PI World 2020 Lab

PI System: From Data Exploration to Notification

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PI System software

The VM (virtual machine) used for this lab has the following PI System software installed:

Software	Version
PI Data Archive	2018 SP3
PI Asset Framework (PI AF) server	2018 SP3
PI Asset Framework (PI AF) client (PI System Explorer)	2018 SP3
PI Analysis & PI Notifications Services	2018 SP3
PI Vision	2019
PI Integrator for Business Analytics	2018 R2 SP1
PI DataLink	2019 SP1 (5.5.1)

For details on PI System software, please see http://www.osisoft.com/pi-system/pi-capabilities/product-list/

1. Lab Overview

1.1 Objective

In this lab, we use analytical features of PI System to evaluate and then implement an idea for improving plant operation. First, we'll use Asset Analytics to add descriptive features to gain process insight from the raw measurement data. The PI Integrator for Business Analytics will be used to provide data to Power BI where we'll perform multidimensional analysis allowing us to validate our idea and quantify its value. Using DataLink, we develop a simple predictive model for real-time operationalization in Asset Analytics. Then finally, we'll use PI Notification to recommend a process action based on the result of this prediction.

1.2 Gathering Domain Knowledge – PI Vision

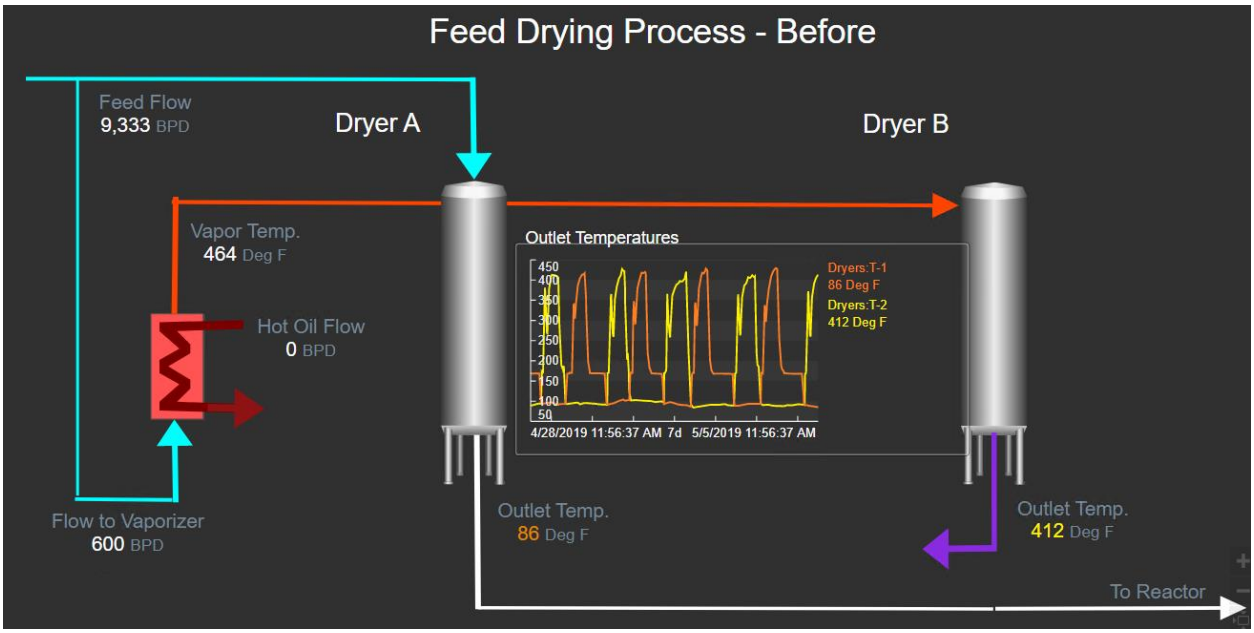
The data we are using was taken from a years' operation of two liquid feed dryers. These are large cylindrical vessels (right), filled with molecular sieve pellets. They are used to continuously remove moisture from a hydrocarbon stream in an oil refinery. The liquid feed stream must be completely dry before it combines with a strong acid which serves as a catalyst for the chemical reaction. Even small amounts of water entering the reaction create a highly corrosive environment that will damage and compromise the equipment metallurgy.

The dryers are designed to be redundant, cycling between two operating states. The "Drying" state is when dryer is actually removing moisture from the liquid fed to the reactor. Once saturated, the dryer is switched to a "Regenerating" state. In this state, a hot vapor stream is used to remove water from the molecular sieve pellets inside the dryer. Thus, the dryers are cycled back and forth between operating states to continuously remove moisture from the feed before it combines with the strong acid catalyst for the chemical reaction.

The Feed Drying Process – Before

Solidify your process knowledge by looking at the process measurement data in PI Vision.

1. From the desktop icon, open **'PI Vision'** application.
2. From the PI Vision display thumbnails, double-click on the **'Drying Process – Before'** tile to open the display shown below.



In the display above, Dryer A is in its "Drying" state while Dryer B is in its "Regenerating" state. The moist liquid feed flows into the top of Dryer A, water is adsorbed in the molecular sieve pellet bed and the dried liquid flows out the bottom and on to the reactor. Meanwhile, a small amount of the feed is heated, vaporized and sent to Dryer B, which is in its "Regenerating" state. The hot vapor stream raises the temperature of Dryer B's bed, driving water out of the molecular sieve and thus preparing it for its next drying cycle once Dryer A is saturated.

The process measurements available for this lab are shown in the display's value and trend objects.

Shown as values are:

Feed Flow - the moist, undried, liquid feed, (barrels per day)

Flow to Vaporizer - a small amount of feed which gets vaporized to regenerate molecular sieve pellets (barrels per day)

Vapor Temp. - vapor temperature, (Deg. F)

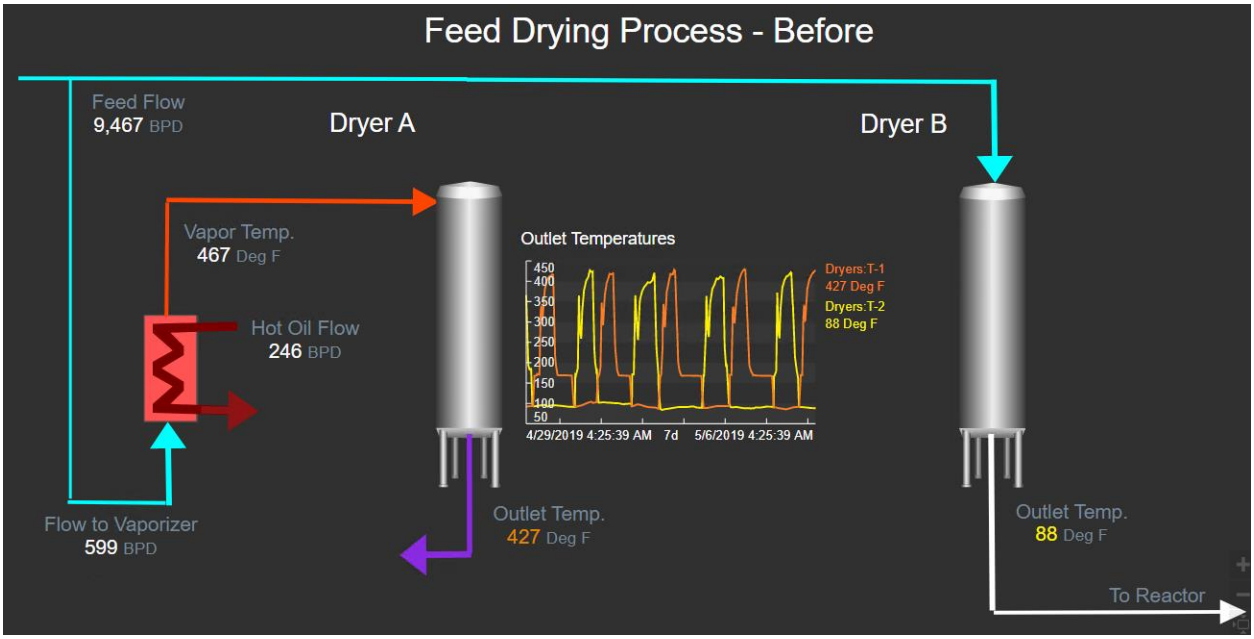
Show as values and trends are:

Outlet Temp. - Dryer A orange - temperature of stream leaving Dryer A, (Deg. F).

Outlet Temp. - Dryer B yellow – temperature of stream leaving Dryer B, (Deg. F).

Notice, there is no variable in the display showing the dryer's current state. However, the Outlet Temperature trend in the middle of the display shows the dryer outlet temperatures peaking in an alternating fashion as they rise and fall with each regeneration. These temperature patterns will be the basis for everything we do in this lab.

3. Select the **'Outlet Temperatures'** trend and using the time scroll at the bottom adjust display end time to find a time when Dryer A is in its "regenerating" state. This will occur when Dryer A's outlet temperature, the orange trace is peaking. An example of this operation is shown below, everything works the opposite way.



1.3 Process Improvement Idea – PI Vision

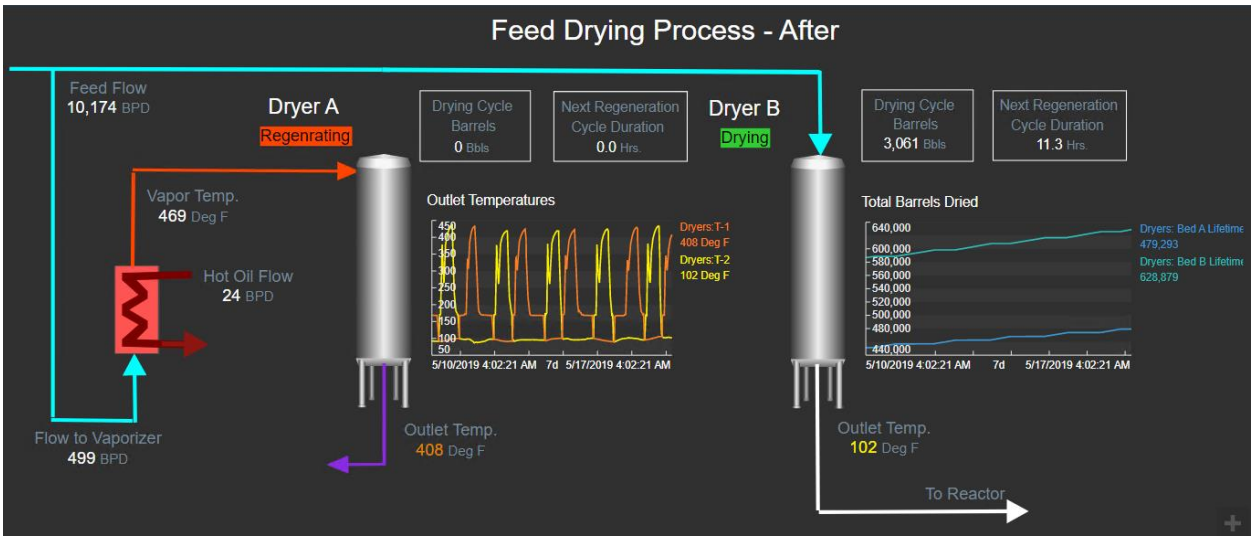
After several years of service, the molecular sieve beds will reach their end-of-life and need to be replaced. The replacement of both beds will occur at the next planned refinery shutdown. The most efficient way to manage the condition of these beds is to treat them equally throughout their service life. The condition each bed sees could be measured by the amount of time they operate in a particular state, however a more equitable metric is one based on the volume of moist hydrocarbon feed they see during the drying cycle. The feedrate to this process can vary greatly so times of high throughput are more taxing than times when the feedrate is low.

Our idea for process improvement is to provide more visibility and proactive management of the dryers' molecular sieve beds. We would like to display an indication of dryer state and to provide a running total of barrels processed by each dryer for the life of this load of molecular sieve. This will show how well we are managing the beds over time. As additional assistance, we would like to provide an estimate of how long the next regenerating cycle will take for a dryer currently in its "Drying" state. AF Notifications can send an email reminder to the process operator whenever the estimated regeneration duration exceeds a prescribed time.

The Feed Drying Process – After

Take a look at the implementation of our idea. During the lab, you'll be going through the steps to make this happen.

1. Click the OSIsoft PI Vision logo on the upper left-hand corner of the PI vision display. This will return you to the display thumbnails.
2. Double-click on the **'Drying Process – After** tile to open the display shown below.



The same process measurements are shown however, we have added several others to add visibility into the dryer's current state, the total barrels of hydrocarbon feed it has dried and a prediction of the time required for the next regenerating cycle.

Additional values are:

Dryer State – multi-stated value, "Drying", "Regenerating", or "Standby"

Drying Cycle Barrels – total barrels of feed through Dryer during current "Drying" cycle (barrels).

Next Regeneration Cycle Duration – predictive model results estimating duration of next regenerating cycle (hrs.)

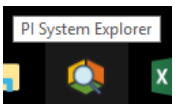
Additional trends are:

Lifetime Barrels - Dryer A Teal – total barrels of feed through Dryer A during "Drying" cycles (barrels).

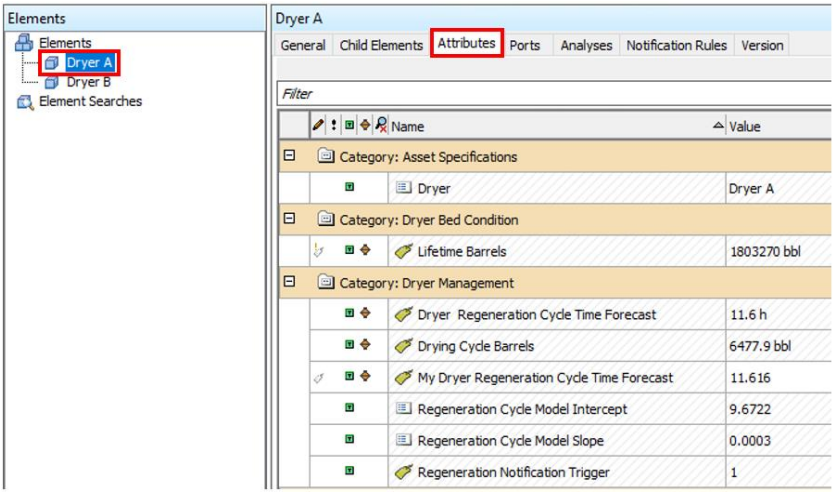
Lifetime Barrels - Dryer B Cyan – total barrels of feed through Dryer A during "Drying" cycles (barrels).

The AF Model

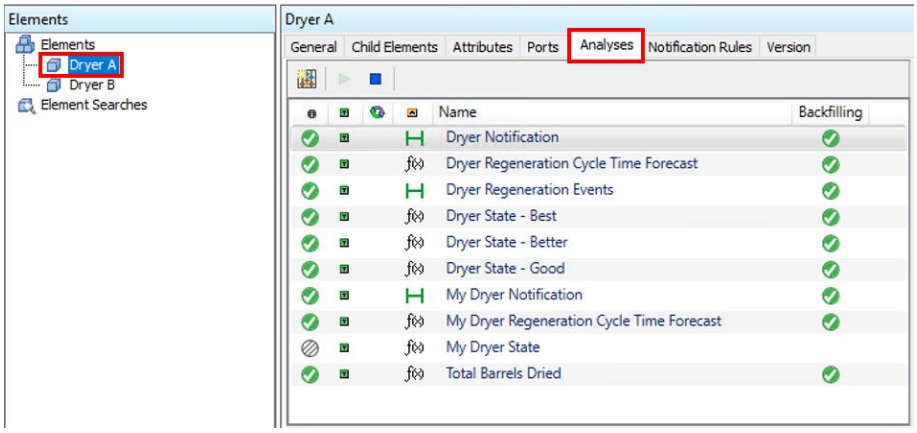
Of course, everything we do in this lab is based on an AF database. For this lab we use one named 'Dryers'. Familiarize yourself with the Dryers by completing the following steps.

1. From the Windows taskbar, open PI System Explorer 

and be sure you're connected to the **'Dryers'** database and that the **Elements** view is selected in the lower left-hand corner.
2. Select the **Dryer A** element and the **Attributes** tab at the top. Take a look at the various attributes configured for each dryer. (We won't be using all of them for this lab.)

