality performance.

8. To ensure safe and efficient operation at all times.
9. To maximize output over the next five years.
10. To maintain a reasonable good appearance of plant.
11. To maintain a plant spotlessly clean at all times.
12. To minimize maintenance expenditure and maximize profit.

3 Results and Discussions

3.1 The case to study airport terminal equipment

Maintenance at the airport terminal involves three broad classes of maintenance. In the first class, the maintenance crew is responsible for controlling and monitoring terminal mechanical equipment consisting of refrigeration and air conditioning systems, conveyors, elevators, escalators, travolators, extractors and aviobridge. The aviobridge is a set of equipment, such as the passenger tunnel and automatic doors. The chiller system is the last group member of the terminal equipment maintained by the engineer in the airport terminal. The second class of equipment within the responsibility of the maintenance engineer to control and monitor is the heavy-duty and light vehicles, which include tractors, slashers, hydraulic platforms, cars, fabrication and welding equipment, as well as forklifts. The last category of equipment under the maintenance engineer at the airport terminal is the power-generating plant. However, the scope of maintenance of all three mentioned categories of equipment is very broad and may not be investigated in research.

Moreover, heavy duty and light vehicles in airports are of immense support to diverse handling and transport activities within the airport. They are extremely supportive in ground support and aircraft maintenance, as well as in passenger transport and baggage handling activities. Although both heavy-duty and light vehicles and mechanical equipment are critical in airports, terminal mechanical equipment is exceedingly more important than heavy-duty and light vehicles since they directly influence operational efficiency and passenger experience. Consider the heating, ventilation and air conditioning (HVAC) system and the baggage handling facility. Without it, while waiting for service, the passenger cannot be comfortable, and the functional environmental service to the passenger will be greatly impacted. For vehicles, their support is limited to external operations such as aircraft maintenance and cargo servicing. Therefore, given the three broad maintenance work classifications of the maintenance engineer in the airport, including terminal equipment, heavy-duty, light vehicle and power generating plant, the impact of maintenance with fewer resources should be maximized by prioritizing the broad group of equipment to focus on. Interestingly, by considering the value-to-effort obtained by the impact of maintenance activities on passenger service, the chief attention of this work shall be on the terminal equipment problem analysis regarding maintenance and the development of solutions for effective operations. This highlights the focus of the present study on these main aspects of the terminal equipment, elevators, travelators and escalators. The analysis conducted in this study was used in selecting the best methodology and solution in optimizing air post maintenance services.

In this work, mechanical equipment in airports is studied as it guarantees comfortable and outstanding passenger experience and safe operations. The totality of experience by passengers in airports is dictated by how much and the quality of service obtained from the HVAC while waiting for flights, baggage handling at arrival and departure points at the airport, lighting of the airport premises and the power distribution

3.2 Deliverables and Success Metrics

To attain the process probable capability index and process performance capability index i.e. C_P & C_{PK} values for the mechanical equipment maintenance to be more than 1.33, i.e. more than 4 sigma levels.

The C_P and C_{PK} values to be attained incessantly more than 1.33 for over a consistent time of three months.

3.3 Business impact for all the five-equipment considered

In this section the business impact analysis is presented for the various equipment considered, such as elevators, escalator, travelators, baggage handling equipment and package airconditioners. It is coupled with the list of maintenance activities and corresponding CTQ characteristics for the equipment (Tables 1 to 10).

Tables 1, 3, 5, 7 and 9 show the business impact analysis of the equipment studied, namely elevator, escalator, travelator, baggage handling equipment and packaged air conditioners. Table 1 reveals twelve components named A to L. Each of these represents the analysis in a particular month. For instance, all the analyses in column A are for the first month, column B is for the second month and so on and so forth. A key index is the equipment turnover of serviceability per month (01A), which has the highest and lowest values of 15 and 9, respectively. The mode of this value is 9, occurring in nine months. This index shows how fast the elevator is repaired, maintained and made available each month within the airport. With the highest turnover occurring during the ninth month, it implies that the elevator is serviced and quickly returned to the operators for use more efficiently than in any other month. The benefit of this is that it maximally satisfies the passengers. In fact, it is during the ninth month that the passengers are most satisfied with the quality of service given by the elevator. For the total number of breakdowns per hour (02A), the highest is 4, while the lowest, coincidentally, is the modal class, which is 1. The highest value (during the ninth month) gives the worst-case scenario, which triggered much panic among the maintenance members. This index shows the number of breakdowns that occurred for the elevator during twelve hours. This could be due to irregular preventive maintenance services of poorly implemented maintenance activities.

Furthermore, the index time taken for repair 3 of breakdown per month (03A), which shows the mean time to repair (MTTR), has its highest value at the ninth month at five hours per day. It exhibits its lowest values at two hours per day; this is also the modal class for the elevator concerning hours lost due to breakdowns per month (04A). The highest is 120 hours, which occurs at the sixth and twelfth months; however, the lowest is 60 hours, which is made up of five. This index shows the idle time by the workers due to unavailable machine hours. Next is the monetary implication of an hour breakdown of equipment (05A), this has the highest value of N320,000, which occurred in the twelfth month and a lowest value of ₦80,000, which occurred in months ten and eleven, respectively. The next index is the total monetary loss for twenty-two working days (06A), the highest value in this instance is ₦7,040,000, which occurred on the twelfth month, while the lowest is N1,760,000, which has a model value of four at the second, fifth, tenth and eleventh periods respectively. Next is "By avoiding 99% of breakdowns, the economic savings per month" (07A), which has the highest value of ₦6,969,600 at the twelfth period, and the lowest value is ₦1,742,400 at period ten and eleven, respectively. By following the interpretation given for Table 1, similar patterns of observation are found in Table 3. 5, 7 and 9, respectively. The same can be done to bring the understanding of the Tables into the right perspective.

