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Planning in Geophysics Utilizing an Adjusted Failure Mode Effect Analysis Process on Historic Sites

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Abstract

Pre-construction planning encompasses many factors and is practiced utilizing many techniques. Most construction sites have commonalities between them however, there are some sites that require an additional focus in pre-construction planning. Construction on historic sites is a project that requires additional attention to planning. This paper is part of a dissertation study developed when researching a planning system with focus on applying geophysical surveys to improve contractor production and assist the archaeologist in preservation techniques in Egypt. The study included a literature review, interviews, case study, contractor survey questionnaire, and personal experience. The study found that inadequate planning resulted in a higher risk in contractor delays and conflicts between the contractor and the archaeologist. The idea behind the study is to reduce the delays and claims while at the same time provide a focus on preservation on archaeological material. In assessing a planning tool, it was necessary to address several constraints in improving current planning processes. The greatest obstacle was to introduce a process that did not interfere with current planning processes and could "best fit" in current practices without major adjustments or complicated procedures. Failure Mode Effect Analysis is a proven tool in anticipating problems by talking actions to avoid potential impacts. As part of the "best fit" scenario, adjustments were made to simplify and adjust the FMEA for the production and preservation planning process. Data shows that all affiliated participants benefit from proactive planning.

Keywords: *Geophysics, Failure Mode Effect Analysis, FMEA, Planning, Risk, Preservation*

INTRODUCTION

Construction planning is widely studied and published outlining many techniques. Advances in technology present new tools in construction planning and implementation. With the advancement of technology, change in an industry where some individuals have difficulty in adapting, may present barriers to improved efficiency. Although tremendous technological and strategic advances have been developed and implemented in the construction sector in recent years, there is substantial room for improvement in the areas of productivity growth, project performance, and schedule reliability [1]. Improved productivity, performance and reduced time factors associated with the project schedule are objectives that all contractors pursue. Technology has made it possible to reduce risk and other problems that effect production, but some have been cumbersome and individuals associated with the project may find it difficult to implement. One main reason is that new methods have a tendency to change current habits and methods of project planning. Some in the construction industry have had difficulty in fully accepting change, especially if additional training is required. An example shows that a major barrier to BIM adoption is related to the inherent resistance to change by construction stakeholders, inadequate organizational support and structure to execute BIM [2]. This phenomenon is supported by other research [3]. A "best fit" approach with an organization that would have difficulty adapting new planning tools would provide the best results. The definition of "best fit" in this instance is a term meaning a new system or tool that does not drastically change current practices of an organization and would be easier to be adapted by individuals.

BACKGROUND AND NATURE OF THE PROBLEM

Planning for a construction project on a historical site in Egypt and elsewhere requires the contractor to consider the risk of delays and possible damage caused by unexpected encounters with subsurface archaeological material. These delays can be compounded with the extended time required to assess and salvage (rescue) important archaeological finds that are exposed from the contractor's activity. It has been noted, based on a survey questionnaire as part of a research study of contractors registered to excavate on historic sites in Egypt, that delays associated with projects on historic sites are frequent, costly (time and money), and is a major cause of conflicts between the contractor and the archaeologist [4]. This is correlated with a reactive mode as there was little planning in place to avoid the unexpected finds. Construction activity on historic sites needs a thorough geophysical survey and a planning tool to implement a strategy in a proactive manner when it comes to encounters of subsurface archaeological material. The plan needs to be proven effective and also conform as much as possible to the "best fit" scenario to current practices of the management of the project.

FAILURE MODE EFFECT ANALYSIS (FMEA)

FEMA was developed as a quality control tool in the manufacturing industry. It has been adopted as a proven quality control planning tool. [5] FMEA is a method designed to:

- Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process.
- Assess the risk associated with the identified failure modes, effects, and causes, and prioritize issues for corrective action.
- Identify and carry out corrective actions to address the most serious concerns.

A FMEA is an engineering analysis done by a cross-functional team of subject matter experts that thoroughly analyzes product designs or manufacturing processes early in the product development process. Its objective is finding and correcting weaknesses before the product gets into the hands of the customer. A FMEA should be the guide to the development of a complete set of actions that will reduce risk associated with the system, subsystem, and component or manufacturing/assembly process to an acceptable level. It is essentially a proactive system rather than a reactive one. Other professions are utilizing the effectiveness of the FMEA tool. When using FMEA to assess risks associated with aerial photography, one major objective of the study was to provide necessary precautions for potential risks before they are even realized. The situation will result in important advantages with regard to reducing cost, time and manpower [6].