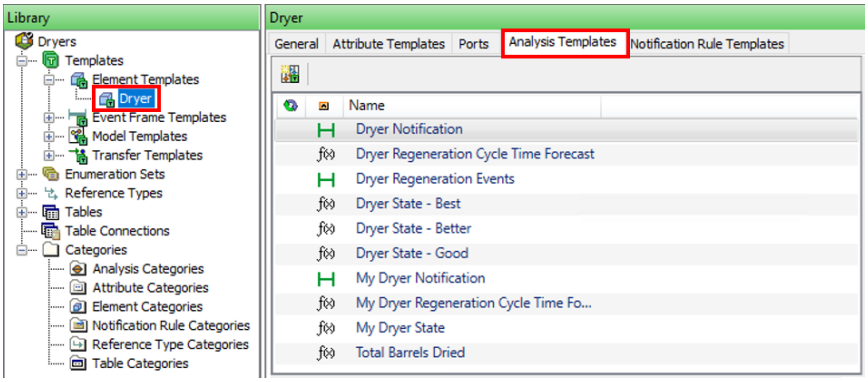


3. With **Dryer A** element still selected, click the **Analysis** tab at the top. Here are the Asset Analytics we'll be using to help implement our improvement idea.



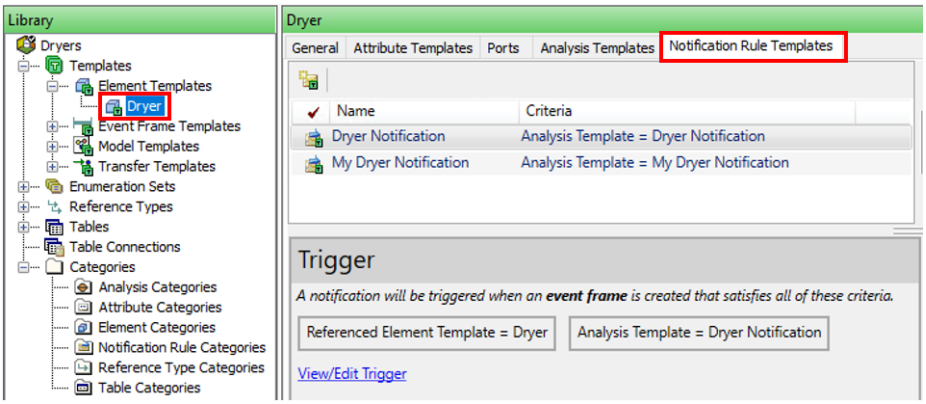
Both **Dryer A** and **B** elements have been derived from the **Dryer** template. The lab exercises will be done in this template so everything we do will be applied both dryers.

4. Select the **Library** view in the lower left-hand corner of PI System Explorer. Under the **Templates** branch of the hierarchy, expand **Element Templates** to expose the **Dryer** template we are using for this lab. Click on the **Dryer** template and select the **Analysis Template** tab at the top.



We will be configuring an email notification to proactively remind process operators when it may be time to switch dryers. Notification rules are also configured in asset templates.

5. Select the **Notification rule Template** tab at the top of the Dryer template.



2. Exploration and Data Engineering

2.1 Objective

There are two objectives for this exercise. First, we'll calculate the operating state of each dryer based on patterns in its outlet temperature. Status tags named **'Dryers:My State A'** and **'Dryers:My State B'** have been created to store your results. This will require some trial and error to configure a rule that accurately identifies the state of each dryer and that works well for all of 2019. You will be using the **Preview Results** and **Backfill/Recalculate** features of Asset analytics to test and evaluate your results.

The second objective will be to calculate the total volume of hydrocarbon feed each dryer sees during "Drying" cycles only. We will review the Asset Analysis configuration for the calculation of two totals:

Lifetime Barrels – accumulated volume of feed during all drying cycles in 2019 (barrels)

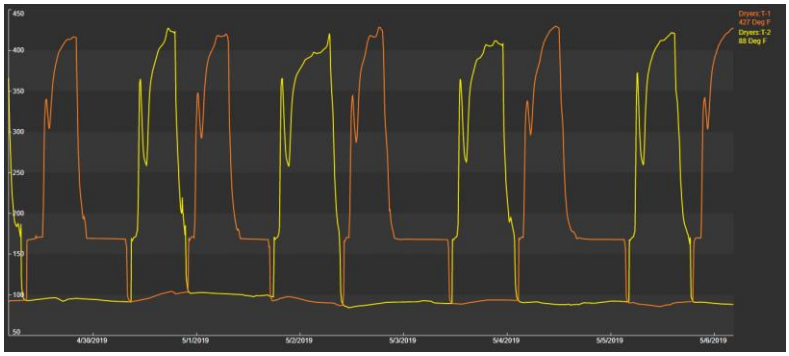
Drying Cycle Barrels – total volume of feed during each drying cycle (barrels)

2.2 Define and Label Dryer Operating States – Asset Analytics

Take a closer look at the dryer outlet temperature patterns in PI Vision.

1. Open PI Vision from the desktop.
2. Click the 

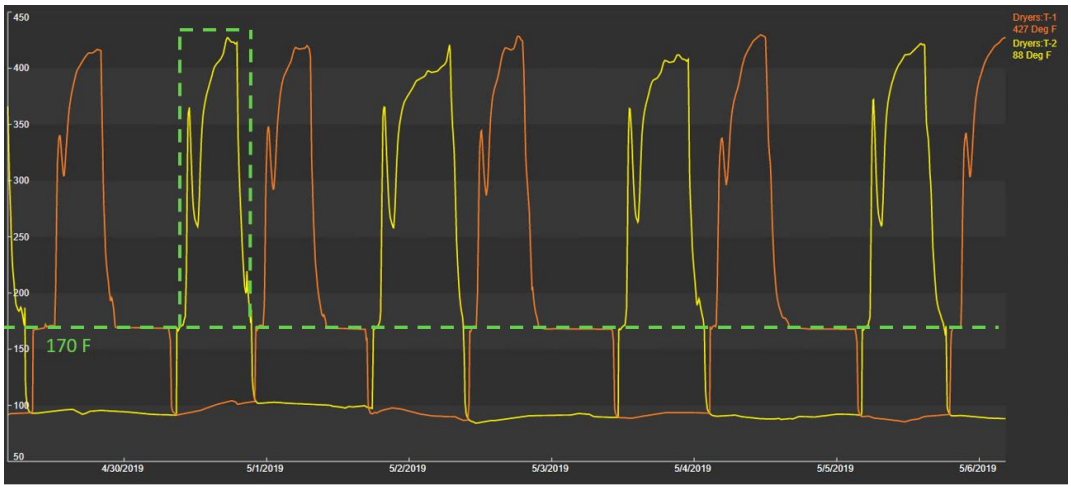
logo on the upper left-hand corner of the PI vision display. This will return you to the display thumbnails.
3. From the PI Vision display thumbnails, double-click on the **'Drying Process – Before'** tile to open this display.
4. Expand the **'Outlet Temperatures'** trend by double-clicking on it.

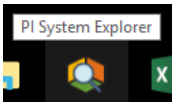


This trend clearly shows the heating and cooling of the dryer's molecular sieve bed during the regenerating cycle. We will use Asset Analytics to develop a rule, based on this outlet temperature pattern, to identify each operating state and record it in a PI Tag. Sometimes rule development requires several tries to get it right. This will be the case here as we work through the process to develop the best rule for providing the labelling required for the rest of our analysis.

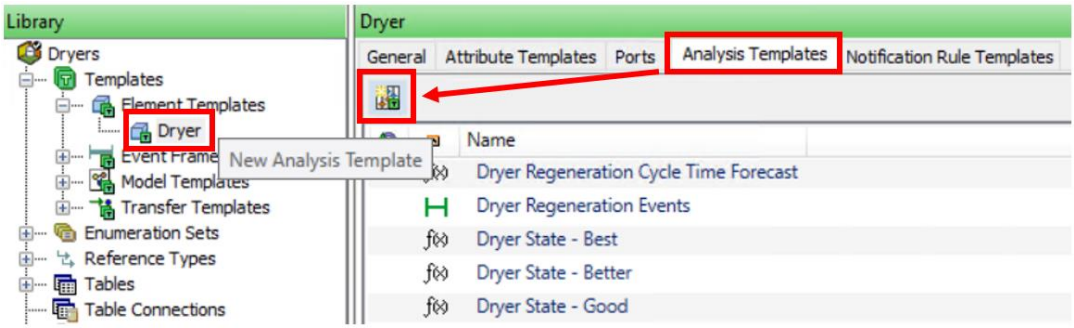
Good Operating State

Configure an Asset Analytic that defines dryer's "Regenerating" cycle when be when its outlet temperature goes above 170 Deg. F.



1. From the Windows taskbar, open PI System Explorer 

and be sure you're connected to the 'Dryers' database.
2. In the lower left-hand corner of PI System Explorer, select the **Library** view. Under the **Templates** branch of the hierarchy, expand **Element Templates** to expose the **Dryer** template we are using for this lab. Click on the **Dryer** template.
3. To access the Asset Analytics defined for this template, click on the **Analysis Templates** tab at the top of the window.



4. Click on the **New Analysis Template** icon and change the name of your new Analysis Template to **'My Dryer State'**. By default, you have created a new **Expression** type analysis. This is what we need.
5. Uncheck **Enable analysis when created from template** to prevent automatically enabling this analytic. We have some testing to do first.

By default, new Analysis Templates are configured to automatically start when elements created from this template. In many cases you will want to test your analysis first. Unchecking the 'Enable analysis

Tip	**when created from template' option will give you complete control as to when your analysis is run.**

6. Copy and paste the following equation into the **Expression** field for **Variable1** of the **My Dryer State.**

```
// State based on dryer outlet temperature.
If 'Outlet Temperature' >= 170
Then (If PrevVal('My Operating State','*')="Regenerating"
      Then NoOutput()
      Else "Regenerating")
Else (If PrevVal('My Operating State', '*') = "Drying"
      Then NoOutput()
      Else "Drying")
```

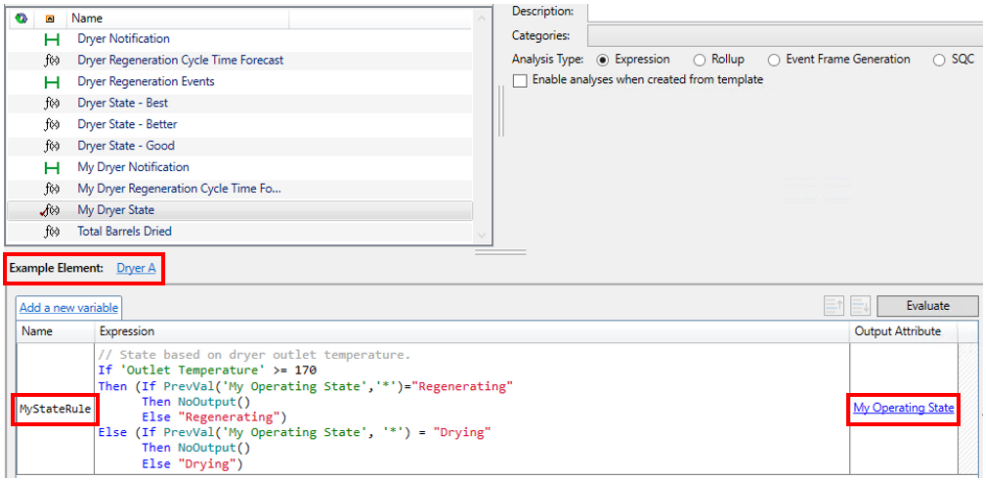
This analysis simply changes the dryer state value to "Regenerating" whenever a temperature value greater than 170 is observed. Once it falls below 170, the state is "Drying". Values are only posted upon a change in state.

7. The Dryer template has already been configured to have an attribute named **'My Operating State'** which point to the PI tags **'Dryers:My State A'** and **'Dryers:My State B'** for Dryer elements **Dryer A** and **Dryer B,** respectively**.**

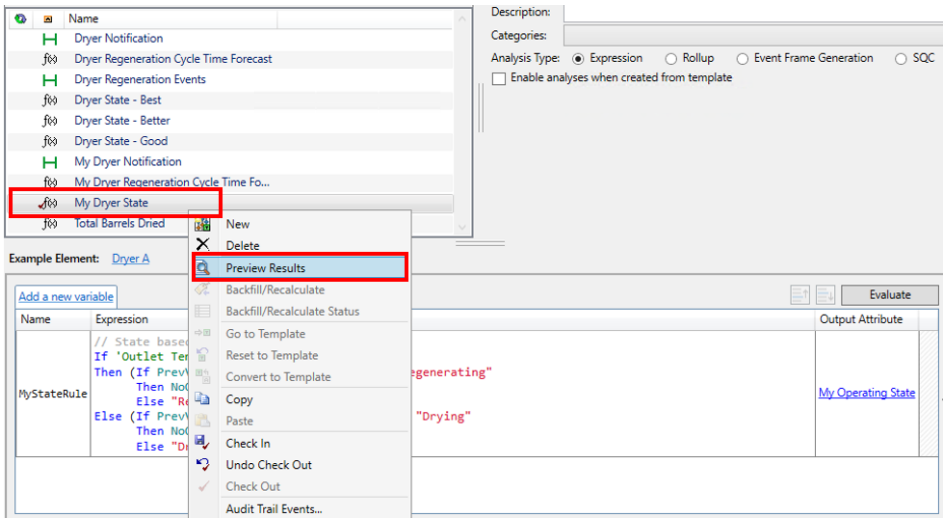
   To the right of the **Expression** field, under **Output Attribute**, click the **Map** link and assign the **'My Operating State'** template attribute.

   Also note that the **Example Element** for this template has be set to **Dryer A**. These means that all evaluations and preview calculations will be done using Dryer A data. You can change to another element by clicking the link and selecting a different one, e.g. Dryer B.

   You can rename the variable of your analysis from **'Variable1'** to **'MyStateRule'**, (spaces are not allowed in variable names).



8. Preview the results of this analytic using the Preview Results feature of Asset Analytics. Right-click on the **'My Dryer State'** analytic in the Analysis list. Select **Preview Results**.



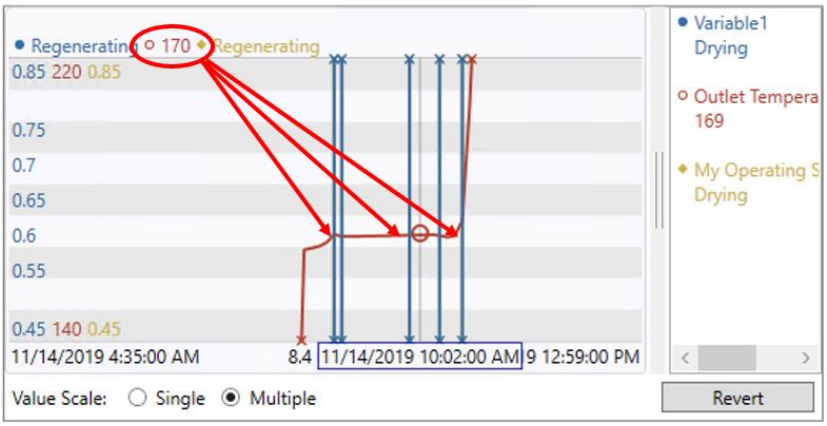
9. In the Preview Results window, set the **Start Time** to 11/10/19 and the **End Time** to 11/15/19. Click **Generate Results** to run the analysis for this time range. Select the **Multiple** option for the Value Scale.

Note

We are not saving results to PI tags yet. The Preview is just giving us a way to check the results for errors within the Asset Analytics environment.

The Preview shows a table and trend of analysis result over the specified time range. The results table list the value of each variable for each calculation interval. In the trend, the stepped blue trace shows the dryer's operating state and the red trace is the dryer outlet temperature. There appears to be something indecisive at the beginning of the regeneration cycles. We would expect to see one step indicating the switch from the "Drying" to "Regenerating" state regeneration cycle and we are getting several before there is a clear indication that the dryer is in the "Regenerating" step.

10. Investigate the problem by zooming in on the trend to get more a more detailed view of the data. Draw a box around the areas of interest until you determine the problem. Use the **Revert** button to return to the original trend.



11. Further investigate these result in Excel. Click the **Export Results** button in the lower right-hand corner of the Preview and download the data to a .CSV file on your desktop. Open the file in Excel and scroll down the rows. The problem is more clearly illustrated below.

	A	B	C	D
1	Trigger Time	Variable1	Outlet Temperature (deg F)	My Operating State
536	11/12/2019 5:24	-	167.6	Drying
537	11/12/2019 5:30	-	168.4	Drying
538	11/12/2019 5:36	Regenerating	170.7	Regenerating
539	11/12/2019 5:42	Drying	169.8	Drying
540	11/12/2019 5:48	-	169.5	Drying
541	11/12/2019 5:54	-	169.5	Drying
542	11/12/2019 6:00	-	169.6	Drying
543	11/12/2019 6:06	-	169.6	Drying
544	11/12/2019 6:12	-	169.7	Drying
545	11/12/2019 6:18	-	169.8	Drying
546	11/12/2019 6:24	-	169.8	Drying
547	11/12/2019 6:30	-	169.9	Drying
548	11/12/2019 6:36	-	169.9	Drying
549	11/12/2019 6:42	Regenerating	170	Regenerating
550	11/12/2019 6:48	-	170.1	Regenerating
551	11/12/2019 6:54	-	170.1	Regenerating
552	11/12/2019 7:00	-	170.1	Regenerating
553	11/12/2019 7:06	Drying	169.4	Drying
554	11/12/2019 7:12	-	169.9	Drying
555	11/12/2019 7:18	Regenerating	172.5	Regenerating
556	11/12/2019 7:24	-	210.7	Regenerating
557	11/12/2019 7:30	-	256.3	Regenerating
558	11/12/2019 7:36	-	293.8	Regenerating

Apparently, the output temperature oscillates around 170 Deg. F at the start of the regeneration cycle before it rises consistently. We must try a better approach.