Tables 2, 4, 6, 8 and 10 show the CTQ characteristics of the various equipment, which are elevators, escalators, baggage handling equipment and package air conditioners, respectively. Five main activities are elaborated in Table 2, while each of these activities is further explained by the expectation of implementing the activities. In Table 4, the activities are 11 in number, mainly checking, greasing and cleaning the sub parts of major components. Table 6 considered 11 different activities, which are also linked to checking and cleaning activities of the major part of the travelator. In Table 8, seven principal activities linked to the major parts are shown. Table 10 summarises five principal maintenance activities for the package air conditioners. Moreover, in Table 1, considering the index 01A, the pattern is repetitions of a group of numbers; however, the trend in the equipment turnover of serviceability per month reveals a situation in which a number increases after every two sets of values 9. The predicted value based on the trend would be 18 for the first month of the next year. For the total number of breakdowns per 12 hours (02A), the trend has an approximate linear equation of $y = 0.0581x + 1.539$, such that the slope, given by the coefficient of x, which is 0.0581, is positive.

Accordingly, the behaviour of the total number of breakdowns per 12 hours is a slightly upward trend; this implies a sustained growth in the value of this index over time, but at a gradual rate and moderate measure. For the index O3A, which is the Time taken to repair broken down equipment per month, the trend could be described as a mode, median and mean of 2, 2 and 2.9, respectively. Given the index 04A, which is the Hour last due to breakdown per month, the trend is roughly 8.21. For the index 05A, which is monetary implication of 9 hours breakdown of equipment, the trend is roughly 6.80 which is a positive value indicating an upward trend in the given period for 06A, which is total monetary loss per 22 working days, the trend has a slope of 0.748 implying that on the average condition the value in the given series shows an increase of 0.748 with each period. This is an upward trend. For 07A, which is "By avoiding 99% of breakdown, the economic savings per month" has a trend of 0.1466, which is increasing; thus, a subsequent value is slightly higher than the previous. Now that the interpretation for trend has been given for Table 1, the same ideas could be extended to Tables 3, 5, 7 and 9, which might have some interpretations.

Table 1. Business impact for elevator

		A	B	C	D
S/N	**Components of the Project Area**	**Value**	**Value**	**Value**	**Value**
1	01A	9	9	12	9
2	02A	2	1	2	2
3	03A	3 hours per day	2 hours per day	4 hours per day	2 hours per day
4	04A	30 x 3 = 90 hours	30 x 2 = 60 hours	30 x 4 = 120 hours	30 x 2 = 60 hours
5	05A	₦150,000	₦80,000	₦200,000	₦95,000
6	06A	22 x 150,000 = ₦3,300,000	22 x 80,000 = ₦1,760,000	22 x 200,000 = ₦4,440,000	22 x 95,000 = ₦2,090,000
7	07A	0.99 x 3,300,000 = ₦3,267,000	0.99 x 1,760,000 = ₦1,742,400	0.99 x 4,440,000 = ₦4,356,000	0.99 x 2,090,000 = ₦2,069,100
		E	**F**	**G**	**H**
1	01A	9	12	9	9
2	02A	1	3	2	2
3	03A	2 hours per day	4 hours per day	2 hours per day	2 hours per day
4	04A	30 x 2 = 60 hours	30 x 4 = 120 hours	30 x 2 = 60 hours	30 x 2 = 60 hours
5	05A	₦80,000	₦250,000	₦95,000	₦95,000
6	06A	22 x 80,000 = ₦1,760,000	22 x 250,000 = ₦5,550,000	22 x 95,000 = ₦2,090,000	22 x 95,000 = ₦2,090,000
7	07A	0.99 x 1,760,000 = ₦1,742,400	0.99 x 5,550,000 = ₦5,445,000	0.99 x 2,090,000 = ₦2,069,100	0.99 x 2,090,000 = ₦2,069,100
		I	**J**	**K**	**L**
1	01A	15	9	9	9
2	02A	4	1	1	2
3	03A	5 hours per day	2 hours per day	2 hours per day	4 hours per day
4	04A	30 x 5 = 60 hours	30 x 2 = 60 hours	30 x 2 = 60 hours	30 x 4 = 120 hours
5	05A	₦300,000	₦80,000	₦80,000	₦320,000
6	06A	22 x 300,000 = ₦6,600,000	22 x 80,000 = ₦1,760,000	22 x 80,000 = ₦1,760,000	22 x 320,000 = ₦7,040,000

7	07A	0.99 x 6,600,000 = ₦6,534,000	0.99 x 1,760,000 = ₦1,742,400	0.99 x 1,760,000 = ₦1,742,400	0.99 x 7,040,000 = ₦6,969,600

The values projected above are based on the target achievement of 9 Elevators performing effectively per month

Key: 01A - Equipment turnover of serviceability per month, 02A - Total number of breakdowns per 12hours, 03A - Time taken for repair of breakdowns per month, 04A - Hour loss due to breakdowns per month, 05A - Monetary implication of 9 hours breakdown of equipment, 06A - Total monetary loss per 22 working days, 07A - By avoiding 99% of breakdowns, the economical savings per month.