A FMEA was developed associated with quality control in manufacturing. To describe the process in manufacturing, a multi-diversified group meets to generate the FMEA spreadsheet. Although spreadsheet vary, the definition of the FMEA process connected with Table 1 that is used in manufacturing is as follows:

<u>Process Function</u> starts in the first column. This is a description of the process that will be analyzed.

<u>Potential Failure Mode</u> is the next column where factors are listed as to what can go wrong with the process.

<u>Potential Failure Affect</u> is a description of what the impact will be if the failure mode is not prevented or corrected.

<u>Severity Rating</u> is a number from 1 to 10 on how serious the problem is to the customer. This is rated based upon what the group determines. (1 being the lowest severity and 10 being the highest severity).

<u>Potential Failure Cause</u> is a description on what would cause the process to go wrong.

<u>Occurrence Rating</u> is a number from 1 to 10 on the probability (or how often) the cause would occur again. This is rated based upon what the group determines. (1 being the lowest chance it would occur and 10 being that it would occur at the highest rate).

<u>Preventive Action</u> is asking the question of what controls are currently in the process that prevent the failure from occurring.

<u>Detection Action</u> is asking the question of what controls are currently in the process that detect the failure.

<u>Detection Rating</u> is a number from 1 to 10 on the possibility that detection or cause of the problem will be detected (noticed or discovered). This is rated based upon what the group determines. (1 being the lowest chance it would be detected and 10 being that it would for sure be detected).

<u>Risk Priority Number</u> (RPN) is a factor derived from multiplying the groups analysis numbers derived from Severity Rating X Occurrence Rating X Detection Rating. Generally, a high RPN or a Severity Rating of 9 or 10 requires definite further action.

<u>Recommended Actions</u> is a description of what is to be done to reduce the occurrence of the cause or for improving its detection.

<u>Responsible & Deadline</u> is the individual or individuals responsible for following up on the actions and the date for the corrective actions.

<u>Actions Taken</u> is a description of what actions were actually taken on this line item.

Table 1. FMEA spreadsheet

FAILURE MODE AND EFFECTS ANALYSIS

Process: Responsibility: Page:
Product: Prepared by: Number:
Core Team: Created:
Modified:

Process Function	Potential Failure Mode	Potential Failure Effect	Severity Rating	Potential Failure Cause	Occurrence Rating	Preventive Action	Detection Action	Detection Rating	RPN	Recommended Actions	Responsible & Deadline	Actions Taken
The planned construction process (example: trenching)	In what ways can the process go wrong?	What is the impact on the owner if the failure mode is not prevented or corrected?	How severe is the effect on the customer?	What causes the step to go wrong (i.e., how could the failure mode occur)?	How frequently is the cause likely to occur?	What are the existing controls that prevent the failure mode from occurring?	What are the existing controls that detect the potential failure mode?	How probable is detection of the failure mode or its cause?	Risk Priority Number calculated	What are the actions for reducing the occurrence of the cause or for improving its detection? Provide actions on all high RPN's and on severity ratings of 9 or 10	Lead individual responsible and the date for assuring corrective measures	What were the actual actions taken?

SEVERITY: Severity of impact of failure event. It is scored on a scale of 1 to 10. A high score is assigned to high impact events while a low score is assigned to low impact events.

OCCURRENCE: Frequency of occurrence of failure event. It is scored on a scale of 1 to 10. A high score is assigned to frequently occurring events while events with low occurrence are assigned a low score.

DETECTION: Ability of process control to detect the occurrence of failure events. It is scored on a scale of 1 to 10. A failure event that can be easily detected by the process control is assigned a low score while a high score is assigned to a not easily seen or not immediately obvious event.

RISK PRIORITY NUMBER: The overall risk score of an event. It is calculated by multiplying the scores for severity, occurrence and detection. An event with a high RPN demands immediate attention while events with lower RPN's are less risky.

