

Using Lean Principles in Maintenance Operations with Application to Water Treatment Plant

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Abstract:- Background: maintenance operations and management are so expensive, and costs too much money, Lean principles can serve maintenance sector and any sector like manufacturing and services, since it will reduce costs and efforts of workers. Lean principles first used in Toyota and then distributed in all over the world, it aims to minimize costs and eliminate all wastes in any operation or processes. Costs of water treatment plants maintenance operations are so high and contains a lot of wastes.

Objective: this paper aims to apply Lean principles in maintenance operations in all sectors and then apply them in a water treatment plant as a case study. Also the paper discussing the capability of applying Lean tools like 5S which can be applied on maintenance operation to measure Lean applicability. MTBF, MTTR, 5S audit scores, Availability and reliability are calculated here.

Methods: The methodology followed in this study depending of reviewing related studies and collecting some data from water filtration station maintenance department, then analyze them and deriving some conclusions to prove the presented claims. Availability and reliability are calculated for some given data from literature and collecting data from special water treatment plant in Kuwait.

Results: It is found that applying lean principles and tools like 5'S and others will enhance both availability and reliability of the maintenance system. Applying 5S audit scores shows the statues of the maintenance department and its availability and then reliability to be in good case. The costs and wastes of maintenance operations in like stations after applying lean are reduced.

Conclusion: Applying lean principles like 5'S tool on maintenance management system and maintenance operations will improve the maintenance quality, MTTR, MTBF, availability and reliability and 5S audit scores of the systems are improved and so number of failures and downtime of the maintained component will be decreased

Key-words: Lean, maintenance, water treatment, 5S audit, MTTR, MTBF, Reliability, Availability.

1. Introduction

Lean maintenance is a proactive maintenance activity utilizing arranged and booked maintenance exercises through all out profitable support (TPM) works on utilizing maintenance procedures created through utilization of unwavering quality focused support (RCM) choice rationale and rehearsed by enabled (self-coordinated) activity groups utilizing the 5S procedure, week after week Kaizen improvement occasions, and self-sufficient maintenance together with multi-talented, support expert performed support through the submitted utilization of their work request framework and their PC oversight maintenance framework (CMMS) or venture resource the board (EAM) framework. They are bolstered by a disseminated, lean support/MRO storeroom that gives parts and materials on a without a moment to spare (JIT) premise and sponsored by an maintenance and unwavering quality building bunch that performs underlying driver disappointment investigation (RCFA), bombed part examination, maintenance technique viability investigation, prescient support (PdM) investigation, and inclining and investigation of condition checking results. That is lean support basically, yet a fairly enormous nut (aside from a couple of subtleties that were discarded here however will be shrouded later in the article). How about we examine the highpoints of this definition to be certain everybody comprehends the terms utilized [1]:

- Proactive: This is something contrary to responsive where the maintenance activity responds to gear disappointments by performing fixes. In the proactive maintenance activity the avoidance of gear disappointments through execution of preventive and prescient support activities is the target. Fix isn't comparable to

maintenance.

- Planned and booked: Masterminded support incorporates the usage of recorded maintenance assignments that recognize task movement steps, work resource necessities, parts and materials essentials, time to perform, and concentrated references. Arranged maintenance is the prioritization of the work, issuance of a work demand, errand of available work resources, task of the time period to play out the endeavor (made with exercises/creation), and breakout and organizing of parts and materials.

- Total Predictive maintenance: TPM is the establishment of lean maintenance. It is an activity for enhancing the unwavering quality and adequacy of assembling gear. TPM is group based, proactive maintenance and includes each level and capacity in the association, from top administrators to the shop floor. TPM addresses the whole creation framework life cycle and assembles a strong, shop floor-based framework to forestall all misfortunes. TPM destinations incorporate the end everything being equal, imperfections, and breakdowns.
- Reliability Centered Maintenance (RCM): RCM is a procedure used to decide the maintenance necessities of physical resources in their present working setting. While TPM destinations center on keeping up gear dependability and adequacy, RCM focused on upgrading maintenance viability.
- Empowered (self-coordinated) activity groups: Activity group exercises are task-arranged and structured with a solid exhibition center. The group is sorted out to perform entire and incorporated undertakings, subsequently requiring multi-office enrollment. The group ought to have characterized self-governance (that is, power over its very own considerable lot authoritative capacities, for example, self-assessment and self-guideline—all with limits characterized). Moreover, individuals

ought to take part in the choice of new colleagues. Numerous aptitudes are esteemed. This urges individuals to adjust to arranged changes or event of unforeseen occasions [1, 2]. There are many lean principles and tolls like: 5S, Kaizen, CMMS and other lean tools which will discussed here.

