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Assessment of the COPQ due to Poor Maintenance Practices in Saudi Industry

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Abstract — *In the approach to outstanding manufacturing, many organizations recognize a necessity for the use of appropriate maintenance of industrial plants, production facilities, and systems; machines and equipment are becoming more industrially advanced and, subsequently, more multifaceted and harder to control. As such, the significance of the maintenance function is larger than previously thought. This is due to its responsibility for performance efficiency, improving and maintaining availability, on-time deliveries, safety requirements, and general plant productivity. From this perspective, Saudi industries are increasingly recognizing the importance of the maintenance function. This paper aims to assess the cost of poor quality (COPQ) due to poor maintenance practices in regional industries. To achieve this purpose, a questionnaire was designed to investigate maintenance practices and COPQ. The questionnaire was delivered to a selected sample of Saudi industries and was sponsored by the Chamber of Commerce and Industry in Jeddah. Industries from all current sectors and ranges responded to the questionnaire. The collected data were tested and analyzed to reveal that nearly all the industrial firms in Saudi Arabia have maintenance departments, and most of them allocate budgets to these departments. All medium and giant firms operate preventive maintenance and corrective maintenance, whereas micro and small firms rely solely on corrective measures. In this study, the foremost problem was in identifying the COPQ as a result of maintenance problems. Where medium and giant firms spent more money on preventive and appraisal measures to avoid failure costs, most of the micro and small firms spent less on preventive and appraisal measures; thus, these smaller firms have a higher number of defective products to be scrapped or reworked. A conclusion to generally improve the maintenance practices to optimize the COPQ was arrived at.*

Keywords — *Appraisal maintenance, cost of poor quality (COPQ), preventive maintenance, Saudi industry.*

I. INTRODUCTION

Manufacturing and industrial sectors are the most significant sectors, particularly in a country where industrialization generates economic growth by exporting local products to foreign countries. Moreover, it helps to solve the unemployment dilemma by providing numerous positions for national candidates. Industrialization can also open a substantial pathway for the development of technology, particularly in Saudi Arabia, where there is considerable production of oil-based products that benefit most areas of manufacturing. Besides, industries in Saudi Arabia play a critical role in the country's economic future. Hence, the vision for 2030 concentrates on all manufacturing levels to increase reliance on local production and products, rather than just on oil products, minimizing the need and use of imported products. Thus, developing and improving this industry sector will improve the country's economic position.

Based on [1], maintenance is defined as ensuring that facilities, machine systems, components, and all other physical assets stay functional, as they are designed to. Previously, the focus on maintenance was limited to corrective measures and fixing existing problems to keep the system functional, whereas less effort was given to scheduled maintenance activities. However, over time, the mentality regarding maintenance practices has focused on planned and scheduled maintenance activities. Nowadays, rapidly evolving manufacturing technology, with new advanced technological processes, techniques, and procedures, requires an increased effort to ensure a firm's machines and equipment's availability and workability. Therefore, controlling, improving, and developing industrial maintenance practices will directly improve the industrialization sector. Moreover, [2] states that you can avoid all unplanned stoppages and poor-quality production due to maintenance-related causes by having effective maintenance practices. Thus, maintenance is not cost consuming—it can generate revenue.

In manufacturing, maintenance quality control is one of the most important aspects of the sustainability of manufacturers. Control and improving quality are key factors to reduce the variability in producing products, minimizing defect rates, minimizing waste, and reducing the cost of poor quality, using effective, high-quality maintenance procedures towards whole systems and components. As a result, this will lead to manufacturer success, growth, and boosted competitiveness [3]. This study aims to reveal the cost of poor quality caused by maintenance practices and problems in the industrialization sector and use these findings to generate recommendations to solve these issues.

II. LITERATURE REVIEW

A. MAINTENANCE PRACTICES

Many researchers subscribe to the notion of the effectiveness of maintenance practices, strategies for total quality management, general, and, more specifically, on the cost of poor quality.

Reference [2] assures that increasing and investing in automation processes minimizes production costs, as it reduces the need for workforce and increases production rates with high-quality standards. It is crucial to improve maintenance practices and strategies to ensure the availability and workability of all machines and equipment, as investments in automation and machinery are continuously increasing [4]. Based on [5], the objective of maintenance is "maximizing the availability and reliability of the assets and equipment to produce the desired quantity of products, with the required quality specifications, in a timely, cost-effective way following environmental and safety regulations" (p. 22). Poor maintenance practices will affect direct aspects, such as performance, quality, time, costs, productivity, resources, and many other indirect aspects, such as opportunity, reputation, customer satisfaction, and market share. Moreover, [6] illustrates direct and indirect costs related to maintenance practices, as shown in Figure 1. Based on [7], the cost of poor maintenance should be considered a loss of outputs.