MODIFICATION OF FAILURE MODE EFFECT ANALYSIS (FMEA)

The FMEA process has been modified several times to better fit construction activities. Many sheets do not include the column of Preventative Action and Detection Action. Modification has been performed on the standard FMEA to include fuzzy logic and fuzzy analytical hierarchy process (AHP) to improve risk management assessment especially concerning RPN values. The values may be underestimated. Severity (S) was modified into three dimensions to include cost impact, time impact and scope/quality impact [7]. Cost, time and quality are very much related to each other. The sliding scale diagram shown in Figure 1 visually demonstrates the relationship between the three factors. In general terms, with the sliding scale moving toward decreased time, both cost and quality also decreases. With an increase in time, cost and quality also increases [8]. Using broad characterization, to deliver a quality product usually means costs are greater and it takes more time to produce. The factors of contractor's production rates also influences time, cost and quality. Summarizing, the relationship indicates that all factors are critical. As illustrated in Figure 2, On the majority of larger projects where plans and specifications are utilized, they control, to a large extent, cost and quality that in turn affects time.

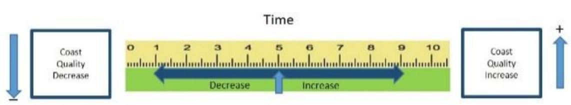


Figure 1. TCQ Sliding Scale Diagram[1]

Figure 2. Diagram of project plans and specification impact on cost, quality and time[2]

[1] Scale created by John Shearman with graphics by Khadija Adam Toh Moalem

[2] Diagram created by John Shearman with graphics by Khadija Adam Toh Moalem

Some research has shown that the current FMEA technique has limitations and problems. Measuring severity and detection is very subjective with no universal scale. Some uncertainties are reduced by utilizing a formula of a cost based FMEA that also entails applying a Monte Carlo simulation to account for uncertainties [9]. The problem with this assessment is that utilizing FMEA is a subjective instrument and the subjectivity is useful due to variations of the project site conditions and scope. It is also based on the team's specialty knowledge basis. This is why it is extremely important that qualified and knowledgeable professional are part of the team. The subjectivity can vary and be modified dependent on the conditions. Also, adding a Monte Carlo simulation is an added burden and although the current FMEA may have certain flaws, the simplicity and the added use of participant's intuition and experience makes up for any deficiencies. One method in describing Criticality, utilizes Severity and Occurrence in order to emphasize the product's effect on the customer [10]. This rating of Severity X Occurrence is what the U.S. military[3] called a Criticality Matrix. Examples of the matrix is shown in Figure 2, Figure 4 and Figure 5.

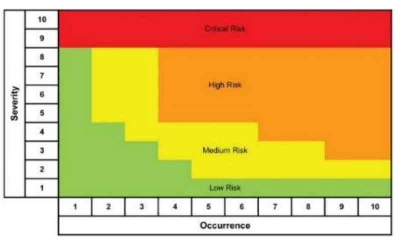


Figure 3. Example 1 of a Criticality Matrix utilizing Severity and Occurrence.

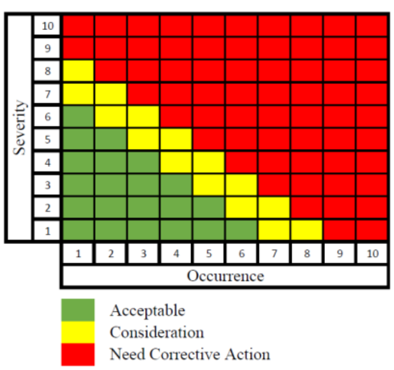


Figure 4. – Example 2 of a Criticality Matrix utilizing Severity and Occurrence.

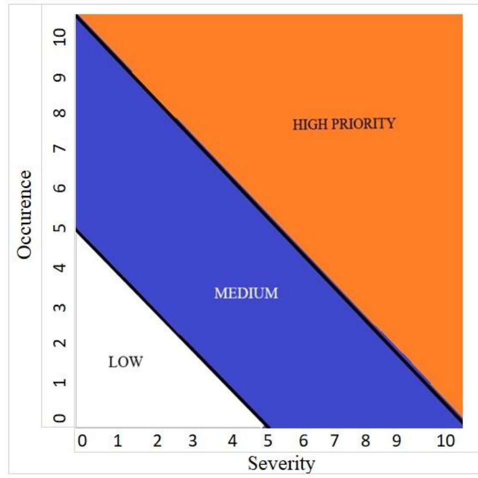


Figure 5. Example 3 of a Criticality Matrix utilizing Severity and Occurrence.

