Improving Reliability of Test Fixture Tracking
Baker Hughes Group 1

Senior Design Project Report

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Executive Summary

Baker Hughes' Broken Arrow location builds safety valves for the oil industry. Each valve must undergo high pressure testing as part of the final inspection. In order to perform the pressure test, a combination of test fixtures must be affixed to the ends of the safety valve. There are roughly 5000 of these test fixtures in the warehouse so keeping track of them is challenging. A Senior Design Team from Oklahoma State University's School of Industrial Engineering and Management partnered with the Broken Arrow location to help make the process of test fixture tracking more visible.

According to the American Petroleum Institute, all test fixtures need to be inspected after a certain number of uses because they have to withstand up to 30,000 psi on a regular basis. The client is unable to reliably track usage which poses a great safety risk. The contributing factors identified include a lack of test fixture serialization and a failure to return fixtures to storage after each use. Storing fixtures after use is the lowest priority of the warehouse staff and as a result, fixtures may be used repeatedly with no indication.

Data gathering was conducted by the SDT through interviews with those involved in the process and historical inventories for the test fixtures as well as production and demand data from the past 14 months. Qualitative data allowed the root cause of the poor tracking to be analyzed, while the quantitative data allowed the SDT to determine what fixtures were being used the most– or not at all.

Following this analysis, the SDT provided recommendations on serialization of test fixtures, a strategy to track usage reliably, data analysis of information provided by Bill of Materials, and recommendations for improvements in warehouse storage that will allow for a more efficient and repeatable process . The SDT also used the data analysis to provide context to assist management in their goal of inventory reduction across the test fixtures in stock. In addition to these recommendations, the SDT created an Implementation Plan for each department so that each key player is well informed as to the next steps and how to make the recommended changes and maintain reliable tracking to get the full benefits from the process improvement.

The anticipated benefits include not only a nearly 25% reduction to current test fixture inventory, but also safety benefits, a warehouse that follows engineering principles of workplace organization, and a significantly easier and more visible way to track the usage statistics of the fixtures. This would be incurred at a roughly $2500 cost for printing of barcode travelers, two pallet jacks to be stored within the warehouse, and three Zebra DS2200 scanners (the same type already used in the plant).

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1.0 Introduction

The client for this project was the Broken Arrow plant of Baker Hughes. As an international organization, Baker Hughes has four primary operating segments: oilfield services, oilfield equipment, turbomachinery and process solutions, and digital solutions. Baker Hughes- Broken Arrow is a facility that employs over 300 people and assembles subsurface safety valves for oil wells. The estimated output is 800-1000 valves per fiscal year. The Senior Design Team (SDT) focused on process improvements at this Broken Arrow location.

1.1 Baker Hughes- Broken Arrow Background

Baker Hughes receives and creates components of subsurface safety valves from suppliers and raw material vendors. When a new order from a customer is requested, planners begin to create a Work Order in SAP. This requires checking that any components required of the assembly are in inventory. If not, the planner will create a new work order for the shop to fabricate those parts necessary. The Bill of Materials (BOM) details all required materials. One of the materials for each assembly is test fixtures. While these fixtures are not a permanent component of the assembly, they remain an integral part of the process. Upon completion of an assembly, the valves are taken to testing. There, the test fixtures are attached to the assembly and high pressure testing is performed to ensure quality before the valves are sent to the customer.

1.2 Problem Background

For approximately 15 years, the test fixtures have been stored in the warehouse. Previously, they were located at the testing area in assembly. Over time, the shear amount of various test fixtures became too much to be stored in testing. Now, test fixtures have a section within the warehouse. The warehouse also stores inbound component inventory and completed valve assemblies. There are two warehousemen who have the responsibility of inventory maintenance and distribution. Whether preparing components to be delivered to a certain point along the assembly line or- in the case of this particular project- locating and delivering test fixtures to the testing center, the warehousemen have a multitude of roles within the facility.

For the day to day operations of the facility to remain fluid, the warehousemen must take priority of certain tasks over others. One task that is usually performed as a backlog item is the return of test fixtures into warehouse inventory upon completion of a test. This concern was portrayed to the SDT during our preliminary site visit. Since there isn't an immediate delay in operations if a test fixture is not promptly returned to inventory, the warehousemen are able to focus on more pressing responsibilities. Over time, this created a large amount of test fixtures that were on temporary shelving just outside of the warehouse. This created two problems:

1. The usage of these fixtures wasn't properly tracked when they underwent multiple uses before being fully returned to inventory.
2. When unreturned fixtures were requested, their location in SAP was in "IN USE," rather than a true bin location within the warehouse.

1.3 Problem Statement

With SAP being the requested medium for solutions, the establishment of a problem statement required the SDT to focus on improvements to the use of this Enterprise Resource Planning (ERP) system. The problem statement naturally split into the following:

1. How to integrate a fixture tracking system into the current processes?
2. How to improve fixture tracking at the warehousing level?

1.4 Objective and Scope

As a result of feedback from audits by the American Petroleum Institute (API), Baker Hughes aimed to improve the usage and location tracking of test fixtures within their facility. The current process showed opportunities for improvement to further their goal of creating "proactive and preventative programs to deliver safe, secure, and sustainable operations."[1] At the beginning of the project, Baker Hughes was unable to effectively track usage and location of test fixtures within SAP. The objective for this project aimed to address the organizational and systematic problems addressed in the Problem Statement.

1. Provide an updated work flow process for all departments who interact with the test fixtures both physically and within SAP.
2. Implement common sense organization to the storage of test fixtures within the warehouse.

Successful delivery on the aforementioned objectives led to the following benefits:

- Increased quality and safety of the testing process.
- Transparency to test fixture inventory for all parties.
- Automated process of rework, scrap, and inspection for test fixtures.

The scope of this project was confined to the test fixtures used at the Broken Arrow plant. Other components of the assembly process were not within the scope and thus were not included in the final solution. The scope did include procedures that may affect other areas of the facility beyond just testing and warehousing. The Data and Information Gathering section expands upon the methodology which ensured that the effects for all key players were considered.

[1] Baker Hughes, 'Safety,' https://www.bakerhughes.com/company/corporate-responsibility/principles-new/safety.

2.0 Project Methodology

The methodology of the SDT's approach to this project can be divided into five main steps:

- Data Collection and Interviews
- Analysis of Data
- Investigation of Possible Solutions
- Creation of Project Solution Proposals
- Generation of Final Recommendations

These steps can be broken into many substeps and are shown in Figure 1, along with their respective anticipated durations and dates of completion.

