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Risk Based Inspection: Reliability Analysis for Preventative Maintenance on Equipment and Components Through Software

Risk based inspection (RBI) is a method in which assets are identified for inspection based on their associated risks as opposed to predetermined fixed time intervals. The method was developed by the American Petroleum Institute (API) and is predominantly used within the oil and gas industries to identify high risk equipment and to assess the probability of failure, as well as the consequences of such a failure, for that equipment.

API has created several standards on risk based inspection, specifically API RP 580[1] and API RP 581[2]. These two standards combine to form the basis for RBI, with API RP 580 outlining the method qualitatively and API RP 581 as a tool to help perform quantitative analyses on both probability of failure (reliability) and consequence of failure in order to determine risk. The method also provides guidance to owners, operators, and managers in ranking their equipment based on risk and helping allocate limited resources for inspections.

Through managing risk and optimizing inspections, RBI helps prevent shut downs and damage to surrounding assets, people, and the environment. The prevention of shutdowns maintains current personnel schedules and prevents productivity loss, translating to stronger financial statements. In the oil and gas industries, as well as other industries, leaked chemicals have the potential to create very expensive environmental disasters with widespread long lasting consequences on plants, animals, and people. One disaster can easily bankrupt a company as it could require settlements, cleanup costs, and scrutiny from the media leading to negative public perception.

RISK

In RBI the equation for risk is calculated as the product of the probability of failure (POF) and the consequence of failure (COF). This equation provides a more precise measurement for prioritization than either the POF or the COF alone. It is important to note that it is assumed that the COF is constant unless a change is made in the process conditions. This makes POF, and therefore reliability, the only variable which is dependent on maintenance.

$$Risk(t) = POF(t) \times COF$$

The POF is determined using applicable damage mechanisms, Df(t), a generic failure frequency, gff, and a management system factor, FMS. Damage mechanisms are factors or methods in which the equipment or component being inspected is damaged. Examples of damage mechanisms within the oil and gas industry include thinning damage, amine cracking damage, caustic cracking damage, sulfide stress cracking

Published Quarterly

Russell A. Vacante, Ph.D.

Is the Defense Acquisition System Broken?

The title of this article is intended to be provocative and this may be a good thing, if it leads to discussions regarding the need for acquisition reform. Acquisition change that casts aside existing policies, procedures and existing assumptions is required. This does not mean reforming the current acquisition system; we must start with a blank slate and redesign it from the bottom up.

Yes, the acquisition system is broken! Its current state is inefficient and very costly. Endemic tinkering with acquisition policy, procedures and guidance is the operational nature of DoD policy administrators. Internal governmental career pressure on new leaders to make their mark upon the

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damage, as well as many more. Generic failure frequency is based upon industry averages of historical equipment failures. The management system factor is a measure of how well the management and labor force of the plant is trained to handle both the day-to-day activities of the plant and any emergencies that may arise due to an accident. It is calculated through a survey given to management.

The rigorous form of the POF equation is:

$$POF(t) = 1 - e^{-gff \times D_f(t) \times FMS)}$$

This can be often approximated by:

$$POF(t) = gff \times D_f(t) \times FMS$$

The *COF* includes both an area (safety) consequence, COF_{CA}, and a financial consequence, COF_{FC}. While the area consequence only incorporates the area effects of fire injury, CA_{inj}, and toxic hazards, CA_{tox}, for personnel, the financial consequence includes the cost to repair the equipment, FC_{cmd}, the cost to repair the surrounding equipment, FC_{affa}, loss of production, FC_{prod}, liabilities due to personnel injury, FC_{inj}, and costs due to environmental clean-up, FC_{env}. Risk ranking can be assigned to equipment based on either safety or financial risk, or a combination of the two.

$$COF_{CA} = max(CA_{inj}, CA_{tox})$$

$$COF_{FC} = FC_{cmd} + FC_{affa} + FC_{prod} + FC_{inj} + FC_{env}$$

Once each asset within a plant has been analyzed and ranked based on the risk of its operation, optimized inspection planning and thus better maintenance schedules can be created with greater emphasis on those assets that pose a higher risk.

The major downside in having to perform an RBI analysis on a plant is the vast amount of data and computation required for both a qualitative and especially a quantitative risk ranking.

Software packages such as ReliaSoft Corporation's RBI software tool help automate API RBI guidelines by performing the complex calculations and reliability analysis.

Next is an example of the RBI method using ReliaSoft's RBI software which facilitates RBI analysis for oil, gas, chemical, and power plants in adherence to the principles and guidelines presented in the American Petroleum Institute's recommendations in API RP 580 and API RP 581 publications, as well as the American Society of Mechanical Engineer' recommendations in the ASME PCC-3-2007 publication.

EXAMPLE

A crude oil distillation column is analyzed for risks associated with loss of containment. The column is made of carbon steel, and it operates at a temperature of 300 °C and a pressure of 2 bars (abs). The column was installed in 1982 and is due to undergo preventative maintenance in 2022.