The U.S. military specification MIL-STD-882D also has a simplified rating of severity and probability (which in our case would be the probability of occurrence). Descriptions of the ratings are shown in Table 2 and Table 3 although the ratings relate to a different subject [11]. Table 4 shows percentage occurrence and adjusted to fit a new model [12]. Table 5 and Figure 6 revises the ratings to reflect the construction and archaeology focus. Figure 6 combines these ratings to a matrix that simplifies evaluations other than the standard of 1 to 10 as mentioned above.

[3] U.S. Military Standard MIL-STD-1629A was cancelled in November 1984.

Table 2. Severity rating from MIL-STD-882D associated with safety

Description	Category	Environmental, Safety and Health Result Criteria
Catastrophic	**I**	**Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation**
Critical	**II**	**Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation**
Marginal	**III**	**Could result in injury or occupational illness resulting in one or more lost work day(s), loss exceeding 10K but less than $200K, or mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished**
Negligible	**IV**	**Could result in injury or illness not resulting in a work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation**

Table 3. Probability rating from MIL-STD-882D associated with safety

Frequent	**A**
Probable	**B**
Occasional	**C**
Remote	**D**
Improbable	**E**

Table 4. Percentage of Occurrence adjusted to fit new model

Frequent	**≥100%**
Probable	**50% to 99%**
Occasional	**10% to 49%**
Remote	**1% to 9%**
Improbable	**< 1%**

Table 5. Revised Severity and Occurrence ratings to meet the construction and archaeology criteria

Severity	Rating	Probability of Occurrence	Rating
Critical	**1**	**Frequent**	**1**
High	**2**	**Probable**	**2**
Medium	**3**	**Occasional**	**3**
Low	**4**	**Remote**	**4**
		Improbable	**5**

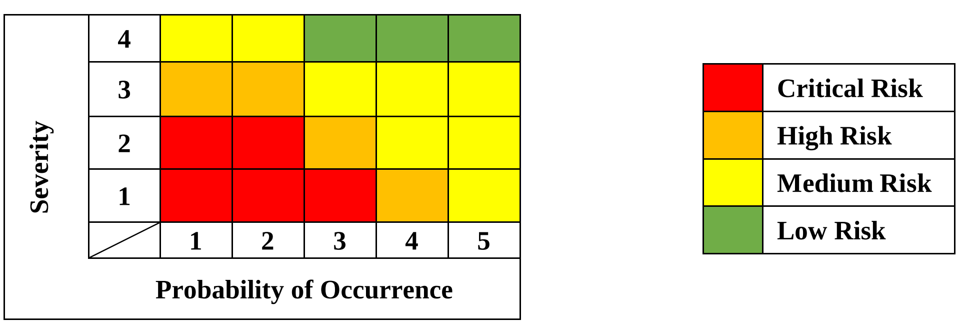


Figure 6. Revised Criticality Matrix utilizing Severity and Probability of Occurrence to meet the construction and archaeology criteria

The disadvantage of using the RPN number is that the three factors of Severity (S), Occurrence (O) and Detection (D) are not equal and have different weights. For example; weights for S and O are higher than D and must be factored to obtain a reliable RPN. It is also a factor that an RPN does not represent fully the impact of Severity (S) and/or the Occurrence (O) has on a project [13]. There are certain limitations to using RPNs, and FMEA teams need to understand those limitations. There is no single number that can represent the entirety of risk in an FMEA [5]. It is also known that Detection is better utilized in Design FMEA's and our model is focused more on the Process FMEA. Detection is a relative ranking within the scope of a specific FMEA and is determined without regard to the severity or likelihood of occurrence [5]. In our case, detection does not fit in our preconstruction risk assessment utilizing FMEA.