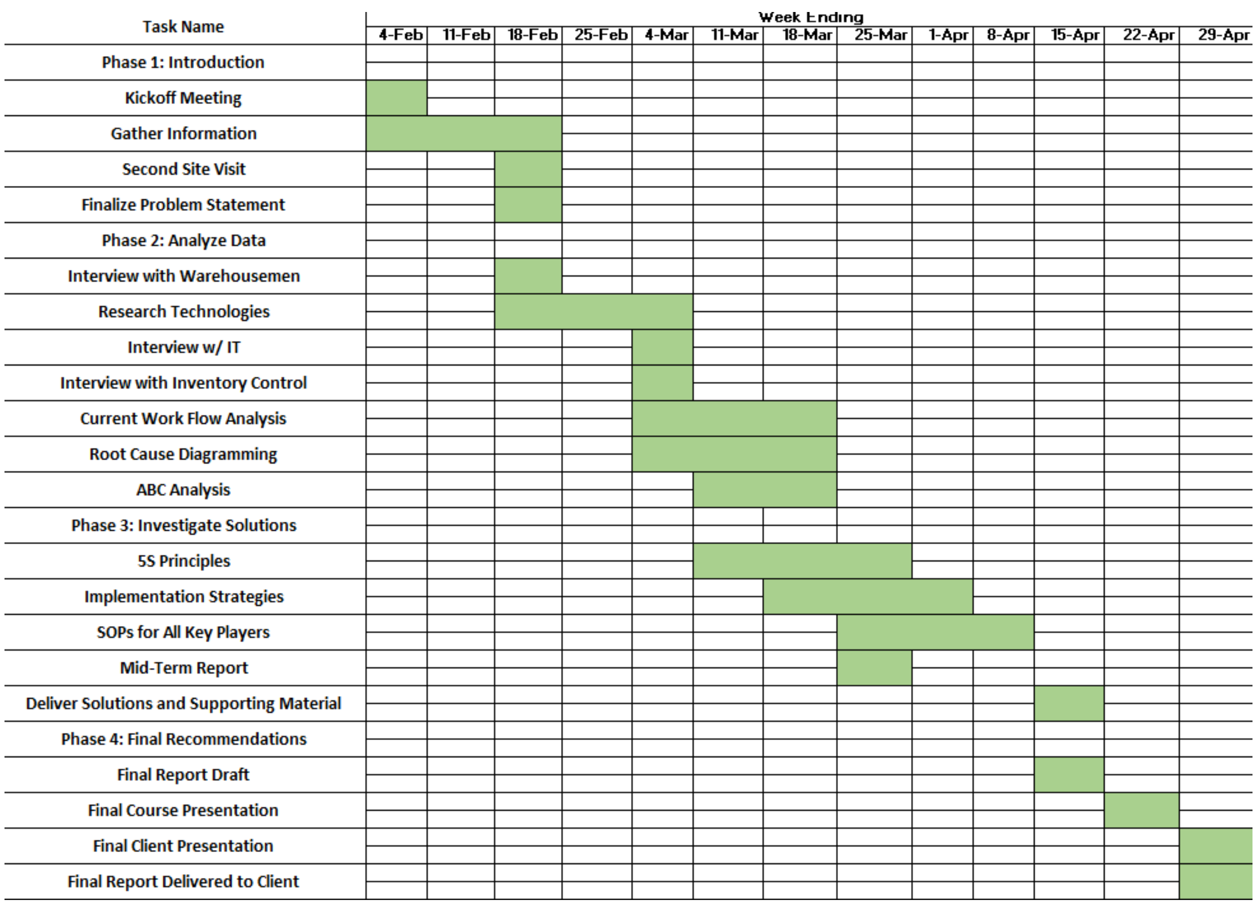

Figure 1: Anticipated Schedule of Work Progress

2.1 Data and Information Gathering

The project at hand is one that is intricate, involving qualitative and quantitative factors in the areas of plant capabilities, staffing constraints, human factors, technological difficulties, and more. Due to the broad, expansive nature of the project combined with the relative lack of data from the past, the SDT's approach has been formed by working with management closely to ensure that the entire problem is completely understood.

The SDT's approach to the problem heavily relies on the integration of technologies that are already present in the plant to the areas in which the test fixtures are stored. Because of this, the approach heavily relied on mainly the management of the standardization of one process across many departments. To do this, factors such as current practices from each department involved, management principles, and sorting and serialization would be utilized.

An essential aspect of the SDT's approach was discovering as much information as possible about the processes already in place and why they have not been adapted to utilize across the facility. Using this information, the processes would be adjusted in a way that would utilize small but significant changes to adapt them to different areas of the plant.

2.1.1 Quantitative Data Collection

Quantitative data collection in regards to previous fixture usage statistics is a complicated matter for a number of reasons. A couple of methods were discussed by the SDT for the purpose of gathering usage statistics for current inventories, but each had inherent limitations that would not provide ample information to attribute each fixture with a specific number of uses.

The team first discussed reviewing the LT24 (Display Order Transfer/Material) Screen for each fixture and attributing one use for each move from a storage location to an "IN USE" location. However, as the movement of a fixture from a storage location to "IN USE" is not always recorded between uses, each "IN USE" period could represent multiple uses. Additionally, fixtures are loaned to and borrowed from other locations often and as the same SAP is not used across all sites. Therefore, some offsite uses could not be accounted for and attributed to the proper fixtures.

The team then discussed instead the gathering of the Bills of Materials for the 2021 fiscal year and analyzing which fixtures were used the most on-site during this time. This data would be revealing of at least what types of fixtures were used most often and how serialization of these fixtures could be improved to lead to the process more carefully being followed. This data was provided to the team by Kenny Mott of Baker-Hughes in Broken Arrow and included the valves ordered in 2021 and the test fixtures required for each.

2.1.2 Qualitative Information Collection

With the problem being one of process quality, a significant portion of the information that could be gathered was qualitative in nature. The preferred method of qualitative information collection would be via interview with as many members of key departments as possible. Departments identified that had the largest stake in this process were testing, material handling and warehousing, and information technology.

The tracking process that the SDT sought to improve is one that is used on the valves themselves by other departments such as assembly and planning, but not by warehousing on the valves. Investigating the ways the process is used by these departments would constitute a great amount of the data collection, as would discussions with management and the warehouse workers about the feasibility of any proposed solutions.

2.2 Analysis of Data

With the process of tracking the test fixtures being ineffective in practice, a root cause analysis would be conducted to discover what factors have prevented the process from being effectively completed by the workers consistently and effectively prior to this project.

This root cause analysis would be divided into 5 different primary areas, and an Ishikawa diagram would be constructed to show factors contributing to this issue in a handful of areas:

- Human and personnel factors that describe accurately why the process is not currently being followed or developed by the workers at each opportunity.
- Management factors that contribute to the level of process implementation and support by both in-house and out-of-house management
- Material factors which prevent the use of some “common-sense” solutions due to the need for near perfect replication of field conditions during tests.
- Factors contributing to the current method’s inefficiencies.
- Qualities of the Machine (SAP) that cause inefficient tracking and difficulty for the workers.

The team would also investigate the information learned about potential features within SAP and speak to IT and other departments to analyze the implementation of certain features and the plausibility of each. In fact, large amounts of information analysis would be done in conjunction with management, and the departments that have a key stake in the success of the project.

The team would also analyze the end valve assembly and test fixture data provided by Kenny Mott using Pareto analysis. A main goal of this analysis would be to determine if a significant portion of the fixtures were used a majority of the time, and if some were obsolete and consuming large amounts of storage space leading to difficulties in the material handling process. This would allow for the 5S Principles of Workplace Organization to be implemented and allow for a repeatable process that involves not only making a physical move but also representing it in SAP, leading to more reliability. Analysis through deseasonalization of work order dates would also identify the “off season” to begin implementation of the strategy in.

2.3 Investigation of Possible Solutions

The third step of the methodology used to solve this problem and optimize the process, the investigation of possible solutions, would begin upon the completion of gathering the data. Potential solutions would be generated with help from management depending on the plausibility of implementation and ability to meet a set of basic criteria that follow engineering principles and show regard to the original problem of ineffective test-fixture tracking.

The most significant criterion to be met with an implementation that would greatly affect the entire workplace is a solution that adheres as strictly as possible to the 5S Principles of Workplace Organization. Additionally, a good solution would be one that addresses specifically the five areas discussed in the root cause analysis. Finally, a preferred solution would be one that could be implemented with ideal timing and minimal cost.

2.3.1 5S Principles of Workplace Organization

The standardization of the current barcode usage across the entire facility, as previously mentioned, is one facet of the SDT's successful solution. Bearing in mind that standardization is only one of the 5S Principles of Workplace Organization. an implementation strategy would be developed to help with the adaptation of the new barcode technology across the facility:

1.) **Sort**: As it applies to both the SAP and the physical fixtures themselves, only what is absolutely needed should be utilized. Although the plant currently has a method for removing fixtures with exceptionally low usage, the method can be improved on. Removal of obscure fixtures from physical storage and within the SAP will save space in the warehouse and allow for data regarding the stored fixtures to be used.
2.) **Straighten**: Once the key fixtures are identified, this process should allow for them to be stored more efficiently. As some fixtures are undoubtedly used more than others, keeping them near the front of the warehouse or by the testing facility in lower positions would reduce the work needed to be done by material handlers and allow for more frequent storage and reduced risk of a misplaced scanner. SAP data could allow for more than an "IN USE" representation as a catch-all for fixtures not currently in dedicated storage. This will help clarify current location to improve efficiency of material handling.
3.) **Shine**: Currently the warehouse is full of clutter and shelves that are used for all fixtures recently used but not present. With clean, organized, barcode technology, the number of parts laying around should be reduced. The "data-workspace" within the SAP will be a much cleaner, defined system with less "junk" bogging down the tracking of fixtures.
4.) **Standardization**: As the focus of this project is taking the multiple current ways that SAP and material tracking is handled across the facility and making it one that can be used by the entire plant, specifically in the area of test fixture tracking, standardization is of the utmost importance to our project. By having a solution that is easy to implement, understood by all workers in the plant, and comprehensive, the fourth of the 5S could be accomplished. Barcode technology that is already present will assist greatly in standardizing the process of storing and retrieving fixtures.
5.) **Sustain**: For the solution including the other 4 S's to make any sort of impact it must be able to be sustained. For this to be possible, everybody from the material handlers to the plant manager would have to be on board with the initial changes and the long-term nuances that arise as a result. This would require incentives for the change and ways that the change makes work and life at the plant easier. A thorough implementation strategy will be provided to management to ensure that the necessary tools for guiding workers through this change are being used.