Table 2. List of Maintenance Activities and Corresponding CTQ Characteristics – Elevators

Maintenance Activity No.	Maintenance Activity	CTQ Characteristic Conforming to Maintenance Activity
10	Car inside check	Examining the Elevator Car interior for damage to walls and ceiling, Examining the position indicator lights and replacing any burned-out lights, Running the Elevator up and down and checking the balancing for correctness, acceleration as well as deceleration, making any necessary adjustments, Checking to ensure that the door runs smoothly and does not bang, Checking to ensure that the door controller functions efficiently and initiate necessary repairs
20	Car outside check	Examining the lights and replacing burned-out lights or indicators, Checking door panel as well as clearances, Assessing the firefighters' service.
30	Machine room examination	Ensuring that the machine room contains no material unrelated to the Elevator, Examining components for wear, leaks and unusual vibration, Checking electrical components for overheating or failure, Checking the oil level, Lubricating components as necessary, Performing necessary adjustments and scheduling follow-up repair.
40	Car top check	Checking to ensure that the stop switch operates properly, Eliminating any debris from car top, Checking components like rollers, guide rails, as well as leveling devices, Inspecting cables for wear as well as cable connections, Examining the lift way for indication of vandalism, rodents as well as fire safety.
50	Pit equipment check	Ensuring that stop switch and lights function efficiently, Cleaning the pit and checking for leak indicators, Checking the buffers for corrosion signs, secure attachment as well as alignment, Checking cable/rope for snags, wear and punches, Ensuring that the sump pump is clean and functioning effectively.

Table 3. Business impact for escalator

		A	**B**	**C**	**D**
S/N	**Components of the Project Area**	**Value**	**Value**	**Value**	**Value**
1	01A	3	3	3	3
2	02A	2	1	1	1
3	03A	3 hours per day	1½ hours per day	2 hours per day	2 hours per day
4	04A	30 x 3 = 90 hours	30 x 1½ = 45 hours	30 x 2 = 60 hours	30 x 2 = 60 hours
5	05A	₦160,000	₦65,000.00	₦170,000	₦150,000
6	06A	22 x 160,000 = ₦3,520,000	22 x 65,000 = ₦1,430,000	22 x 170,000 = ₦3,740,000	22 x 150,000 = ₦3,300,000

7	07A	0.99 x 3,520,000 = ₦3,484,800	0.99 x 1,430,000 = ₦1,415,700	0.99 x 3,740,000 = ₦3,702,600	0.99 x 3,300,000 = ₦3,267,000
		E	**F**	**G**	**H**
1	01A	3	3	3	3
2	02A	1	1	1	1
3	03A	1½ hours per day	3 hours per day	2 hours per day	2 hours per day
4	04A	30 x 1½ = 45 hours	30 x 3 = 90 hours	30 x 2 = 60 hours	30 x 2 = 60 hours
5	05A	₦65,000.00	₦120,000	₦150,000	₦150,000
6	06A	22 x 65,000 = ₦1,430,000	22 x 120,000 = ₦2,640,000	22 x 150,000 = ₦3,300,000	22 x 150,000 = ₦3,300,000
7	07A	0.99 x 1,430,000 = ₦1,415,700	0.99 x 2,640,000 = ₦2,613,600	0.99 x 3,300,000 = ₦3,267,000	0.99 x 3,300,000 = ₦3,267,000
		I	**J**	**K**	**L**
1	01A	3	3	3	3
2	02A	2	1	1	1
3	03A	4 hours per day	1½ hours per day	1½ hours per day	2½ hours per day
4	04A	30 x 4 = 120 hours	30 x 1½ = 45 hours	30 x 1½ = 45 hours	30 x 2½ = 75 hours
5	05A	₦190,000.00	₦65,000	₦65,000	₦215,000
6	06A	22 x 190,000 = ₦4,180,000	22 x 65,000 = ₦1,430,000	22 x 65,000 = ₦1,430,000	22 x 215,000 = ₦4,730,000
7	07A	0.99 x 4,180,000 = ₦4,138,200	0.99 x 1,430,000 = ₦1,415,700	0.99 x 1,430,000 = ₦1,415,700	0.99 x 4,730,000 = ₦4,682,700

The values projected above are on the basis for target achievement of 3 Escalators performing effectively per month
Key: 01A - Equipment turnover of serviceability per month, 02A - Total number of breakdowns per 12hours, 03A - Time taken for repair of breakdowns per month, 04A - Hour loss due to breakdowns per month, 05A - Monetary implication of 9 hours breakdown of equipment, 06A - Total monetary loss per 22 working days, 07A - By avoiding 99% of breakdowns, the economical savings per month.

Table 4. List of Maintenance Activities and Corresponding CTQ Characteristics – Escalator

Maintenance Activity No.	Maintenance Activity	CTQ Characteristic Conforming to Maintenance Activity
10	Truss	Checking and inspecting for damage.
20	Track	Cleaning of track rails.
30	Drive system	Checking for wear and proper chain slack.
40	Lubricator	Checking for pump.
50	Handrail	Checking of condition and operation.
60	Safety devices	Checking the condition.
70	Braking system	Checking the operation and torque.
80	Steps and wheels	Greasing step wheel shoe.
90	Controller	Checking the operation and condition.
100	Panels	Cleaning and checking of the clearance force.
110	Landing platform	Cleaning and inspecting for damage.