PRODUCTION-PRESERVATION CRITICALITY FMEA (PPCFMEA)

To modify FMEA to fit the engineering-construction and the archaeology processes, a simplified procedure based on site information coupled with current practices is the logical approach. Combining certain characteristics of the Process FMEA combined with the Criticality Matrix and simplified severity and occurrence ratings would provide risk assessments based on geophysical information and historical references coupled with the input of a multi-diversified composite of project participants and consultants for analysis utilizing a worksheet. The revised product is a Production-Preservation Criticality FMEA (PPCFMEA). A good team leader is paramount [10]. The team leader will direct the activities of the team consisting of experienced professionals such as a Property Owner Representative, Financier, Engineers, Construction Personnel, Archaeologists, Conservators, Geologists, Government Officials, specialists and other stakeholders for a specific site would meet and assess potential problems utilizing a PPCFMEA to reduce contractor encounters with archaeological remains and reduce interference with contractor production. The use of the subsurface map (including information gained from geophysical surveys), desk-based assessment and other critical site information is required for the assessment of potential encounters during construction. The data from this information created with the use of the appropriate geophysical assessments, is employed as a guide on what action to take dependent on the opinions of the specialists in conjunction with the PPCFMEA factors on the worksheet. Risk assessment can be improved, and decisions and plans can be better obtained with superior data and a multi-disciplined team. A PPCFMEA is an agreement on what action to take. As an example, determinations and plans can be made to perform a test pit excavation on an anomaly and salvage an artifact prior to general construction activities if necessary to avoid contractor delays or damage to the archaeological remains.

COMBINING THE PPCFMEA WITH THE CASE STUDY AS AN EXAMPLE

As the evidence shows in a case study performed by the author for a groundwater lowering project at Kom Ombo Temple near Aswan, Egypt, an extensive and well developed geophysical survey and analysis was performed on the site. Sections were developed to show the potential for archaeological material encounters. Even with this development, there was still interferences with contractor production and archaeological material preservation. This is where the combination of the PPCFMEA and current practices can improve processes and reduce the contractor delay risks when performing excavations on archaeological sites. One important factor is the added cost to a project for performing a detailed geophysical study of the site. Many local universities have the necessary equipment and expertise to perform a proper geophysical study as do private companies. The costs involved in the work should not be excessive and the benefits for subsurface mapping of anomalies could be analyzed by the experts and discussed with the PPCFMEA team and would be the subsurface map of record where the lessons learned on the types of anomalies can be recorded for future use or predictions models could be developed.

The PPCFMEA using the Revised Criticality Matrix should be used as a powerful "best fit" preconstruction planning tool. Using the current practices, a thorough geophysical mapping of the site utilizing several geophysical methods including ground-penetrating radar (GPR) scans, magnetometry, electrical-resistivity tomography (ERT), gravimetry, electrical conductivity, seismic, borings, test pits and other methods could be performed and the excavation areas could be divided into sections as was executed in the Kom Ombo Temple project. With a desk-based assessment and the geophysical information, the multi-diversified group would use the PPCFMEA worksheet on each section with the Criticality Matrix to highlight critical anomalies that would need additional action. Since test pits are commonly used in Egypt, the subsurface map could assist the group of experts utilizing the PPCFMEA worksheet to determine the critical areas of anomalies where test pits (or other forms of archaeological investigation) should be designated and perform salvage operations prior to construction operations if necessary to reduce the contractor work stoppage, improve the production factor, reduce the project duration and reduce the chances of archaeological material damage. An example of a PPCFMEA worksheet is shown in Table 6 using the Kom Ombo Temple project desk-based assessment. The authors of the desk-based assessment used pipe runs as one of their identified areas. Fictitious cardinal point and station designations were added for possible significant anomalies as shown in Figure 7 for the purpose of PPCFMEA worksheet explanation. The system can use zones or any other area designations as long as anomaly points can be located.