2.3.2 Timely Introduction and Minimal Cost

The Broken Arrow branch of Baker Hughes produces engineered-to-order safety valves to be used on rigs. As the equipment is highly specialized and produced in relatively low volume (800-1000 units a year), roughly 3-4 units are produced per day. With consistent need for the process to be optimized, and with the ability to expand business operations dependent on the excess downtime that could be created as the result, an ideal solution would be able to be implemented quickly to allow for management to help smooth over any "growing pains" that result from the process modification. Because of this, a possible solution should begin being implemented immediately prior to the "off season" of production and demand.

A solution with minimal cost would also be preferred, and the introduction of new and expensive equipment, one-use equipment, or technologies that cost hundreds of dollars in implementing, training costs, and labor hours should be avoided. Any improvement on this process would include some new material handling costs and on-the-job training, but would ultimately need to result in great enough benefit to be economically justified.

2.4 Creation of Solution Proposals

After the data analysis phase and generation of solutions, one preferred solution, selected by the SDT and agreed upon by management would be pursued mainly, with an implementation strategy to be drafted shortly thereafter. This final solution would combine all previously discussed factors above, and meet the ultimate goal of improving the test fixture tracking process at the location.

Accompanying this solution would be a number of alternatives that could be selected from should the final solution unfortunately be too hard to implement or not effective. These solutions would meet many of the same benefits as the one ultimately recommended but include reductions of quality and wholeness with the tradeoff of being cheaper, easier to implement, or preferred by the workers.

While the mission is to make the process as optimal as possible, the significance of employee involvement with any solution is necessary. Changes to the process of tracking the test fixtures only benefit the client if they are being utilized and, are therefore, agreeable to the people involved. With this in mind, a meeting with all parties involved in the process of test fixture tracking (previously mentioned in Section 2.1.2) would be held prior to creating any final proposals.

2.5 Generation of Final Recommendations

The final recommendations and deliverables would include the following:

- A full, detailed explanation of the steps taken to reach the conclusion including what is included in this report and the final presentations made to the School of Industrial Engineering and Management at Oklahoma State University as well as the client, Baker Hughes at Broken Arrow.
- An implementation strategy for the chosen solution, complete with a new process mapping and ways for management to ease the transition as the process changes. This will include a list of benefits so that workers and management alike may understand the benefits and importance of the changes being made.
- Graphic representations of the industrial engineering tools used to reach the conclusions, including full results of the Pareto/"A-B-C" analysis, deseasonalization results, root cause diagram, and 5S Principles of Workplace Organization.
- An analysis of the costs incurred by implementing the new plan as well as the benefits that would result.

3.0 Current State Analysis

After gathering data pertaining to the historical use of test fixtures in the facility and the shortcomings of the current tracking process, the SDT analyzed the data to provide meaningful statistics. These statistics would provide the basis on which recommendations would be made.

3.1 Qualitative Analysis– Root Cause

As mentioned during the methodology section, the qualitative analysis assesses the shortcomings of the way the process is currently carried out in the facility. Gathering data from workers in the multiple departments that have a stake in the way the tracking system is currently used allowed the team to assemble an Ishikawa Diagram (Figure 1), analyzing the "5 M's" (Manpower, Management, Machine, Methods, and Material).

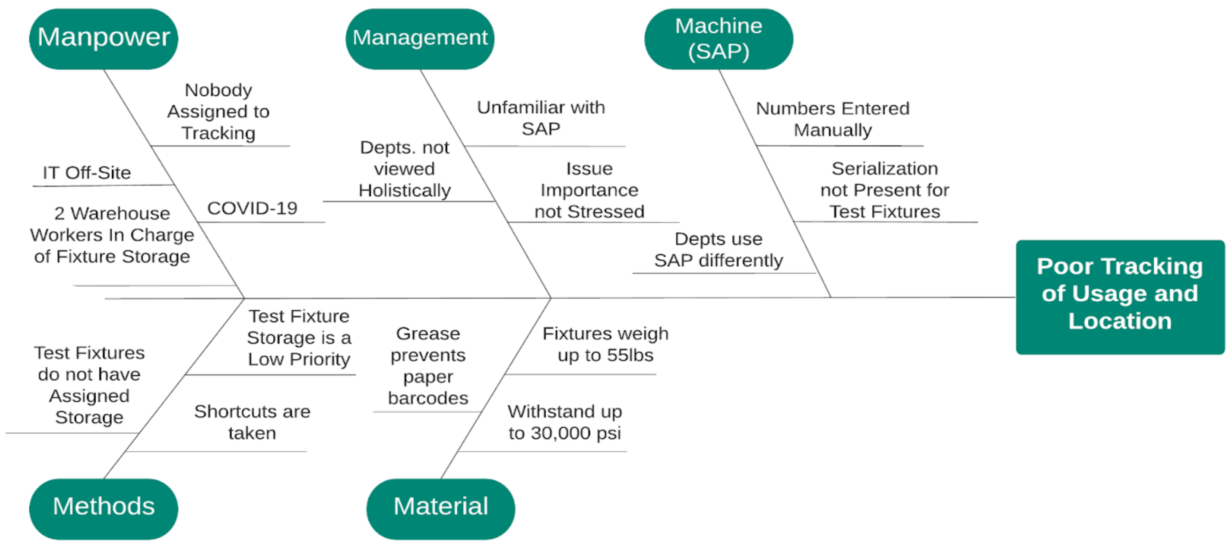

Figure 2: Ishikawa Diagram Root Cause Analysis

The problem is that the process of tracking test fixtures as it stands currently is not working, and a deeper understanding can be revealed by using the Ishikawa Diagram to answer the question of *why* the process does not work. In the five following subsections, each of the 5M's are explained further with additional detail.

All five of the causal areas have multiple contributing factors as to why they are not as effective as they could be, which make the "5 M's" causes of the overall issue of ineffective tracking.

All potential solutions must be robust– the preferred solution would improve the usability of SAP (Machine) to make the workers (Manpower) more likely to adhere to a process that is easier than before (Methods) without affecting the ways the test fixtures need to be in order to replicate field conditions (Material). Most importantly, management (the final M) would need to be willing to help the workers buy into the improved process so that implementation follows the 5S principles discussed in Section 2.3.2.

3.1.1 Manpower

Since the process is carried out by people, an investigation into why the people are not completing the process as it currently stands was the first priority. Communications with management and the warehouse workers introduced a few reasons why replacing the test fixtures is low-priority.

1. Nobody is specifically assigned to tracking the location and usage of each fixture because it has not been a high-priority task until this point. Warehouse workers move fixtures, log the moves in SAP, and have other responsibilities of material handling around the plant. Nobody at all is assigned to tracking the actual usage statistics.
2. There are only two warehouse workers in charge of moving fixtures and logging the moves, with additional material handling responsibilities.
3. With many responsibilities assigned to just a few people, and some not explicitly assigned at all, any sudden decrease in personnel causes the workload outside of our process to increase and thus the quality of tracking fixtures to decline. Like many other businesses, COVID-19 is a strong cause of personnel issues.
4. There are no subject-matter experts with SAP located within the facility, as a result of the Information Technology Department being off site.

3.1.2 Methods

The methods used for storing and retrieving test fixtures is not one followed closely due to difficulties and lack of the process itself being unattractive to the workers responsible for carrying it out.