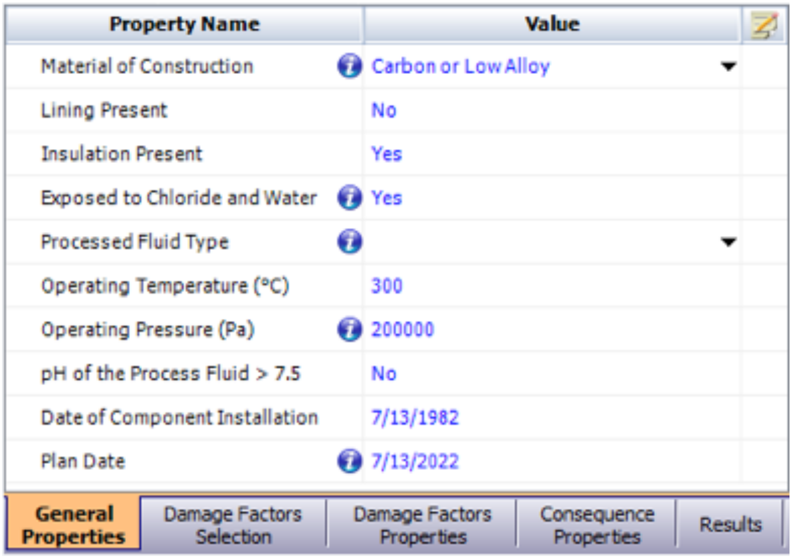
The expected damage mechanisms (factors) are thinning (internal corrosion), sulfide stress cracking, and hydrogen induced cracking due to hydrogen sulfide (FIGURE B, following page).

The properties required to calculate the probability of failure based on the damage factors are physical properties of the column, information regarding previous inspections, and properties of the process fluid. A distribution is fitted to the calculated probabilities at different times to generate a probability of failure model.

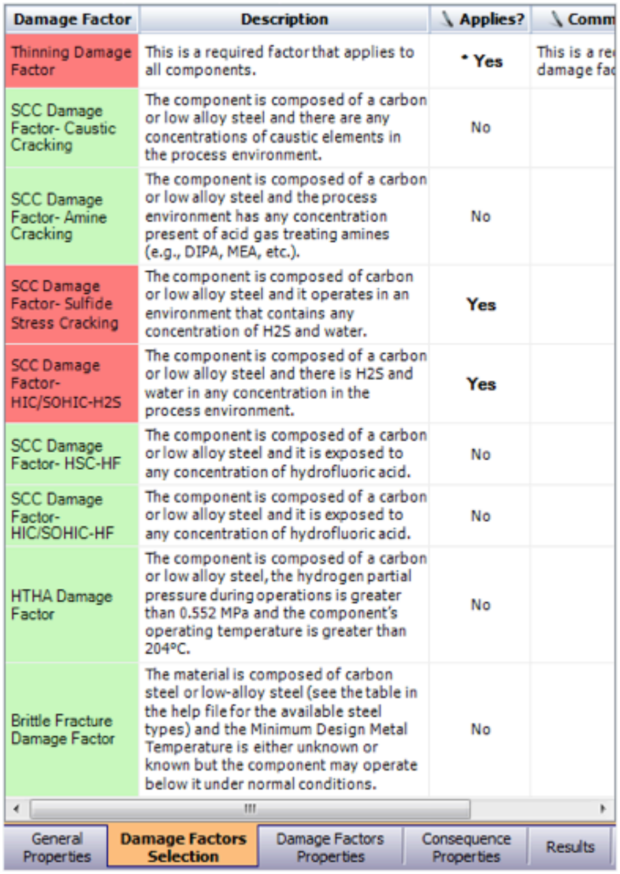
The properties required to calculate the consequence of failure are a combination of physical properties of the asset and surroundings, safety systems protecting the asset and surroundings, the process fluid, and the various costs associated with repairs, liabilities, clean-up (FIGURE C, following page).

Also, the maximum allowed risk for both area (safety) and financial (cost) consequences are required to determine if the asset is estimated to exceed the allowable risk before the next planned turnaround (maintenance) date. These maximums are decided upon by management.

Figure D, on following page, shows the inputs required for both the consequences of failure and the maximum allowable risks (highlighted in red).

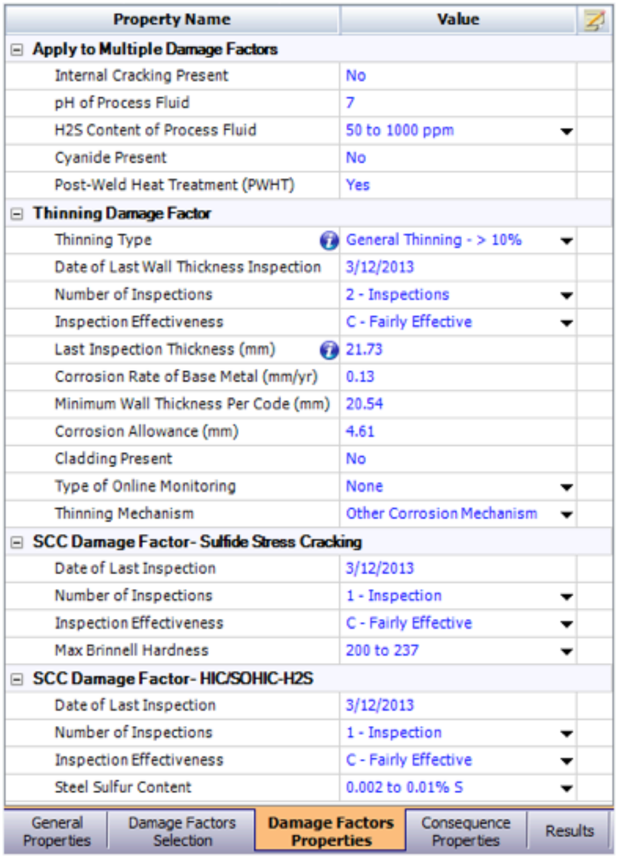


Property Name	Value
Material of Construction	Carbon or Low Alloy
Lining Present	No
Insulation Present	Yes
Exposed to Chloride and Water	Yes
Processed Fluid Type	
Operating Temperature (°C)	300
Operating Pressure (Pa)	200000
pH of the Process Fluid > 7.5	No
Date of Component Installation	7/13/1982
Plan Date	7/13/2022