Better Operating State

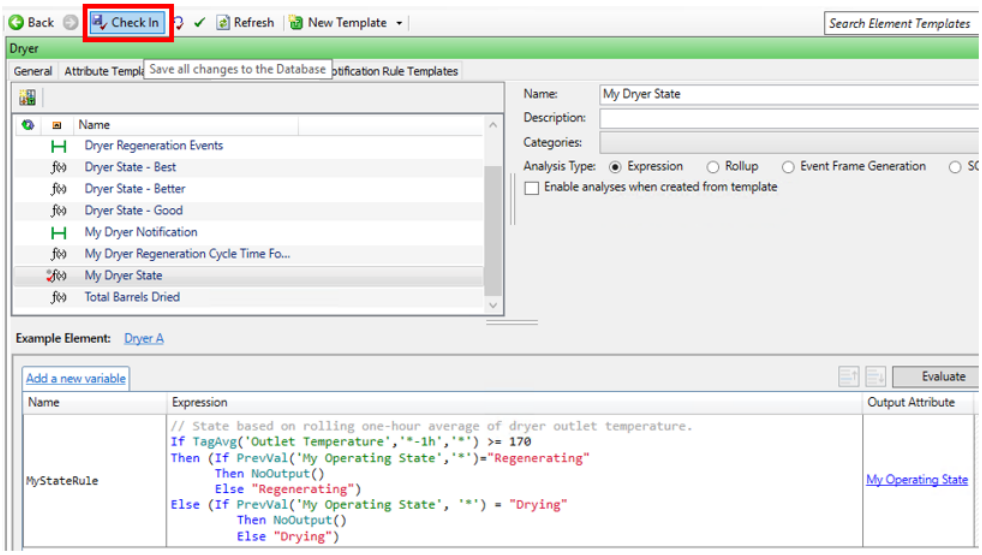
Configure an Asset Analytic that defines dryer's regeneration cycle starts when the rolling hourly average of its outlet temperature goes above 170 Deg. F. This should solve the oscillation outlet temperature problem.

1. Select the **My Dryer State** analysis and, using copy and paste, replace the **Expression** for **MyStateRule** with the one shown below.

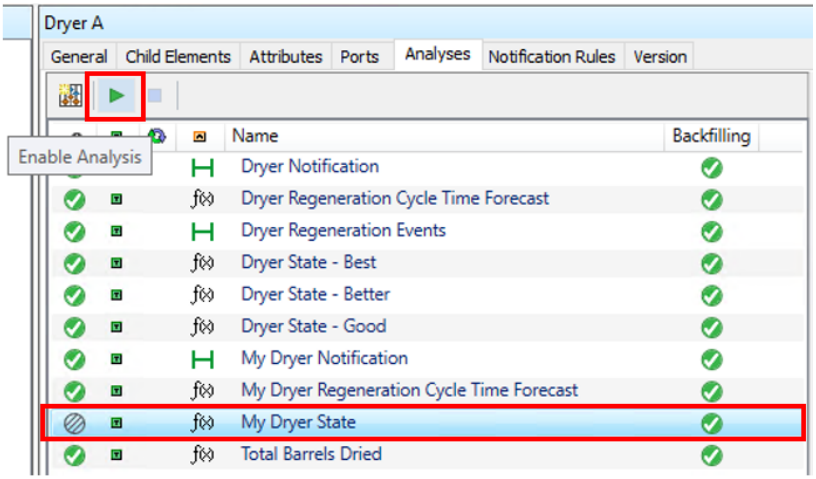
```
 // State based on rolling one-hour average of dryer outlet temperature.
If TagAvg('Outlet Temperature','*-1h','*') >= 170
Then (If PrevVal('My Operating State','*')="Regenerating"
      Then NoOutput()
      Else "Regenerating")
Else (If PrevVal('My Operating State', '*') = "Drying"
       Then NoOutput()
       Else "Drying")
```

Feeling more confident, we will test this analysis using the Backfill\Recalculate feature of Asset Analytics. We will run the backfill from the **'Dryer A'** element which will publish results into the PI Tag, **'Dryers:My State A'**, which we have previously configured. We'll check things over in PI Vision when we're done.

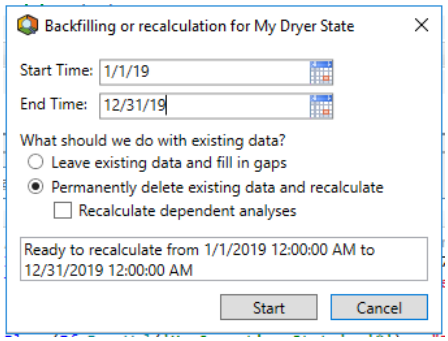
2. To run our analysis from the **Dryer A** element, we must first check in our changes to the Dryer template. Click **Check In** at the top of PI System Explorer.



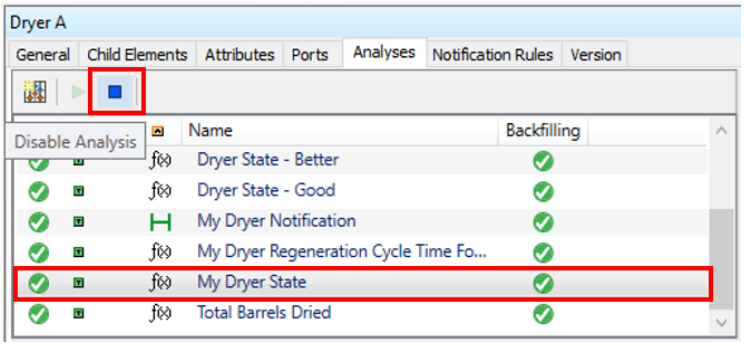
3. Select the **Elements** view in the lower left-hand corner of PI system explorer. Click on the **Dryer A** element and go to its **Analysis** tab at the top.
4. Enable the 'My Dryer State' analysis by selecting it and clicking the **Enable Analysis** button at the top. You will see a green checkmark appear once the analysis is running.

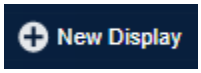


5. Right-click on the **'My Dryer State'** analysis in the Analysis list. Select **Backfill\Recalculate**. In the dialog, enter a **Start Time** of **1/1/19** and an End time of 12/31/19. Check **'Permanently delete existing data and recalculate'**. Click **Start** to backfill the results.



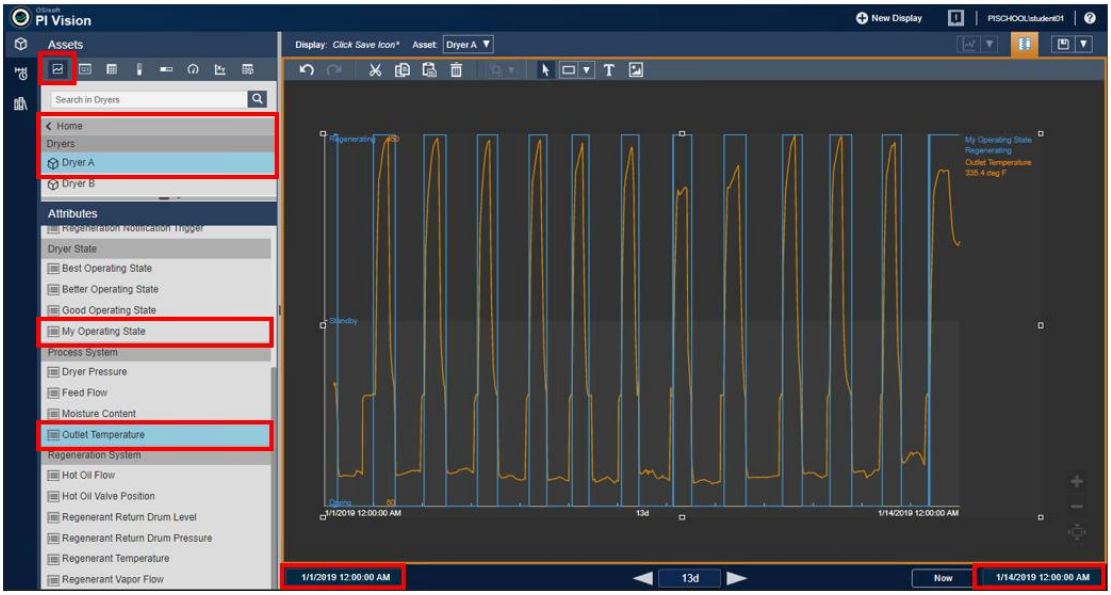
6. Once the green checkmark show up in the **Backfilling** column, disable the analysis by clicking the **Disable Analysis** button at the top.



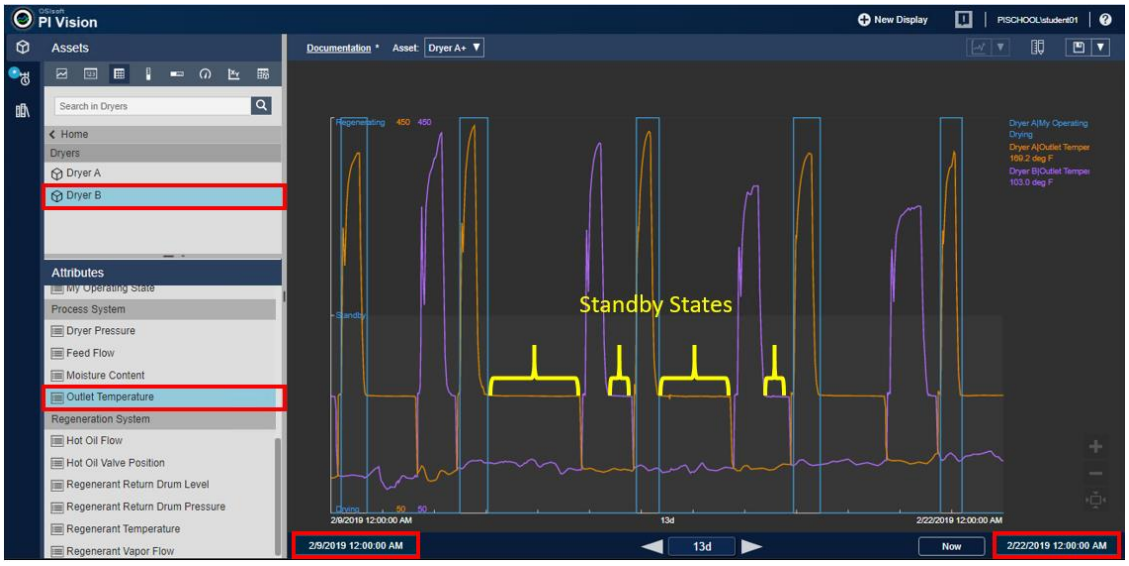
7. Open PI vision from the desktop. Launch a new PI Vision by clicking the 

link in the upper right-hand corner of the browser. Under **Assets**, navigate the **Dryers** AF Database and select **Dryer A**. Make sure a trend selected as the default visualization object (upper left-hand corner). Drag attribute **My Operating State** onto the blank PI Vision display to create a trend of this value. Select attribute **Outlet Temperature** and

drag it on top of the trend to add its trace. Change the start and end times of the display to be 1/1/19 and 1/1519, respectively.



8. Scroll the display through the year and visually inspect the results. Using an average value of the Outlet Temperature works much better for defining the start and end times of each regeneration cycle.
9. Return to the **Assets** pane, navigate the **Dryers** AF Database and select **Dryer B**. Select this dryer's attribute **Outlet Temperature** and drag it on top of the trend to add its trace. Scroll the display to set the time range to someplace around 2/9/19 to 2/22/19.



Upon further review, it appears there are times when the dryer is neither in a Drying or Regenerating state. We can define a third state, Standby, to account for this time. Minimize the PI Vision window.

Best Operating State

Configure an Asset Analytic that defines all three states of the dryer's operation, "Drying", "Regenerating" and "Standby".

1. Return to the **Library** view in PI System Explorer. Select the **Dryer** Element Template ad click on the **Analysis Templates** tab at the top of the window.
2. Select the **My Dryer State** analysis and, using copy and paste, replace the **Expression** for **MyStateRule** with the one shown below.

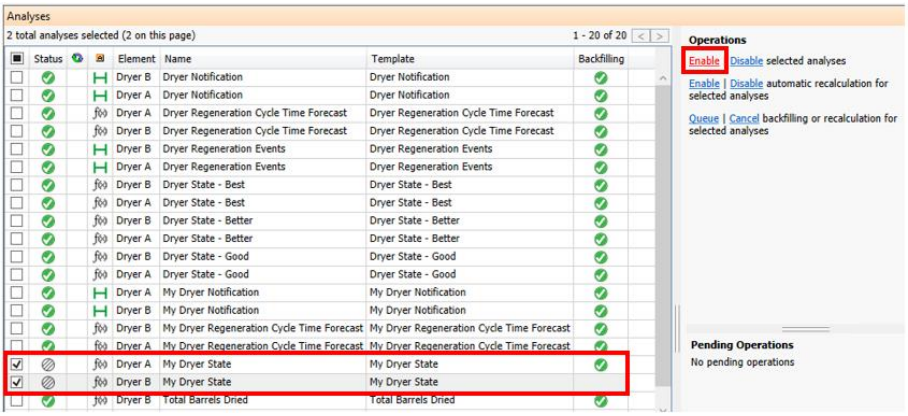
```
// Check for Regeneration State.
If TagAvg('Outlet Temperature','*-1h','*') >= 170
Then (If PrevVal('My Operating State','*')="Regenerating"
    Then NoOutput()
    Else "Regenerating")
// Check for Standby State.
Else (If 'Outlet Temperature' >= 120
    Then (If PrevVal('My Operating State', '*') = "Standby"
        Then NoOutput()
        Else "Standby")
    // Must be Drying state.
    Else (If PrevVal('My Operating State', '*') = "Drying"
        Then NoOutput()
        Else "Drying"))
```

3. Check in your changes by clicking **Check In** at the top of PI System Explorer.

Feeling even more confident, we will backfill the results into the PI Tags for both dryers.

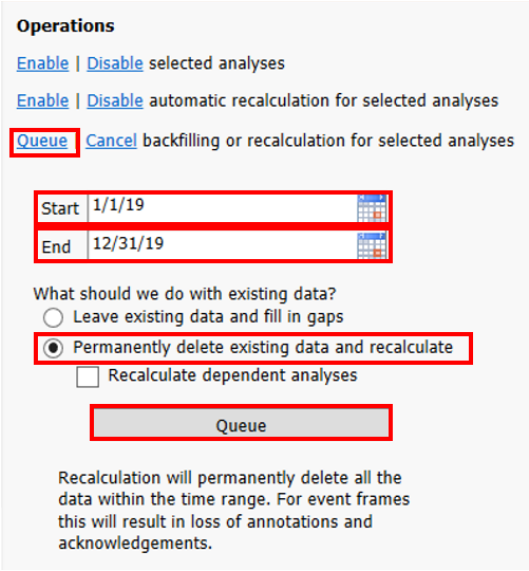
4. In the lower left-hand corner of PI System Explorer, select the **Management** view. Here is where you manage all the Asset Analytics configured for an AF Database. This includes enabling, disabling and backfilling calculations.

5. Select the **'My Dryer State'** analyses for the **Dryer A and B** elements. On the right-hand side under **Operations**, click **Enable**.



6. Once the  appears in the **Status** column the analyses are up and running. Again under **Operations**, click on **Queue**. This exposes the backfilling configuration dialog.

   Configure the **Start** and **End** times to be **'1/1/19'** and **'12/31/19'**, respectively. Check '**Permanently delete existing data and recalculate'**. This will allow the backfill service to overwrite the results we stored for Dryer A in the previous step. And finally, click **Queue** start backfilling results for the two dryers.



