Use of Design Operating Window (DOW) Violation Monitoring Tool to reduce equipment design violations in a crude oil refinery

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Industry codes and standards advise that operating outside equipment design parameters can lead to equipment failures. Equipment failures result in loss of containment and can escalate to a major process safety incident. Detection and tracking of violations to equipment design windows is essential for quantitative understanding of adherence to operating design parameters of said equipment. This simple yet effective concept was first utilised at SAPREF in 2007. SAPREF is a joint venture between Shell and BP and is the largest crude oil refinery in South Africa processing 24 000 tons of crude per day.

A Microsoft Excel based tool was developed to report on Design Operating Window (DOW) violations on a weekly basis. Utilising the refinery PI[1] (Plant Information) system, together with a database of all equipment design pressures and temperatures, the macro based tool was able to compare historised plant data for a chosen time period, against the equipment design limits. A proactive monitoring tool, shift exceedance reports and a weekly assurance report was produced indicating the number of violations as well as the duration of the violation. Equipment pressure violations were further analysed to determine the equipment %overpressure and whether relief valves in the system had lifted. Tank high and high high level limits are also included in the tool to give an indication of potential tank overfill incidents.

Key performance indicators (KPIs) were developed for the site based on the DOW violations i.e. no of tags[2] in violation and % time that the tag violated for the week. From the introduction of the KPIs in 2009, the site has managed to reduce the number of tag violations from an average of 30 per week to as low as 10 per week in 2016. The total number of pressure violations for 2013 was 150 and gradually reduced to a total of 32 in 2016. By focusing on the reasons for the DOW violations, the site was able to resolve systemic or design problems that were resulting in the design window violations i.e. operational, maintenance, compliance etc.

The tool was later updated to include Integrity Operating Windows (IOWs) and Product Quality (PQ) Window limits. IOW violation monitoring allowed the site to proactively determine if a specific material degradation mechanism was favoured which could result in a loss of containment. PQ windows are utilised to minimise the potential of having an off spec product.

Monitoring DOW violations has helped SAPREF focus on the “big issues” by gaining control of the design envelopes and working inward instead of being overwhelmed with trying to control the operating envelope violations. The concept that the DOW monitoring tool is based on can be easily applied to any industry especially since it is Excel based.

Problem statement

Subjecting a piece of equipment to operating conditions outside of its design parameters can result in equipment failures. Equipment failures lead to loss of containment which subsequently could result in a major process safety incident. Process safety incidents typically refer to fires, vapour cloud explosions or toxic releases. These incidents have consequences of fatalities or asset damage which need to be prevented.

SAPREF is a crude oil refinery which utilises a design operating window (DOW) monitoring tool to quantify and monitor violations to the DOW. By detecting and analysing design limit violations, the site was able to resolve systemic or design problems that were resulting in the design window violations. For example, during a power failure, a pressure violation is recorded on a vessel. The initial assumption is that the power failure was the reason for the overpressure. On further investigation it is identified that the power failure case is not identified as a valid overpressure scenario for this vessel. The actual root cause for the pressure violation was that a controller was in the incorrect mode which resulted in the overpressure.

Monitoring Tool Structure

SAPREF utilises the PI (Plant Information) system which is a plant data historian software supplied by OSIsoft®. The PI system has an interface with Microsoft Excel which allows plant data to be viewed in a spreadsheet format. In addition to data viewing functionality, the PI Data Link Excel Add in, allows the user to view data subject to a user defined formula e.g. data can be viewed on a daily or hourly average basis. Various other functions exist via PI Data Link but for the purposes of developing the DOW monitoring tool, the PI Time Filtered function is used. Each component of the monitoring tool is detailed below with the overview of how they interact given in 2.1.

Overview of software tools interaction

Refer to Figure 1 below which illustrates how the various files interact with each other. Details of each file is provided in subsequent sections.

[1] PI system refers to a plant data historian software and is supplied by OSIsoft®
[2] Tag refers to the name of the equipment parameter measuring instrument e.g. 14TI1 (temperature) or 17PCA3 (pressure)