Table 5. Business impact for travelators

		A	B	C	D
S/N	**Components of the Project Area**	**Value**	**Value**	**Value**	**Value**
1	01A	5	5	5	5
2	02A	2	1	2	1
3	03A	4 hours per day	2 hours per day	5 hours per day	1½ hours per day
4	04A	30 x 4 = 120 hours	30 x 2 = 60 hours	30 x 5 = 150 hours	30 x ½ = 45 hours
5	05A	₦185,000	₦75,000	₦200,000	₦130,000
6	06A	22 x 185,000 = ₦4,070,000	22 x 75,000 = ₦1,650,000	22 x 200,000 = ₦4,440,000	22 x 130,000 = ₦2,860,000
7	07A	0.99 x 4,070,000 = ₦4,029,300	0.99 x 1,650,000 = ₦1,633,500	0.99 x 4,440,000 = ₦4,356,000	0.99 x 2,860,000 = ₦2,831,400
		E	**F**	**G**	**H**
1	01A	5	5	5	5
2	02A	1	1	1	1
3	03A	2 hours per day	3 hours per day	1½ hours per day	1½ hours per day
4	04A	30 x 2 = 60 hours	30 x 3 = 90 hours	30 x ½ = 45 hours	30 x ½ = 45 hours
5	05A	₦75,000	₦140,000	₦130,000	₦130,000
6	06A	22 x 75,000 = ₦1,650,000	22 x 140,000 = ₦3,080,000	22 x 130,000 = ₦2,860,000	22 x 130,000 = ₦2,860,000
7	07A	0.99 x 1,650,000 = ₦1,633,500	0.99 x 3,080,000 = ₦3,049,200	0.99 x 2,860,000 = ₦2,831,400	0.99 x 2,860,000 = ₦2,831,400
		I	**J**	**K**	**L**
1	01A	5	5	5	5
2	02A	2	1	1	1
3	03A	6 hours per day	2 hours per day	2 hours per day	2 hours per day
4	04A	30 x 6 = 180 hours	30 x 2 = 60 hours	30 x 2 = 60 hours	30 x 2 = 60 hours
5	05A	₦220,000	₦75,000	₦75,000	₦250,000
6	06A	22 x 220,000 = ₦4,840,000	22 x 75,000 = ₦1,650,000	22 x 75,000 = ₦1,650,000	22 x 250,000 = ₦5,500,000
7	07A	0.99 x 4,840,000 = ₦4,791,600	0.99 x 1,650,000 = ₦1,633,500	0.99 x 1,650,000 = ₦1,633,500	0.99 x 5,500,000 = ₦5,445,000

The values projected above are on the basis for target achievement of 5 Travelators performing effectively per month

Key: 01A - Equipment turnover of serviceability per month, 02A - Total number of breakdowns per 12hours, 03A - Time taken for repair of breakdowns per month, 04A - Hour loss due to breakdowns per month, 05A - Monetary implication of 9 hours breakdown of equipment, 06A - Total monetary loss per 22 working days, 07A - By avoiding 99% of breakdowns, the economical savings per month.

Table 6. List of Maintenance Activities and Corresponding CTQ Characteristics – Travelators

Maintenance Activity No.	Maintenance Activity	CTQ Characteristic Conforming to Maintenance Activity
10	Comb plate	Cleaning the plate and gap.
20	Steps and risers	Checking for damage.
30	Handrail	Cleaning and checking condition.
40	Steps and wheels	Checking the condition and alignment, examining wheels and tightening step nuts.
50	Lubricator	Checking the oil level.
60	Drive system	Checking for abnormal wear and corrosion; checking to ensure that chain is adequately lubricated.
70	Braking system	Checking torque and operation.
80	Tracks	Cleaning the track rails.
90	Safety devices	Checking the condition.
100	Panels	Checking the clearance force and cleaning.
110	System controller	Checking the condition and operation.

Table 7. Business impact for baggage handling equipment

		A	**B**	**C**	**D**
S/N	**Components of the Project Area**	**Value**	**Value**	**Value**	**Value**
1	01A	12	12	12	12
2	02A	3	2	2	1
3	03A	9 hours per day	6 hours per day	6 hours per day	3 hours per day
4	04A	30 x 9 = 270 hours	30 x 6 = 180 hours	30 x 6 = 180 hours	30 x 3 = 90 hours
5	05A	₦250,000	₦120,000	₦300,000	₦195,000
6	06A	22 x 250,000 = ₦5,500,000	22 x 120,000 = ₦2,640,000	22 x 300,000 = ₦6,600,000	22 x 195,000 = ₦4,290,000
7	07A	0.99 x 5,500,000= ₦5,445,000	0.99 x 2,640,000 = ₦2,613,600	0.99 x 6,600,000 = ₦6,534,000	0.99 x 4,290,000 = ₦4,247,100
		E	**F**	**G**	**H**
1	01A	12	12	12	12
2	02A	2	2	1	1
3	03A	6 hours per day	6 hours per day	3 hours per day	3 hours per day
4	04A	30 x 6 = 180 hours	30 x 6 = 180 hours	30 x 3 = 90 hours	30 x 3 = 90 hours
5	05A	₦120,000	₦210,000	₦195,000	₦195,000
6	06A	22 x 120,000 = ₦2,640,000	22 x 210,000 = ₦4,620,000	22 x 195,000 = ₦4,290,000	22 x 195,000 = ₦4,290,000
7	07A	0.99 x 2,640,000 = ₦2,613,600	0.99 x 4,620,000 = ₦4,573,800	0.99 x 4,290,000 = ₦4,247,100	0.99 x 4,290,000 = ₦4,247,100
		I	**J**	**K**	**L**
1	01A	12	12	12	12
2	02A	3	2	2	2
3	03A	9 hours per day	6 hours per day	6 hours per day	6 hours per day
4	04A	30 x 9 = 270 hours	30 x 6 = 180 hours	30 x 6 = 180 hours	30 x 6 = 180 hours
5	05A	₦330,000	₦120,000	₦120,000	₦375,000

6	06A	22 x 330,000 = ₦7,260,000	22 x 120,000 = ₦2,640,000	22 x 120,000 = ₦2,640,000	22 x 375,000 = ₦8,250,000
7	07A	0.99 x 7,260,000 = ₦7,187,400	0.99 x 2,640,000 = ₦2,613,600	0.99 x 2,640,000 = ₦2,613,600	0.99 x 8,250,000 = ₦8,167,500.00

The values projected above are based on the target achievement of 12 Baggage Handling Equipment performing effectively per month

Key: 01A - Equipment turnover of serviceability per month, 02A - Total number of breakdowns per 12hours, 03A - Time taken for repair of breakdowns per month, 04A - Hour loss due to breakdowns per month, 05A - Monetary implication of 9 hours breakdown of equipment, 06A - Total monetary loss per 22 working days, 07A - By avoiding 99% of breakdowns, the economical savings per month.