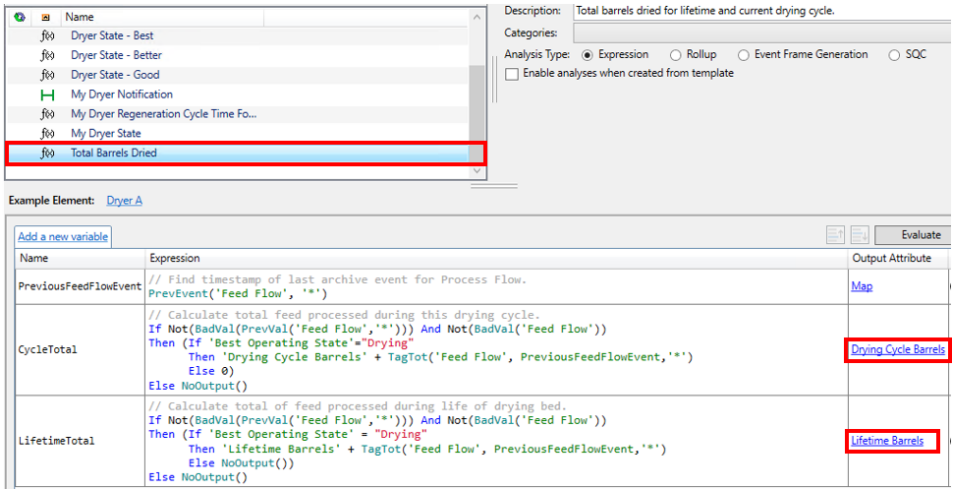
7. Once  appear under the **Backfilling** column, disable the analysis by clicking **Disable**.

8. Reopen the PI vision display. You should see that the state tag has correctly identified the "Standby" state.

2.3 Calculate Dryer Utilization Metrics – Asset Analytics

We have successfully defined a rule for determining dryer operating states and populated PI Tags with these values. Now we can add two analyses to measure the utilization of the molecular sieve beds. The first will calculate the volume, in barrels throughput, for each drying cycle. The second will be a running total for all drying cycles since the start of 2019, when this load of molecular sieve was first put into service. As you will see, these calculations are only possible because we first created the required process context in the PI System, i.e. the dryer operating state values.

1. Return to the **Library** view in PI System Explorer. Select the **Dryer** Element Template and click on the **Analysis Templates** tab at the top of the window.
2. Select the **Total Dried Barrels** analysis.



The Total Dried Barrels analysis generates two results which are stored into PI Tags referenced by the AF Attributes **Drying Cycle Barrels** and **Lifetime Barrels**. This is a three-step analysis that breaks down as follows;

Assign a variable, **PreviousFeedFlowEvent** to contain the timestamp of the last archive value of the **Feed Flow** attribute (BPD).

```
// Find timestamp of last archive event for Process Flow.
PrevEvent('Feed Flow', '*')
```

Calculate **Drying Cycle Barrels**. Check for bad values of either the previously archived or current value of the **Feed Flow**, the endpoints of the incremental total. If good values are returned, add the incremental total to the **Drying Cycle Barrels** attribute when the dryer is in a Drying state. Otherwise reset its value to zero. If either value of the Feed Flow is bad, do nothing.

```
// Calculate total feed processed during this drying cycle.
If Not(BadVal(PrevVal('Feed Flow','*'))) And Not(BadVal('Feed Flow'))

Then (If 'Best Operating State'="Drying"
    Then 'Drying Cycle Barrels' + TagTot('Feed Flow', PreviousFeedFlowEvent,'*')
    Else 0)
```

```
Else NoOutput()
```


Note

In this calculation we are converting a flow rate in barrels/day to a volume, barrels. The 'TagTot' function handles this conversion AND also handles cases where values stored in the PI Archive are not evenly time spaced.

Calculate **Lifetime Barrels**. Check for bad values of either the previously archived or current value of the **Feed Flow**, the endpoints of the incremental total. If good values are returned, add the incremental total to the **Lifetime Barrels** attribute when the dryer is in a Drying state. Otherwise do nothing. If either value of the Feed Flow is bad, do nothing.

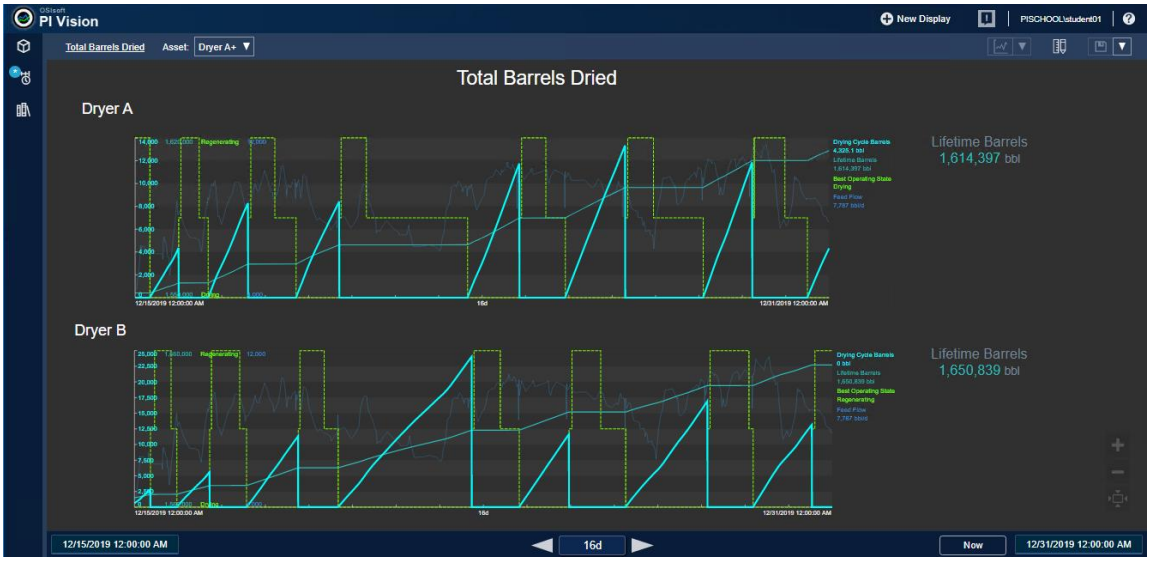
```
// Calculate total of feed processed during life of drying bed.
If Not(BadVal(PrevVal('Feed Flow','*'))) And Not(BadVal('Feed Flow'))

Then (If 'Best Operating State' = "Drying"
    Then 'Lifetime Barrels' + TagTot('Feed Flow', PreviousFeedFlowEvent,'*')
    Else NoOutput())

Else NoOutput()
```

5. Open PI Vision from the desktop.
6. Click the 

logo on the upper left-hand corner of the PI vision display. This will return you to the display thumbnails.
7. From the PI Vision display thumbnails, double-click on the **'Total Barrels Dried'** tile to open this display.



3. Contextualization and Data Preparation

3.1 Objective

In this exercise we will configure Event Frames to prepare useful process information for each dryer regeneration cycle. The Event Frame attributes we choose are ones we will find useful for qualifying our idea and for building the model to estimate the duration of the next dryer regeneration cycle.

3.2 Prepare Dryer Regeneration Features - Event Frame Template

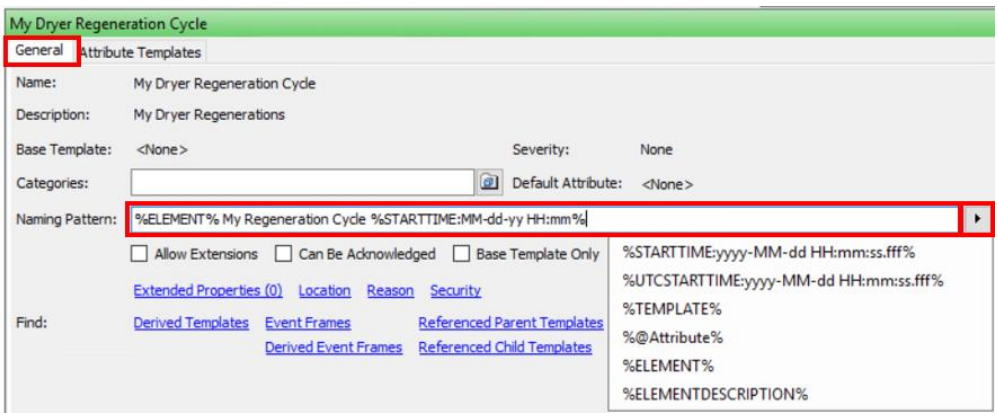
Event Frames produce records, stored in the PI System, containing the start time, end time and duration of significant processing periods, like dryer regeneration cycles. We can add other values, pertaining to the regeneration cycles, to the Event Frame records using Asset Analytics. Here, we will add the following attributes of interest.

- Average Outlet Temperature, Deg. F.
- Maximum Outlet Temperature, Deg. F.
- Average Regenerating Temperature, Deg. F.
- Maximum Regenerating Temperature, Deg. F.
- Drying Cycle Barrels, barrels
- Drying Cycle Duration, hrs.
- Regen Cycle Vapor, barrels

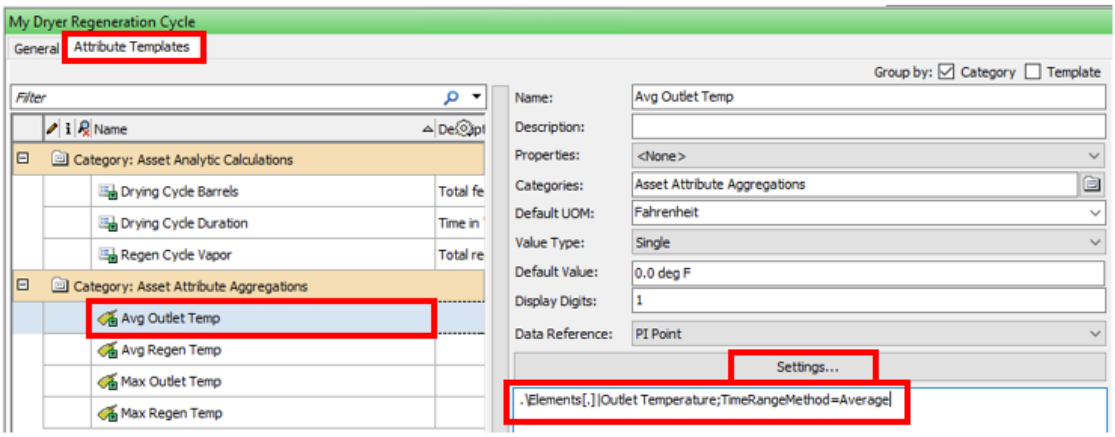
There are two steps in configuring Event Frames. The first is creating an Event Frame template which defines the naming pattern and attributes. The second is configuring the Asset Analytic to trigger the start and end of the Event Frame period. In this example, we will also generate values for several of the attributes in the above list using Asset Analytics. This is a very powerful feature, as you will see.

An Event Frame template has been created for you to use. After walking through its configuration, we will configure an analytic to generate the event Frames themselves.

1. In PI System Explorer, select the **Library** view. Under the **Templates** branch of the hierarchy, expand **Event Frame Templates** and select the **My Dryer Regeneration Cycle** template. The **Naming Pattern** is specified under the **General** tab. Event Frame names use substitution parameters. Click the  at the far right-hand of the name field to get some hints.



2. Select the **Attribute Templates** tab at the top to see the list of attributes. Expand the attribute configuration dialog by clicking the  along the right-hand boarder of PI System Explorer. Select the **Avg Outlet Temp** attribute.



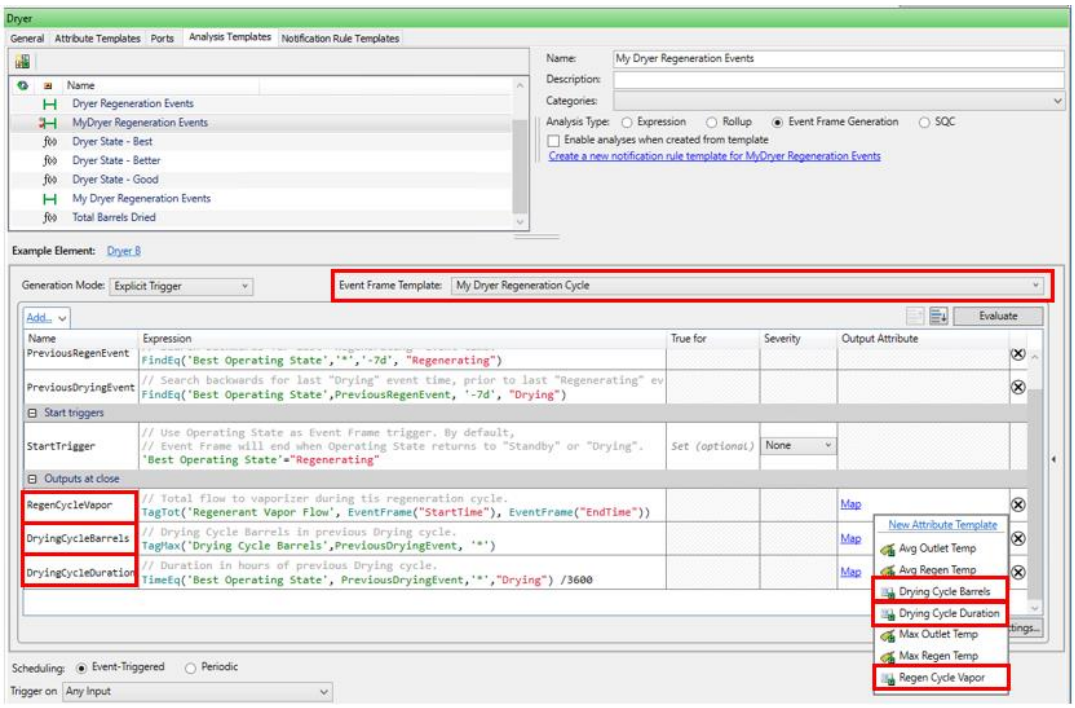
There are two attribute categories for this template, **Asset Analytic Calculations** and **Asset Attribute Aggregations**. Let's take a look at the second group first.

3. Click through the list of **Asset Attribute Aggregations**. These values will be calculated when the Event Frame ends and are derived from the attributes defined in the associated element. In this case, the Dryer A and Dryer B elements. They all have a PI Point Data Reference since their values will come from a PI Point aggregation.

   The following table shows the expression syntax used to define these attributes.

Attribute	**Settings**
Avg Outlet Temp	.\Elements[.]|Outlet Temperature;TimeRangeMethod=Average
Avg Regen Temp	.\Elements[.]|Regenerant Temperature;TimeRangeMethod=Average
Max Outlet Temp	.\Elements[.]|Outlet Temperature;TimeRangeMethod=Maximum
Max Regen Temp	.\Elements[.]|Regenerant Temperature;TimeRangeMethod=Maximum

4. Click on any one of the attributes in the **Asset Analytic Calculation** list. Notice there are no settings specified and they have no Data Reference specified. These are merely placeholders to contain the result of an Asset Analytics calculation which occurs upon the end or close of the Event Frame. We will configure this calculation next section.
5. Under **Element Templates,** return to the **Dryer** template and select **Analysis Templates** tab at the top.
6. Make a copy of the **Dryer Regeneration Events** analysis by right-clicking on it and selecting **Copy**. Then, right-click again and select **Paste**. Select the copied analysis, **Dryer Regeneration Events1** and rename it to **My Dryer Regeneration Events**.
7. Change the Event Frame Template this analysis will use to be **My Dryer Regeneration Cycle.** This is done from the Event Frame Template dropdown shown below.



8. Click the **Map** link for each Output at Close expression and match it with its corresponding Attribute in the Event Frame Template. Be careful the order is not the same.
9. Review the **Start Trigger expression**. When this condition it TRUE, the Event Frame starts. Once it becomes FALSE, the Event Frame ends.

StartTrigger	// Use Operating State as Event Frame trigger. By default,
	// Event Frame will end when Operating State returns
	// to "Standby" or "Drying".
	'Best Operating State'="Regenerating"

Two of the values we want included in the Event Frame are calculated with respect to the Drying cycle that immediately precedes a Regeneration Cycle. To find out when the last

Drying cycle started, we use two Variable expressions to perform a two-step backward search into the PI Archive to retrieve timestamps of these events.

Name	Expression

PreviousRegenEvent	// Search backwards for last "Regenerating" event time.
	FindEq('Best Operating State','*','-7d', "Regenerating")

PreviousDryingEvent	// Search backwards for last "Drying" event time,
	// prior to last "Regenerating" event.
	FindEq('Best Operating State',PreviousRegenEvent, '-7d', "Drying")

10. We use **Output Expressions** to calculate the needed aggregations the remaining values for our Event Frame Template. These expressions leverage the Event Frame Start and End times, as well as, the timestamp variable retrieved above. They are evaluated when the Event Frame closes and are posted as values to the “placeholder” attributes we have configured in the Event Frame Template.