- 5S process: There are five exercises for improving the work place condition: sort (expel pointless things), fix (compose), thoroughly clean (everything), institutionalize (standard everyday practice to sort, fix, and scour), and spread (extend the procedure to different zones).
- Kaizen improvement occasions. Kaizen is the way of thinking of nonstop improvement, which each procedure can and ought to be consistently assessed and improved regarding time required, assets utilized, resultant quality, and different perspectives pertinent to the procedure. These occasions are frequently alluded to as a Kaizen rush—a quick turnaround (multi week or less) utilization of Kaizen improvement instruments to acknowledge brisk outcomes.
- Autonomous maintenance. This alludes to routine support (e.g., hardware cleaning, grease, and so on.) performed by the creation line administrator. The maintenance supervisor and creation administrator should concede to and set up strategy for where in the creation forms self-sufficient support will be performed, what level and sorts of maintenance the administrators will perform, and how the work procedure for self-sufficient support will stream. Explicit preparing in the presentation of assigned maintenance duties must be given to the administrators preceding doling out them self-governing support obligations.
- Multi-gifted, support professional. Multi-talented maintenance experts are getting progressively significant in present day fabricating plants utilizing PLCs, PC-based

hardware and procedure control, mechanized testing, remote procedure checking and control, and comparative current creation frameworks. Support specialists who can test and work these frameworks just as make mechanical and electrical alterations, alignments, and parts swap forestall the requirement for numerous specialties in numerous maintenance errands. The plant procedures ought to decide the requirement for and favorable circumstances of incorporating numerous abilities preparing in the general preparing plan.

- Work request framework. This framework is utilized to design, appoint, and plan all maintenance work and to secure gear execution and dependability information for advancement of hardware accounts. The work request is the foundation of a proactive maintenance association's work execution, data information, and input from the CMMS. All work must be caught on a work request—8 hours hands on approaches 8 hours on work orders. The sorts of work requests will incorporate classifications, for example, arranged/planned, restorative, crisis, and so on. The work request will be the essential instrument for overseeing work assets and estimating office viability.
- Computer managed maintenance system. The data (support) the board programming framework performs, as a base, work request the executives, arranging capacity, booking capacity, gear history amassing, spending plan/cost work, work asset the executives, saves the executives, and a reports work that uses key execution pointers (KPI). To be viable, the CMMS must be completely actualized with complete and exact hardware information, parts and materials information, and maintenance plans and strategies.
- Enterprise resource the executives. The EAM framework plays out similar capacities that the CMMS does however on a more association wide, coordinated premise,

fusing all destinations and resources of an enterprise. Significantly more extensive venture frameworks fuse completely incorporated modules for all the significant procedures in the whole association and offer the guarantee to adequately coordinate all the data streams in the association. • Distributed, lean maintenance/MRO storeroom. A few stores areas supplant the concentrated storeroom so as to put region explicit parts and materials closer to their place of utilization. Lean stores utilize institutionalized materials for basic application use. The lean stores activity additionally utilizes arranging and determining strategies to settle the buying and storeroom the executives procedure. This strategy necessitates that a drawn out gear plan is created and hardware bills of material (BOM) are gone into the CMMS when the buy request for new hardware is given. • Parts and materials on an in the nick of time premise. Stores inventories are radically diminished (just like the expenses of conveying huge inventories) through a solid production network supervisory crew that utilizes JIT providers, and practices, for example, seller oversight inventories in which the merchant is given the obligation regarding keeping up great stock practices in renewal, in requesting, and in giving the materials. The seller is accused of the obligation of controlling expenses and stock levels, the sharing of data with the office, and making enhancements simultaneously. The inventory network supervisory crew advocates everyday provider correspondence and collaboration, free trade of business and specialized data, responsive win-win dynamic, and provider benefit sharing. • Maintenance and unwavering quality designing gathering. Since insights show that up to 70 percent of gear disappointments are self-prompted, a significant obligation of support designing includes disclosure of the reasons for all disappointments. Unwavering

quality building is a significant duty of a support designing gathering. Their duties right now incorporate assessing preventive maintenance activity adequacy, creating PdM strategies/methods, performing condition checking/hardware testing, and utilizing building procedures to broaden gear life, including determinations for new/reconstructed gear, exactness modify and establishment, fizzled part examination, main driver disappointment investigation, dependability designing, remake accreditation/confirmation, age investigation, and repeat control [1, 2].