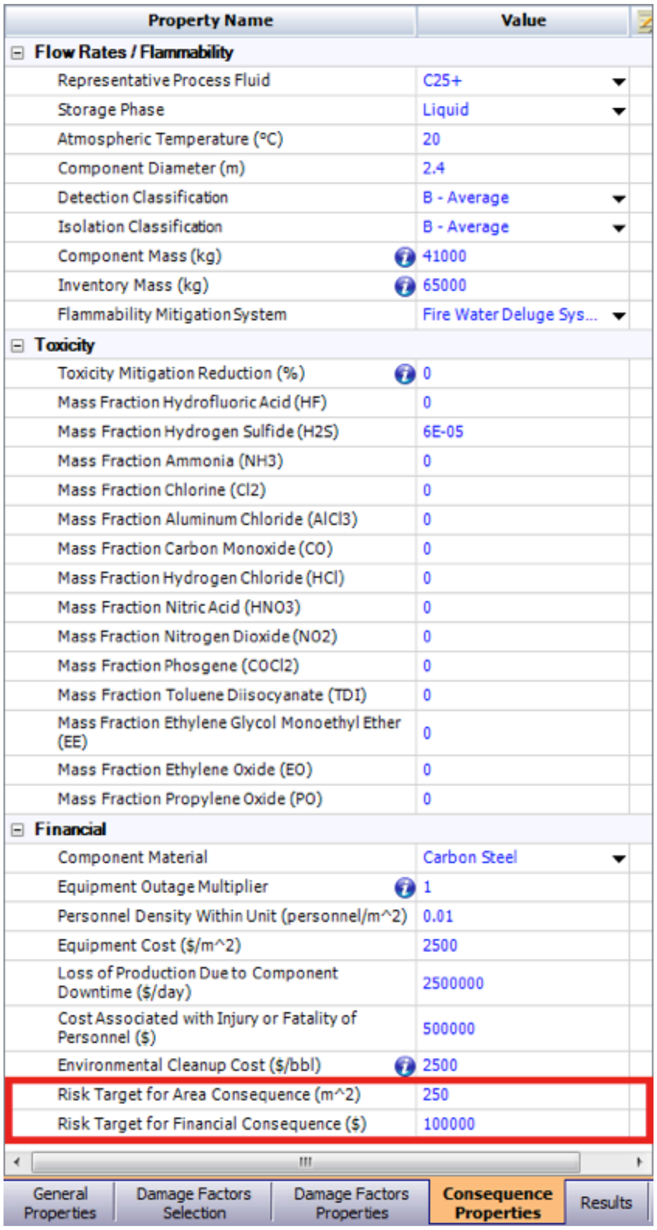
Damage Factor	Description	Applies?	Comm
Thinning Damage Factor	This is a required factor that applies to all components.	* Yes	This is a re damage fac
SCC Damage Factor- Caustic Cracking	The component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment.	No	
SCC Damage Factor- Amine Cracking	The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.).	No	
SCC Damage Factor- Sulfide Stress Cracking	The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water.	Yes	
SCC Damage Factor- HIC/SOHIC-H2S	The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment.	Yes	
SCC Damage Factor- HSC-HF	The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid.	No	
SCC Damage Factor- HIC/SOHIC-HF	The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid.	No	
HTHA Damage Factor	The component is composed of a carbon or low alloy steel, the hydrogen partial pressure during operations is greater than 0.552 MPa and the component's operating temperature is greater than 204°C.	No	
Brittle Fracture Damage Factor	The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions.	No	

Figure B



Property Name	Value
Apply to Multiple Damage Factors	
Internal Cracking Present	No
pH of Process Fluid	7
H2S Content of Process Fluid	50 to 1000 ppm
Cyanide Present	No
Post-Weld Heat Treatment (PWHT)	Yes
Thinning Damage Factor	
Thinning Type	General Thinning - > 10%
Date of Last Wall Thickness Inspection	3/12/2013
Number of Inspections	2 - Inspections
Inspection Effectiveness	C - Fairly Effective
Last Inspection Thickness (mm)	21.73
Corrosion Rate of Base Metal (mm/yr)	0.13
Minimum Wall Thickness Per Code (mm)	20.54
Corrosion Allowance (mm)	4.61
Cladding Present	No
Type of Online Monitoring	None
Thinning Mechanism	Other Corrosion Mechanism
SCC Damage Factor- Sulfide Stress Cracking	
Date of Last Inspection	3/12/2013
Number of Inspections	1 - Inspection
Inspection Effectiveness	C - Fairly Effective
Max Brinnell Hardness	200 to 237
SCC Damage Factor- HIC/SOHIC-H2S	
Date of Last Inspection	3/12/2013
Number of Inspections	1 - Inspection
Inspection Effectiveness	C - Fairly Effective
Steel Sulfur Content	0.002 to 0.01% S