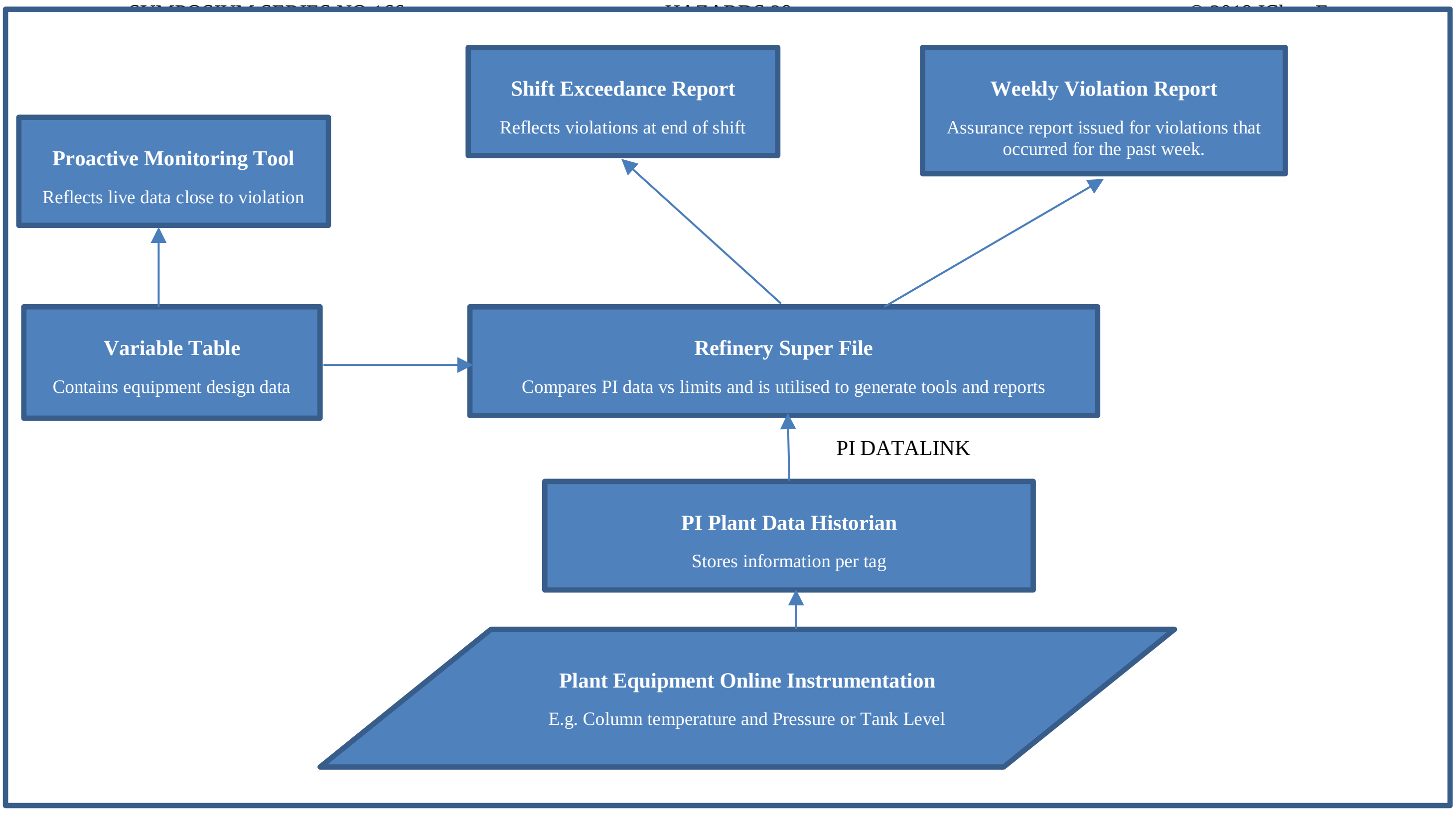

Figure 1. Overview of software tools interaction

Variable table

A variable table is a database containing equipment information e.g. tag number, design pressures or temperatures, is populated in Excel and stored in a fixed location. Note that only equipment with online measurements that are historised in PI can be captured in the database. Refer to table 1 which reflects the database fields with a detailed description below.

									Associated Equipment	
Disabled	**Unit No.**	**Window**	**Tag No**	**Description**	**Min Limit**	**Max Limit**	**Level**	**Priority**	**Number**	**Description**
0	4000	Design	40PI20	C4001 TOP		350	1	1	C4001	
0	4000	Design	40TI101	C4001 FLASH ZONE		360	1	1	C4001	
0	4000	Design	40PC76	V4001 PRESSURE CONTROL		3000	1	1	V4001	
0	4000	Design	40TA23	E4004/07/10 CRD TO M4001		160	1	1	V4001	

Table 1. Variable table fields

Disabled: A “0” in this field indicates that the tag is active in the variable table. A “1” in this field indicates the tag is inactive. A tag would be inactive if for example the equipment is out of service for a period of time.

Unit No: Refers to the unit number which the equipment belongs.

Window: Indicates that the parameter is a design parameter for the equipment. Other windows exist such as Integrity, Product Quality and Tank Operating Windows (TOWs).

Tag No: Refers to the name of the equipment parameter measuring instrument.

Description: Describes the location or function of the tag.

Min Limit: Minimum window limit e.g. vacuum pressure setting on a vessel (Design Pressure low limit).

Max Limit: Maximum window limit e.g. Design Temperature of the shell side of a heat exchanger

Level: Level 1 indicates parameters that can be controlled by the panel operator and Level 2 indicates parameters that cannot be controlled by the panel operator. Level 1 parameters have an operator action associated with them. Level 2 parameter violations require further analysis regarding the impact of the violation.