2. Literature Review

LM term was instituted in the most recent decade of the twentieth century. Smith (2004) characterizes LM as a proactive maintenance activity utilizing arranged and booked support exercises through TPM works on utilizing support systems created through use of unwavering quality focused maintenance (RCM) choice rationale and rehearsed by engaged (self-coordinated) activity groups. LM produces an alluring result by limiting utilization of information sources (Smith and Hawkins, 2004). LM speaks to receiving lean standards into the maintenance, fix, and upgrade (MRO) tasks. It could diminish unscheduled DT through streamlining maintenance bolster exercises and support overhead. The lean instruments are speaking to the lean standards for the execution procedure (Mostafa, Dumrak, and Soltan, 2013). To accomplish LM improvement viably, key lean apparatuses, for example, VSM, 5S, and visual administration should be utilized (Smith, 2004; Smith and Hawkins, 2004). A far reaching lean devices produced for maintenance exercises inside an association incorporate 5S, TPM, OEE, Kaizen, Poka-Yoke, process movement

mapping, Kanban, PC oversight support framework (CMMS), venture resource the board (EAM) framework, and Takt time (Davies and Greenough, 2010; Smith, 2004). Regardless of the advantages of LM referenced before, the audit of past examinations led right now that the examination on the pertinence of lean standards into maintenance is peripheral. The current research works have been to a great extent restricted to the assembling condition where LM is rehearsed as an essential for lean assembling (Tendayi, 2013). This suggestion has been referenced in Davies and Greenough (2010) underlining on the need of directing more research on handy utilization of lean assembling standards in maintenance tasks. It was found that the past investigations for the most part centered around positioning the support methodologies dependent on some particular extension. Also, scarcely any activities have included exhaustive structures or models that can coordinate lean intuition in operational maintenance conditions outside of the assembling setting. Ghayebloo and Shahanaghi (2010) plan a model for deciding the insignificant degree of maintenance prerequisites and fulfilling unwavering quality level using the lean idea. Tendayi and Fourie (2013) utilize a consolidated methodology among QFD and AHP to assess the significance of support greatness criteria and organize the lean apparatuses upon these criteria [3].

One of the ways that are employed in years to enhance maintenance functions is Lean Maintenance. In each improvement project, it's necessary to outline and apply a procedure to guide to higher operational results. Lean Maintenance isn't Associate in nursing exception. Therefore, they developed a procedure that covers all the phases required to implement the lean

thinking in maintenance operations in an exceedingly thermoelectrical power [18]. Ayeni (2015) tried to gift however competitive advantage will be achieved through flourishing Lean realization in aviation maintenance operations. it absolutely was found that the aviation Maintenance and Repair Operations (MRO) worth Delivery System (VDS) is additionally diagrammatical providing the whole system at intervals that Lean is to be deployed (as hostile the current restricted application of Lean in operational context alone)..

3. Methodology

3.1 Lean Maintenance Tools and Its Effectiveness

The Maintenance work needs to actualize plans to incorporate and develop its strategies to satisfy the new needs set on it by Lean Manufacturing. A far reaching lean instruments created for maintenance exercises inside an association incorporate VSM, 5S, by and large gear viability (OEE), Kaizen, work institutionalization TPM, SMED, PC support oversight framework (CMMS). The previously mentioned lean maintenance instruments are utilized in ventures speaking to various businesses, aftereffects of level execution are assessed with measurements and markers of budgetary and non-money related character. Lean philosophy aim to decrease the costs of operations. The cost of maintenance activities could be ranged from 15% to 70% of the total production costs [16]. The cost is considered as the second largest after energy costs of the operational budget [17].