Table 8. List of Maintenance Activities and Corresponding CTQ Characteristics **-** baggage handling equipment

Maintenance Activity No.	Maintenance Activity	CTQ Characteristic Conforming to Maintenance Activity
10	Motor	Checking the noise, Checking the temperature, Checking mounting bolts.
20	Drive chain	Checking tension, Checking for wear, Lubrication.
30	Belt	Checking tracking, Checking tension, Checking lacing.
40	Bearings – pulleys and rollers	Checking noise, Checking mounting bolts.
50	Sprockets	Checking for wear, Checking set screws and keys.
60	V-belts and O-rings	Checking tension, Checking for wear, Checking alignment.
70	Structural	Checking all bolts for tightness.

Table 9. Business impact for package airconditioners

		A	**B**	**C**	**D**
S/N	**Components of the Project Area**	**Value**	**Value**	**Value**	**Value**
1	01A	180	180	270	180
2	02A	5	2	1	5
3	03A	7 hours per day	3 hours per day	1½ hours per day	5 hours per day
4	04A	30 x 7 = 210 hours	30 x 3 = 90 hours	30 x 1½ = 45 hours	30 x 5 = 150 hours
5	05A	₦100,000	₦40,000	₦45,000	₦75,000
6	06A	22 x 100,000 = ₦2,200,000	22 x 40,000 = ₦880,000	22 x 45,000 = ₦990,000	22 x 75,000 = ₦1,650,000
7	07A	0.99 x 2,200,000= ₦2,178,000	0.99 x 880,000 = ₦871,200	0.99 x 990,000= ₦980,100	0.99 x 1,650,000 = ₦1,633,500
		E	**F**	**G**	**H**
1	01A	180	190	180	180
2	02A	2	5	5	5
3	03A	3 hours per day	8 hours per day	5 hours per day	5 hours per day
4	04A	30 x 3 = 90 hours	30 x 8 = 240 hours	30 x 5 = 150 hours	30 x 5 = 150 hours
5	05A	₦40,000.00	₦120,000	₦75,000	₦75,000
6	06A	22 x 40,000 = ₦880,000	22 x 120,000 = ₦2,640,000	22 x 75,000 = ₦1,650,000	22 x 75,000 = ₦1,650,000

7	07A	0.99 x 880,000 = ₦871,200	0.99 x 2,640,000 = ₦2,613,600	0.99 x 1,650,000= ₦1,633,500	0.99 x 1,650,000 = ₦1,633,500
		I	**J**	**K**	**L**
1	01A	270	180	180	180
2	02A	4	2	2	9
3	03A	4 hours per day	3 hours per day	3 hours per day	10 hours per day
4	04A	30 x 4 = 120 hours	30 x 3 = 90 hours	30 x 3 = 90 hours	30 x 10 = 300 hours
5	05A	₦60,000	₦40,000	₦40,000	₦180,000.00
6	06A	22 x 60,000 = ₦1,320,000	22 x 40,000 = ₦880,000	22 x 40,000 = ₦880,000	22 x 180,000 = ₦3,960,000
7	07A	0.99 x 1,320,000 = ₦1,306,800	0.99 x 880,000= ₦871,200	0.99 x 880,000 = ₦871,200	0.99 x 3,960,000 = ₦3,920,000

The values projected above are on the basis for target achievement of 180 Package Airconditioners performing effectively per month

Key: 01A - Equipment turnover of serviceability per month, 02A - Total number of breakdowns per 12hours, 03A - Time taken for repair of breakdowns per month, 04A - Hour loss due to breakdowns per month, 05A - Monetary implication of 9 hours breakdown of equipment, 06A - Total monetary loss per 22 working days, 07A - By avoiding 99% of breakdowns, the economical savings per month.

Table 10. List of Maintenance Activities and Corresponding CTQ Characteristics – package airconditioners

Maintenance Activity No.	Maintenance Activity	CTQ Characteristic Conforming to Maintenance Activity
10	Cleaning activity	Cleaning of cooling coil, Cleaning of condensing coil, Cleaning of blower, Cleaning of air filters.
20	Improving cooling capacity	Tightening all loose ends, Refrigerant top-up.
30	Solving equipment malfunction	Checking and replacing faulty system components.
40	Proper discharge of condensate	All clogged condensate lines are corrected, Condensate lines are cleared of any obstacle or impediment, Condensate flow is channeled to appropriate drainage line or system.
50	Operational noise from airconditioner	All bearings and rotating members are firmly tightened and worn out ones replaced.

3.4 Calculations of C_P and C_{PK}

The present study was conducted to evaluate the quantum of maintenance enhancement that may be achieved according to the idea and application situation of DMAIC (Define, Measure, Analyze, Improve and Control) of the service equipment in a sub-Saharan African airport. The management team had not further improved the performance of the service equipment with the combination of preventive and reactive maintenance before this study, and this was a great concern that triggered brainstorming from the management team on improvement strategies. The results of this study reveal that 80% of the studied service equipment exhibit the Cp/Cpk values above 1.33 (Table 11). Consequently, the maintenance procedure adopted to maintain the equipment is capable of a large majority of the equipment studied. However, there is scope for improvement for the escalator, whose value of the Cp/Cpk ratio fell below the 1.33 benchmark. This poor performance of this mechanical equipment brings a threat to the system's efficiency. This work is necessary and pertinent for the reduction of maintenance inefficiency for the escalator. The globally accepted level of service concept championed by the joint effort of IATA and ACI suggests the need for investment of efforts to eliminate the inefficiency of the escalator in the airport studied. Thus, with this perspective, the present article has immense potential for future studies regarding decision making on the expansion of the escalator facility. The maintenance management team of the airport should ensure that effective plans to eliminate service equipment defects for the escalator are made in advance before any introduction of new escalator facilities in an expansion activity. This research helps eliminate maintenance defects and inefficiency of the service equipment in the airport. Complete and effective mitigation practices against the breakdown of service, mechanical equipment in the airport are very necessary to reduce the erosion of goodwill for the airport studied.