1. As previously mentioned, only 2 warehouse workers (accounting for only 16 labor hours a day) are present, and storing test fixtures is only one of their many responsibilities. This causes it to become a low-priority issue.
2. Since storing and logging moves is low priority, shortcuts are taken often to prevent the rework of storing and retrieving a fixture. The design team likens this to washing a plate and not wanting to put it back in the cabinet because it will just be used again at the next meal.
3. There is no dedicated storage for the fixtures, mainly due to shortcuts being taken. Dedicated storage used to be in place but the workers did not favor it, and now store fixtures wherever there is a convenient opening.

3.1.3 Management

The goal of the plant, like any other, is to make money. Management is concerned with the “big picture” goals of being safe and profitable. With management having hundreds of responsibilities around the plant, this causes other issues like delegation of tracking and SAP use to be overlooked.

1. The importance of the issue of test fixture tracking is not stressed. It is widely known to be an issue in the plant, but due to the ambiguity of the problem, management prior to this project has not had a deep enough understanding of the causes and negative effects of this process being overlooked.
2. Management is unfamiliar with many intricacies of the SAP system and leaves it mainly to the workers using it. This causes a disconnect between the workers and the managers on how SAP is used currently and how it could be better used to improve the process.

3.1.4 Material

Many common solutions used at other plants cannot be used to solve this problem due to the ways the materials (in this case, the test fixtures) are used. This rules out a number of "simple solutions" that could have already been implemented to solve this problem.

1. RFID chips were an initial idea, however the chips cannot be attached to an actual fixture in the field and the point of the test is to replicate the field conditions as much as possible. Furthermore, worry exists that the RFID chips could not function properly for an extended period of time being consistently tested at pressures up to 30,000 psi.
2. Fixtures weigh up to 55 pounds meaning that the storage of them typically requires a material handler to operate a forklift to store them, especially the higher the pallet to be placed on is up on the shelf.
3. Paper barcodes can not be applied directly to the fixtures, which must be lubricated with grease often prior to testing. The barcodes would, over a period of time, become rendered unusable by the consistent application of lubrication

3.1.5 Machine (SAP)

SAP is the main "machine" used to record the storing and usage of the fixtures. While SAP is used daily throughout the facility and is the primary tool offered by Baker Hughes for information technology solutions, it is not being used to its full efficiency, which is a root cause of the problem.

1. SAP is used throughout the facility, but is used in different ways from department to department. Planning uses it to scan in work orders, warehousing uses it to find whether a location is in use or not, and assembly uses it to send requests to warehousing for specific test fixtures.
2. Serialization within SAP is not currently used to draw a distinction between fixtures of a specific type. Batch numbers and part numbers are used to denote a type of fixture, but with some fixtures having 3-5 replications, there is no way to distinguish between the fixtures and which specific one may have been used.
3. The numbers of the test fixtures must be entered manually when the warehousemen log a move. This requires writing down the fixtures or making multiple trips while putting up a relatively small number of fixtures, and causes the wrong input to be inserted often.

3.2 Current Work Flow Process

The SDT conducted a series of interviews with key stakeholders who interact with the test fixtures to varying capacities throughout the facility's standard operations. The processes are split into the physical movements of the test fixtures and the SAP system movements. The physical movement of test fixtures was primarily between warehousing and the testing department. Exceptions include the construction of new test fixtures or the routine inspections with the Research and Development (R&D) department.

3.2.1 Current Flow of Test Fixtures within SAP

When the facility receives a new order, the Planning department is the first to act. The planner accesses the BOM for the ordered subsurface safety valve. The BOM lists the required test fixtures needed for that particular order. The amount of test fixtures required for any particular safety valve ranges from two to ten, with some intricate safety valves requiring upwards of thirty test fixtures. Having obtained the list of required test fixtures, the planners check whether that safety valve is currently in stock at the Broken Arrow plant. If all test fixtures required for a safety valve are in stock, the planner proceeds with releasing the Work Order to production .If any test fixtures are not in stock, the planner must release a separate Work Order for production to create that test fixture. This must be done in a manner that ensures the test fixtures will be available when the safety valve is assembled and arrives at the testing department.

Once planning releases a work order to production, their involvement with test fixtures is finished. At this point, the test fixtures have been attached to the work order to a certain extent. At the start of the project, the test fixtures were only attached to the Work Order and the BOM through a part number and batch number. This meant that, once the warehouse retrieves the test fixtures from inventory, it is at their discretion to obtain any test fixture that satisfies part and batch number requirements. This diminishes the quality of any data being tracked. When the safety valve hits production, the test fixtures are not needed until assembly is completed. After the valve is fully assembled, it arrives at the testing department. There, the tester goes into SAP and prints out all required test fixtures for that valve. This sheet is taken to the warehouse where they will be pulled from inventory. The warehouse worker searches SAP for the location of each required test fixture and discovers one of two things. Either the test fixture has a bin location in SAP or the test fixture is still labeled as “IN USE” and is on the temporary storage shelves outside of the warehouse. Once all required test fixtures have been accounted for, the warehouse worker updates their locations in SAP to “IN USE” and delivers them to the testing department. This is the last SAP interaction that the test fixtures will have with that safety valve. After the fixtures are used, they are returned to the temporary shelving outside the warehouse. When the warehouse worker has time, the test fixtures are returned to a bin location and their status is updated in SAP with that information.

3.3 Quantitative Analysis

3.3.1 ABC (Pareto) Analysis

As mentioned in Section 3.1, test fixtures do not have dedicated storage, which is one of the root causes pertaining to the issue of the methods used for storing fixtures. Fixtures that are commonly used may occupy difficult-to-access storage, while prime storage is occupied by non-essential items. When conducting an analysis of essential inventory, a Pareto analysis is a commonly used engineering tool. Pareto’s Principle states that roughly 80% of the consequences can be attributed to 20% of causes. The goal here of a Pareto Analysis is to determine which fixtures can be attributed with the highest number of uses and group the fixtures into classes ranked by importance.

In the years prior to this project, dedicated storage was used and enforced so that everything would be in a specific location and would be retrieved and stored directly prior to and following each use. However, this was seen by management and the workers as largely ineffective as fixtures commonly used would be located on difficult-to-access pallets. Historically, whichever pallet was down was loaded with any fixtures needing to be stored– even if the pallet was relatively inaccessible and the fixture was essential. Any immediately accessible storage was utilized, even if bins were located near the back of the facility or located on high shelving. Eventually, fixtures would just be stored in the closest and most available location, and then logged in SAP.

This provides a few problems:

- A fixture may be used once in 2 years and stored in a prime location, and sit idly consuming valuable storage space that is in an easy-to-retrieve location.
- The most easy storage space to store a fixture in may be a pallet that is already down from the top rows. A commonly used fixture could be stored here and then need to be retrieved soon, which would result in another time-consuming move.

  - Even worse, somebody not in warehousing could see an empty pallet on the floor and put the fixture on it. The fixture will be taken to the top of the facility without the move even being logged.
- A lost fixture does not have one or two possible locations, but could be located anywhere within the confines of the warehouse.

Since two of these three problems are directly related to the significance of a fixture (accounted for by rate of usage), a quantitative analysis that inspects how often a fixture is used would provide great insight into different storage techniques.

The SDT has elected to conduct an ABC Analysis of the usage of test fixtures. Using BOM data from the past 14 months, which shows which types of fixtures were used for each test, the team was able to analyze which fixtures are very commonly used and which ones go mostly untouched during this time.

A new storage solution would be able to be configured from this, reducing the problems of easy moves being made for fixtures that are not often used and difficult moves being made for fixtures that need to be used commonly. Reducing the difficulty of material handling would provide workers with more time to store and retrieve fixtures, and would make the process more efficient and more likely to be followed.

The BOM data provided by Mr. Kenny Mott detailed all of the valves and end subs that were produced from January 4, 2021 through March 18, 2022. The total amount of finished products was 719 during this period. Of this 719, there were 225 unique items. This means that, on average, each unique valve was produced approximately 3 times. However, 129 of the 225 different valve types were only produced once or twice. All of this furthered the SDT's confidence in an ABC Analysis to create classification for the test fixtures associated with these assemblies.