3.2 -Worth Stream Mapping - VSM

Worth stream mapping has supporting strategies that are frequently utilized in Lean environments to examine and configuration streams at the framework level (over different processes) [30]. Worth stream mapping dissects both material and data stream. By drawing the VSM, the professionals had the option to: envision and plainly observe the whole stream, recognize the loss in the worth stream, set up the linkage between the data stream and the material stream and see how the association will be later on, if all the improvement exercises are executed appropriately and if the distinguished squanders were disposed of or evacuated. In spite of the fact that worth stream mapping is frequently connected with assembling, it is additionally utilized in support. 5S practices are a part of lean support which makes space for institutionalized condition for work, with an attention on squander end and includes five stages. Effective utilization of 5S may give the accompanying focal points in support: work environments progressively proficient, sorted out, spotless, gainful and safe; improvement of working conditions; better perspective on the issues; decrease of costs, ineffective time, space and developments; and decrease of misfortunes related with disappointments and breaks [2].

4. -5'S Policy

In order to solve some portion of the weaknesses identified by the association's conclusion, for example, the absence of the executives of extra parts and supplies, the absence of adherence to the techniques in the stockroom and the sloppiness and request in some work zones, 5S was actualized in the offices referenced previously. Related to the mechanical designing zone, before starting the main period of the 5S execution, an

appraisal was made of the shop's present circumstance. At that point, the group talked about and recorded the exercises required to finish the usage and characterized a Gantt outline where dates, agents, dependable and rates of satisfaction were set up. Among the most significant strides in the execution of 5S in the shop we can make reference to: ID and grouping of manual devices disposing of the superfluous or unused ones, making of a 5S guide where the restriction of every manual apparatus in the shop is shown, migration of the current hardware as indicated by fix schedules, meaning of cleaning schedules where the fundamental capable is the relating administrator, and so forth. Likewise, the visual administration actualized permits to know the state in which the machines are. With this, both the administrator and the maintainer can know whether they are in conditions for their activity or on the off chance that they require any support activity. Through another circulation of hardware and workstations in the workshop, it was conceivable to characterize courses with complete wellbeing, all around characterized working areas, crisis exits and hence, the advancement of accessible space. The instance of the extra parts stockroom was very surprising from the one of the workshop. Sloppiness, poor dissemination of room and lost extra parts largely affect the support and viability of gear. The exertion that was made in the distribution center was a lot more noteworthy than in the workshop. For this case, new racks were joined so as to have the option to accomplish an ideal dissemination of the pre-owned space, ordering materials and extra parts by producing unit, recurrence of utilization, measurements, and different qualities. A great deal of material was disposed of, for example, effectively utilized extra parts, old parts and unusable basic

material. These were sold, creating about USD 20,000 in additional benefits that were utilized to back different pieces of the tasks. It was conceivable to confirm significant advances in cleaning, new dispersion of physical space, utilization of visual administration for data, acknowledgment of existing stock, foundation of new administration pointers and institutionalization of calculated systems inside the distribution center [15]. Applying or implementing 5’S on any industrial or service sectors like maintenance going through many phases shown in figure 1 below [21].

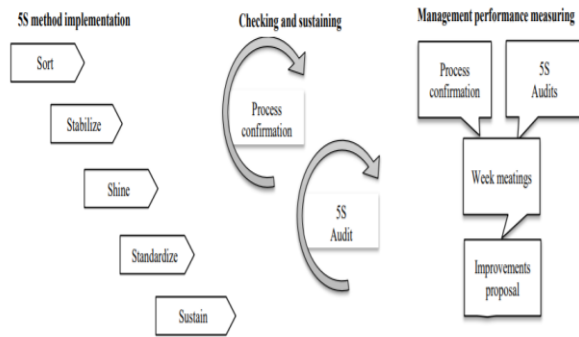


Figure 1 Implementing 5’S phases [21]

We need here to calculate what is called 5S score such that

$$5S\ score = \sum_{i=1}^{i=n} Xi \tag{1}$$

Where X: audit point grade mark (i.e. 1 for compliance and 0 for incompliance), and i: the 5S assessment points

Other parameters used to measure the effects of using lean tools such as 5’S tool in improving maintenance operations. Such of these measures are as following [20].