Figure C

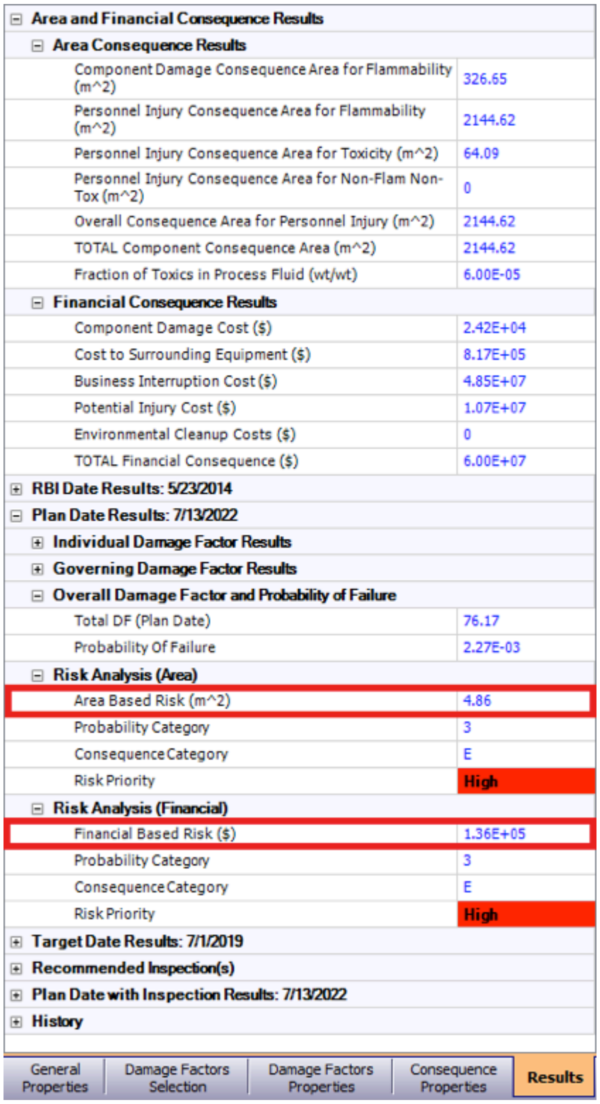


Property Name	Value
Flow Rates / Flammability	
Representative Process Fluid	C25+
Storage Phase	Liquid
Atmospheric Temperature (°C)	20
Component Diameter (m)	2.4
Detection Classification	B - Average
Isolation Classification	B - Average
Component Mass (kg)	41000
Inventory Mass (kg)	65000
Flammability Mitigation System	Fire Water Deluge Sys...
Toxicity	
Toxicity Mitigation Reduction (%)	0
Mass Fraction Hydrofluoric Acid (HF)	0
Mass Fraction Hydrogen Sulfide (H2S)	6E-05
Mass Fraction Ammonia (NH3)	0
Mass Fraction Chlorine (Cl2)	0
Mass Fraction Aluminum Chloride (AlCl3)	0
Mass Fraction Carbon Monoxide (CO)	0
Mass Fraction Hydrogen Chloride (HCl)	0
Mass Fraction Nitric Acid (HNO3)	0
Mass Fraction Nitrogen Dioxide (NO2)	0
Mass Fraction Phosgene (COCl2)	0
Mass Fraction Toluene Diisocyanate (TDI)	0
Mass Fraction Ethylene Glycol Monoethyl Ether (EE)	0
Mass Fraction Ethylene Oxide (EO)	0
Mass Fraction Propylene Oxide (PO)	0
Financial	
Component Material	Carbon Steel
Equipment Outage Multiplier	1
Personnel Density Within Unit (personnel/m^2)	0.01
Equipment Cost ($/m^2)	2500
Loss of Production Due to Component Downtime ($/day)	2500000
Cost Associated with Injury or Fatality of Personnel ($)	500000
Environmental Cleanup Cost ($/bbl)	2500
Risk Target for Area Consequence (m^2)	250
Risk Target for Financial Consequence ($)	100000

Figure D

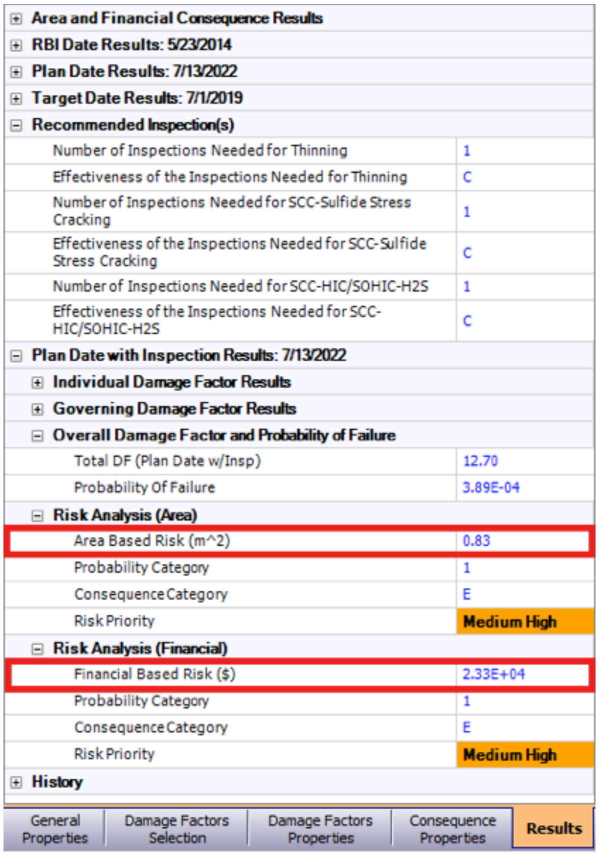
The results, based upon the estimated consequences and the predicted probability of failure, indicate that the estimated financial risk will exceed the maximum allowable financial risk by the next planned turnaround date.