Furthermore, downtime is not just a capacity loss, but it is also an opportunity loss [8]. For instance, American Grocery Products Inc. found that the costs of downtime and maintenance expenses reached $3.6 million per year. Simultaneously, the company made cuts of 30–35% to the downtime and maintenance expenses after implementing total productive maintenance [8]. Reference [9] states that organizations face problems in achieving performance targets, even after having the proper maintenance systems in place to fulfill these production objectives due to various problems in maintenance practices. Moreover, increasing maintenance activities will decrease production losses, while the maintenance cost will increase. Subsequently, management needs to optimize, find the trade-off point where maintenance costs and production losses are minimized, as shown in Figure 2 [6].

Based on [10], maintenance costs are categorized into direct and indirect costs. Direct costs are needed to cover maintenance practices, such as repair, overhaul, preventive maintenance, labor hours, and materials. On the other hand, indirect costs include opportunity loss, low production rate due to breakdowns, unavailability of standby systems to cover, poor quality outputs, deterioration of machinery, and machinery life-span.

Reference [11] categorizes maintenance costs as planned and unplanned costs. The total maintenance cost can be calculated as the summation of both planned and unplanned maintenance costs, as shown in Figure 3.

The planned cost function is linear, while the unplanned cost function is non-linear. The total maintenance costs' summation curve has a single bottom, which indicates the optimum number of preventive maintenance activities ($\boldsymbol{n_{opt}}$). This optimum point is linked to the minimum amount of total maintenance costs ($\boldsymbol{K_{I\,min}}$).

Many researchers stressed the significant impact of maintenance practices and strategies on all aspects that might cause catastrophic consequences for an organization's sustainability if it was not implemented correctly.

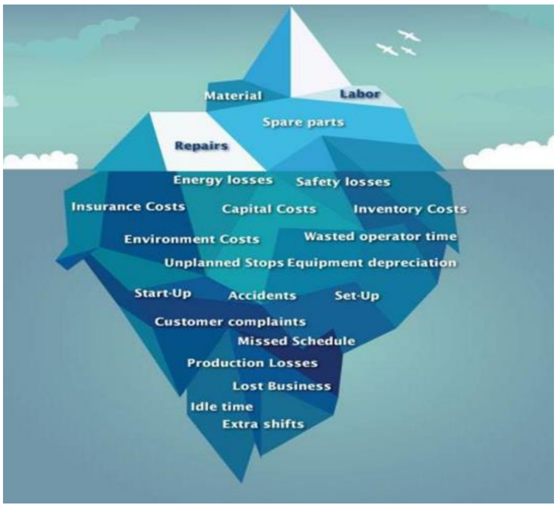

Figure 1. The direct and indirect costs in maintenance (Diana Barraza-Barraza et al. 2014)

B. Cost of Poor Quality

Continuous improvements are the driving factor towards, among others, sustainability and possessing competitive advantages. Thus, measuring the cost of quality (COQ) is one model that is often associated with an organization's profit [12]. While COQ is strongly related to improving performance, strategies, processes, operations, overall quality, profit, market shares, and many other aspects, [12] defines QOC as the total costs needed to assure the good quality and the costs associated with product defects.

Feigenbaum was the first to describe the COQ in a 1956 Harvard Business Review article. It was categorized into the following four categories: prevention costs, appraisal costs, internal failure costs, and external failure costs [13].

a) Prevention costs

This is the cost of all actions needed to prevent defects and nonconformities from occurring [14],[15]. The need for prevention costs relates to increasing the level of quality and minimizing the probability of negative impact on an organization's outputs [12]. An investment in prevention costs aims to do things right the first time [16]. Thus, only prevention costs can provide a return on investment by reducing the total cost of quality. Prevention costs include training programs, maintenance activities, quality improvements, and spare parts, to name a few.

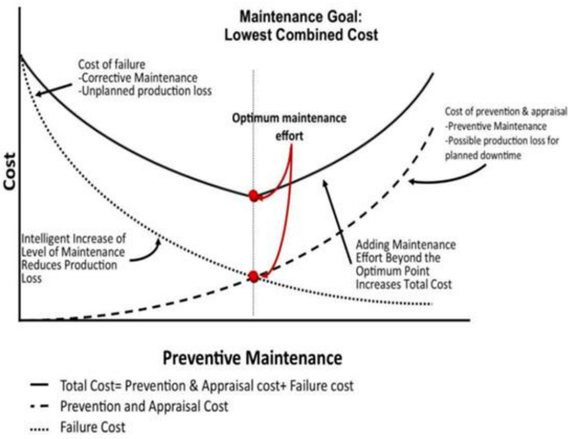

Figure 2. Maintenance costs trade-off (Foster & van Tran, 1990)

b) Appraisal costs

c) This is the cost associated with assessing quality levels and measuring or evaluating the quality requirements and standards [14], [15], [16], [17]. Appraisal costs aim to assess conformance to quality standards and meet customer expectations. For instance, appraisal costs include the costs of inspection processes, measuring, lab testing, and the costs of the equipment required.