Priority: Indicates a hierarchy for response to a violation.

1= critical (Requires immediate response), 2 = standard (Medium to long term equipment damage) and 3 = monitoring (Tag utilised for monitoring purposes. No immediate threat)

Number: Associated equipment number that the tag is monitoring

Description: Contains further details of the equipment e.g. if heat exchanger shell or tube side

Refinery Super File

An Excel file (known as the Refinery Super file) is used to compare the plant data in PI against the limits in the variable table for a user defined time period. This is done using the PI Time Filtered function which outputs the number of minutes a tag met the formula criteria e.g. 40PI20 > 350. The PI Calculated Value function is used to determine the minimum, maximum and average values, the particular tag reached during the specified time period. A macro is used to copy and paste data from the Variable table and Refinery Super file into a report format. Refinery Super is also utilised to output the shift exceedance reports and weekly assurance reports. Below is the user interface for the Refinery Super file. The user enters the time period for which data is required and clicks the "Update" button. The output from the file is reflected in Table 3. The output can be customised via the macro to paste parameters the user requires to view.

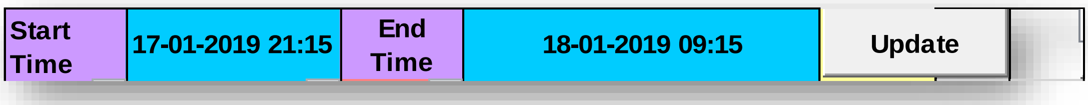

Figure 2. Refinery Super User Interface

Shift Operating Window Exceedance Report

At the end of each shift, an operator log is produced per operating panel. At the bottom of each operator log, the shift exceedance report is reflected. The exceedance report generation is incorporated into the macro that produces the template for the operator log. The Refinery Super file is utilised to produce the exceedance report. Referring to Table 2 below, the red highlighted fields are as per the variable table (copied and pasted via the Refinery Super file). The grey highlighted fields are generated using the Refinery Super file. Min Actual refers to the minimum value reached for that tag. Max Actual refers to the maximum value reached for that tag. Minutes outside window refers to the duration for which the tag operated outside of the design limit in the variable table. The panel operator enters reasons for the violations at the end of the shift in the comments field.

DESCRIPTION	WINDOW	TAG	MIN	MAX	Min Actual	Max Actual	Minutes Outside Window	COMMENTS
ECOM OUTLET TO V7208	Design	72TI149		300	455.90	487.32	688	Invalid as instrument has been relocated temporarily as per MoC.
CD2 TOPS 95%REC-F	PQ	72YM21		78	74.00	79.00	440	Valid. Moves made to correct.
CD2 TOPS R/D TVP	Design	72YXA75		86	68.96	90.82	12	Valid. Power dip resulting in high CWS temperature and high TVP.

Table 2. End of shift operator log exceedance report

Weekly DOW Violation Report

On a weekly basis, the Refinery Super File is used to generate a DOW violation report which lists the violations for the week as well as the durations. Reasons for the violations are then populated by the production engineers who also take into account the comments entered in the shift exceedance report. The violations are discussed at a meeting between the process safety department and the production engineers. The meeting serves to validate the reasons entered for the violations. Action items are also agreed upon and tracked to prevent the DOW violations from occurring again.

Table 3 below shows the violation report that is issued on a weekly basis. Grey highlighted columns are generated by the Refinery Super File. Green highlighted columns are populated by the production engineers and validated at the weekly meeting with Process Safety Department. Type of violation refers to the category which resulted in the violation i.e. Maintenance, Design, Operational, Process Control or Other.

Tag No.	Description	Current Value	Min Limit	Max Limit	Equip No	Minutes Outside Window	Min Actual	Max Actual	Avg	Comments	Corrective Action	Action Party	Action Closeout Date	Type of Violation
03TA49	F301 MID N/E COIL	529.6		538	F301	90.0	516.3	544.0	529.5	One burner currently not functional and results in imbalanced firing.	New burner has been ordered. Will be installed when received. Expected end dec 18.			Maintenance
32TC29	HP STM EX F3202	479.0		482	F3202	3795.6	466.0	491.5	478.7	Valid: 32TCV29 was commissioned	Determine why this valve is controlled on manual			Process Control
650TA17	C6502 TRAY	97.3		210	C-6502	22.0	24.3	220.8	72.2	Valid				Operational
650PA3	V6503A PRESSURE	609.3		865	V6503A	1.5	39.0	931.9	416.7	Valid due to overfill. Overpressure <10% allowable. RV did lift. Overfill is in SGM.	Review startup procedure to determine how overfill is meant to be prevented.			Operational
V1411	C3 PUREGAS LEVEL	1.5		2.5	V1411	18.5	1.1	2.5	1.8	Valid, r/d valve is passing.	Maintenance to check and verify installation of stopper			Maintenance

Table 3. Weekly DOW violation report

Proactive Monitoring Tool

The proactive monitoring tool was developed to give an early warning signal to the panel operator that they are close to violating the operating window. Each panel operator has the Excel monitoring tool installed on a dedicated screen at the control panel. The tool utilises the limits from the variable table together with the PI Time Filtered function and displays tags that are in violation. A pre min and pre max limit is calculated as the early warning signal which is set at 5% before the limit. An added functionality is that the current value will be highlighted in a corresponding colour accordingly if the pre min, min, pre max or max limit is violated. The tool also displays the time the tag operated in the warning window and outside the limit window.