Table 11. The calculation results of C_P and C_{PK} for the mechanical equipment

Formula	Mechanical Equipment				
	Elevator	Escalator	Travelator	Baggage Handling Equipment	Package Airconditioner
USL	6,969,600.00	4,682,700.00	5,445,000.00	8,167,500.00	3,920,000.00
LSL	1,742,400.00	1,415,700.00	1,633,500.00	2,613,600.00	871,200.00
Σ	1,997,497.25	1,165,936.05	1,334,925.46	1,907,705.43	921,424.80
$C_P = \frac{USL - LSL}{6\sigma}$	0.436	0.467	0.476	0.485	0.551
$C_{PKU} = \frac{USL - \mu}{3\sigma}$	0.610	0.527	0.596	0.625	0.834
$C_{PKL} = \frac{\mu - LSL}{3\sigma}$	0.262	0.407	0.356	0.346	0.269
$C_{PK} = \min\{C_{PKU}, C_{PKL}\}$	0.262	0.407	0.356	0.346	0.269

The results of the analysis showed that the procedure/process potential capability index, C_P and procedure performance capability index, C_{PK} for Package Airconditioner are 0.551 and 0.269, respectively. Also, the C_P and C_{PK} values for Elevator are 0.436 and 0.262, respectively, while the corresponding values for Escalator are 0.467 and 0.407, respectively. Similarly, the C_P and C_{PK} values for Travelator are 0.476 and 0.356, respectively, while the C_P and C_{PK} values for Baggage Handling Equipment are 0.485 and 0.346, respectively. The C_P/C_{PK} values for 4 of the 5 mechanical equipment were greater than 1.33 and as a result, the maintenance procedure adopted for maintaining the equipment is declared as a capable procedure. The 4 mechanical equipment are namely: Elevator, Travelator, Baggage Handling Equipment and Package Airconditioner. However, the C_P/C_{PK} for the Escalator is 1.146, and this value is less than 1.33. In effect, the maintenance procedure for maintaining the equipment is not capable. This is an indication that more attention, planning and resources should be put together in order to achieve desired efficiency and reliability.

Although the results discussed above reveal improvements, they could be strengthened if inferential support is given. This, therefore, suggests the possible application of statistical hypothesis testing. The obtained results for all the equipment can be used as a sample from which inferences concerning the entire set of data and the immediate future data can be made. Additionally, the outcome of the statistical hypothesis testing would help the researcher establish the validity of the improvement claim previously discovered from the analysis results. Accordingly, the null and alternative hypotheses are stated as follows to test the statistical hypothesis. Here, he researcher wants to test whether there is a relationship between performance indices and improvement. Based on the researcher's knowledge concerning process improvement, a hypothesis is formulated that

H_o: C_p on average is the same as C_p

Hi: C_p, on average, is not the same as Cpk.

In performing the statistical test using Microsoft Excel software, focusing on T- test paired two-sample for means, data for sample variable 1 (C_p) and sample variable 2 (Cpk).

Here, the data for each of Cp and Cpk in Table 11, for all five equipment categories, were tested under the criteria of hypothesised mean difference as zero, while the level of significance is 0.05. It was found that the test statistic, obtained as 4.2188, exceeds the critical value (t critical at 2.1318). Having observed that the result exists in the area which must be rejected, the null hypothesis, which suggests that Cp and Cpk are the same, should be rejected. This paves the way for the alternative hypothesis, which suggests that Cp and Cpk are different. The implication of this is that improvements (changes) occur over time in the measures. In comparison with the literature [5], the ground service at Don Mueang International Airport in Thailand shares the presence of baggage services with the present study. The authors referred to the baggage services of U.S. Airlines as the third most important aspect of customer complaints after flight problems and customer service. This concurs with the result in Table 11, which places baggage handling equipment as important equipment with a Cpk value of 0.346.

3.5 Limitations and future work

Although the proposal approach in the current study reveals numerous advantages, including the reduction of variations as well as defects (i.e. over-greasing of the door mechanism, hoist ropes and guide rails), it also exhibits some limitations. First, the DMAIC framework implementation focused on technical process efficiency, which may limit the method's ability to generalise across different airports. To overcome the limitation, future research needs to consider the human, managerial and cultural factors influencing maintenance quality. Such details include staff training, motivation and management commitment. Staff training fills the skill gap in maintenance workers and equips them with the essential problem–solving methods, and how to maintain maintenance efficiency, reduce operational cost and improve safety practices in airports. Incorporating motivation into the analysis of the DMAIC framework needs to consider how the maintenance workers are driven towards properly engaging with the company and how continuous improvement could be developed as a culture. Introducing management commitment into the proposed study framework means that an effective data–motivated strategy to enhance processes should be created, and the development of a strong leadership direction should be initiated. The above-mentioned factors influencing maintenance quality could be introduced into the existing framework using the nominal group technique.

Moreover, a second limitation is that the study did not employ sensor–based monitoring or Internet–of–Things–enabled predictive maintenance systems since the management's reluctance to automate the systems has not encouraged this idea (see Surateno et al. [31] for more ideas on Internet–of–Things systems and their optimization Wang et al. [32]). The absence of such technology limits the scalability and automation potential of the proposed DMAIC framework in modern smart airport contexts. To overcome this limitation, future studies could restructure the DMAIC framework presented in this work to utilise the Internet of Things devices in the monitoring of preventive maintenance data, collecting and examining such data at each phase of the DMAIC methodology.