Internal failure costs

This relates to all costs associated with any failure on a product before its delivery to the customer. These costs represent things that went wrong with the process [14], [15], [16], including internal failure costs, costs of reworked materials, re-inspection, retesting of the product, and scrapped material.

d) External failure costs

This is any cost associated with any failure that occurs on a product after delivery to the customer [15]. External failure costs include customer returns, warranty claims, processing customer complaints, and product recalls.

Reference [14] states that the share of internal and external failure costs forms around 65–70% of the total COQ and appraisal costs around 20–25%, while prevention cost does not exceed 5–10% of the total COQ.

Moreover, many researchers have stressed the benefits of having QOC systems in place. According to [18], QOC can provide numerical data, making it easier to demonstrate, by portraying results as numbers. Using COQ can also allocate the required budgeting for quality processes, to compare the assumed improvements, and to identify the level of effectiveness. Besides, COQ can identify the highest quality cost areas to be improved upon and reduce the costs associated with either the costs of good quality or the costs of poor quality.

In [19], three objectives for measuring the COQ are defined: Firstly, it helps to identify the size of the problem in a numerical way that will impress higher management; secondly, it helps to identify major improvement scopes to reduce the cost of poor quality; and, thirdly, it is a way for measuring the results of any quality improvements that have been made. Moreover, [20] found that the objectives for implementing the COQ model in the industry are as follows: (1) total quality improvements, (2) measuring progress and set targets, (3) improving the control level of quality, (4) continuously improve and set strategic plans, and (5) evaluating the effectiveness of the quality system.

Reference [21] introduces the Prevention, Assessment, and Failures (PAF) model, which clarifies the trade-off among prevention, appraisal costs, and failure costs, as shown in Figure 4. When the prevention costs increase, the failure costs are reduced.

After introducing the PAF model, some authors opposed the concept behind the model, as the exponential shape of the good quality costs is unrealistic, while also presuming that the manufacturer has poor quality performance, requiring high preventive and appraisal costs [22]. In response, [19] introduced a revised model (Figure 5), where the total COQ is minimized when the quality level reaches the maximum.

The PAF model is a COQ standard that allows for the implications of opportunity losses [23]. According to [24], the Chartered Institute of Management Accountants defines opportunity costs as the value of the benefits sacrificed for alternative action. Although they are not considered actual money, they are still considered economic value foregone due to undertaking another alternative [25].

The optimal segment in the COQ model is summarized in [26], as shown in Figure 6.

COQ optimization does not solely rely on optimizing a particular category; rather, there is a vital relationship among the categories. Therefore, this is extremely important when assessing the COQ to minimize this relationship and ensure that the overall COQ is not raised. It might have occurred while decreasing the cost of quality. Other costs not related to quality might increase disproportionately.

Many other researchers have introduced a variety of models to cover the variables of COQ and maintenance costs. In this context, [25] defines six different invisible quality costs: Material cost, machine cost, labor cost; setup cost; failure repairing cost, and ordering, receiving, and delivery costs. They also define two visible costs: Preventive maintenance cost and product sampling, inspection, and testing cost.

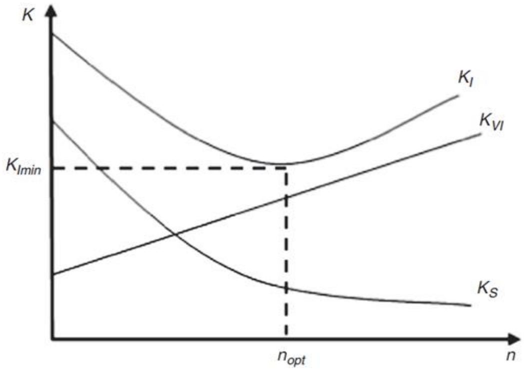

Figure 3. Describing the cost model (Hahn and Laßmann 1993)

Opportunity costs include idle cost, waiting for cost, and lost opportunity cost.

Chiadamrong's model is modified in [27]—they propose that the COQ can be calculated as:

$C_{COQ} = C_{PIQC} + C_{OC} + C_{VQC}$ (1)

Where:

C_{PIQC} is the production of invisible quality costs.

C_{OC} is the opportunity cost.

C_{VQC} is the visible quality cost.