The date at which the risk (product of the probability of failure and consequence of failure) reaches the maximum allowed risk is the target date. In this case, the target date is July 1st, 2019 and is the date at which inspections are recommended. If during those inspections everything is found to be within expectations, then the newly estimated risk will not exceed the maximum allowed risk by the turnaround date.



⊟ **Area and Financial Consequence Results**	
⊟ **Area Consequence Results**	
Component Damage Consequence Area for Flammability (m^2)	326.65
Personnel Injury Consequence Area for Flammability (m^2)	2144.62
Personnel Injury Consequence Area for Toxicity (m^2)	64.09
Personnel Injury Consequence Area for Non-Flam Non-Tox (m^2)	0
Overall Consequence Area for Personnel Injury (m^2)	2144.62
TOTAL Component Consequence Area (m^2)	2144.62
Fraction of Toxics in Process Fluid (wt/wt)	6.00E-05
⊟ **Financial Consequence Results**	
Component Damage Cost ($)	2.42E+04
Cost to Surrounding Equipment ($)	8.17E+05
Business Interruption Cost ($)	4.85E+07
Potential Injury Cost ($)	1.07E+07
Environmental Cleanup Costs ($)	0
TOTAL Financial Consequence ($)	6.00E+07
⊞ **RBI Date Results: 5/23/2014**	
⊟ **Plan Date Results: 7/13/2022**	
⊞ **Individual Damage Factor Results**	
⊞ **Governing Damage Factor Results**	
⊟ **Overall Damage Factor and Probability of Failure**	
Total DF (Plan Date)	76.17
Probability Of Failure	2.27E-03
⊟ **Risk Analysis (Area)**	
Area Based Risk (m^2)	4.86
Probability Category	3
Consequence Category	E
Risk Priority	**High**
⊟ **Risk Analysis (Financial)**	
Financial Based Risk ($)	1.36E+05
Probability Category	3
Consequence Category	E
Risk Priority	**High**
⊞ **Target Date Results: 7/1/2019**	
⊞ **Recommended Inspection(s)**	
⊞ **Plan Date with Inspection Results: 7/13/2022**	
⊞ **History**	

Figure E



⊞ **Area and Financial Consequence Results**	
⊞ **RBI Date Results: 5/23/2014**	
⊞ **Plan Date Results: 7/13/2022**	
⊞ **Target Date Results: 7/1/2019**	
⊟ **Recommended Inspection(s)**	
Number of Inspections Needed for Thinning	1
Effectiveness of the Inspections Needed for Thinning	C
Number of Inspections Needed for SCC-Sulfide Stress Cracking	1
Effectiveness of the Inspections Needed for SCC-Sulfide Stress Cracking	C
Number of Inspections Needed for SCC-HIC/SOHIC-H2S	1
Effectiveness of the Inspections Needed for SCC-HIC/SOHIC-H2S	C
⊟ **Plan Date with Inspection Results: 7/13/2022**	
⊞ **Individual Damage Factor Results**	
⊞ **Governing Damage Factor Results**	
⊟ **Overall Damage Factor and Probability of Failure**	
Total DF (Plan Date w/Insp)	12.70
Probability Of Failure	3.89E-04
⊟ **Risk Analysis (Area)**	
Area Based Risk (m^2)	0.83
Probability Category	1
Consequence Category	E
Risk Priority	**Medium High**
⊟ **Risk Analysis (Financial)**	
Financial Based Risk ($)	2.33E+04
Probability Category	1
Consequence Category	E
Risk Priority	**Medium High**
⊞ **History**	

Figure F

CONCLUSION

Risk based inspection methodologies are a useful tool in the optimization of inspection planning and maintenance scheduling for pressurized equipment, leading to a decrease in the overall risks and costs associated with day-to-day operations by minimizing the uncertainty in the reliability of the asset.

As demonstrated in the above example, performing the recommended inspections based on RBI at the target date decreased the financial risk at the plan date from $136,000 to $23,300 (assuming everything is found to be within expectations). ●

REFERENCES

1) API RP 580: Risk-Based Inspection, Downstream Segment. API Recommended Practice 580, Second Edition, November 2009

2) API RP 581: Risk-Based Inspection Technology. API Recommended Practice 581, Second Edition, September 2008

ABOUT THE AUTHORS

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John Leavitt *is a research scientist within ReliaSoft, where he works to develop and support the development of new ideas for new and existing software. His reliability orientated interests include risk based inspection, probabilistic event and risk analysis, and customizable reliability software using API calls. His recent past non-reliability involvements include developing a small business, serving on the board of a credit union, and teaching business classes. Mr. Leavitt holds a B.S. in Accounting and a M.S. in Management Information Systems from the University of Arizona.*

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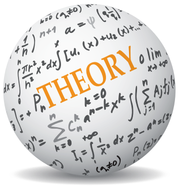

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M440	Reliability and Maintainability Analysis for Repairable Systems
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Dev Raheja

Flawed Design, Production, and System Integration Requirements are Preventing the Turnaround from the Inflection Point

The Spring 2014 issue of The Journal of RMS in Systems Engineering, James Rodenkirch discussed how the acquisition process has reached an inflection point, i.e., become a negative process. We have been edging along this negative trend for a long time. It is time for the acquisition process to once again move in a positive direction. But this cannot be done until we fix the fundamentals. As shown in Figure 1 each of the major acquisition requirements are flawed. Therefore the entire life cycle engineering process is flawed.