In order to determine the test fixtures associated with the high frequency, Kenny Mott also provided a dataset that included the required test fixtures for each subsurface safety valve. The SDT created a SQL database in SQL Server to compile this data. To create an estimate of the usage for all test fixtures based on the past 14 months of production data, the SDT created the following logic and applied it across the dataset:

Uses for a Test Fixture = Σ (# of Valves Produced with that Test Fixture on its BOM)

From this logic, the SDT was able to quantify the most commonly used test fixtures across the period of review. There were 481 different test fixtures used, and a total of 5,253 uses across all test fixtures. From an ABC Analysis approach, it was determined that 62.90% of the tests done were completed by just 19.48% of the test fixtures. This set of 109 test fixtures made up the Class A test fixtures. The table below details the classes further:

Class	Amount of Fixtures	% of Used Inventory	% of Uses	Range of Uses
A	109	19.48%	62.90%	15 or more
B	159	34.45%	27.49%	4 to 14
C	213	46.07%	9.61%	1 to 3
Sub Total	481		100.00%	
D	1171	76.14%		0

Table 1: ABC Classifications

The implementation of the results of the ABC Analysis are detailed in Section 4.1.1. Note that Classes A, B, and C consist of test fixtures that have been used in the past 14 months. These figures are further represented as a Pareto Chart in Figure 3 below. This subtotal of Class A, B, and C fixtures only makes up 23.86% of the total test fixture inventory. The remaining 76.14% of test fixtures have not been used in the past 14 months and make up Class D. Class D has been created to represent any test fixtures that have not been used during the time period of analysis. Figure 4 represents the Pareto Chart resulting from considering all test fixtures in inventory, including those with 0 uses in the recent past. Baker Hughes has communicated that a process for determining which test fixtures can be removed from inventory is not established. Using this set of Class D test fixtures, the SDT provided the client with context to begin to audit the test fixture inventory. Further recommendations for the action to take regarding test fixtures in Class D are detailed in Section 5.1.1.

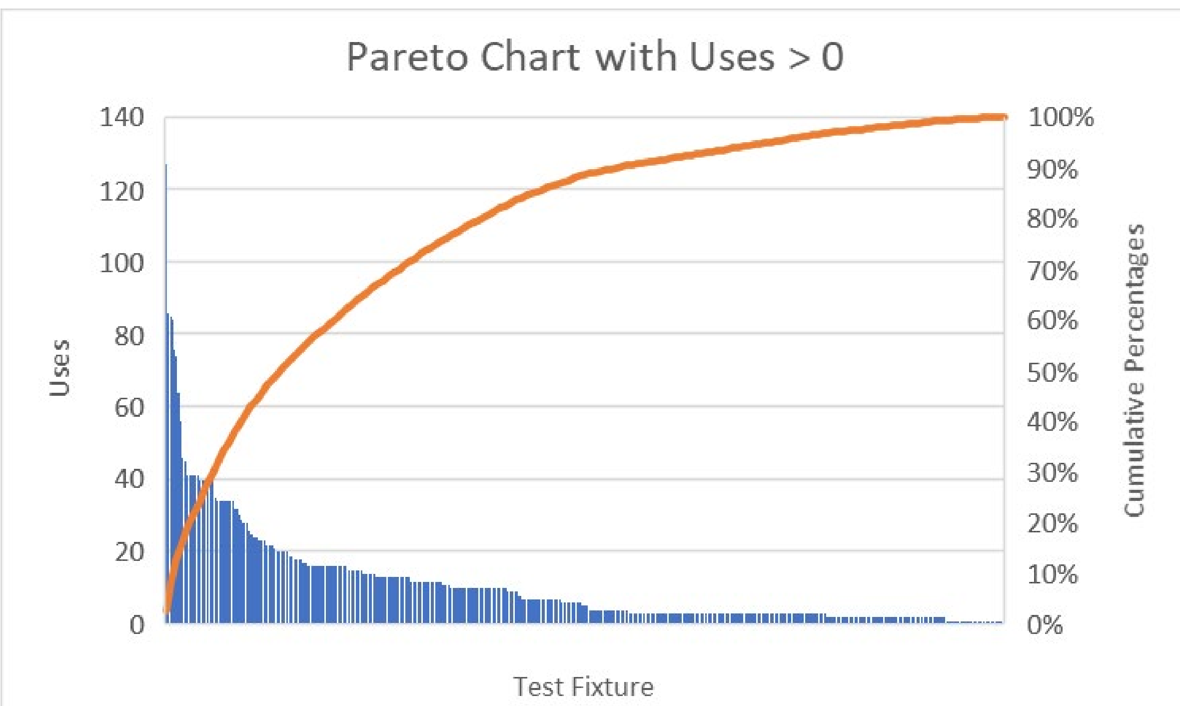

Figure 3: ABC Analysis Chart with Uses > 0

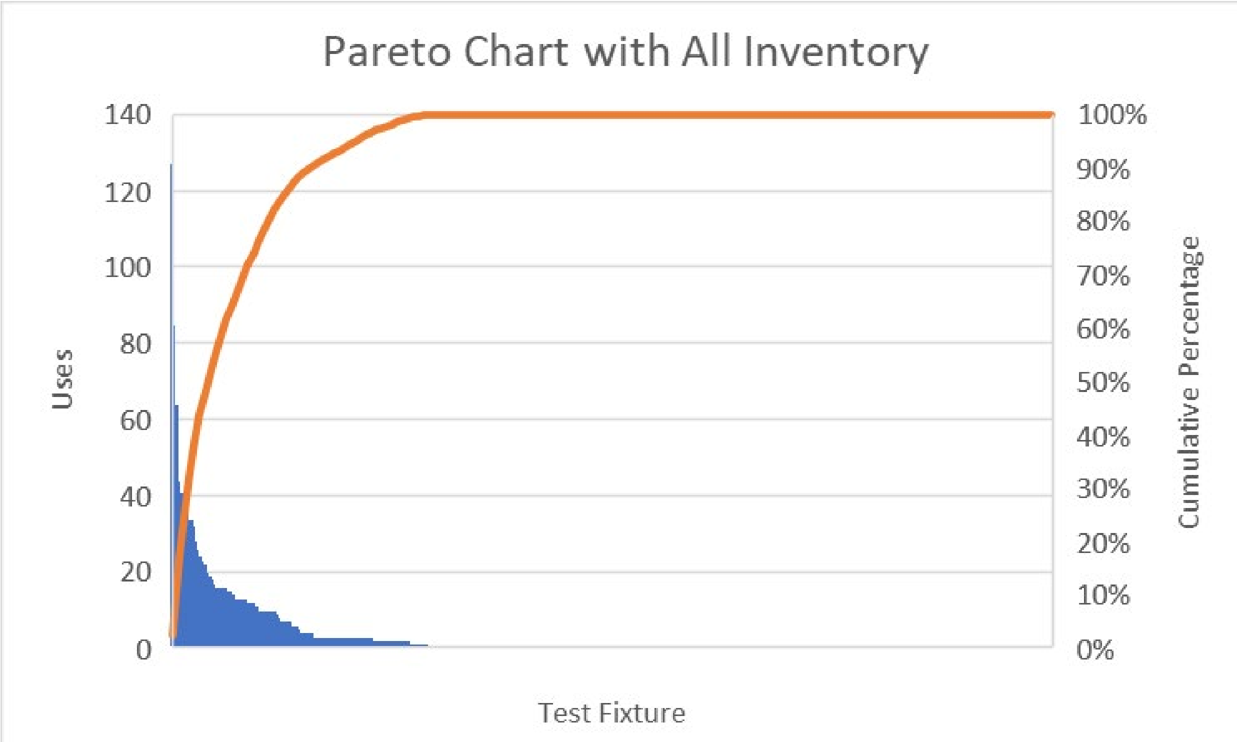

Figure 4: ABC Analysis Chart with All Inventory

3.3.2 Analysis of Deseasonalization for Implementation Start Date

Part of the useful implementation strategy to be provided along with this report includes an analysis of the most strategic time to begin the process overhaul. Historical data regarding the number of end subassemblies produced since 2018 was arranged by week and deseasonalized to indicate what times of year historically have less demand, allowing us to predict when the next "off season" would be for the plant. The seasonalization decomposition results follow:

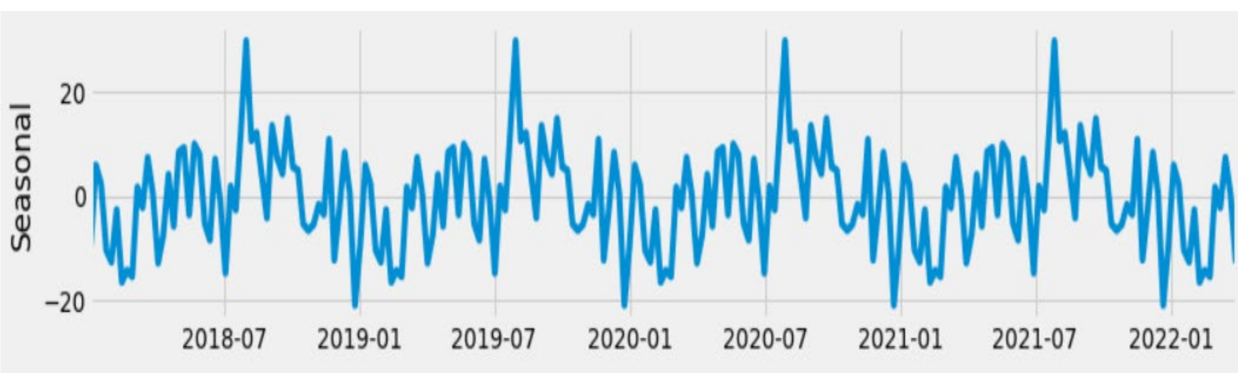

Figure 5: Seasonalization Decomposition

Within one cycle the absolute minimum falls in point 52 of 52, or the last week of the year. This is to be expected as demand slows during the holiday season. Due to potential PTO being taken during this time, or the plant being closed in general, the absolute maximum should not be used as a projected start date.

Excluding this point we see that the absolute minimum becomes point 6 of 52, with the 3 points before it and one point after it also below the average seasonalized demand. This makes the beginning of the year more attractive for implementation according to the graph, and February being among the lowest demand-months.

4.0 Solutions

Utilizing the 5S Principles of Workplace Organization in our principles, the proposed solution involves using statistical analysis to simplify the process. By introducing material handling alternatives and barcode technology, assigning SAP responsibility to trained employees, and making the process one that can easily be followed, the poor tracking of test fixtures should be a mitigated problem as the result of our solution.

4.1 Barcode Technology Implementation

In installing new barcode scanners, the decisions needed to be made would be reliant on historical data and relate to the current state of the process as well as the quality improvements being made. Furthermore, justification of the barcode technology is reliant on justification of other significant changes made to the warehousing process.

Barcode technologies are already present in the assembly of the safety valves, as each assembly has a "traveler" that has a barcode to be scanned. To avoid human error and technological discrepancies, using the same scanners and barcodes for the warehouse would be preferred. An investigation into the type(s) of scanner already used (and how they are used) would be necessary to determine if the capabilities needed for improved warehousing are present. If not, tradeoffs in introducing another type of scanner to the facility would need to be made.

4.1.1 Location of Scanners

The proposed location of the scanners is another important consideration in the overall implementation. The distance between the scanners and the fixtures being scanned most commonly has a direct impact on the likelihood of the scanner being properly returned between each use. Since the scanners will need to be used in multiple locations they should be portable, and located both within the warehouse and testing facility. Lastly, returning scanners to their predetermined locations should be a priority within the warehouse.

4.1.2 Cost of Scanners

Implementation of the scanner depends on economic feasibility which depends on several factors including:

- On-the-job training costs associated with the barcodes and their relation to SAP
- Costs of the physical scanners and any materials needed for the assignment of barcodes
- Financial benefits of a reduced failure chance with new usage statistics/inspection practices
- Financial benefits of reduced material handling costs
- Other factors

Currently, most scanners cost between $300-$700, with the Zebra DS2200 Model that is already commonly used in the facility costing around $370.00.

4.2 Serialization

Serialization is an integral part of the solution process. While many test fixtures have a stock of only one, there is still a large portion with duplicates in inventory. Differentiating between different test fixtures to the serial degree is not currently possible. Batch number serves as the lowest level differentiator, but there are still many occurrences where multiple test fixtures with the same batch number are in inventory. For the SDT's implementation strategy to work, serialization of test fixtures is a necessary task. Serialization is a key solution to the tracking problem, as well as, the usage data problem. Without serialization, there is no way to tell each duplicate test fixture from the other.

The implementation plan in Section 5.2 further discusses how serialization will be implemented over time within the warehouse.

Once each duplicate fixture is serialized, they will be able to be grouped together and storage will become more organized based on their A, B, or C classification. Usage tracking will also be helped immensely since now auditors will be able to go through SAP and see how many times a specific fixture was taken out of storage and used for testing. After a certain amount of tests, the auditor can then take it out of the rotation to be inspected for safety purposes. In general, serialization is a key part of our solution and implementation is necessary to improve the current process flow.

4.3 SAP Improvements

Backend overhauls of SAP for Baker Hughes- Broken Arrow fell beyond the scope of this project as the IT department for Baker Hughes- BA is out of house. As a result of this, the SDT focused on analyzing the current flow of test fixtures within SAP and provided suggestions for how to improve that process.

Based on the current flow detailed in Section 3.2.1, there is first a need to change the way that the Planning Department interacts with test fixtures. With serialization in effect, the planning department should now be able to build work orders that call for specific test fixtures rather than just test fixture type. This will be the first point of accurate data being collected, as the Inventory Manager will be able to audit the usage of test fixtures based on the work orders being released.

The workflow process for testing has changed only slightly. Before, they went into SAP and printed out all the required test fixtures for a given assembly. Now, the work order will have the exact serialized test fixtures required for testing. The process for making a warehouse move by the warehouse workers will look the same, with the usage tracking being done at planning serving as accountability for more effective tracking.

5.0 Implementation

5.1 Inventory Management

Through interviews with key stakeholders as well as a quantitative analysis of test fixture usage, the SDT has created recommendations regarding management of test fixture inventory.

5.1.1 Inventory Reduction Strategy

The Class D test fixtures discussed in Section 3.3 consist of 1,171 test fixtures that have not been used in the past 14 months. Within this set of test fixtures, 334 have more than one test fixture in stock. There are 534 test fixture duplicates that could be removed from inventory while maintaining at least 1 of each type of test fixture currently being carried. Appendix A contains the full table of test fixtures in Class D along with the current stock. The SDT recommends reducing the inventory to 1 for all test fixtures with zero uses in the past 14 months. This move alone would clear up 23.8% of the space currently being taken by test fixtures in the warehouse. This accomplishes the "Sort" principle of 5S.

5.1.2 Remaining Inventory Serialization

The SDT recommends that Baker Hughes go add a -1, -2, -3, etc. to the batch numbers on all the duplicate test fixtures in their inventory. This will individualize the fixtures and help accomplish the new process flow goal. Table 2 below shows what these new serialized IDs will look like and how they can also be put into SAP for further data work.

Class A		
testfixture	Uses	Stock
H052847405	64	5
H052847405-1	?/64	1
H052847405-2	?/64	1
H052847405-3	?/64	1
H052847405-4	?/64	1
H052847405-5	?/64	1

Table 2: Duplicate Fixture Serialization and Unknown Usage Data

This will serve to differentiate the fixtures by actual usage and provide a failsafe tracking method in case an error arises with the barcodes, as the specific fixtures will now be called for in BoMs as they are printed.

5.1.3 Inventory Reorganization

Once serialized, the remaining inventory should be organized following the "Straighten" principle of 5S, with the "A" class fixtures being located on ground-level of the facility as near to the testing bay as possible. Additionally, if storage exists near the testing bay, it should be filled using the most commonly used fixtures.