While the production of invisible quality cost is calculated as:

$CPIQC = C_{mat} + C_{m/c} + C_{lc} + C_{m/h} + C_{fr}$ (2)

Where:

C_{mat} is the expected material cost.

$C_{m/c}$ is the expected machine cost.

Clc is the expected labor cost.

$C_{m/h}$ is the expected handling cost.

C_{fr} is the expected repair cost.

And The opportunity cost can be calculated as:

$C_{COQ} = C_{setup} + C_{idle} + C_{inv} + C_{wc} + C_{efc}$ (3)

Where:

C_{setup} is the expected setup cost.

C_{idle} is the expected idle cost.

C_{INV} is the expected inventory cost.

C_{wc} is the expected waiting cost.

C_{efc} is the expected external failure cost.

And the visible quality cost is calculated as:

$C_{VQC} = C_{prevention} + C_{appraisal} + C_{failure}$ (4)

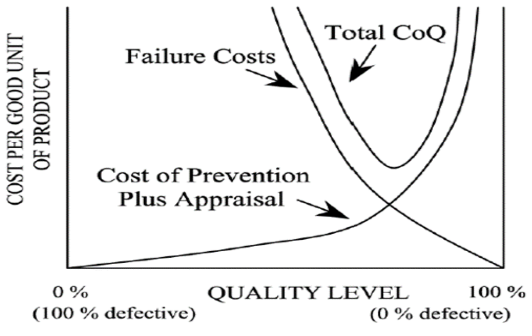

Figure 4. Juran's PAF Model

After reviewing the existing models, no integrated economic model is addressing the cost of quality and maintenance. However, some researchers focused on presenting models through which costs can be analyzed using the PAF categories and excluding opportunity cost.

On the other hand, following [25], [27] modified a model where the opportunity costs are present, and the prevention and appraisal costs are not considered.

In turn, [28] integrate COQ to the maintenance function by introducing a COQ model for maintenance; it is such that preventive and predictive maintenance are related to the prevention costs category, while inspection and testing represent the appraisal costs category. However, the failure cost category summarizes all components related to corrective maintenance [30], and the opportunity cost category is compounded into all PAF categories.

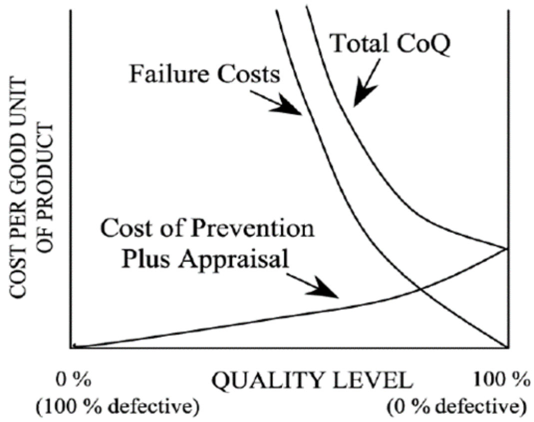

Figure 5. Juran's PAF Revised Model

The following equations present the proposed PAF model structure for maintenance:

$C_P = C_{DIRECT(P)} + C_{OPPORTUNITY(P)} + C_{INFANT\ MORTALITY(P)}$ (5)
$C_A = C_{Direct(A)} + C_{Opportunity(A)} + C_{Infant\ mortality(A)}$ (6)
$C_F = C_{Direct(F)} + C_{Opportunity(F)} + C_{Infant\ mortality(F)}$ (7)

Where:

C_P represents the prevention costs.

C_A represent the appraisal costs.

C_F represents failure costs.

C_{DIRECT} represents a direct cost associated.

$C_{OPPORTUNITY}$ is the opportunity cost incurred.

$C_{INFANT\ MORTALITY}$ represents the early failure cost after the disruptive intervention.

To describe each category, first of all, the prevention costs, which can be modeled by Equation 8, must be considered:

$C_P = C_m + C_{ml} + C_{wol} + C_{we} + C_{pne} + Ci_{nfF}$ (8)

Where:

C is the material cost.

C_{ml} is the maintenance labor cost.

C_{wol} is the wasted operator labor cost.

C_{we} is the wasted equipment cost.

C_{pne} represents the profit net earned.

C_{infF} represents the cost of infant mortality.

Along with the appraisal cost category, which can be modeled by Equation 9:

$$C_A = C_{ml} + C_{wol} + C_{we} + C_{pne} + Ci_{nfF} \quad (9)$$

And, finally, the failure cost category, which can be modeled by Equation 10:

$$C_F = C_{du} + C_{cd} + C_m + C_{ml} + C_{wol} + C_{we} + C_{pne} + C_{inf} \quad (10)$$

Where:
C_{du} is the cost due to defective units.
C_{cd} is the cost of any collateral damage.