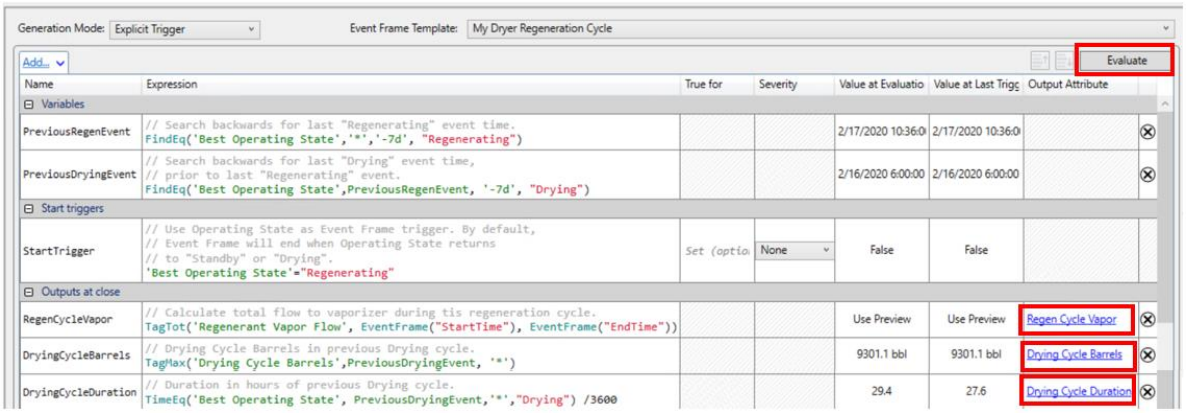
Name	Expression

RegenCycleVapor	// Calculate total flow to vaporizer during tis regeneration cycle.
	TagTot('Regenerant Vapor Flow', EventFrame("StartTime"), EventFrame("EndTime"))

DryingCycleBarrels	// Drying Cycle Barrels in previous Drying cycle.
	TagMax('Drying Cycle Barrels', PreviousDryingEvent, '*')

DryingCycleDuration	// Duration in hours of previous Drying cycle.
	TimeEq('Best Operating State', PreviousDryingEvent,'*',"Drying")
	/3600

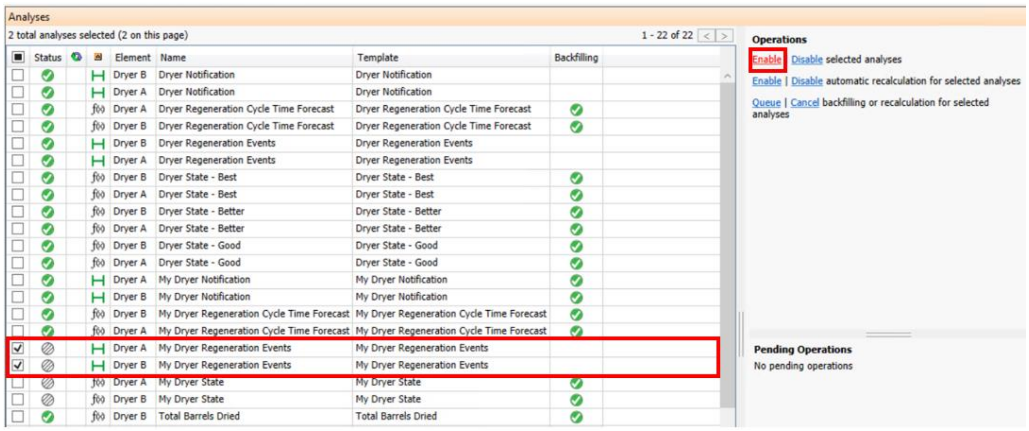
11. Click the **Evaluate** button to preview the results and make sure there are no errors. If it all looks good, **Check In** your changes.



3.3 Generate Regeneration Data for Analysis - Event Frames

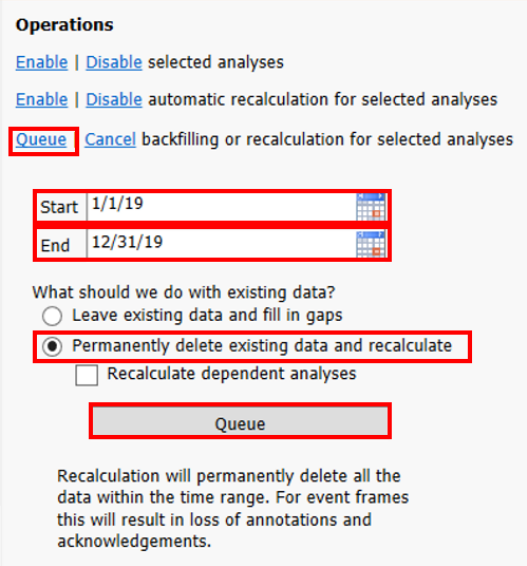
Generate the Event Frames to capture the data needed to analyze the dryer regenerations for 2019.

1. Return to the **Management** view in PI System Explorer. Select the **'My Dryer Regeneration Events'** analyses for the **Dryer A and B** elements. On the right-hand side under **Operations**, click **Enable**.

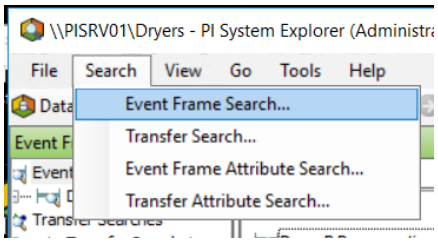


2. Once the  appears in the **Status** column the analyses are up and running. Again under **Operations**, click on **Queue**. This exposes the backfilling configuration dialog.

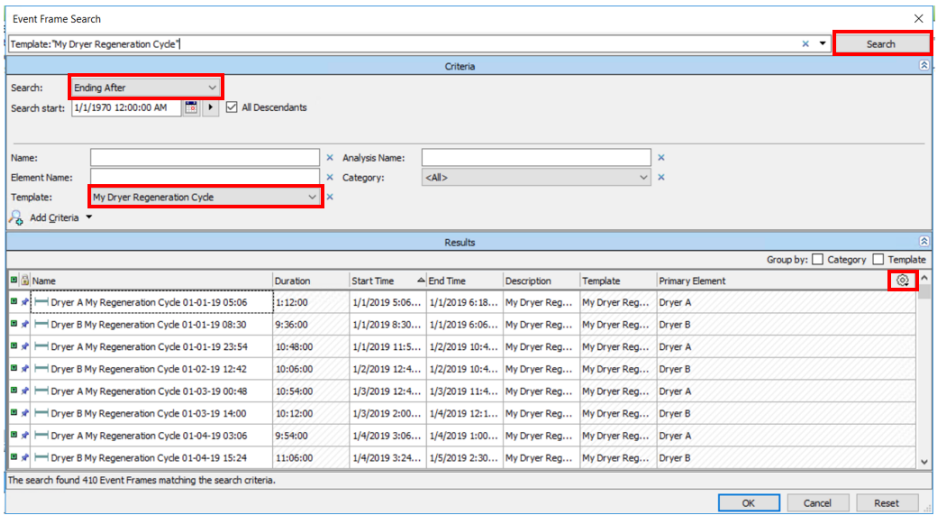
   Configure the **Start** and **End** times to be **'1/1/19'** and **'12/31/19'**, respectively. Check '**Permanently delete existing data and recalculate**'. This will allow the backfill service to overwrite the results we stored for Dryer A in the previous step. And finally, click **Queue** start backfilling Event Frames for the two dryers.



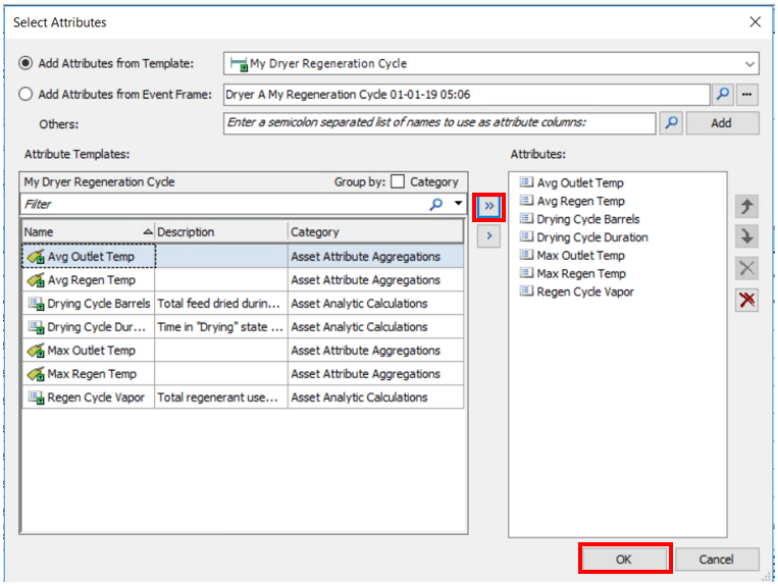
3. Once the  appears under the **Backfilling** column, disable the analysis by clicking **Disable**.
4. Select the **Event Frames** view in the lower left-hand corner of PI System Explorer. Launch the **Event Frame Search** from the top menu.



5. Set the **Search** to '**Ending After'** and the **Template** to **'My Dryer Regeneration Cycle'.** Click **Search** to find the Event Frames matching this criteria.



6. The default Event Frame search does not show attributes in the results. Click the  at the upper right-hand corner of the results grid and click **Select Attributes** to bring up the dialog below.



7. Click  to select all attributes. Click **OK**. Then click OK in the Event Frame Search dialog. This brings all Event Frame records into PI System Explorer. We are now ready to extract this data from PI for analysis.

4. Data Analysis and Qualification

4.1 Objectives

The previous sections of this lab have so far provided us with the data set necessary to start to formulate a model to predict the behavior of the regeneration times for the dryers. In the following section we will be taking the event frame Dryer Regeneration Cycle data and analyzing this set of data to find relationships between the parameters we have and the resulting regeneration times.

The objective of this section is to analyze the Dryer Regeneration Cycle event frame data using various tools at our disposal including Power BI and Excel, and to qualify which variables are important to take into account for our predictive model. We will also be demonstrating how the PI System can enable data analysis and qualification within these tools through the use of the PI Integrator for Business Analytics as well as the PI DataLink Add-In for Excel.

In the following section we will:

- Export the Dryer event frame data into a .CSV file using the PI Integrator for Business Analytics
- Import the .CSV Dryer data into Power BI and examine the relationships between the dryer operating states to confirm the initial problem assessment
- Examine the Dryer Event Frame data in Excel using PI DataLink and decide on a variable to use for predicting Dryer Regeneration Time
- Utilize basic charting and best fit line functionality within Excel to generate a linear model to predict Dryer Regeneration Time

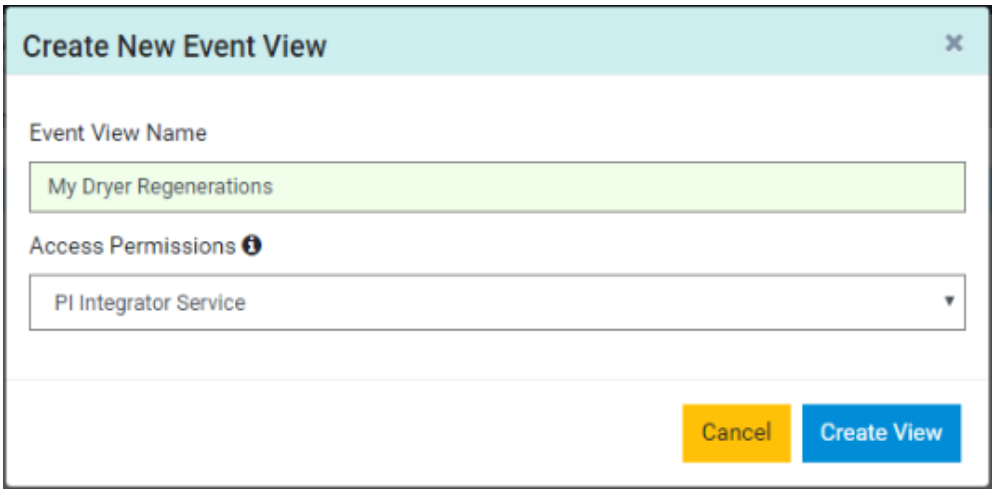
In addition to providing you with hands-on experience using the PI Integrator for Business Analytics and Power BI, the main reason we are going through the trouble of bringing in this data into Power BI is to confirm our initial hypothesis that there is in fact an imbalance in the use of these two dryers. Remember that the overall goal of this analytics project is to formulate a model to predict and standardize the dryer phases in order utilize the dryers in a more balanced way. It is extremely beneficial from a financial and maintenance standpoint to have these dryers end of life around the same time, and the goal of looking at the dryer phases in Power BI is to confirm that they are not currently being used evenly. From a bigger picture perspective, it is helpful to do this sort of 'sanity check' in the middle of a larger analytics project to confirm that the problems you are trying to solve are in fact real, and that the project is worth taking to the next stages of completion.

4.2 Problem Assessment – PI integrator for Business Analytics and Power BI

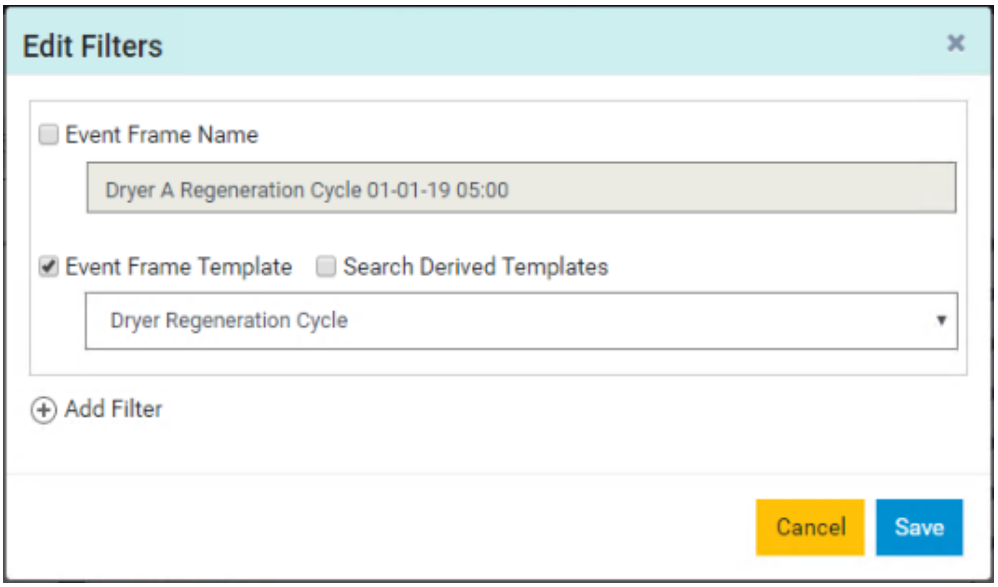
From the Windows taskbar, open PI System Explorer and review the 'Dryers' database. We will be using the PI Integrator for Business Analytics to create an event frame view publication based on the event frames built upon this asset model. The publication target will be a .CSV file posted in the subdirectory C:\PI World\ (this

is also the 'PI World' folder shortcut on the desktop). This .CSV file will provide the data for populating our dataset and analyzing in Power BI.

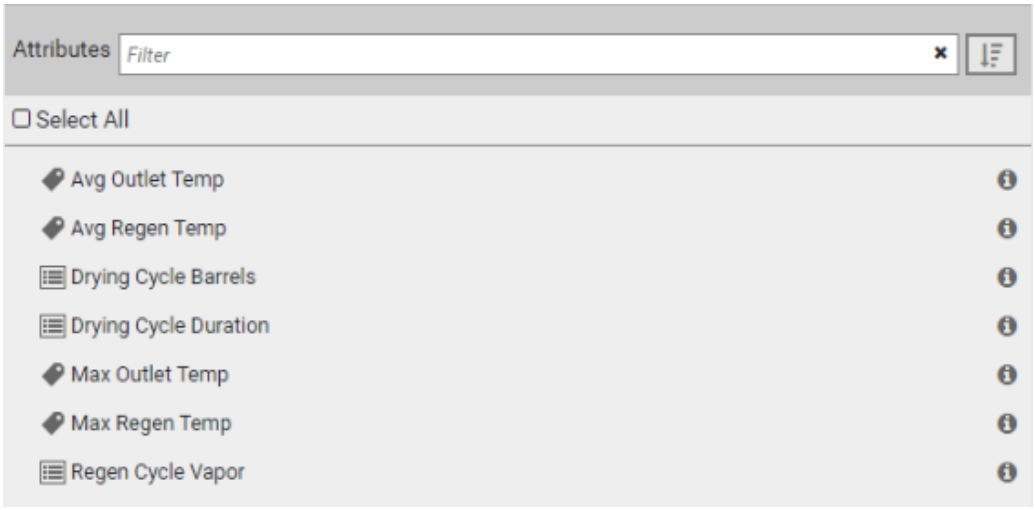
1. Open the PI Integrator for Business Analytics from the desktop shortcut.
2. Click **Create Event View** on the top menu. Name your view **'My Dryer Regenerations'** and click **Create View.**



3. On the Select Data page, select the **Dryers** database. Select one of the listed event frames under the **Source Events** Section on the left. Drag and drop this event into the **Search Shape** area in the middle of the screen under **Event Shape**.
4. On the event frame that was just dragged to the center, click on the Edit pencil icon to the right to bring up the **Edit Filters** option. Adjust the filter to use the '**Dryer Regeneration'** event frame template rather than the Event Frame Name.