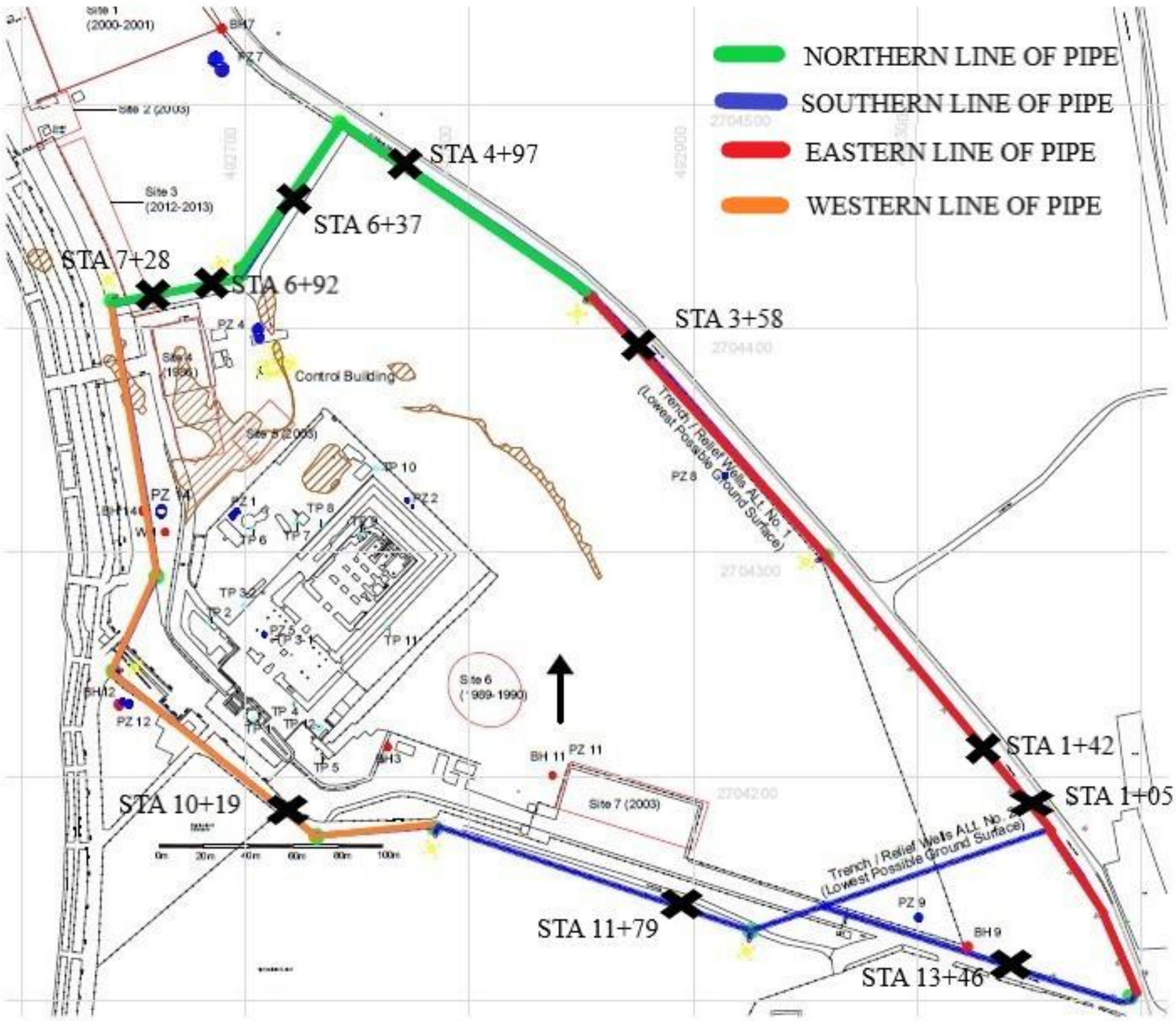


Figure 7. Proposed groundwater collection pipes, manholes and relief wells. Kom Ombo Temple Project. Drawing showing fictitious pipe line identities and stations for anomaly locations. Map source: [14].

Table 6. PPCFMEA Worksheet example utilizing FMEA basics as a risk assessment tool for preconstruction planning on improving preservation of archaeological material and contractor production.

PPCFMEA WORKSHEET

Core Team: — **Page 1 of 1**

Design Engineer — **Prepared by: Eng. Shearman**

Ministry of Tourism and Antiquities

Contractor — **Date: January 12, 2015**

Archaeologist — **Modified:**

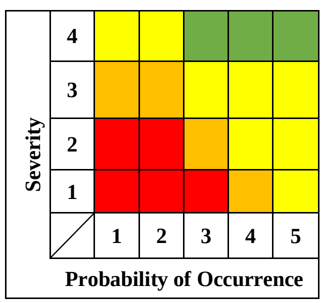
Geophysical Engineer — **Surveyor** — **Historian**