This article will discuss the details of those flaws while offering ways to remedy, via suggested fixes, the entire life cycle engineering process.

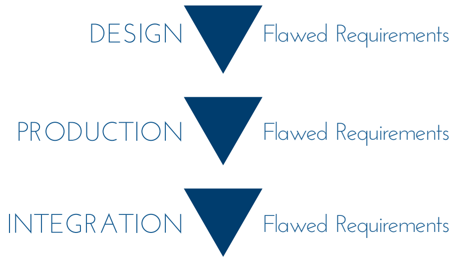


Figure 1

Design Requirement Flaws

System failures can cost billions. The NASA Challenger shuttle accident was one of them. The shuttle with over one million components exploded and eight astronauts died. The entire program was on hold for two years. This was a classic example of a design requirements flaw. The flaw was that the design required that the shuttle should not be allowed to fly if the ambient temperature is below 40 degrees Fahrenheit. It appeared to be a technical requirement. However, what the designers failed to anticipate was that management decisions could be made that circumvents technical requirements that in turn could jeopardize mission success. In addition to cost and schedule pressure, there was a timing pressure—President Reagan was going to witness the flight and planned to talk about it in the State of the Union address!

Some hard questions should have been asked and information shared relevant to technical requirements and weather conditions. Someone should have asked why the shuttle should not fly when the temperature falls below 40 degrees Fahrenheit. Better yet, non-retribution lines of communication should have been open among the technical and non-technical decision makers so that all shared the same information. This being the case all would have understood that "because the rubber seal can freeze at this temperature it will not protect against fuel leaks." This shared information would have resulted in the postponement of the flight, avoiding a human tragedy—with little or no lasting negative political consequences. In the end, the installation of a heating wire around the rubber seal allowed the shuttle to fly at much colder temperatures.

This example fits in to one of three serious deficiencies in developing system requirements. These deficiencies can be classified as:

- Known requirements deficiency
- Unknown requirements deficiency
- Unknown-unknown requirements deficiency

Known Requirements Deficiencies

The NASA shuttle example is an example of this type of deficiency. The requirements are known but review teams are not challenging them in light of final flight worthiness system decisions. Teams should also be looking for and making design decisions pertaining to requirements such as durability, resiliency, minimum system life, minimum life of critical components, elimination of most corrective maintenance by design, and many other life cycle engineering requirements. The early-on and continuous examination of these requirements during a system's total life cycle will help to mitigate the occurrence of deficiencies related to known requirements.

Unknown Requirements Deficiencies

Requirement deficiencies can be discovered using risk analysis tools such as Failure Mode Effects and Criticality Analysis (Mil-std-1629), Preliminary Hazard Analysis (Mil-Std-882), Fault Tree Analysis (Mil-Std-882), Hazard and Operability Study (used in chemical and medical device industry) and Operations & Support Hazard Analysis (Mil-Std-882). Unfortunately I have rarely seen a good FMECA, the most popular and highly regarded reliability engineering risk analysis tool. Having the appropriate tool to identify unknown deficiencies may not be enough in itself. Knowing when and how to apply them is equally important. Often, FMECAs are conducted late in the life cycle process and as a result such analysis frequently proves to be inadequate.

Unknown-Unknown Requirements Deficiencies

Requirements are often unknown during formal analyses or even during brainstorming sessions by the new personnel working on new systems. The following data on a major airline, announced at an FAA/NASA workshop [3] provides examples of unknown-unknown failures, i.e., failures not known to FAA or maintained in American airlines files:

- Number of near misses known to FAA - 160
- Problems reported confidentially by American Airlines employees—about 13,000

This case history shows there could be hundreds, if not thousands, of unknown-unknowns that escape the requirement review process. The term unknown-unknown may be a misnomer since, as is often the case, employees are aware of issues. The fact that such incidents are not documented and considered in the requirements and design process suggests that, intentionally or otherwise, many knowledgeable people are not being asked to provide important input to the cradle to grave life cycle management model process. It may also suggest that there exists in various organizations a culture of intimidation that discourages folks from speaking out on such issues.

PRODUCTION REQUIREMENT(S) FLAWS

The situation is worse regarding production requirement flaws. Seldom do contractors' within the U.S. conduct a requirement(s) analysis for the production processes. As a result, the need for corrective maintenance actions can be traced to production flaws. Second, few contractors conduct FMECAs prior to initiating the production process. As a result, they may wind up choosing the wrong manufacturing requirements. The Navy recently did this with a wire bonding process for integrated circuits chips. They required the bond strength of 8 grams. The process met the 8 grams mean strength requirement but produced over 40% defective production. The requirement flaw was that the Navy did not clearly and accurately stipulate the requirement: i.e., the minimum bond strength had to be 8 grams. Third, many contractors do not aim for achieving Zero Defects like the commercial industry reportedly does. Philip Crosby, the former senior vice president at ITT Defense, brought this concept to the defense industry years ago. However, it has been mostly ignored as a contract requirement. Most contracts still use MTBF as the preferred way to measure defects.