Unit No.	Tag No.	Description	Current Value	Min Limit	Pre Min Lim	PreMax Limit	Max Limit	Minutes Inside Warning Window	Minutes Outside Actual Window
Design	327TCA2	F3271 S/HEATED HP STEAM	444.3			451.3	475	806	0
Design	327TCA88	F3273 SUPERHEATED STEAM	449.4			451.3	475	937	0
Design	326TC64	F3263 ATTEMP-1 OUTLET	320.0			319.2	336	835	0

Table 4. Online monitoring tool display

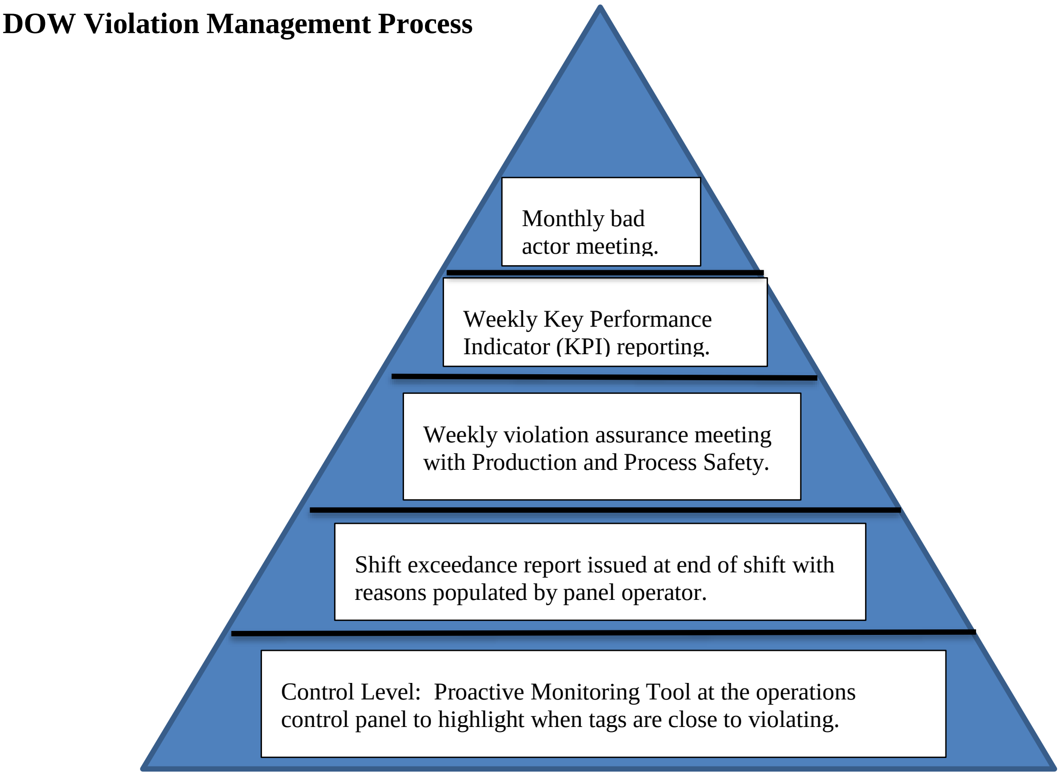

Figure 3. Pyramid reflecting different levels of control for DOW violations

Proactive Monitoring Tool and Shift Exceedance report

This online monitoring tool serves to warn the panel operator that a window violation is close to occurring. If the violation is unable to be prevented, it will be reflected at the end of shift log where the panel operator needs to provide reasons for the violation. Reasons are validated by the shift team leader.

Weekly Violation Assurance Meeting

During the weekly violation assurance meeting, focus is placed on determining the root causes of violations and ensuring that the consequences of the violations are mitigated, thus improving operation. The focus areas are categorised below with some of the prompting questions further detailed.

Pressure violations

When a piece of equipment is subject to pressures in excess of its design pressure, this can lead to equipment failure and potentially catastrophic failure. Hence, pressure violations are scrutinised during the weekly violation meeting discussion. For each pressure violation reported, the below questions need to be answered.