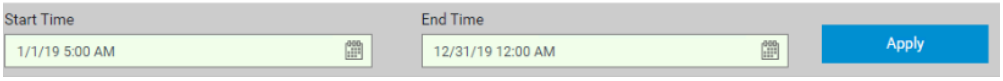
5. With the same event frame highlighted on the left section under **Source Events**, notice the attributes associated with these event frames just below in the **Attributes** Section.



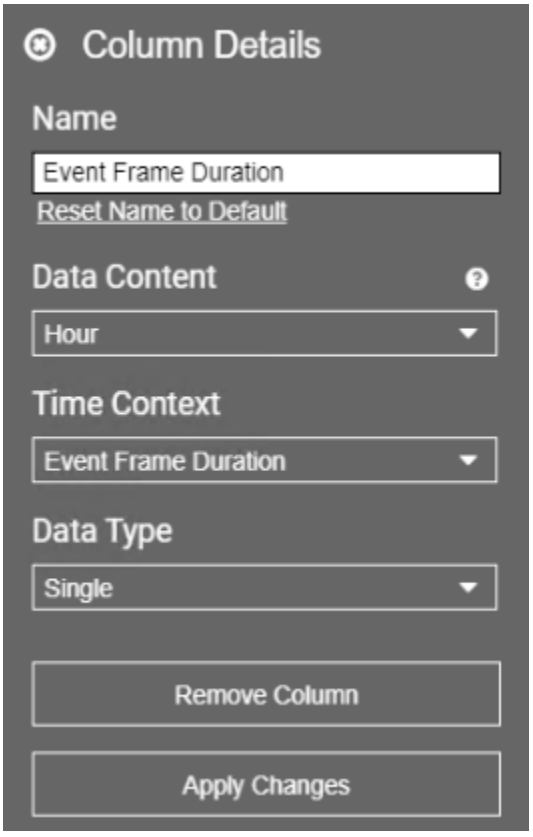
6. Click and drag each of these attributes to the center of the screen under the **'Dryer Regeneration Cycle'** parent that was just created in the middle of the screen. Your event shape should now look like the one below:

7. With the shape selected and the filters set, you should see 100+ event frames matching the criteria listed in the **Matches** area on the right.

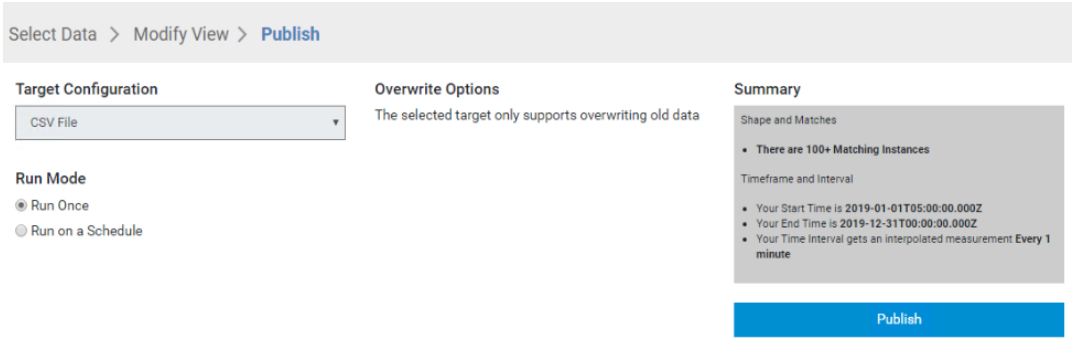
8. Click on the **Next** button on the upper right corner to proceed to the **Modify View** page.
9. The **Modify View** page shows a preview of the first 100 rows of data from the first 100 event frames matching the **Event Shape.** Set the time range, 1/1/19 5:00 AM to 12/31/19 12:00 AM, to match the available PI data for the lab. Click **Apply.**



10. Highlight the **Event Frame Duration** column to bring up the **Column Details** pane on the right. Adjust the **Data Type** to '**Single**' to get the additional digits for duration.



11. Click **Next** to proceed to the **Publish** page.
12. Select **CSV File** as the Target Configuration and click **Publish**, then **Confirm** to publish the data as a .CSV file.

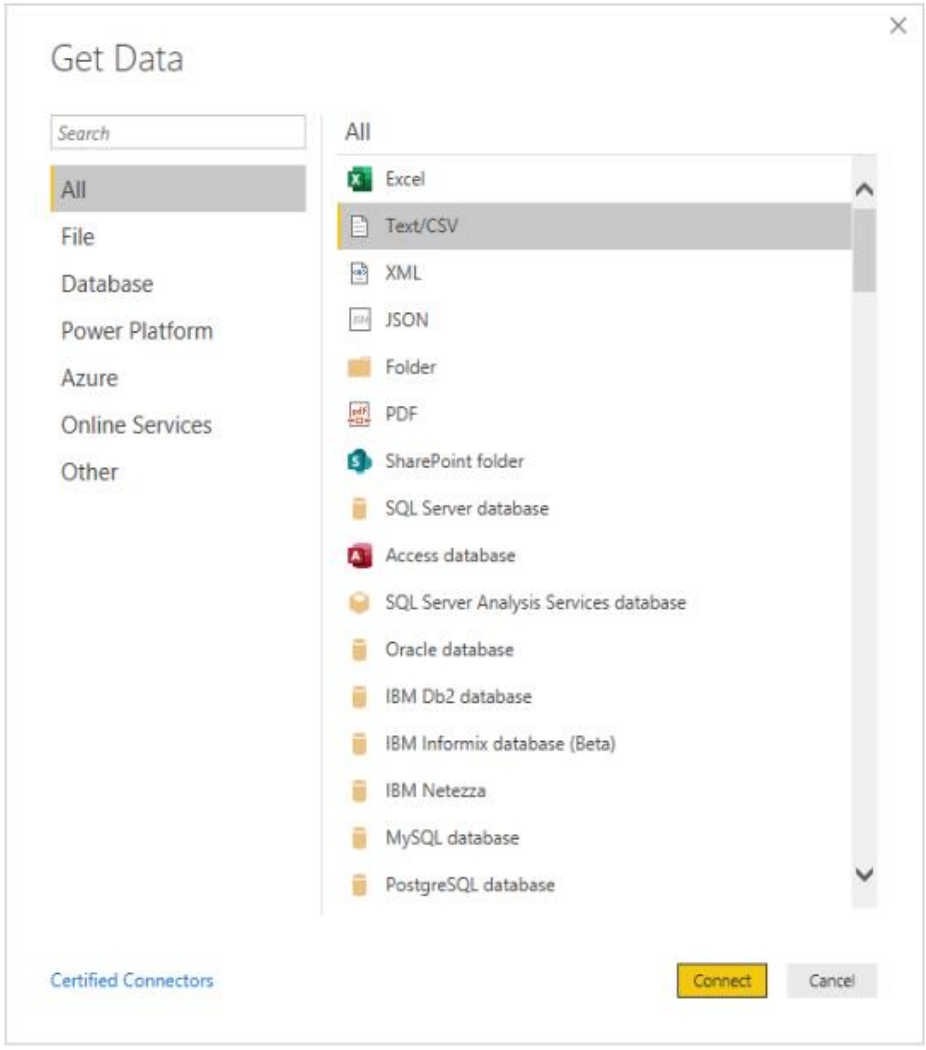


13. The file name will be the name of the asset view, **My Dryer Regenerations**, and it will be in the subdirectory, C:\PI World (this is also the 'PI World' folder shortcut on the desktop). This target was configured using the Administration pages of the PI Integrator for Business Analytics.

Assessment of Dryer Regeneration Data in Power BI

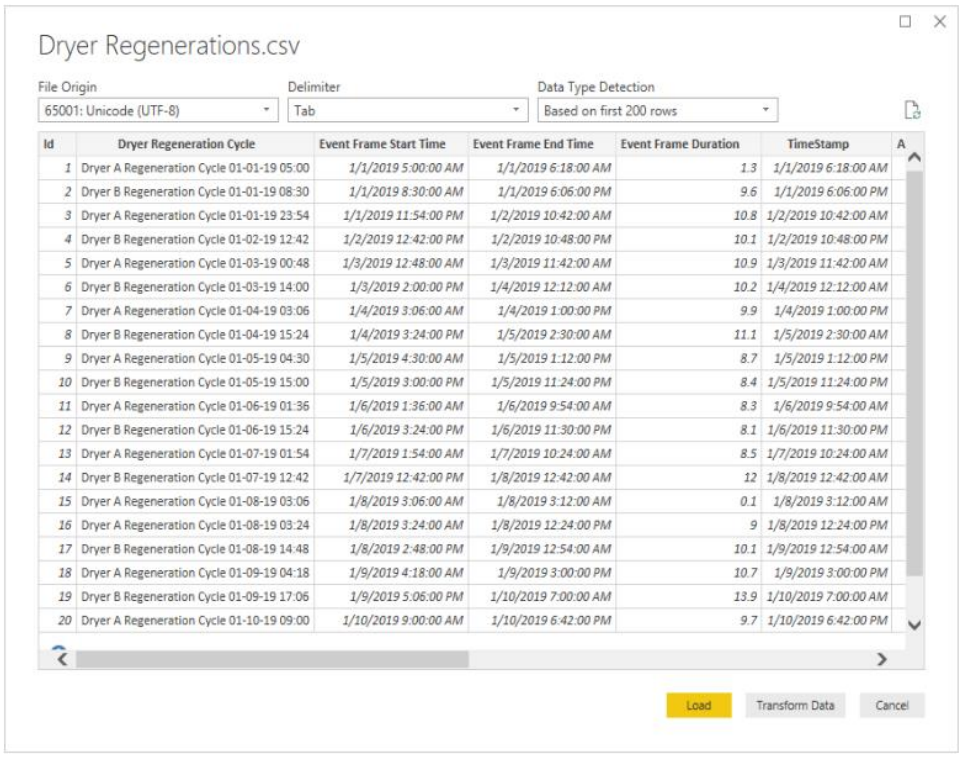
Now that we have the years' worth of dryer regeneration event data in .CSV file format, we can easily ingest it into Power BI for further analysis. Within Power BI, we will be plotting the dryer states (Drying, Standby, Regenerating) for each dryer as a function of time (using weeks as our unit of time). This type of analysis lends itself very well to the capabilities of Power BI and illustrates the benefits of using the PI Integrator for BA to shape the data.

1. From the desktop, open the Power BI Report **'Regeneration Analysis.pbix'**
2. Alternatively, if you'd like to build out the Power BI Report yourself, follow these steps:
    I. From the desktop, open the **'Power BI Desktop'** application.
    II. Import the 'Dryer Regenerations.csv' file. Click on the '**Get Data'** option at the top of the application and choose the '**Text/CSV'** file option. Click on **'Connect**'



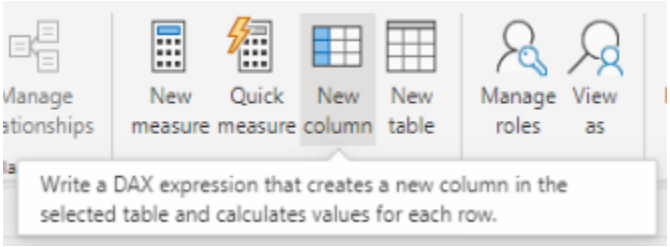
III. Choose the **'Dryer Regenerations.csv'** file in the **C:\PI World** location and click **'Open'**

IV. Click **'Load'** to import the dataset into Power BI.



Id	Dryer Regeneration Cycle	Event Frame Start Time	Event Frame End Time	Event Frame Duration	TimeStamp
1	Dryer A Regeneration Cycle 01-01-19 05:00	1/1/2019 5:00:00 AM	1/1/2019 6:18:00 AM	1.3	1/1/2019 6:18:00 AM
2	Dryer B Regeneration Cycle 01-01-19 08:30	1/1/2019 8:30:00 AM	1/1/2019 6:06:00 PM	9.6	1/1/2019 6:06:00 PM
3	Dryer A Regeneration Cycle 01-01-19 23:54	1/1/2019 11:54:00 PM	1/2/2019 10:42:00 AM	10.8	1/2/2019 10:42:00 AM
4	Dryer B Regeneration Cycle 01-02-19 12:42	1/2/2019 12:42:00 PM	1/2/2019 10:48:00 PM	10.1	1/2/2019 10:48:00 PM
5	Dryer A Regeneration Cycle 01-03-19 00:48	1/3/2019 12:48:00 AM	1/3/2019 11:42:00 AM	10.9	1/3/2019 11:42:00 AM
6	Dryer B Regeneration Cycle 01-03-19 14:00	1/3/2019 2:00:00 PM	1/4/2019 12:12:00 AM	10.2	1/4/2019 12:12:00 AM
7	Dryer A Regeneration Cycle 01-04-19 03:06	1/4/2019 3:06:00 AM	1/4/2019 1:00:00 PM	9.9	1/4/2019 1:00:00 PM
8	Dryer B Regeneration Cycle 01-04-19 15:24	1/4/2019 3:24:00 PM	1/5/2019 2:30:00 AM	11.1	1/5/2019 2:30:00 AM
9	Dryer A Regeneration Cycle 01-05-19 04:30	1/5/2019 4:30:00 AM	1/5/2019 1:12:00 PM	8.7	1/5/2019 1:12:00 PM
10	Dryer B Regeneration Cycle 01-05-19 15:00	1/5/2019 3:00:00 PM	1/5/2019 11:24:00 PM	8.4	1/5/2019 11:24:00 PM
11	Dryer A Regeneration Cycle 01-06-19 01:36	1/6/2019 1:36:00 AM	1/6/2019 9:54:00 AM	8.3	1/6/2019 9:54:00 AM
12	Dryer B Regeneration Cycle 01-06-19 15:24	1/6/2019 3:24:00 PM	1/6/2019 11:30:00 PM	8.1	1/6/2019 11:30:00 PM
13	Dryer A Regeneration Cycle 01-07-19 01:54	1/7/2019 1:54:00 AM	1/7/2019 10:24:00 AM	8.5	1/7/2019 10:24:00 AM
14	Dryer B Regeneration Cycle 01-07-19 12:42	1/7/2019 12:42:00 PM	1/8/2019 12:42:00 AM	12	1/8/2019 12:42:00 AM
15	Dryer A Regeneration Cycle 01-08-19 03:06	1/8/2019 3:06:00 AM	1/8/2019 3:12:00 AM	0.1	1/8/2019 3:12:00 AM
16	Dryer A Regeneration Cycle 01-08-19 03:24	1/8/2019 3:24:00 AM	1/8/2019 12:24:00 PM	9	1/8/2019 12:24:00 PM
17	Dryer B Regeneration Cycle 01-08-19 14:48	1/8/2019 2:48:00 PM	1/9/2019 12:54:00 AM	10.1	1/9/2019 12:54:00 AM
18	Dryer A Regeneration Cycle 01-09-19 04:18	1/9/2019 4:18:00 AM	1/9/2019 3:00:00 PM	10.7	1/9/2019 3:00:00 PM
19	Dryer B Regeneration Cycle 01-09-19 17:06	1/9/2019 5:06:00 PM	1/10/2019 7:00:00 AM	13.9	1/10/2019 7:00:00 AM
20	Dryer A Regeneration Cycle 01-10-19 09:00	1/10/2019 9:00:00 AM	1/10/2019 6:42:00 PM	9.7	1/10/2019 6:42:00 PM

V. Add a column to the dataset to assign the week number. Click on the **'Data'** View rather than the **'Report'** view on the top left of the application to see the tabular dataset we just imported. Click on the **'New Column'** action on the top toolbar.



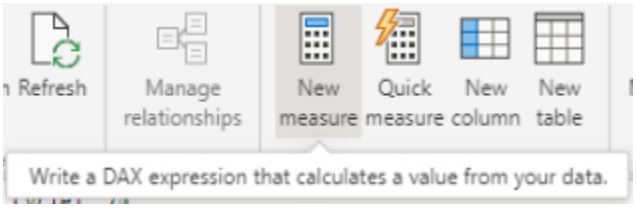
VI. In the formula bar with the new column highlighted, type the following and click the check box to commit :

Week = WEEKNUM('Dryer Regenerations'[TimeStamp])

VII. Add a column to the dataset to note which dryer is involved in each event. Click on the **'Data'** View rather than the **'Report'** view on the top left of the application to see the tabular dataset we just imported. Click on the **'New Column'** action on the top toolbar. In the formula bar with the new column highlighted, type the following and click the check box to commit :

Dryer = LEFT('Dryer Regenerations'[Dryer Regeneration Cycle], 7)

VIII. Add a new measure to calculate the total time each dryer is in the **'Drying'** stage. Click on the **'New Measure'** action on the top toolbar.