III. METHODOLOGY

There are many types of data-gathering tools and methods, so it is crucial to determine the most suitable one to be used as a research methodology. Data can be collected through face-to-face interviews, questionnaires and surveys, documents and records, and direct observations. In this particular case, the aim is to gather data covering all the industrialization sectors in the region (or as many as possible) to obtain sufficient data to reflect the real picture of the population. After taking all constraints into accounts, such as confidentiality, time consumption, accessibility, policies, and regulations, a questionnaire was selected as the most efficient collection tool for this study. This research methodology can be divided into four parts: Questionnaire design, conducting the questionnaire, responses and analysis, and test and results.

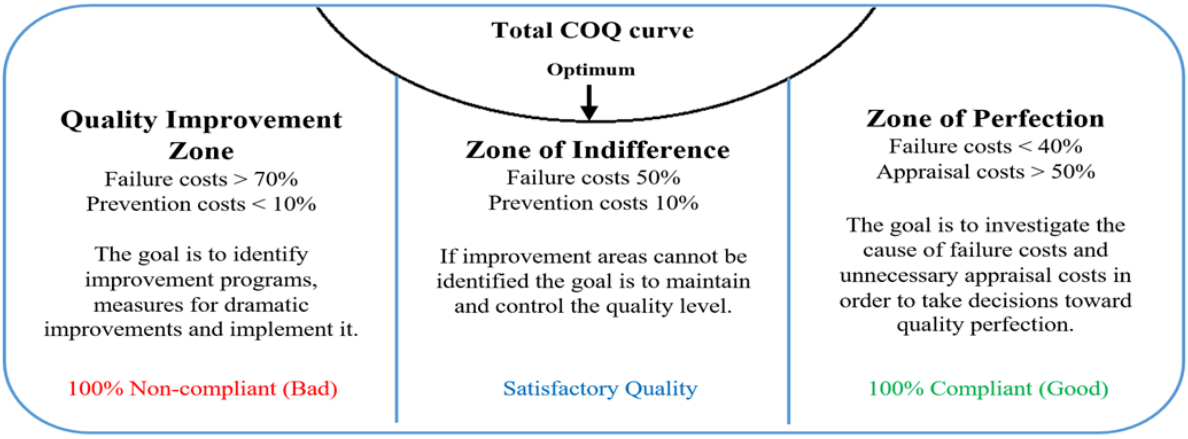

Figure 6. Cost of quality segments model adapted from (Kondic et al., 2016)

A. Questionnaire design

Before designing a questionnaire, it is important to know the research goal to use the most efficient and effective questions to achieve the desired results. This research aims to assess the cost of poor quality due to poor maintenance practices in the industrialization sector of Saudi Arabia.

The process of designing a questionnaire must carefully consider all statistical requirements. To ensure the questionnaire design's effectiveness, a review of related literature [20], [29] was conducted and considered. Also, steps were taken to assess and improve the questionnaire during the design process. The questionnaire was divided into three main sections:

The first section covered general information about the providers and classified them by sector, capital, and size.

Classification by sector is based on the Chamber of Commerce and Industry in Jeddah. The industrial sector is classified into 16 categories: Food or beverages, clothes and textiles, medical or pharmaceutical, leather, plastics and rubber, furniture, packaging, construction, chemical, glass, paper, electricity, metal, engineering, agricultural, and other activities.

Classification by capital is based on [29], where capital is classified by five categories: Less than 0.25 million SR, 0.25–1 million SR, 1–5 million SR, 5–15 million SR, and more than 15 million SR.

Classification by size is based on [29], where size is classified by five categories, according to the number of employees: Micro (<50 employees), small (50–100 employees), medium (100–500 employees), large (500–1000 employees), and giant (>1000 employees).

The second covered the maintenance department, focusing on gathering detailed information, including a budget, the adopted maintenance type, maintenance schedule, machine records, breakdown history, maintenance tools and equipment, calibration process, technicians, and training programs.

The third section covered the cost of poor quality due to poor maintenance practices. Questions were divided according to the four types of quality costs: prevention, appraisal, internal failure, and external failure costs.

Three types of questions were used in the questionnaire: Limited choice or closed (yes or no) questions, questions providing respondents with ranges to choose from, and multiple-choice questions. The questionnaire was reviewed at least once after completing the final draft to ensure that it fulfilled the study requirements while ensuring that the questions were brief, easy to understand, and relevant.

B. Conducting questionnaire

It isn't easy to conduct a questionnaire covering the whole industrialization sector in a country such as Saudi. To ensure a suitable number of respondents to satisfy the study needs, the questionnaire was sponsored and issued by the Chamber of Commerce and Industry, Jeddah, and aimed to cover all of the Mecca regions.