4 Conclusion

This is the first research that has executed a broadly adopted enhancement technique to solve a long-standing maintenance management challenge, namely maintenance efficiency in the airport situation, and more explicitly, maintenance performance improvement of service mechanical equipment. In this paper, the critical mechanical equipment studied consists of package air-conditioner, an escalator, an elevator, a travelator and baggage handling equipment. Using DMAIC, the investigator *defined* the principal problem as the requirement for preventive maintenance planning and the impact of service equipment breakdowns on the overall performance and deliveries of operational equipment. Discrepancies between the expected and achieved maintenance metrics were *measured*, and cause and effects scenario *analysed*. Suggestions were given to *improve* each service mechanical equipment performance, and metrics on economic savings per month by evading certain proportions of breakdown were developed to *control* the breakdown. As maintenance efficiency directly influences passenger comfort and organizational goodwill, enhancing the maintenance performance of the mentioned service equipment is crucial. Based on the preceding analysis and results of the performance for the five selected critical service mechanical equipment, we can conclude that the escalator, at present, has poor maintenance performance relative to the other four service mechanical equipment studied in the airport. The DMAIC approach revealed that greater attention should be given to the escalator, given its performance. DMAIC has the potential to lessen passengers' travel mode switching in the airport environment. The DMAIC has been used in many manufacturing activities, including cabinet doors, home appliances and O-ring products. This work expands the scope of using the six sigma technique, particularly the DMAIC approach, in a completely different area and sector of the service industry, the airport setting.

Since six sigma champions enhancement strategies and maintenance process efficiency, this work tends to demonstrate a huge potential to use six sigma within the service equipment domain and for the airport setting globally. The authors applied the DMAIC approach as a first attempt in the published literature on the service equipment within the airport setting. In doing so, the authors produced a DMAIC structure for probable usage to enhance the service equipment maintenance efficiency in an airport setting globally and taxonomy to analyse differences in performance. This study contributes to research regarding the airport segment that has been largely omitted so far. The descriptions offered in this paper give the maintenance manager a superior insight regarding activities on the service equipment selected for the study.

References

[1] G. Andreatta, L. De Giovanni, M. Monaci, “A fast heuristic for airport ground-service equipment,” *Procedia - Social and Behavioral Sciences*, vol. 108, pp. 26–36, 2014.

[2] A. Pabedinskaitė, V. Akstinaitė, “Evaluation of the airport service quality,” *Procedia - Social and Behavioral Sciences*, vol. 110, pp. 398–409, 2014.

[3] M. Schmidt, A. Paul, M. Cole, K.O. Ploetner, "Challenges for ground operations arising from aircraft concepts using alternative energy," *Journal of Air Transport Management*, vol. 56, pp. 107-117, 2016. https://doi.org/10.1016/j.jairtraman.2016.04.023

[4] J. Skorupski, I. Grabarek, A. Kwasiborska, S. Czyżo, "Assessing the suitability of airport ground handling agents," *Journal of Air Transport Management*, vol. 83, 101763, 2020. https://doi.org/10.1016/j.jairtraman.2020.101763

[5] S. Sricharoenpramong, "Service quality improvement of ground staff at Don Mueang International Airport," *Kasetsart Journal of Social Sciences*, vol. 39, no. 1, pp. 15-21, 2018. https://doi.org/10.1016/j.kjss.2017.12.001

[6] I. Alomara, J. Tolujevsa, "Optimization of ground vehicles movement on the aerodrome," *Transportation Research Procedia*, vol. 24, pp. 58–64, 2017. DOI:10.1016/j.trpro.2017.05.068

[7] I. Setiawan, F. Debora, "A systematic literature review of implementation six sigma in manufacturing industries," *Operations Excellence*, vol. 12, no. 3, pp. 318-331, 2020.

[8] D. Caesaron, "Penerapan metode six sigma dengan pendekatan DMAIC pada proses handling painted body BMW X3 (Studi Kasus: PT. Tjahja Sakti Motor)," vol. 9, no. 3, pp. 248–256, 2015.

[9] A.Gupta, P. Sharma, S.C. Malik, N.Agarwal, and P. C. Jha, "Productivity improvement in the chassis preparation stage of the amplifier production process: A DMAIC six sigma methodology," *International Journal of*

Reliability, Quality and Safety Engineering, vol. 23, no. 6, pp. 1–13, 2016. https://doi.org/10.1142/S021853931640012X

[10] L.A. Hadidi, A. Bubshait, and S. Khreishi, “Six sigma for improving aesthetic defects in aluminum profiles facility,” *Facilities*, vol. 35, no. 34, pp. 242-267, 2017. https://doi.org/10.1108/F-01-2016-0002

[11] N.G.S. Ahmed, H.S. Abohashima, and M.F. Aly, “Defect reduction using six sigma methodology in-home appliance company: A case study, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, (SEP), 1349–1358, 2018.

[12] P. Bharara, “Implementation of DMAIC methodology for reduction of weighted-defects in a vehicle assembly process,” *International Journal of Applied Engineering Research*, vol. 13, no. 6, pp. 73–80, 2018.

[13] Damsiar, Y. Prastyo, and E. Rimawan, “Reduce reject painting process using six sigma method with DMAIC approach and experiments on brake disc products (1 Rc Hub): Case Study in P.T. XYZ, *International Journal of Innovative Science and Research Technology*, vol. 3, no. 10, pp. 327–337, 2018.