IX. In the formula bar with the new measure column highlighted, type/paste the following and click the check box to commit :

Drying Time = CALCULATE(SUM('Dryer Regenerations'[Drying Cycle Duration]), FILTER(ALLEXCEPT('Dryer Regenerations','Dryer Regenerations'[Dryer],'Dryer Regenerations'[Event Frame Duration]),'Dryer Regenerations'[Week]<=MAX('Dryer Regenerations'[Week])))

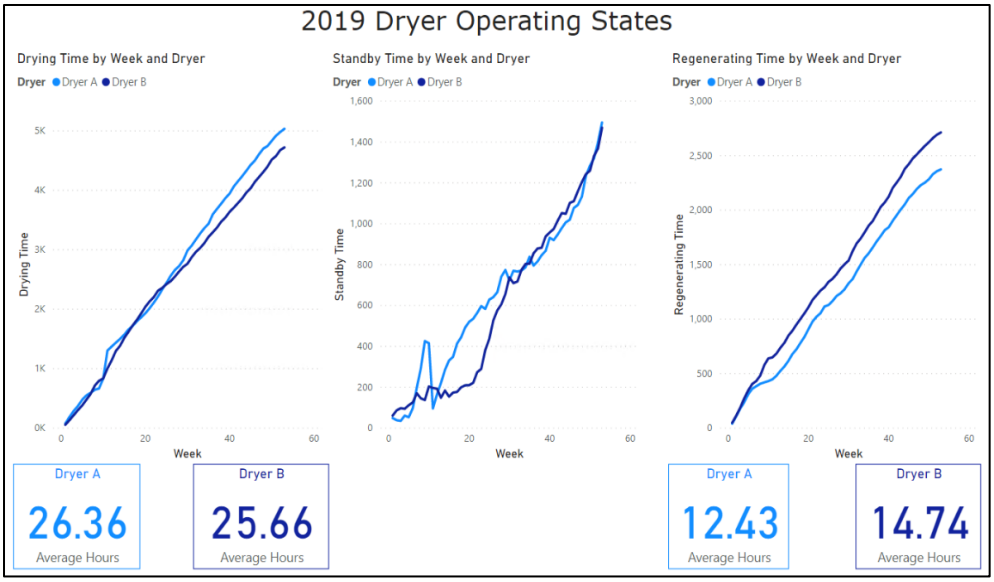
X. Add a new measure to calculate the total time each dryer is in the **'Regenerating'** stage. Click on the **'New Measure'** action on the top toolbar. In the formula bar with the new measure column highlighted, type/paste the following and click the check box to commit:

Regenerating Time = CALCULATE(SUM('Dryer Regenerations'[Event Frame Duration]),FILTER(ALLEXCEPT('Dryer Regenerations','Dryer Regenerations'[Dryer],'Dryer Regenerations'[Event Frame Duration]),'Dryer Regenerations'[Week]<=MAX('Dryer Regenerations'[Week])))

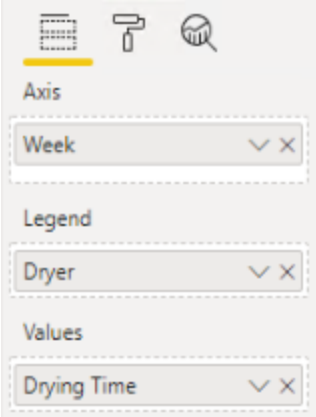
XI. Add a new measure to calculate the total time each dryer is in the **'Regenerating'** stage. Click on the **'New Measure'** action on the top toolbar. In the formula bar with the new measure column highlighted, type/paste the following and click the check box to commit:

Standby Time = CALCULATE(DISTINCTCOUNT('Dryer Regenerations'[Week])*168-SUM('Dryer Regenerations'[Event Frame Duration])-SUM('Dryer Regenerations'[Drying Cycle Duration]),FILTER(ALLEXCEPT('Dryer Regenerations','Dryer Regenerations'[Dryer],'Dryer Regenerations'[Event Frame Duration]),'Dryer Regenerations'[Week]<=MAX('Dryer Regenerations'[Week])))

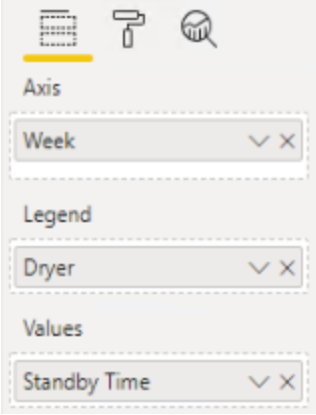
XII. Switch back to the **'Report'** View . We now want to build out three charts displaying each of the Dryer States as a function of Week for each dryer. Your report will eventually look like the one below:



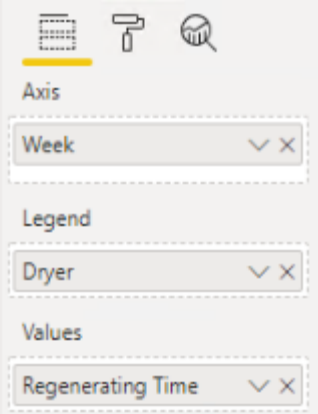
XIII. Create a **Line Chart** for **Drying Time by Week and Dryer.** Choose the **Line Chart** Visual and populate the fields as shown:



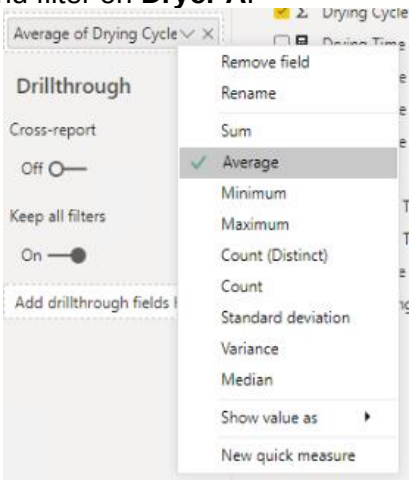
XIV. Create a **Line Chart** for **Standby Time by Week and Dryer.** Choose the **Line Chart** Visual and populate the fields as shown:

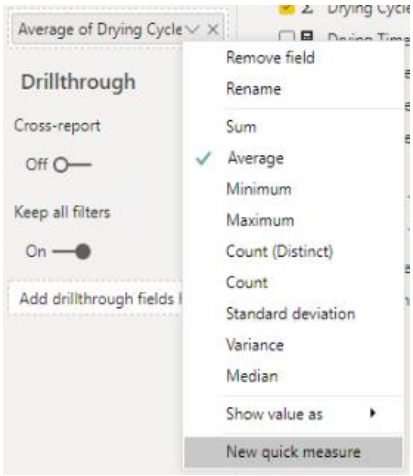


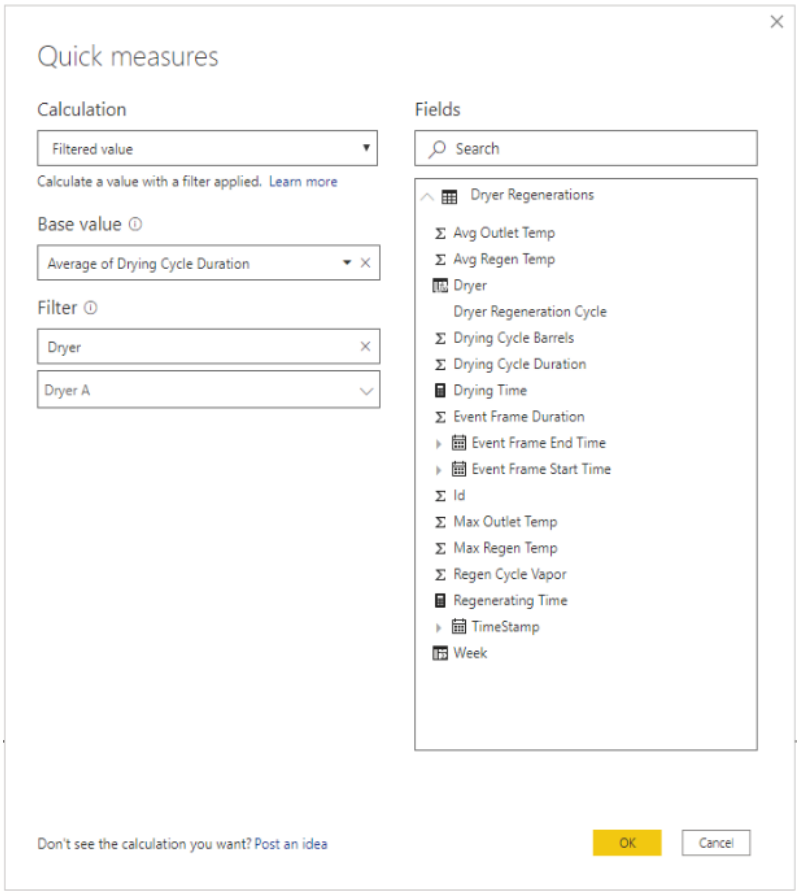
XV. Create a **Line Chart** for **Regenerating Time by Week and Dryer.** Choose the **Line Chart** Visual and populate the fields as shown:



XVI. Create four **Card** visualizations to calculate the average hours of Drying and Regenerating times for each cycle in each dryer. For the Average Drying time card, populate the **Fields** with the **Drying Cycle Duration** item and choose to display the **Average** value. In the dropdown, choose '**New Quick Measure.'** Choose the '**Filtered Value'** Calculation. Drag the **Dryer** item into the **Filter** field and filter on **Dryer A**.

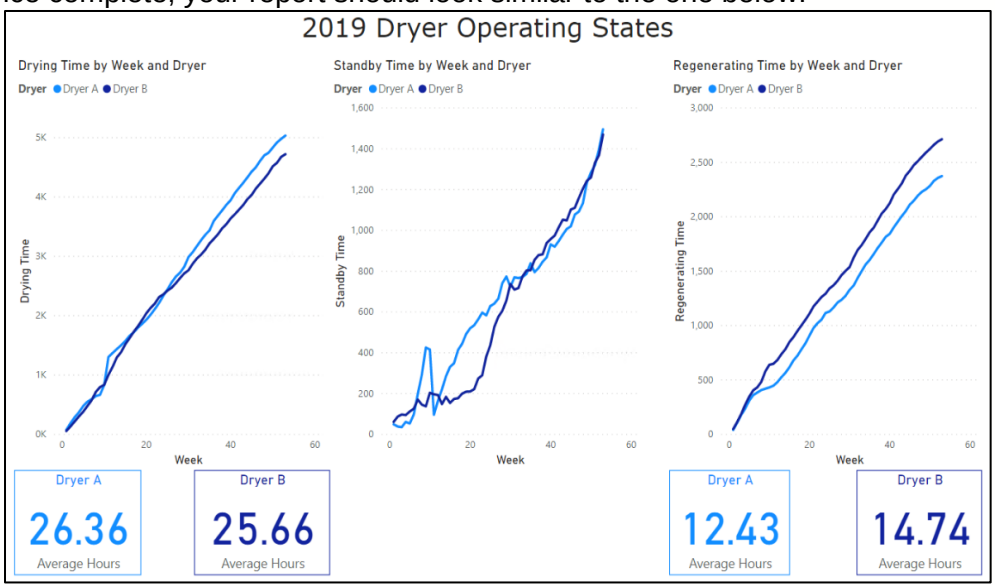






XVII. Repeat this process three more times for the average hours Dryer and Regeneration times for each cycle in each dryer.

XVIII. Once complete, your report should look similar to the one below:



3. Let's take a moment to analyze the 2019 Dryer Operating States Power BI report above. From this report, we can quickly see that there is a clear imbalance between the two dryers in terms of utilization. On average, Dryer A has longer drying cycle times than Dryer B. Conversely, Dryer B has longer Regenerating cycle times on average.

> Tip
>
> **Plotting this data in Power BI, a Business Analytics tool, makes it easy to see the cumulative use of each dryer throughout the year using weeks as the unit of time. The plots above are cumulative slices of data rather than the simple 2-d (x,y) plotting that excel is capable of. This is why we are using Power BI at this step of the project.**

With this visual, we can confirm that the problem we are trying to solve does in fact exist and it is worth moving forward with the project.

4.3 Model Development – PI DataLink

In the previous section, we illustrated the use of the PI Integrator for BA to publish data into Power BI for analysis. In this section, we will illustrate how PI Datalink and Excel can also be used to analyze our Dryer dataset and how we can use basic Excel functionality to generate a linear model to predict regenerating times for each dryer, which we can use for our simple predictive model.

At this point in the Analytics project, it's important to get assistance from Subject Matter Experts (SMEs) who understand the process we are modeling – to ensure we end up with helpful and meaningful results. Our SME in this case has indicated that the **Drying Cycle Barrels** variable that we have – which corresponds to the number of barrels dried in the previous drying cycle – will be the best one to predict preceding regeneration cycle time.

> Note
>
> **For a brief discussion/explanation on why we decided on Drying Cycle Barrels as our predictive variable to inform regeneration time, see the Appendix section 7.1.**

1. On the desktop, open up the Excel file **'PI World Dryer Regen Duration.xlsx'**
2. There are three sheets in the **'PI World Dryer Regen Duration.xlsx'** file.
    a. The first sheet titled **'Dryer A'** has also been built out for you. Since we've chosen the Drying Cycle Barrels as our dependent variable for our linear prediction model, we are focusing on that variable here. The event frame search has brought in the Duration and Drying Cycle Barrels data for the year 2019. We've also filtered out any event frames with a prior Drying Cycle Duration of less than 10 hours – you can see how this can be done in the Event Frame search in the next step. This purpose of this filter is to remove any "false starts" in the

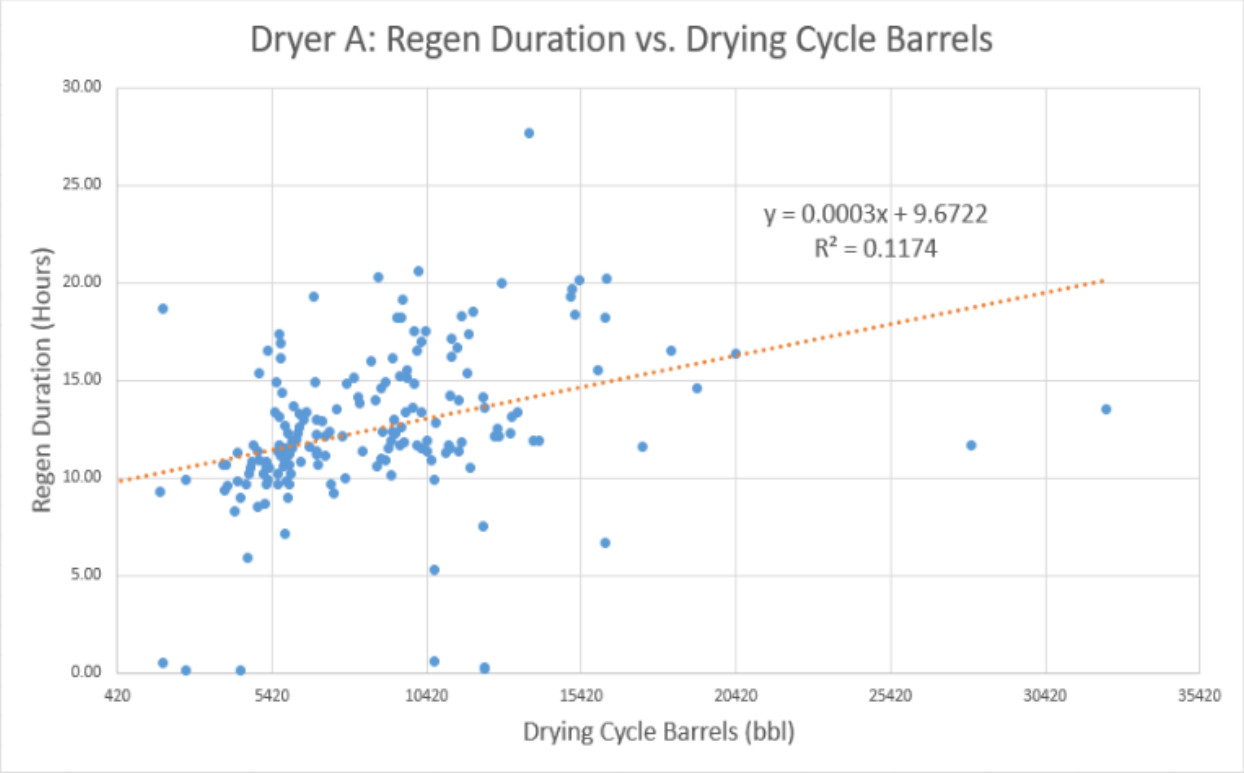
data, when a drying cycle is shorter than typical. This would result in a skewed prediction and we will account for this in our regeneration prediction forecast.