C. Responses and discussion

The questionnaire was sent to industries in the Mecca region and endeavored to target any firm significantly contributing towards the country's economy. There are 1,440 industries in the Mecca region, 20% of which are medium to giant industries, and formed the target segment, representing around 288 firms. The remaining 80% are micro-businesses or small workshops. From the medium to the giant category, 37 responses were received, giving a response rate of around 13%. This response rate was below expectation; however, the received responses would provide an adequate representation of the sector.

D. Questionnaire Responses

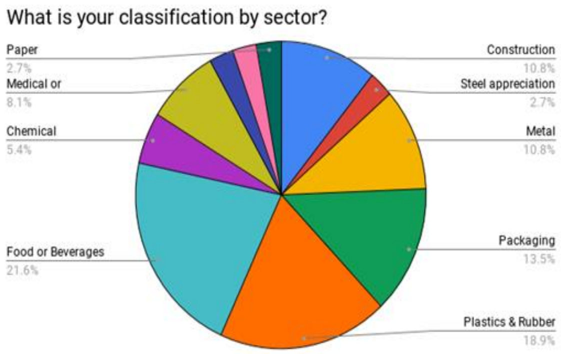

Figure 7. Distribution of the Classification by Sector

From the responses provided, around 89% of firms have a maintenance department. Around 92% of them allocate budgeting for maintenance; however, only 5.4% of these have a maintenance budget of over 10% of the operating cost.

Around 16% of firms depend only on corrective measures, and these firms were mostly from the micro or medium category. On the other hand, large to giant firms mostly adopted preventive and predictive maintenance measures, alongside corrective maintenance.

All medium to giant firms maintain records of machine breakdowns, and the ratio of breakdown to planned maintenance works were almost all less than 10%.

Surprisingly, half of the firms had at least one machine that failed and could not be repaired. Most firms stated that their technicians do not have any problems understanding instructions in machine catalogs or manuals, and they provide their technicians with the required training programs. The first three questions assessed the preventive costs, where the cost of training programs on maintenance activities mostly amounted to less than 5% of the capital. Also, 76% of firms had costs of less than 5% of the capital associated with the cost incurred by all maintenance activities, such as planning, procedures, and documentation costs. The third question resulted in answers giving the highest costs, as it was associated with maintenance equipment and tools. Around 60% of firms spent 5–10% of their capital on equipment and tools, and around 11% spent 10–15% of their capital on them.

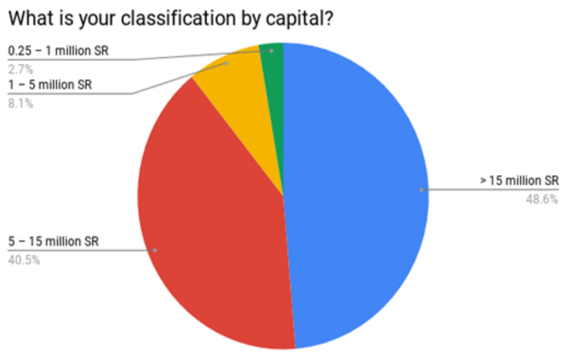

Figure 8. Distribution of the Classification by Capital

The next three questions assessed appraisal costs—the cost spent to perform inspections and audits on maintenance activities. Of the 37 responses received, 70% of firms spent less than 5% of their capital on this, the remaining 30% of firms spent 5–10%. Moreover, the highest category of spending measured equipment and tools, were more than 75% of firms spent 5–10% of their capital. The cost of internal testing associated with maintenance activities was less than 5% of the capital for more than 80% of the respondent firms.

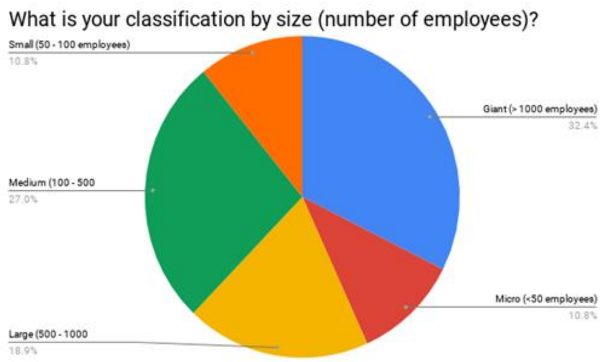

Figure 9. Distribution of the Classification by Size

Table I. Summary of responses related to the maintenance department.