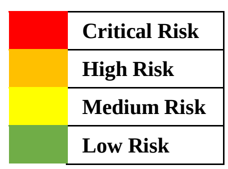
Egyptologist — **Chief Accountant** — **Project Manager**

Conservator — **Geologist** — **Superintendent** — **Scheduler**

Process Function Description	Potential Failure Mode	Potential Failure Effect	Severity Rating (1-4)	Potential Failure Cause	Occurrence Rating (1-5)	Preventative Action	Criticality Matrix	Recommended Actions	Responsible and Deadline	Action Taken & Completion Date
Eastern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Archaeological Finds	3	Test pits for anomaly Station 1+05	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer February 24, 2015	Salvaged Inscribed Blocks February 12, 2015
Eastern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Archaeological Finds	3	Test pits for anomaly Station 1+42	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer February 24, 2015	Salvaged Statue Fragments February 16, 2015
Eastern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Archaeological Finds	3	Test pits for anomaly Station 3+58	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer February 24, 2015	Salvaged Inscribed Blocks February 18, 2015
Northern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Finds	2	Test pits for anomaly Station 6+37	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer March 8, 2015	Salvaged Inscribed Blocks February 20, 2015
Northern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Finds	2	Test pits for anomaly Station 6+92	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer March 8, 2015	Salvaged Uninscribed Block February 28, 2015
Northern Line of Pipe	Construction Delay	Additional Cost and Time	1	Unanticipated Finds	2	Test pits for anomaly Station 7+28	Critical Risk	Test Pit. Salvage Archaeology if required	Design Engineer February March 8, 2015	Salvaged Uninscribed Block February 30, 2015
Western Line of Pipe	Construction Delay	Additional Cost and Time	3	Unanticipated Finds	2	Re-route pipe run to avoid anomaly Station 10+19	High Risk	Re-route pipe run to route with no major anomalies	Design Engineer March 20, 2015	No major anomalies or work stoppage
Southern Line of Pipe	Construction Delay	Additional Cost and Time	3	Unanticipated Finds	2	Test pits for anomaly Station 11+79	High Risk	Test Pit. Salvage Archaeology if required	Design Engineer March 20, 2015	Mud Brick Walls. Preservation by Record
Southern Line of Pipe	Construction Delay	Additional Cost and Time	3	Unanticipated Finds	3	Test pits for anomaly Station 13+46	Medium Risk	Test Pit. Salvage Archaeology if required	Design Engineer March 20, 2015	Non-archaeological material
Discharge Force Main	Construction Delay	Additional Cost and Time	3	Unanticipated Finds	4	Archaeologist Observer	Low Risk	None	Archaeologist Report	Recorded Small Finds No Construction Impact

Severity	Rating	Probability of Occurrence	Rating	Percent Occurrence
Critical	1	Frequent	1	≥ 100%
High	2	Probable	2	50% to 99%
Medium	3	Occasional	3	10% to 49%
Low	4	Remote	4	1% to 9%
		Improbable	5	< 1%





CONCLUSION

Each project requires planning to minimize risk and remove barriers to achieve more efficient production. In many instances, pre-construction planning is a process performed by an organization as a group effort. This study has presented the idea that the modified FMEA (PPCFMEA) is a "best fit" tool that is used in a group meeting setting as part of pre-construction planning. The PPCFMEA can also be custom modified to better serve the organizations routines and needs. This paper has presented the use of a modified FMEA as a pre-construction planning tool but its effect will be reduced substantially unless a thorough geophysical survey is performed to work hand-in-hand with the instrument. The PPCFMEA is used to perform the necessary archaeological investigations or salvage operations prior to the construction activity based upon the severity and occurrence of possible subsurface archaeological material. The geophysical survey (among other benefits) is also used to emphasize anomalies on a historic site that may require further attention. Utilizing the PPCFMEA, archaeologists may identify anomalies that require exposure and salvage prior to construction activities based upon geophysical survey information (proactive). Possible damage to historic material may be avoided and more time may be provided to the archaeologist without pressure from the contractor thus avoiding major conflicts. If unexpected encounters with archaeological material is substantially reduced, the contractor will improve production efficiency and reduce the time to complete the project. This is a win-win scenario for all parties including owners and other stakeholders.

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Conflicts of interest

There are no conflicts to declare.

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