4.1.- Mean Time To Repair (MTTR)

The MTTR can be calculated by dividing the downtime period by the total number of downtimes:

$$MTTR = (\text{SUM of downtime periods} / \text{total number-of-repairs}) \tag{2}$$

4.2- Mean Time Between Failures (MTBF)

MTBF is calculated by divide the total operational time by the number of failures:

$$MTBF = (\text{SUM of operational time} / \text{total number of failures}) \tag{3}$$

-Availability of the module is the percentage of time when system is operational. Availability of a hardware/software module can be obtained by the formula given below.

$$AV. = (MTBF) / (MTBF + MTTR) \tag{4}$$

Availability is typically specified in nines notation. For example 3-nines availability corresponds to 99.9% availability. A 5-nines availability corresponds to 99.999% availability.

The failure rate λ can be given as:

$$\lambda = 1 / MTBF \tag{5}$$

-Reliability R(t) can be given as:

$$R(t) = e^{-(\lambda t)} \tag{6}$$

Where t: is the time in hours.

4.3-Data collected and calculations

Applying 5S in maintenance including the use of 5S audit score which depends on using a checklist of existing of components and scheduled steps of maintenance during the maintenance operations Table 1 below shows a segment of this checklist used usually in these calculations [22].

Table 1 5S audit checklist [22]

5S AUDIT CHECKLIST GARAGE						
Area: Components Isle		Date:				
Area Leader Signature:		Auditor:				
Verify that only required items are stored in the area?		Score	2/5		Comments	Person Responsible
1)	Are there location to store customer parts /materials /components?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
2)	Are there locations to store packaging materials/pallets/co ntainers/ temporary storage items in area.	Yes <input type="radio"/> No <input checked="" type="radio"/> NA <input type="radio"/>				
3)	Are there tools blocking aisle ways & exits?	Yes <input type="radio"/> No <input checked="" type="radio"/> NA <input type="radio"/>				
4)	Is there equipment blocking aisle ways and emergency exit?	Yes <input type="radio"/> No <input checked="" type="radio"/> NA <input type="radio"/>				
5)	Is the furniture in area required ?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
6)	Is the paper w ork/ prints/manuals required in area.	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
Are all items stored in the area, in a designated location & either labeled or marked?		Score	2/2		Comments	Person Responsible
7)	Are Customer parts/ Work in process /components/materials stored properly?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
8)	Are packaging materials/ containers/ boxes/ bins/ pallets stored in and organized?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
9)	Are all tools/tooling/ stored in an organized & safe manner?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
10)	Is equipment stored in an organized fashion?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
11)	Is furniture stored in organized fashion?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
12)	Is there locations for paperw ork/w ork orders/prints/ manuals?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
13)	Are w alkw ays clear and racks accessible?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
14)	Are all locations for tubing/fasteners/filters organized and accessible?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
Is there evidence that audit area and items in area, are maintained & is cleaning scheduled.		Score	3/4		Comments	Person Responsible
15)	Is there a cleaning schedule?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
16)	Are containers, boxes, bins, clean, functional and ready to use?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
17)	Are tools & tooling, clean, functional & ready to use?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
18)	Are prints/w ork orders/labels clean, clear and functional?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
19)	Are Work Surfaces and Tables clean, organized, maintained?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
20)	Are the floors clean, undamaged, and safe for use?	Yes <input type="radio"/> No <input type="radio"/> NA <input checked="" type="radio"/>				
21)	Are the w alls, partitions, railings, clean, painted and undamaged?	Yes <input checked="" type="radio"/> No <input type="radio"/> NA <input type="radio"/>				
22)	Is the cleaning equipment present, and are there cleaning stations?	Yes <input type="radio"/> No <input checked="" type="radio"/> NA <input type="radio"/>				
Summary of Score		7/11		=		%

In this case if the answer on the question is yes it is a score of available items else it will not be considered, as an example in the above table the scores of question 2 is 2/2 because yes are in two items of just two available questions.

5. Results and Discussion

Tables followed shows the results of applying 5S on maintenance of water treatment station taken as a case study.

The 5S score calculations is applied here in the availability of the spare parts in the store which are required for maintenance operations in the water treatment station. Table 1 shows the results of applying 5S on the store of spare parts and its score which gets 3/4.