Question	**Percentage**
Do you have a maintenance department?	
Yes	89.2%
No	10.8%
Do you allocate a budget for maintenance?	
Yes	91.9%
No	8.1%
How do you estimate the maintenance budget relative to total operating costs?	
< 5%	67.6%
5–10%	27.0%
> 10%	5.4%
What is the adopted maintenance type(s)?	
Corrective	16.2%
Corrective and preventive	35.1%
Corrective, preventive, and predictive	48.6%
Do you have periodic maintenance schedules?	
Yes	
No	86.5%
	13.5%
Do you have records of machine breakdowns?	
Yes	
No	89.2%
	10.8%
What is the ratio of breakdown to planned maintenance works?	
< 10%	86.5%
10–20%	8.1%
20–30%	2.7%
> 30%	2.7%
How do you describe the time needed for repair after a breakdown?	
Very short time	10.8%
Short time	54.1%
Moderate	27.0%
Long time	8.1%
Very long time	0.0%
Do you have appropriate equipment for maintenance?	
Yes	89.2%
No	10.8%
Do you have any machine that failed and could not be repaired?	
Yes	51.4%
No	48.6%
Do you calibrate your machines locally or abroad?	
Locally	
Abroad	43.2%
Locally and abroad	0.0%
Do not calibrate	48.6%
	8.1%
Do you have any problems in calibration locally?	
Yes	
No	13.0%
Do not calibrate	81.1%
	5.4%
Are there any problems facing technicians with understanding instructions in machine catalogs or manuals?	
Yes	5.4%
No	94.6%
Do you provide training programs for maintenance staff?	
Yes	91.9%
No	8.1%

The following two questions were associated with internal failure costs, addressing the costs resulting from defective units, retesting, rework, and scrap. For more than 50% of the respondent firms, this cost was 5–10% of the capital. For more than 24% of the businesses that responded to the questionnaire, these costs amounted to 10–20%, representing a relatively high percentage. The estimated cost of any collateral damage due to machine breakdown was split between less than 5% and 5–10% of the capital.

The last two questions were associated with external failure costs. The estimated cost to fix customer complaints due to poor maintenance practices amounted to less than 5%, and the estimated penalty cost paid, due to customer dissatisfaction, was also less than 5%.

Table II Summary of responses related to the cost of poor quality.

Question	Percentage
How do you estimate the cost of training programs on maintenance activities?	
< 5% of the capital	86.5%
5–10% of the capital	5.4%
10–15% of the capital	5.4%
15–20% of the capital	2.7%
>20% of the capital	0.0%
How do you estimate the cost incurred with all maintenance activities, such as planning, procedures, and documentation costs?	
< 5% of the capital	75.7%
5–10% of the capital	21.6%
10–15% of the capital	0.0%
15–20% of the capital	2.7%
>20% of the capital	0.0%
How do you estimate the cost invested in maintenance equipment and tools?	
< 5% of the capital	24.3%
5–10% of the capital	59.5%
10–15% of the capital	10.8%
15–20% of the capital	2.7%
>20% of the capital	2.7%
How do you estimate the cost spent to perform inspections and audits on maintenance activities? (includes all types of reviews and audits)	
< 5% of the capital	
5–10% of the capital	70.3%
10–15% of the capital	27.0%
15–20% of the capital	2.7%
>20% of the capital	0.0%
	0.0%
How do you estimate the cost invested in testing tools?	
< 5% of the capital	21.6%
5–10% of the capital	75.7%
10–15% of the capital	2.7%
15–20% of the capital	0.0%
>20% of the capital	0.0%
How do you estimate the cost of internal testing associated with maintenance activities? (includes people, environment costs)	
< 5% of the capital	
5–10% of the capital	81.1%
10–15% of the capital	13.5%
15–20% of the capital	5.4%
>20% of the capital	0.0%
	0.0%
How do you estimate the cost due to defective units, retesting, rework, and scrap? (include labors, equipment, machines, and materials costs)	

< 5% of the capital	
5–10% of the capital	24.3%
10–15% of the capital	51.4%
15–20% of the capital	16.2%
>20% of the capital	8.1%
	0.0%
How do you estimate the cost of any collateral damage due to machine breakdown?	
< 5% of the capital	
5–10% of the capital	45.9%
10–15% of the capital	45.9%
15–20% of the capital	5.4%
>20% of the capital	2.7%
	0.0%
How do you estimate the cost to fix customer complaints due to poor maintenance practices?	
< 5% of the capital	
5–10% of the capital	86.5%
10–15% of the capital	8.1%
15–20% of the capital	2.7%
>20% of the capital	2.7%
	0.0%
How do you estimate the penalty cost paid due to customer dissatisfaction?	
< 5% of the capital	83.8%
5–10% of the capital	8.1%
10–15% of the capital	5.4%
15–20% of the capital	2.7%
>20% of the capital	0.0%

IV. ANALYSIS

The analysis process was divided into two major parts to be studied: First, the maintenance department and, second, the cost of poor quality due to poor maintenance practices.