SYSTEM INTEGRATION REQUIREMENT(S) FLAWS

The flaws in system integration requirements are similar to the design requirements flaws mentioned in this article. The National Defense Industrial Association has identified the top system engineering issues related to integration flaws [ref. 4]. They are:

- Key systems engineering practices known to be effective are not consistently applied across all phases of the program life cycle.
- Insufficient systems engineering is applied early on in the program life cycle, compromising the foundation for initial requirements and architecture development.
- Requirements are not always well-managed, including the effective translation from capability statements into executable requirements to achieve successful acquisition programs.
- The quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and the defense industry.
- Collaborative environments, including SE tools, are inadequate to effectively execute SE at the joint capability, system of systems (SoS), and system levels.

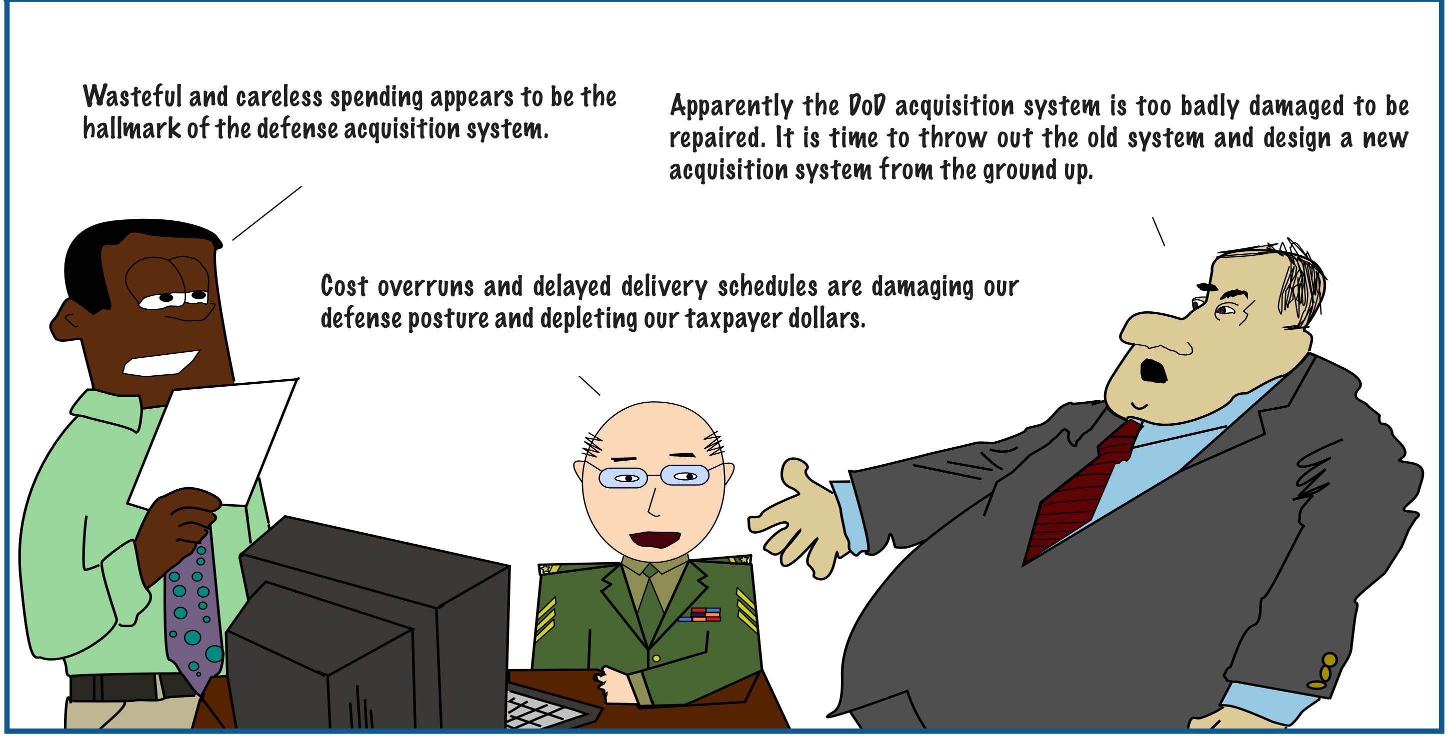
WE CAN INFLECT IN THE POSITIVE DIRECTION

After the Hiroshima bombings, Japan was devastated. They needed to recover economically but their products were known to have the lowest quality rating in the world. General McArthur arranged for Dr. Edward W. Deming to help them; the rest is history as Japan became the world quality leader. Deming's contribution to quality assurance was not recognized in the U.S. until he was 84 years-old. Many industries, including the defense contractors, tried to adopt his methods but they mistakenly focused on his statistical quality control theory. They continue to disregard the insight Deming provided on system theory. Consequently, system theory (i.e., a system engineering perspective) is badly lacking in developing system level specifications within the commercial and defense communities in the U.S.

According to Deming [ref. 5] the prevailing style of management must undergo transformation. An organization reportedly cannot understand itself. Often for the transformation to be achieved a view from "outside" an organization is necessary. Deming advocated that all

Another Day At The Office

by Russell A. Vacante, Ph.D.