- Did a relief valve (RV) lift in the pressure envelope?
- What was the %Overpressure of the piece of equipment? If greater than % allowable, the associated RV sizing needs to be validated. If the RV is sized correctly, then the RV needs to be removed for inspection. RV inlet and outlet lines to be checked for pluggages or restrictions.
- Is the overpressure scenario captured in the unit safeguarding memoranda? If not, documentation to be updated and RV sizing calculations revised.

High tank level violations

The December 2005 Buncefield incident highlighted what can go wrong if tank levels are not properly managed. Hence at SAPREF we treat tank level violations with a high priority. A separate category was introduced to the variable table which indicated if tank high level alarms were being violated. These are known as TOWs. The tank high high level alarms are captured as part of the Design Window and any violation to these limits require a separate investigation to be undertaken by the Operations team.

True Vapour Pressure (TVP) violations

Floating roof tanks are designed with a true vapour pressure limit based on the tank contents. If the TVP limit of the tank is exceeded, there is a potential for 'burping' or sinking the floating roof. This event could potentially result in a fire or vapour cloud explosion leading to fatalities. It is for this reason that the TVPs of rundowns to floating roof tanks are measured and the limits are captured as DOWs in the variable table. Should a TVP violation alarm sound, the operational response is to ensure there is adequate 'soak' in the tank to dissipate the high TVP material. At the weekly violation meeting, this response is confirmed to have been done. In addition, the tank roof is checked visually to determine if any hydrocarbons were released to the roof as a result of the high TVP.

Temperature violations

Design temperatures are specified per piece of equipment and are usually based on the process operating temperature. In most cases, the equipment material can withstand the design temperature excursion but in some cases the equipment cannot. Therefore, when it comes to significant temperature violations, the mechanical design engineer and materials corrosion engineers make an assessment, regarding the impact on the equipment. In some cases, the equipment is rerated to operate at the revised design temperature which follows the management of change process. It's also important to note that some temperature excursions occur on the low design temperature side. In these cases, the mechanical design engineer makes a low temperature embrittlement assessment for the equipment and associated piping.

Weekly Key Performance Indicator (KPI) reporting

DOW violation monitoring commenced in 2007. In 2009, 2 KPIs were developed to monitor DOW violations.

DOW % time in violation: Calculated by determining the total number of minutes that DOWs violated for the week divided by the total possible weekly DOW minutes for the population of DOWs at the site.

DOW % time in violation = Total DOW violation minutes for week / (No of site DOWs * No of minutes in a week)

%Time in violation is reported as a weekly figure. To determine the monthly data, an average of the weekly figures is taken. Similarly, yearly data is an average of the monthly figures. Figure 4 below reflects the KPI progress from the start of reporting in 2009 which shows an overall reduction in time the site operates in violation of the DOWs. The max limit has also reduced over the years in light of continuous improvement. The % time in violation is negatively impacted by unit shutdowns, trips and start-ups. Particularly power dips have had a negative influence on this KPI. Over the years the site has focused on ensuring that process units can be started up and shut down without resulting in DOW violations.