In addition to these essential fixtures being at ground level, the SDT recommends the purchase of two cheap and efficient pallet jacks to remain in the warehouse facility at all times. The purpose of these jacks is so that the move of Class A fixtures to the floor results in the elimination of the need of a forklift to move these fixtures. This saves time for the workers and increases the chances that the process of storing and replacing the physical fixtures is enhanced. Balancing cost with efficiency, the SDT recommends the Uline H-3763 model which can be purchased for $450.00 a unit.

Figure 6: ULine H-3763 48 x 27" Pallet Jack

The shelves immediately above the bottom ones should be occupied with Class B fixtures if no ground storage remains. The progressively less used fixtures should be placed on the third level shelves, and so-on. As anything above ground level will require a forklift to retrieve, only the most essential items should occupy ground storage.

5.1.4 Barcode Assistance With SAP

The facility already uses Zebra DS2200 barcode scanners with the valves, and the SDT recommends the addition of 3 more that should be used with the fixtures. Each fixture, when being serialized and categorized into their respective class should be paired with a laminated "traveler", similar to the valves. This traveler would denote class in a large, bold letter so that storage location is as unambiguous as possible, and would have the fixture number displayed in plain font.

This traveler would accompany the fixtures to the testing facility, wait outside during testing, and immediately be repaired upon test completion. Most importantly, the traveler should have a barcode representation of the serialized fixture that can read it into SAP. Commands that the barcodes should be equipped to handle with pairing of SAP should be:

- Representing exactly one serialized fixture–the one paired to it
- Incrementing the number of usages when checking a fixture in to testing

- Notifying the worker the number of usages when checking out of testing and notifying them if it should be removed for inspection and rework

The Zebra DS2200 models, should, for this reason, be located with one in the testing facility, one in the warehouse, and one kept by management or placed by close-proximity storage where it will be used often. There should be a designated location for these scanners in each department and signage reminding the workers to return their scanners when complete.

5.2 Implementation Strategy

The SDT delivered an Implementation Strategy document to the client which can be found in entirety in Appendix A. The bulk of this strategy is detailed here, with reference to the appendices for further context.

5.2.1 Introduction

Information included within this guide is limited to what the SDT believes is of paramount importance over the course of the coming weeks, months, and years to ensure that the recommendations meet the primary goal without placing undue burden on the workers and management of the Broken Arrow location. This includes:

- Information about when and how gradually the changes should be implemented
- Solutions to problems that may arise because of the new changes
- Management tools that will:
  - Assist with the sustainability of the new changes
  - Help overcome initial blocks to progress
  - Incentivize the changes to the workers affected

Finally, the Implementation Strategy will take place in the following five phases:

Figure 7: Implementation Strategy Phases

5.2.2 Goals of Implementation

The goals of implementation should be established to gradually improve the current way test fixtures are tracked, stored, and registered in SAP without placing an excess burden on the facility's human and material resources. Following the principle of S.M.A.R.T. goal setting, the goals set forth are to be:

- Specific

- Measurable
- Achievable
- Realistic
- Timely

An example of a S.M.A.R.T. goal that could be set by management follows:

"By the end of the 90th day of the implementation process, the 109 types of fixtures that were used 15 or more times during the previous year should be located on the ground level of the facility."

This goal meets all 5 of the S.M.A.R.T. goal setting criteria:

Principle	Example(s)	Explanation
Specific	"the end of the 90th day", "109 types of fixtures… 15 or more times"	Exactly what needs to be done is expressed. No gray area exists.
Measurable	"109 types of fixtures"	A specific number of fixtures is given and progress toward that goal can be tracked to keep on schedule.
Achievable	"end of 90th day…" "located on ground level"	Ample time is given to make the needed moves, and a large portion of these fixtures are already located on ground level.
Realistic	"109 types fixtures used 15 or more times"	Only the most important fixtures are moved immediately. These fixtures only represent a third of inventory.
Timely	"By the end of the 90th day…"	The important work can be completed within a financial quarter and benefits can begin by the next.

Table 3: 5 S.M.A.R.T Goals

(It should be noted that the 109 types of fixtures that should be moved to ground level have been pre-determined by the engineering team and delivered to management, making the only work needed to be done the actual action of moving and logging the moves. No analytics are necessary.)

This is only an example of a goal that *could* be set by management, not one that is. Perhaps 90 days is not an appropriate amount of time, or only 97 types of fixtures are desired to be moved. No matter the scale, any goals set by management that follow the S.M.A.R.T. rubric is more likely to be achieved.

Workers should also have clear goals with the changes being made being ambiguous. With SAP used by both warehousing and inventory analysis, assignment of tasks should be direct. "Somebody needs to serialize the groups of similar fixtures" is a weak assignment that leaves a way for workers to assume others are carrying it out. "Inventory analysis needs to serialize the groups of similar fixtures" is better, but still needs to be elaborated upon to achieve the remainder of the S.M.A.R.T. criteria.

5.2.3 Engaging Workers

The changes recommended cannot be realized without support from the workers. Workers should have a deep understanding of why it may seem they are working harder for a few months; after implementation the plant will be more efficient, the workers' jobs will be streamlined (read: easier), and previous difficulties with test fixtures should not remain.

The way workers should be engaged depends largely on the amount of direction needed with the changes to be made and the amount of support needed from management. These two form the axes of the Hersey-Blanchard Model of Situational Leadership, which helps determine what management strategy may be most effective:

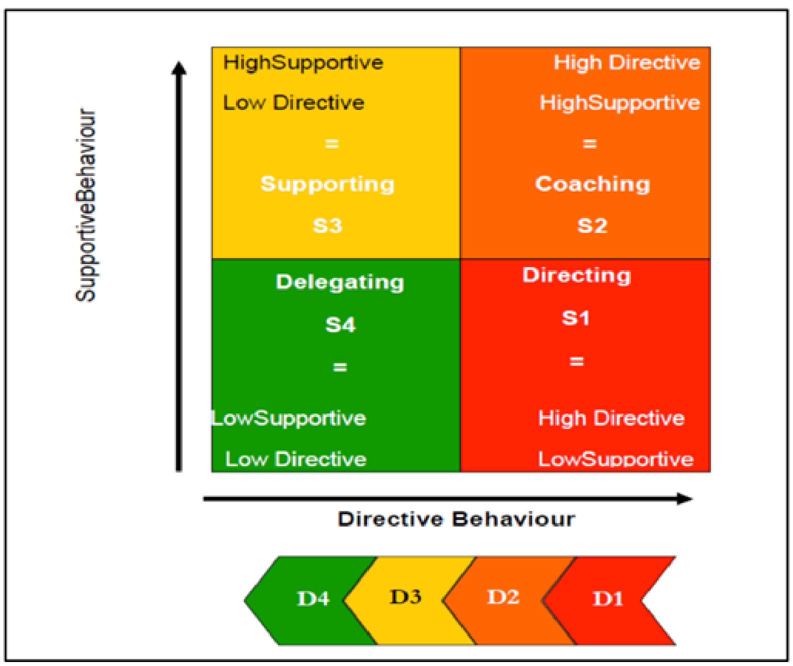

Figure 8: Hersey-Blanchard Model of Situational Leadership

As shown, the amount of support in terms of morale increases from bottom to top, as the amount of direction needed should be increased from left to right.

A few examples of how this rubric may apply to workers within the plant include:

· Warehousing workers may need to be directed more than others to accomplish the specific tasks at hand, but do not need much support as the warehousing department is culturally self-sustained. These workers fit in quadrant S1 and should be directed.

· The inventory analysis department may be highly competent and can easily make the changes needed in SAP and can function without high levels of support from management. These workers fit in quadrant S4 and tasks can be delegated to them with only occasional check-ins from management.

These are just examples—the amount of support needed by a department may increase and need for direction may decrease over time. Management should remain fluid in engaging the workers to ensure goals are not only shared by the workers but accomplished as well.

5.2.4 Execution of Strategic Plan

With goals being set and the workers being engaged, a highly strategic plan should be executed, allowing for the changes to be made as quickly and painlessly as possible. Elements that should be included in the formulation and execution of this plan include:

· Determining a start date immediately prior to a period of relatively slow production during which workers will have more time to complete tasks.

· Formulating a strategy that implements the 5S Principles of Workplace Organization in order.

· Creating ways to make the changes make more sense to workers, and genuinely effective over a period.