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managers acquire what he called a "System of Profound Knowledge," consisting of four parts:

1) *Appreciation of a system*: understanding the overall processes involving suppliers, producers, and customers
2) *Knowledge of variation*: the range and causes of variation in quality, and use of statistical sampling in measurements
3) *Theory of knowledge*: the concepts explaining knowledge and the limits of what can be known
4) *Knowledge of psychology*: concepts of human nature.

Dr. Deming emphasizes the first point as follows: The Appreciation of a system involves understanding how interactions (i.e., feedback) between the elements of a system can result in internal restrictions that force the system to behave as a single organism, automatically seeking a steady state. It is this steady state that determines the output of the system rather than the individual elements.

Therefore, the appreciation and application of the system by the whole organization is the key to rising from the inflection point! ●

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acquisition process, as well as Presidential and Congressional pressure to deliver state of the art technologies at a lower cost makes acquisition reform "tinkering" inevitable. Recent and previous changes to DoD 5000.1, associate policies and guidelines serve as one example of this "need to tinker." While the goal of improving the acquisition process is commendable, the totality of these changes in the past 30-35 years has not curbed weapon system cost overruns significantly nor improved system delivery schedules.

From the defense industry community comes competitive and political pressure to lowball the cost estimates of designing and developing new systems regardless of complexity while, simultaneously, clamoring for less government oversight and mandates. The acquisition reform of the 1900's era is a prime example of how industry managed successfully to place the blame upon the government for cost overruns and schedule delays they were experiencing. Post acquisition reform era hindsight reveals that industry profits continue to soar while cost overruns and schedule delays persist to cause economical injury to our national security.

Millions of dollars and labor hours have been invested in the Joint Strike Fighter (F-35), designed and built by Lockheed Martin Corporation. It is reportedly seven years behind schedule, plagued with costly technical problems that have elevated the price-per-unit which, in turn, has significantly reduced the number of planes that can be delivered. The original DoD plan was to purchase 2443 F-35s at a cost of $323 billion however, due to cost overruns, the Air Force and the Navy will buy fewer than intended. Since delays are expensive these cost(s) will, in all probability, continue to reduce the number of aircraft the Services can afford to buy. Remaining technical problems with the F-35, the most costly procurement project ever taken on by

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DoD, has the potential to further deplete the taxpayer's purchasing dollars at the current procurement levels and reduce the number of aircraft made available to the acquiring Services even more.

The F-22 Raptor is another example of how out of control and damaging the acquisition process has become in recent years. The government is providing extra funding to maintain its stealth coating as well as paying Lockheed Martin $24 million dollars to repair an oxygen delivery deficiency problem that caused shallow breathing and corresponding decreased levels of alertness among pilots. In addition, an off-boresight and lock-on-after-launch missile function failure has increased the price tag of each aircraft to a point where the procurement numbers of these advanced fighters, at a cost of $143 million per aircraft, have been reduced from 750 to 187. The production of the F-22 Raptor was officially ended in 2009 yet critics in Congress and elsewhere question whether or not the F-22 was ever capable of defending U.S. airspace. The technical and schedule shortfall and rising cost of the F-22 Raptor force lead DoD to invest in design and development of the Joint Strike Fighter—the F-35. Thus, the follow on inquiry should be: "How well is this new acquisition strategy working for the American taxpayer?"

Our malfunctioning DoD acquisition process is not restricted to the aviation community. The cancellation of the Army's Future Combat System and the Navy's cancellation of the 14,000-ton, Zumwalt-class destroyer are two other examples of how the acquisition process has run amuck; cost overruns, technical challenges and performance challenges also contributed to the cancellation of these two programs.

When it comes to creating a more streamlined and efficient acquisition process DoD has failed. The economic and political force(s) that come to bear on the DoD leadership from industry and Congress to continuously fix the acquisition process tends to degrade the acquisition process as opposed to making it better. The leadership at OSD that, frequently, revises acquisition policies and procedures ends up creating an acquisition quagmire; inefficient policies and a DoD acquisition workforce are the results.

The defense industry on the other hand, driven by the need for higher and higher profits, tends to box the government into a corner with the promise of delivering advanced technology at a cost while knowing that, as in the case of the F-35 Joint Strike Fighter, other materiel alternatives don't exist once a contract is signed and money committed. Schedule delays, design revisions and upgrades have and always will be a defense industry standard for increasing profits unless radical government acquisition reform measures are taken. However, within the last sentence lies other barriers to acquisition reform—the government may be (for whatever reason) incapable of doing anything radical, especially something as challenging as overhauling the entire acquisition process.

With the slight chance that the message for radical acquisition reform does not fall upon deaf ears, allow me to encourage the greater defense industry community to immediately cease applying pressure to "tweak" acquisition policies and procedures in the hope of streamlining or improving the acquisition process. Let's start anew. Instead of attempting to fix the acquisition system from the top down, let's begin by asking those in charge of designing, developing and producing weapon systems what needs to be fixed and how to fix it. Continue focusing on research and development of state of the art technology but allow the technical experts to share their approach to developing weapon systems that are efficient and can be delivered on time. We owe it to the Warfighter(s) to continue providing systems that are reliable, easy to use and meet the requirements. To the American taxpaying public we owe a vastly improved stewardship of their hard earned dollars. ●