Tables 3 and 4 show that most firms have a designated maintenance department, budget for maintenance, periodic maintenance schedules, machine breakdown records, and appropriate maintenance equipment, except for some micro and small firms. Most medium, large, and giant firms depend on preventive and predictive maintenance, alongside corrective maintenance. Most micro and small firms, however, rely solely on corrective measures.

Tables 5 and 6 present the cost of poor quality, based on the firm's sector type and size.

As shown in Table 5, the sectors food or beverages, medical or pharmaceutical, and plastics and rubber are the highest-spending sectors in prevention and appraisal costs, with relatively high failure rates (except the medical sector, as there is no margin for error in this sector). All sectors have low rates in external failure, as this category is the most important one to be reduced as much as possible, due to its effect on customer loyalty,

Table III: Firms with a maintenance department, budget for maintenance, periodic maintenance schedules, machine breakdown records, and appropriate maintenance equipment.

Sector	Having a maintenance department	Budget for maintenance	Periodic maintenance schedules	Having Machine Breakdown records	Appropriate maintenance equipment
Food or Beverages	100%	100%	100%	100%	100%
Medical or Pharmaceutical	100%	100%	100%	100%	100%
Plastics & Rubber	100%	100%	100%	100%	100%
Packaging	100%	100%	100%	100%	100%
Construction	100%	100%	100%	100%	100%
Chemical	100%	100%	100%	100%	100%
Metal	75%	50%	25%	50%	50%
Other Sectors	50%	50%	50%	50%	50%

Table IIIIV: Discover the effect of sector type on maintenance practices

Sector	n	Preventive costs	Appraisal costs	Internal failure costs	External failure costs
Food or Beverages	8	15–30%	15–25%	10–25%	<10%
Medical or Pharmaceutical	3	30–45%	20–30%	<10%	<10%
Plastics & Rubber	7	15–30%	10–15%	15–25%	<10%
Packaging	5	10–25%	10–15%	10–25%	<10%
Construction	4	10–15%	10–15%	<10%	<10%
Chemical	2	10–15%	10–15%	<10%	<10%
Metal	4	10–15%	10–15%	10–15%	<10%
Other Sectors	4	10–15%	10–15%	10–15%	<10%

Table V. Discover the cost of poor quality based on sector type.

Size	n	Preventive costs	Appraisal costs	Internal failure costs	External failure costs
Micro	4	<15%	<15%	20–35%	<10%
Small	4	<15%	<15%	15–30%	<10%
Medium	10	15–25%	10–15%	15–25%	<10%
Large	7	30–40%	15–25%	10–15%	<10%
Giant	12	25–40%	15–25%	10–15%	<10%
Average		15–35%	10–25%	10–20%	<10%

Table VII. Discover the effect of firm size on the cost of poor quality.

Size	n	Preventive costs	Appraisal costs	Internal failure costs	External failure costs
Micro	4	<15%	<15%	20–35%	<10%
Small	4	<15%	<15%	15–30%	<10%
Medium	10	15–25%	10–15%	15–25%	<10%
Large	7	30–40%	15–5%	10–15%	<10%
Giant	12	25–40%	15–25%	10–15%	<10%
Average		15–35%	10–25%	10–20%	<10%

Reputation, market share, and other market opportunities. Table 6 shows that most medium, large, and giant firms depend on preventive and predictive maintenance, alongside corrective maintenance; thus, the preventive and appraisal costs will be relatively high. Among many micro and small firms, the failure rate is highest, as they rely solely on corrective actions.

V. Conclusion

There were 37 responses from a population of 20%, which means that the response rate was around 13%. This response rate was below expectations; however, 37 responses is an adequate representation of this sector. The more responses gathered by a questionnaire, the better the representation of the Problem being investigated.

Results maintenance practices should be exposed to significant improvement phases to optimize the cost of poor quality, where more than 16% of industries rely purely on corrective actions. Prevention costs and appraisal costs are a worthwhile investment to prevent failures; however, the problem occurs when businesses spend more than they ultimately save. The average cost of preventive and appraisal measures amounted to 25–60% of firms' capital, but the internal and external failure costs were between 10–30%. The margin of difference is unacceptable. As a result, corrective actions must be taken. Simultaneously, the internal failure costs must be minimized as much as possible, and the external failure costs category is generally the most critical for elimination.

VI. RECOMMENDATIONS

For future work, there is a plan to implement six sigma tools to improve the Saudi industry's overall maintenance practices to optimize and minimize the costs of poor quality as much as possible. To optimize the improvement process, each firm should receive an individual assessment to ascertain the required actions, based on its merits and constraints.

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