With demand being dependent on the time of year (there are "on seasons" and "off seasons"), a start date for implementation can be found by finding the relative minimum from year to year on the seasonal time decomposition graph, which can be found in Section 3.3.2 of this report.

This graph is cyclical, with it repeating itself exactly each year. For this reason, we can represent the graph using one cycle:

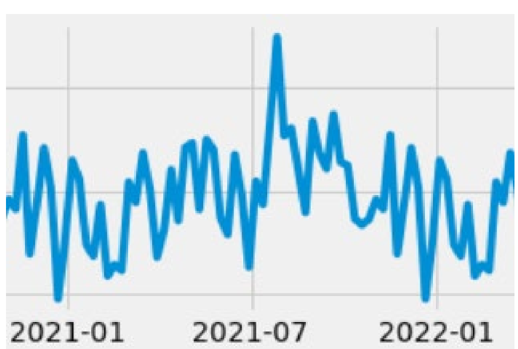

Figure 9: One Cycle of Seasonalized Data

Based on this graph we can see that the absolute minimum seasonally falls around the end of December, during the holiday season. The SDT makes the assumption that work is not conducted during the holiday season, making this an inappropriate time to recommend implementation. However, a significant decline in demand begins at the second point, representing the first day of the second week of January. Aside from the holiday season, the lowest demand of the year falls only 4 weeks later, in the second week of January. With most of the work needing to take place during this period. Because of this, starting during the second work week of February is highly recommended.

Secondly, the storing recommendations made by the SDT are based around the 5S Principles of Workplace Management for a reason—if done in order each should cause the next step to be much less time-consuming. The 5S Principles are as follows:

Figure 10: The 5S Principles of Workplace Organization

The problem to be solved is one of physical storage and digital representation. By following the steps in the recommended order when implementing the strategy, work should be reduced for each. Explanations follow:

· If the fixtures are sorted into two primary categories—keep and scrap, hundreds of fixtures could be scrapped. This results in the number needed to be moved in Step 2 being much smaller.

· If the most used parts are easy to access (i.e., on ground level and accessible by pallet jacks) then keeping the warehouse floor and extra shelves full of clutter should be easier.

· If the warehouse is free of clutter and work is not built up, the process is more likely to repeat itself, making Step 4 much easier.

· If the same process is used and understood by all workers, better statistics will be kept, identifying more unimportant fixtures that can be removed from inventory as the cycle reiterates to Step 1.

· Most importantly, if the work becomes easier over time as a result of cleaner workspace, fewer fixtures, organization that allows for quick handling, and a commonly understood process, the process is more likely to be repeated and refined, making the 5^{th} step the easiest part.

Bearing this in mind, a strong implementation will follow the 5S steps to reduce work as the process changes are made.

Finally, a strategic plan will make sense to the workers and immediately reward them for their work in getting changes implemented. The recommended improvements such as using a pallet jack to make the moving of commonly used fixtures take less time and the use of nearby barcode scanners to reduce manual SAP input enhance the ease of their job. In addition, incentives should be provided so workers see an immediate correlation in the news changes within their work lives. This can be done through workplace incentives, increased breaks, or other systems management sees fit.

5.2.5 Tackling Problems

Even with a highly strategic plan, problems can and most likely will arise that need addressing by management. While not every problem can be projected, a few common problems in implementing new changes on the scale mentioned can be assisted with Deming's 14 Points for Total Quality Management.

Deming's 14 Points are used as a tool by quality engineers when working towards the improvement of a process that is already in control. They are as follows:

- Create constancy of purpose for improving products and services.
- Adopt the new philosophy.
- Cease dependence on inspection to achieve quality.
- End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier.
- Improve constantly and forever every process for planning, production and service.
- Institute training on the job.
- Adopt and institute leadership.
- Drive out fear.
- Break down barriers between staff areas.
- Eliminate slogans, exhortations and targets for the workforce.
- Eliminate numerical quotas for the workforce and numerical goals for management.
- Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system.
- Institute a vigorous program of education and self-improvement for everyone.

- Put everybody in the company to work accomplishing the transformation.

A few examples of problems that may arise and how they can be addressed using the 14 points follow:

Problem	Solution	Corresponding Point
Workers are not effectively using SAP to track the movement of fixtures.	Institute SAP training on the job to reduce employee errors and not cut into their own time.	Point 6: Institute training on the job.
Workers are not feeling like the changes are worthwhile and give up on them after a short period.	Have management adopt a new style of Situational Leadership with more supportive behavior.	Point 7: Adopt and institute leadership.
Warehousing is having difficulty understanding why planning must call for one specific fixture out of a batch of many similar ones.	Arrange a meeting between warehousing, inventory, and planning that allows them to establish common goals.	Point 9: Break down barriers between staff areas.
Workers find a different way of storing the fixtures that is still effective but not what management implemented.	Keep the end goal in mind—if the workers' new methods are effectively leading the company towards final implementation goals, let them proceed.	Point 12: Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system.

Table 4: Problems Within Deming's 14 Points

Not all problems addressed here will occur, and not all problems that will occur are addressed here. Some problems may require resources to be spread out and new tasks to be delegated. Deming's 14 Points may not be applicable to a problem at hand. It is up to the discretion of management to tackle any problems that arise and to remind workers how and why the changes are to be implemented, and the benefits that will ensue.

5.2.6 Continuity Plan

With the bulk of the changes being finalized it is time to reap the benefits of the changes made in the facility. With the continuation of the 5S Principles, the ease of the process of logging fixtures' locations and usage statistics has increased exponentially. Now the main goal shifts from making the changes successfully towards following the process improved by it.

The changes only reap the anticipated benefits if erroneous behavior is cut out of the process entirely, so it becomes essential that the end process becomes as automatic as possible, and that the steps are followed in order, immediately, and exactly.

To ensure that the process is being followed, consider developing an acronym or checklist to hang in the warehousing and testing areas that make sure the process's steps are being followed in order each time. Consider something simple but understandable and easy to remember, such as GOAL CORRAL.

- Get Order
- Obtain Fixture
- Access Scanner
- Log Move
- Conclude Test
- Obtain Fixture
- Return to Inventory
- Replace Fixture and Barcode
- Access Scanner
- Log Move

This is just an example of an acronym that may be selected for usage. Having something easy for the worker to use, however, may prove helpful and reduce the number of errors in the process after changes are made. Management may decide to include more or fewer steps or to use a checklist instead but having a standard expectation for the way the process is conducted and carrying it out every time is essential to success.

6.0 Benefits

Our recommendations will lead to many different benefits across the Broken Arrow facility. Quantitative benefits aren't highly applicable as the test fixtures are carried within the system at zero cost, so instead we will be looking for more qualitative advantages.

- Inventory
  - Reducing all stock to 1 for duplicate fixtures with zero uses in the past 14 months would clear up 23.8% of the space currently being taken.
  - Space will be saved within SAP allowing for better tracking of usage.
- Organization
  - Class A fixtures will be easier to get to since they will be located near the front and bottom of the shelves, saving workers time and increasing odds of process being followed.
  - Duplicate fixtures will be grouped together making them easier to find overall.
- Workflow Process
  - Scanning barcodes will make entering serial numbers into SAP simpler.
  - There will be a reduction in travel time for the warehousemen with new organization.
- SAP
  - Storage improvements will lead to higher return of fixture rates and reduce the constant "In Use" problem.
  - Serialization will lead to a clearer representation of location and fixture history in SAP
  - Using the new detailed fixture history, needed inspection can be seen if a specific fixture is used too many times.
  - Fixture audits will be done quicker now that duplicate fixture history can be seen correctly.
- Safety
  - API standards for usage in test fixtures can now be tracked accurately and rework can be identified before safety is compromised.
  - Pallet jacks being introduced will lead to a safer environment than constant forklift use.

By accomplishing this strategically and during the off season of production, costs of labor would not be incurred, therefore the only incurred cost to receive these benefits would be:

- 2 pallet jacks * $450 = $900
- 3 scanners * $370 = $1,110
- ~$500 printing costs for travelers

For total costs of $2,510.

Appendix A: Test Fixture Usage

REMOVED FOR HONORS THESIS SUBMISSION DUE TO NDA