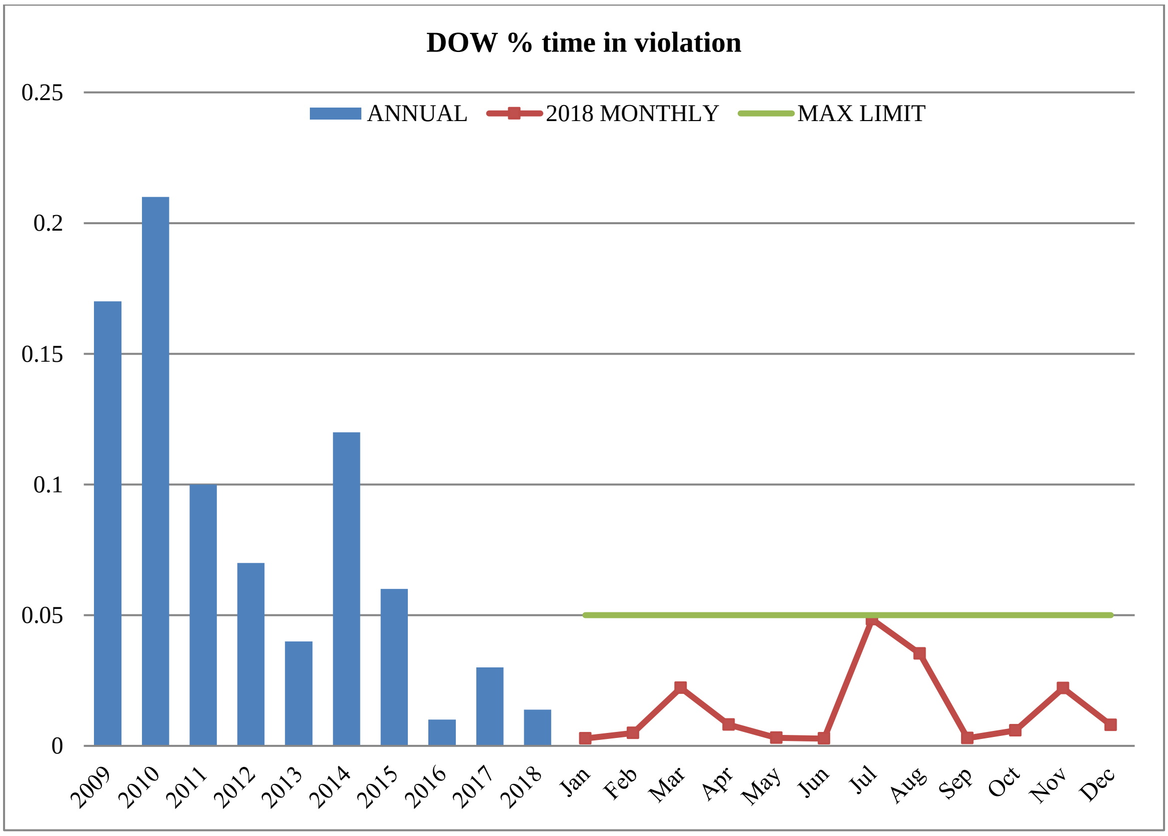

Figure 4. Graph reflecting DOW % time in violation KPI.

DOW violation – Number of tags: This is the total number of tags that violated for the week. The monthly and yearly data is also determined on an average basis as explained for % time in violation above.

The number of tags violating in a week has steadily been decreasing since 2009 which can be attributed to the focus that was placed on ensuring that we operate within the design windows. As described in section 3.3.1, this KPI is also negatively impacted by refinery reliability.

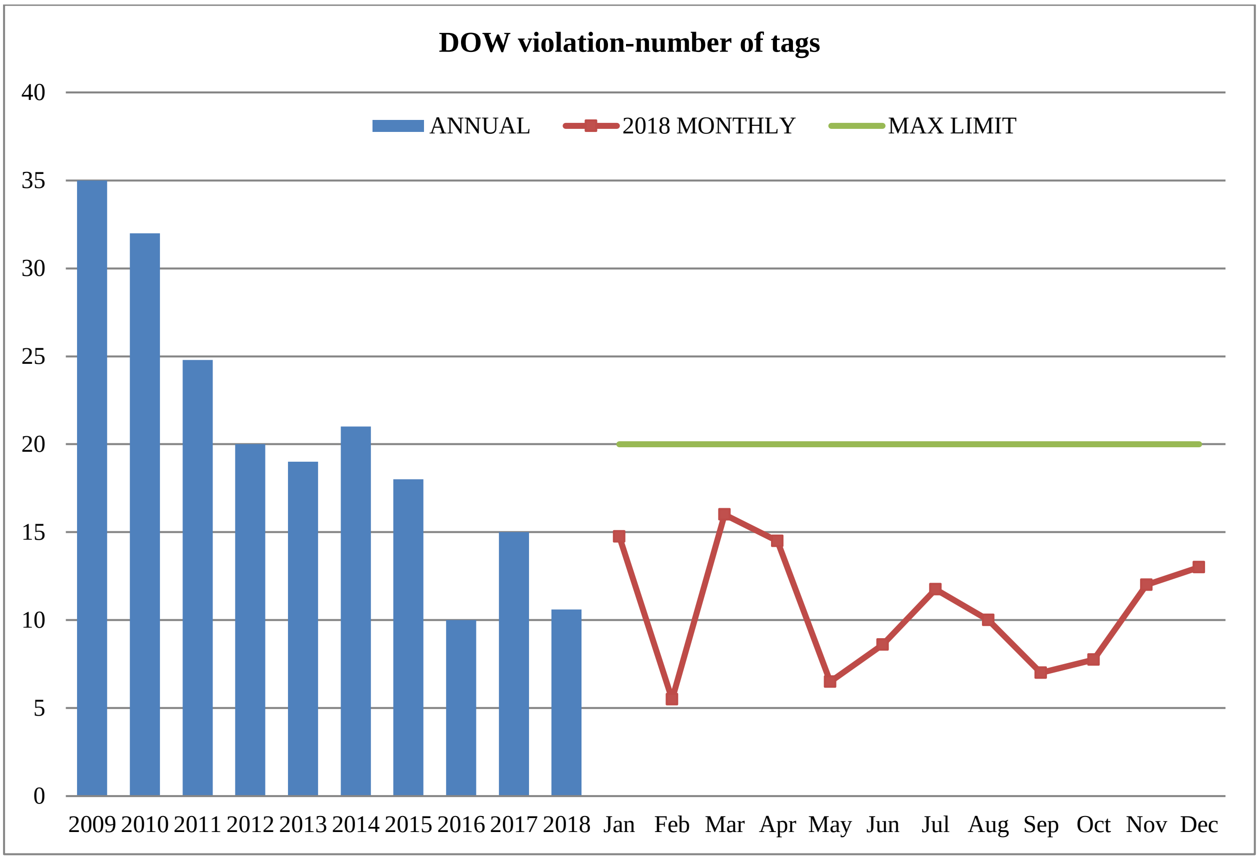

Figure 5. Graph reflecting DOW violation – number of tags.