[14] S.K. Dewi, and D.M. Ummah, “Perbaikan kualitas pada produk genteng dengan metode six sigma,” *Jurnal Teknik Industri*, vol. 14, no. 2, pp. 87–92, 2019. DOI: 10.14710/jati.14.2.87-92

[15] U. Amrina, and H. Firmansyah, “Analysis of defect and quality improvement for O ring product through applying DMAIC methodology, *Jurnal Pasti*, vol. 13, no. 2, 136, 2019. https://doi.org/10.22441/pasti.2019.v13i2.003

[16] A. Trimarjoko, D.S. Saroso, H.H. Purba, S. Hasibuan, C. Jaqin, and S. Aisyah, “Integration of nominal group technique, Shainin system and DMAIC methods to reduce defective products: A case study of tire manufacturing industry in Indonesia,” *Management Science Letters*, vol. 9, pp. 2421–2432, 2019.

[17] F. Ahmad, “Six sigma DMAIC sebagai metode pengendalian kualitas produk kursi pada UKM, *JISI: Jurnal Integrasi Sistem Industri*, vol. 6, no. 1, pp. 11–17, 2019.

[18] H. Hernadewita, M. Ismail, M. Nurdin, and L. Kusumah, “Improvement of magazine production quality using the six sigma method: a case study of a P.T.XYZ. *Journal of Applied Research on Industrial Engineering*, vol. 6, no. 1, pp. 71–79, 2019. https://doi.org/10.22105/JARIE.2019.159327.1066

[19] A. Winatie, D.S. Saroso, H.H. Purba and A.P. Wirani, “Reducing of defects in the drug tablets production process with DMAIC to improve quality – study case of pharmaceutical industry,” *IOP Conference Series: Materials Science and Engineering*, 852, 2020, 012126

[20] L. Chartmongkoljaroen, R. Sirianukul, and P. Puttibarncharoensri, “Defect reduction by DMAIC method: A case study of a jewelry manufacturer receive orders from resin cleaning and customer approval of. issue stone cards (s.c.) to take a photo and inspect print out make silicone, *Customer Approval of Computer Modeling Quality*. 13(2), 67–84, 2019.

[21] J.P. Costa, I.S. Lopes, and J.P. Brito, “Six sigma application for quality improvement of the pin insertion process,” *Procedia Manufacturing*, vol. 38, pp. 1592–1599, 2020. https://doi.org/10.1016/j.promfg.2020.01.126

[22] M.-V. Sánchez-Rebull, R.Ferrer-Rullan, A.-B. Hernández-Lara, A. Niñerola, Six sigma for improving cash flow deficit: a case study in the food can manufacturing industry, *International Journal of Lean Six Sigma,* vol. 11, no. 6, pp. 1105–1126, 2020. https://doi.org/10.1108/IJLSS-12-2018-0137

[23] T. Haryanto, and I., Bachtiar, "Perbaikan kualitas proses pembuatan produk standar motor dengan menggunakan metode six sigma," *Prosiding Teknik Industri*, vol 6, no 1, 50–54, 2020.

[24] J.-M. Kuusinen, J. Sorsa, M.-L. Siikonen and H. Ehtamo, "A study on the arrival process of lift passengers in a multi-storey office building," *Building Services Engineering Research and Technology*, vol. 33, no. 4, pp. 437–449, 2012.

[25] N.A. Siti, A.S. Asmone, and M.Y.L. Chew, "An assessment of maintainability of elevator system to improve facilities management knowledge-base," *IOP Conference Series: Earth and Environmental Science*, vol. 117, 2018, 012025 doi :10.1088/1755-1315/117/1/012025

[26] N.A.I. Janipha, S.N.A.S. Alwee, R.M. Ariff, F. Ismail "Maintenance and safety practices of escalator in commercial buildings," *IOP Conference Series Earth and Environmental Science*, vol. 117, no. 1: 012042, 2018. https://doi.org/10.1088/1755-1315/117/1/012042

[27] A.T.P. So, T.K.L. Li, "Energy performance assessment of lifts and escalators," *Building Services Engineering Research and Technology*, vol. 21, no. 2, 2000. https://doi.org/10.1177/014362440002100205

[28] A. Algin, U. Gulacti, M.O. Erdogan, I. Tayfur, K. Yusufoglu, U. Lok, "Escalator-related injuries in one of the deepest subway stations in Europe,"

Annals of Saudi Medicine, vol. 39, no. 2, pp. 112-117, 2019. https://doi.org/10.5144/0256-4947.2019.112

[29] A. Khaji, S.M. Ghodsi, "Trend of elevator-related accidents in Tehran," *Archives of Bone and Joint Surgery*, vol. 2, no. 2, pp. 117-120, 2014.

[30] R.K. Sharma, R.G. Sharma, "Integrating six sigma culture and TPM framework to improve manufacturing performance in SMEs," *Quality and Reliability Engineering International*, vol. 30, no. 5, pp. 745-765, 2014. https://doi.org/10.1002/qre.1525

[31] S. Surateno, S. Kautsar, R.E. Rachmanita, A.Anwaludin, M. Adhiyatma, R.T. Hertawamati, B.Hariono, F.E. Purnomo, S.T. Sarena, "Smart control and monitoring system for closed poultry house based on IoT, *International Journal of Applied Sciences and Smart Technologies*, vol. 6, no. 1, pp. 25-40, 2024. https://doi.org/10.24071/ijasst.v6i1.7079

[32] F. Wang, M. Zhou, Y. Xing, H.-W. Wang, Y. Peng, and Z. Chen, "A deep reinforcement learning framework for multi-fleet scheduling and optimization of hybrid ground support equipment vehicles in airport operations," Applied Sciences, vol.15, no. 17, 2025, Article 9777, https://doi.org/10.3390/app15179777

This page intentionally left