Are all items stored in the area, in a designated location & either labeled or marked?	Score 3/4		Available /NA	
	Yes	No	Available	Not Available
Pump	X	-	X	-
Tank Sand filtering part	-	-	-	X
Filtered water pump part	-	X	X	-
Pump/osmosis high pressure part	-	-	-	X
Inverse osmosis filter part	X	-	X	-
Micro filters stand part	X	-	X	-

The following data were collected from literature review and experts in water treatment maintenance stations which

represented a components of water filtration station [15]-Table 2 represents the data collected.

Table 2 Data collected

Equipment	Before applying 5'S		After Applying 5'S	
	MTTR (h)	MTBF(h)	MTTR (h)	MTBF(h)
Pump	364	1314	354	1324
Tank Sand filtering	0	100000	0	100000
Filtered water pump	57	1179	55	1181
Pump/osmosis high pressure	19	1847	18	1848
Inverse osmosis filter	620	2856	603	2873
Micro filters stand	29	3446	28	3447

Table 3 shows the results of calculating reliability and availability of the last data for t=1000 hrs.

Table 3 the results of calculating reliability and availability of the last data for t=1000 hrs

Equipment	Before applying 5'S		After Applying 5'S	
	Availability	Reliability	Availability	Reliability
Pump	78.3%	0.467	%78.9	0.469
Tank Sand filtering	100%	0.990	100%	0.990

Filtered water pump	95.38%	0.428	95.55%	0.4288
Pump/osmosis high pressure	98.98%	0.5819	99.03%	0.5821
Inverse osmosis filter	82.16%	0.7045	82.65%	0.7061
Micro filters stand	99.165%	0.7481	99.194%	0.7482

It can be noticed that both availability and reliability are increasing after the use of the lean tool (5'S). It is clearer in some elements like pump, while in other elements it is small, this depends mainly on MTTR and MTBF values. Figure 2 shows the effects of applying 5'S on no the reliability and availability of the pump maintenance in last system.

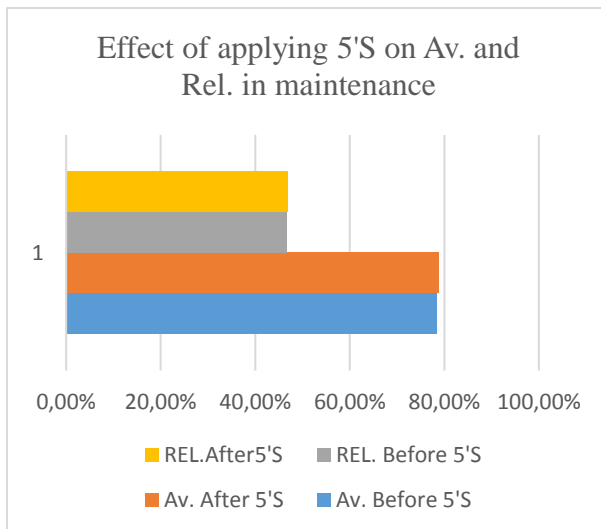


Figure 2 effects of applying 5'S on no the reliability and availability of the pump maintenance in last system.

Reliability, availability, MTTR, and MTBF are calculated for maintenance operations in some application of water filtration system before and after applying one of lean tools in maintenance operations, it seems that applying 5'S policy in maintenance operations improving the maintenance by decreasing MTTR, increasing MTBF, availability, and reliability of the system so, lean maintenance operations minimizes costs and time of such operations. Applying 5S on the case study of water treatment plant, the segment of results shows the scores of 5S audit which was about 3/4 which implies a good availability of spare parts in the maintenance stores. It is clear from last diagrams and figures that there is a progress in maintenance terms like (Reliability and Availability) by a good percentage (about 5-7%).

6. Conclusions

Applying lean principles on maintenance management system and maintenance operations will improve the maintenance quality, MTTR, MTBF, availability and reliability of the systems are improved and so number of failures and downtime of the

maintained component will be decreased. The lean principles improves the quality of maintenance operations applied in many sectors by reducing mean time to repair (MTTR) i.e. the downtime and increase the mean time between failures which means decreasing failure rate or number of failures occurred for many equipments. 5S score audit gives an abstract about the status of the equipment in the station and if it's of high values it will indicate that the status is good else it is bad. In the case study presented here it was 0.75 which means that the maintenance arrangement and state is good.

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