Total number of pressure violations and Total number of Relief Valve (RV) lifts

The total number of pressure violations since the KPI development has shown a significant reduction over the years as reflected in Figure 6. The reduction can be attributed to the resolution of the pressure violations as discussed in section 3.2. Conversely, the total number of RV lifts has increased since 2016 as reflected in Figure 7. This can be explained by the first two KPI impacting factors below:

- Some equipment requires more than 1 RV to be online. Therefore 1 pressure violation can result in 2 RV lifts.
- At SAPREF, traditionally RVs are set at the equipment design pressure. We have had some cases where the RV is set lower than the equipment design pressure, and the RV is still adequately sized. In this case you can have an RV lift without exceeding the equipment design pressure.
- It is also possible that during an overpressure case, an RV does not lift due to a mechanical fault or restriction in the RV inlet or outlet line. In the case of pressure being relieved by another means i.e. depressuring valve, no RV lift occurs.

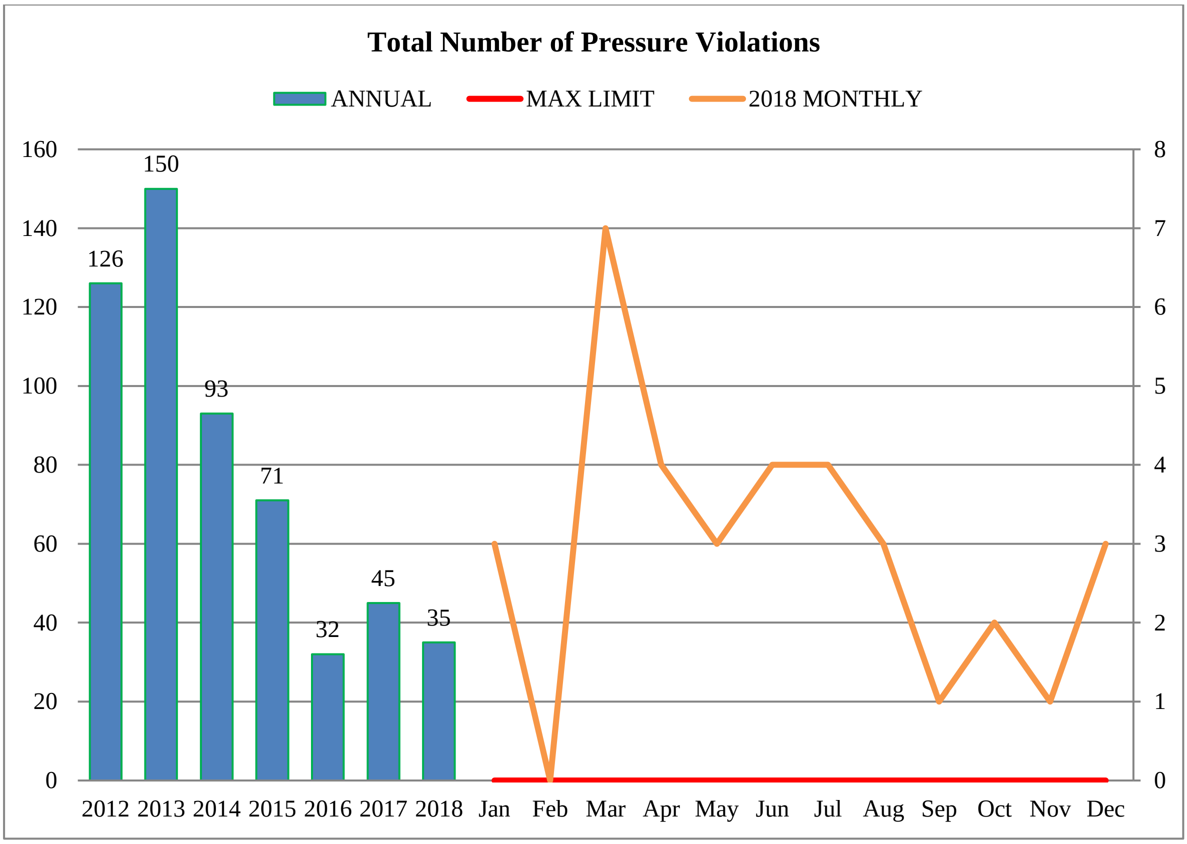

Figure 6. Graph reflecting total number of pressure violations

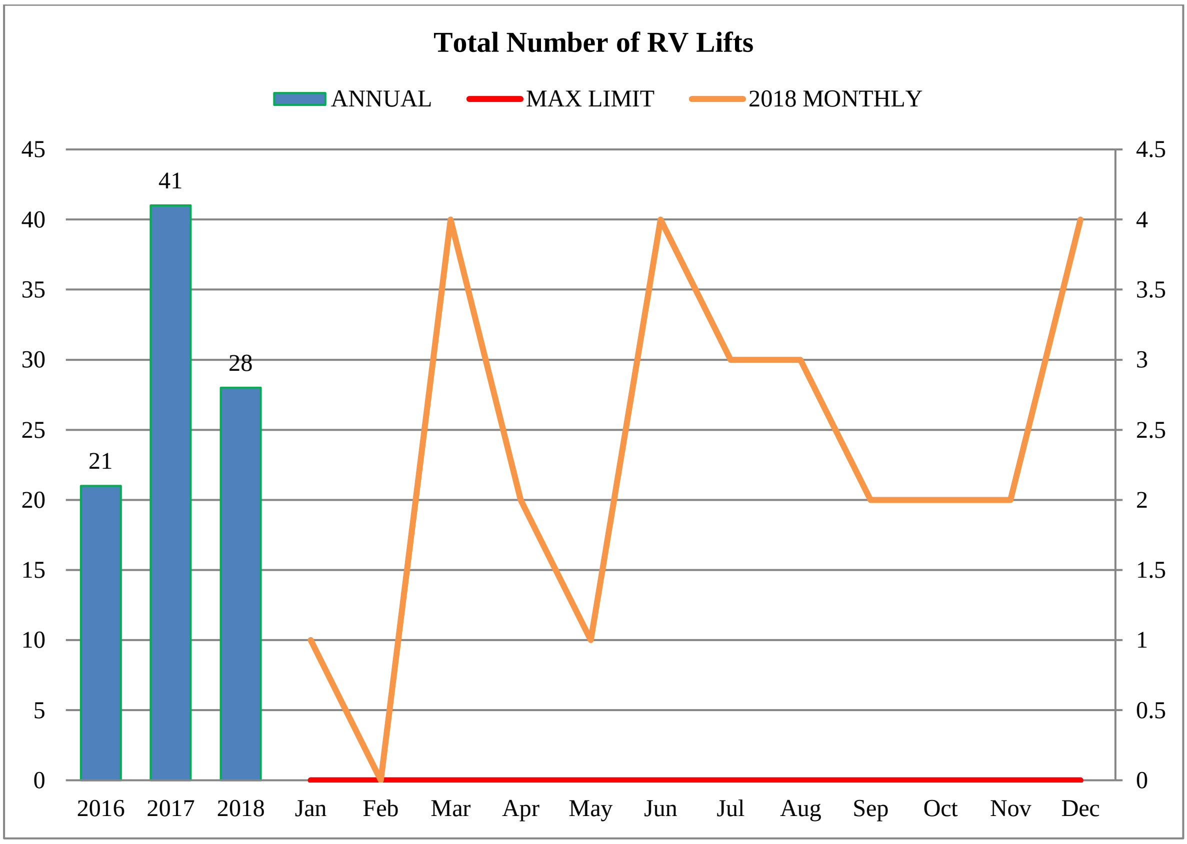

Figure 7. Graph reflecting total number of RV lifts

Monthly Bad Actor Meeting

On a monthly basis, the most frequently violated tags are reviewed. These are known as bad actors. During this meeting, progress of actions for resolution of the bad actors are discussed. Themes are also highlighted, e.g. if frequent DOW violations have been occurring as a result of pump switch over, then a review of operational and training procedures regarding pump switch overs is done. Another example would be if tank level instruments are reading incorrectly due to instrument faults, then further investigation would be done into the nature of the faults and possible common mode failure.

Conclusion and Recommendations

The inclusion of Integrity Operating Windows (IOWs) in the violation monitoring framework has allowed the site to proactively determine if a specific material degradation mechanism was favoured which could result in a loss of containment. The addition of Product Quality (PQ) Window limits is utilised to minimise the potential of having an off spec product. These additions show that the monitoring tool can be customised to focus and report on any type of violation as long as the limits are clearly defined and correctly specified. Based on this, it is imperative that the variable table be controlled via a dedicated administrator and all changes to the variable table should follow the management of change process. Another key requirement for implementation, is having an online historian like PI which can interact with Microsoft Excel. Lastly, equipment parameters need to be measured online in order to be incorporated into the tool.

Monitoring DOW violations has helped SAPREF focus on the “big issues” by gaining control of the design envelopes and working inward instead of being overwhelmed with trying to control the operating envelope violations. Having an established process and framework for identifying, discussing, resolving and reporting violations was key to achieving reduction in the DOW violations. The concept that the DOW monitoring tool is based on can be easily applied to any industry and is probably best summed up by the Peter Drucker quote:

"If you can't measure it, you can't improve it."