This sheet plots the Regeneration Cycle duration as a function of the Drying Cycle Barrels variable – the number of barrels the dryer processed in the previous drying cycle.

This scatter chart has a linear best-fit line indicating the relationship that the Drying Cycle Barrels variable has on the Regeneration Cycle Time. We will be using this equation of the derived linear regression line as our model to predict Regeneration Cycle Duration.

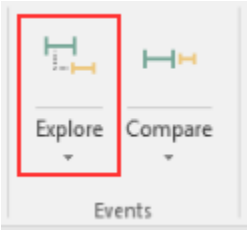
Note

This is clearly a rather simple predictive model that could be more advanced, but for the purposes of this lab we are focusing on the methodology of starting analytics and data science projects with the common tools at our disposal to get us started and familiarized with the basics.



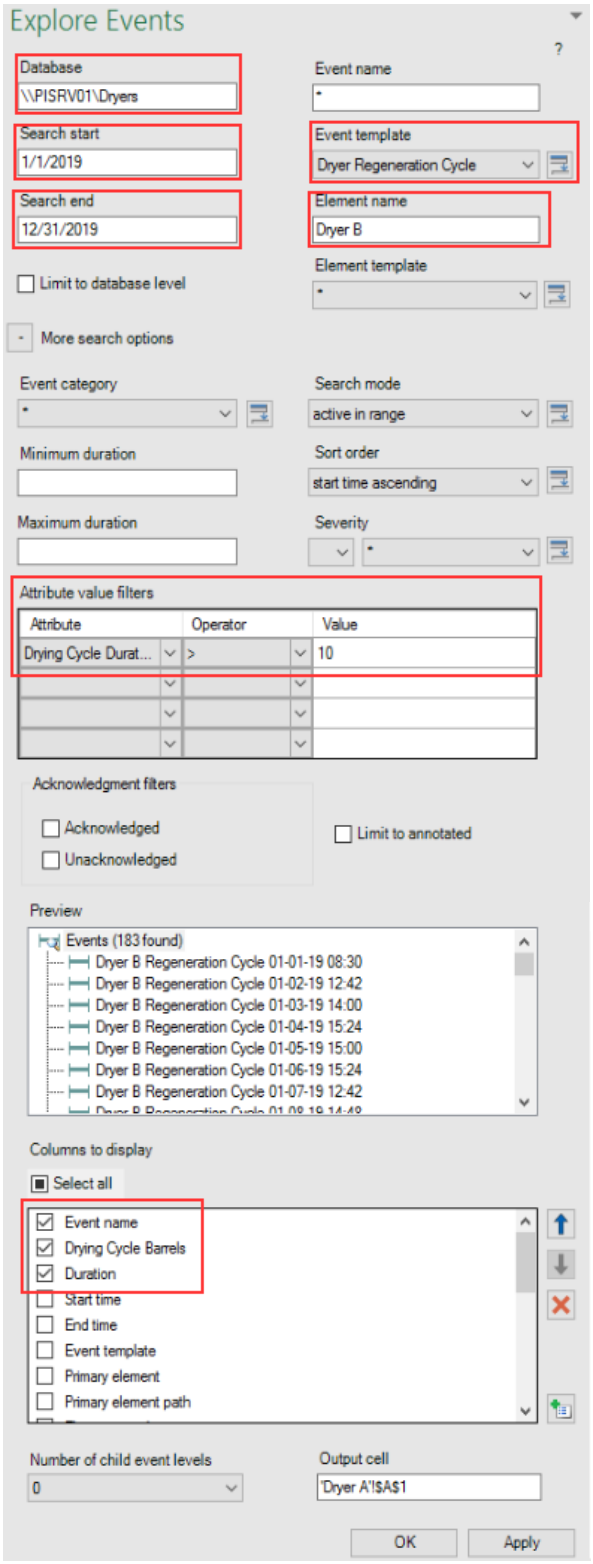
b. The second sheet titled **'My Dryer B'** has not yet been built out for you. To give you experience importing event frame data into Excel using PI DataLink, follow the steps below to build out the same charts as **'Dryer A'** and to develop our linear regression model for Dryer B**.** If you'd prefer to use a pre-built sheet for Dryer B, it is the last sheet in the workbook titled **'Dryer B'**.

i. Bring in all the event frame data for the year 2019 using PI DataLink. Make sure you're in the **'PI DataLink'** ribbon add-in to Excel. Click on **'Explore'** tool in the events tool section of PI DataLink.



ii. Enter the following parameters for your event frame search such that it looks like the one below and click **Apply**:

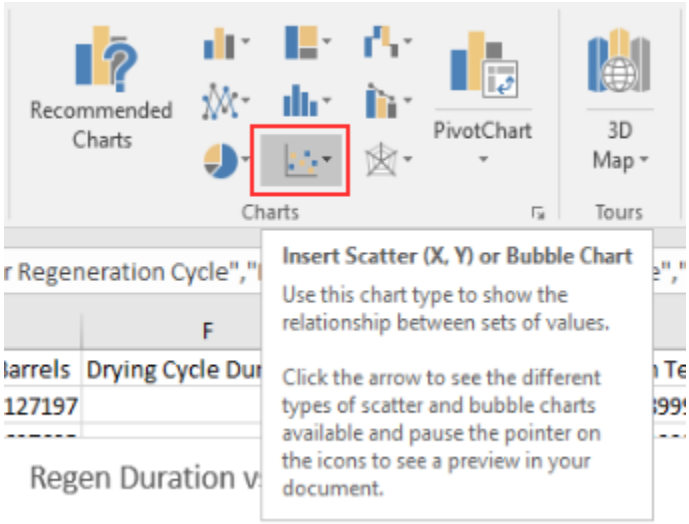
1. **Database:** \\PISRV01\Dryers
2. **Event Name:** *
3. **Search Start:** 1/1/2019
4. **Search End:** 12/31/2019
5. **Event Template:** Dryer Regeneration Cycle
6. **Element Name:** Dryer B
7. **Element Template:** *
8. **+More Search Options>Attribute Value Filters**: 'Drying Cycle Duration' > 10
9. **Select Columns to Display:**
    - Event Name
    - Drying Cycle Barrels
    - Duration



iii. Add a column to the end of the dataset (should be column D) to convert the duration into hours. To do this, simply multiply the imported duration by 24 and change the format of the cells in that column to be of type **Number** with two decimals.

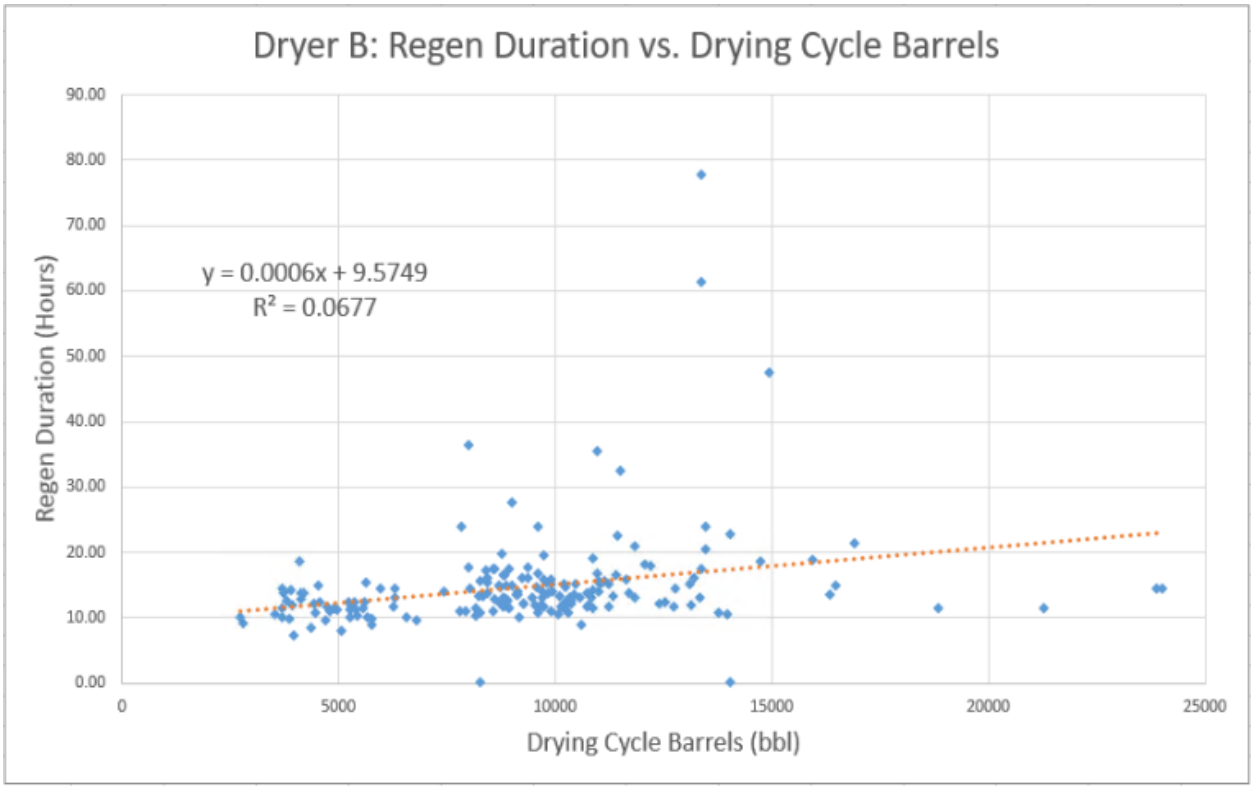
iv. Once the event frame data is brought into the **'Dryer B'** sheet, we can now use Excel's charting functionality to plot the Regeneration Cycle duration as a function of each variable.

v. Within Excel, click on the **Insert** ribbon at the top and choose the **Scatter** plot



vi. Right click on the scatter plot and click **'Select Data.'** On the **Select Data** window, the range of values for **Duration (Hours)** will be the dependent y-axis on this chart and the Drying Cycle Barrels variable will be on the x-axis.

vii. On this chart, click to **Add a Chart Element** of a **Linear Trendline**. Format the trendline to **Display Equation on chart** and to **Display R-squared value on chart**. Once complete, you should have a chart that looks like the one below:



We now have a linear regression model for each dryer using the variable of Drying Cycle Barrels, or the number of barrels dried during the preceding drying cycle, that we will use to predict the proceeding Regeneration Cycle Duration in the next section.

Dryer A

Y = 0.0003X + 9.6722

Where Y = Regeneration Duration and X = Drying Cycle Barrels

Dryer B

Y = 0.0006X + 9.5749

Where Y = Regeneration Duration and X = Drying Cycle Barrels

5. Operationalization and Notification

5.1 Objective

The purpose of this last section of this analytics project is to operationalize the linear model we derived in the previous section to generate a prediction for dryer regeneration time. In the following section we will:

- Create a forecasting analytic using AF Analytics to predict dryer regeneration times
- Create a notification to alert operators when dryer regeneration times are predicted to be 11 hours or more

5.2 Forecast Deployment – AF Analytics

From the Windows taskbar, open PI System Explorer and be sure you're connected to the 'Dryers' database.

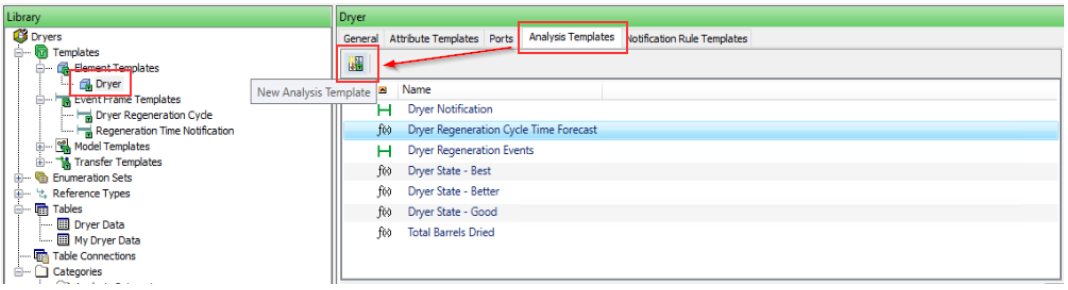
First off, we will be using an AF Table to store the coefficients of our linear regression lines from the previous section.

1. Navigate to the **Library** and the **Dryer Data** under **Tables**. The table and the coefficients for each Dryer's equation have been built for you. Take a moment to confirm that these are correct.

	Dryer	Regeneration Duration Forecast Slope	Regeneration Duration Forecast Intercept
▶	Dryer A	0.0003	9.6722
	Dryer B	0.0006	9.5749
*			

We will be creating an AF Analytic for the forecast equation at the template level for the dryers.

1. Navigate to the **Library** and the **Dryer** template under **Element Templates.**
2. Click on the **Analysis Templates** Tab and click on the **New Analysis Template** option.



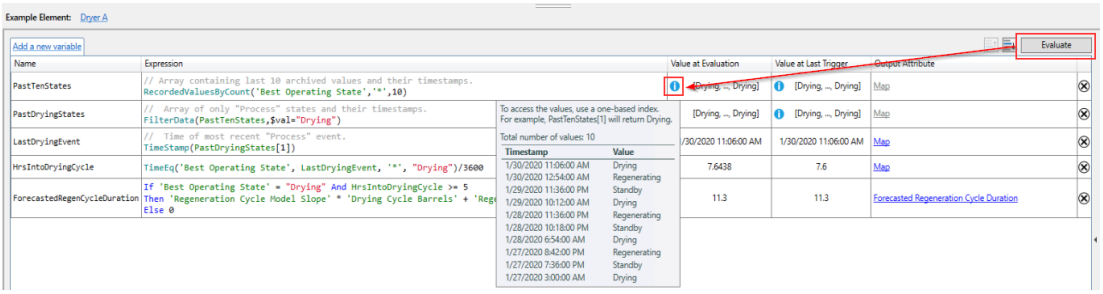
Name your new Analysis Template '**My Dryer Regeneration Cycle Time Forecast.'** This analysis has already been build out under the name '**Dryer**

Regeneration Cycle Time' but we want you to be able to build out the expression on your own. By default, you have created a new **Expression** type analysis. This is what we need.

3. We will be creating a multi-line analysis utilizing the multi-variable capability of AF Analytics. The first step in our analysis is to find the last drying event. We will be making use of new AF Analytics functions that allow for array calculations. Let's us the **RecordedValuesByCount** function to grab the past 10 states of the dryer. Create a variable called **PastTenStates** and input the following formula:

```
RecordedValuesByCount('Best Operating State','*',10)
```

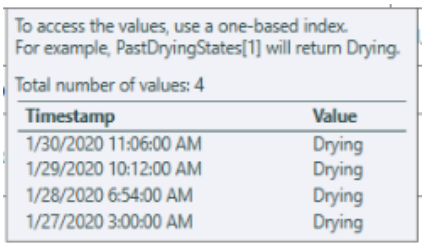
This operation will create an array of 10 values consisting of the past 10 states the dryer has had. To view the output of the operation, click on **Evaluate** and hover your mouse over the **Blue Information Symbol** next to the evaluation.



4. We now want to filter this array to only capture the states where the dryer is in **"Drying**" mode. Create another variable called **PastDryingStates** and input the following formula:

```
FilterData(PastTenStates,$val="Drying")
```

This operation will create an array of filtered values consisting of the past "**Drying"** phases and their associated timestamps.



5. Let's grab the most recent drying event. Create a new variable called **LastDryingEvent** and input the following:

```
TimeStamp(PastDryingStates[1])
```

This operation grabs the timestamp of first value in the **PastDryingStates** array, or the most recent drying phase's associated timestamp.

6. We want the analysis to check how long the dryer has been in the drying state. Create a new variable called **HrsIntoDryingCycle** and input the following:

```
TimeEq('Best Operating State', LastDryingEvent, '*',
"Drying")/3600
```

This operation will output (in hours) the length of time that the dryer has been in the drying phase.

7. Finally, we want to input our forecasting equation. Create a new variable called **ForecastedRegenCycleDuration** and input the following:

```
If 'Best Operating State' = "Drying" And HrsIntoDryingCycle >= 10
Then 'Regeneration Cycle Model Slope' * 'Drying Cycle Barrels' +
'Regeneration Cycle Model Intercept'
Else 0
```

This operation first checks that the dryer is in the drying phase and if it has been in the drying phase longer than 10 hours. If those conditions are met, it then applies the coefficients from our linear regression model stored in the **Dryer Data** table previously created. Otherwise, if the initial conditions aren't met, then the forecast is not performed. Remember – we only want this prediction to be made when the dryer is in the current drying phase.

Note

Why did we add the condition in the previous equation to check if the Drying Phase has been longer than 10 hours?

Remember that during our modeling, we filtered out event frame data where any Drying Cycle Durations shorter than 10 hours. It's important to account for these filters in your prediction logic.

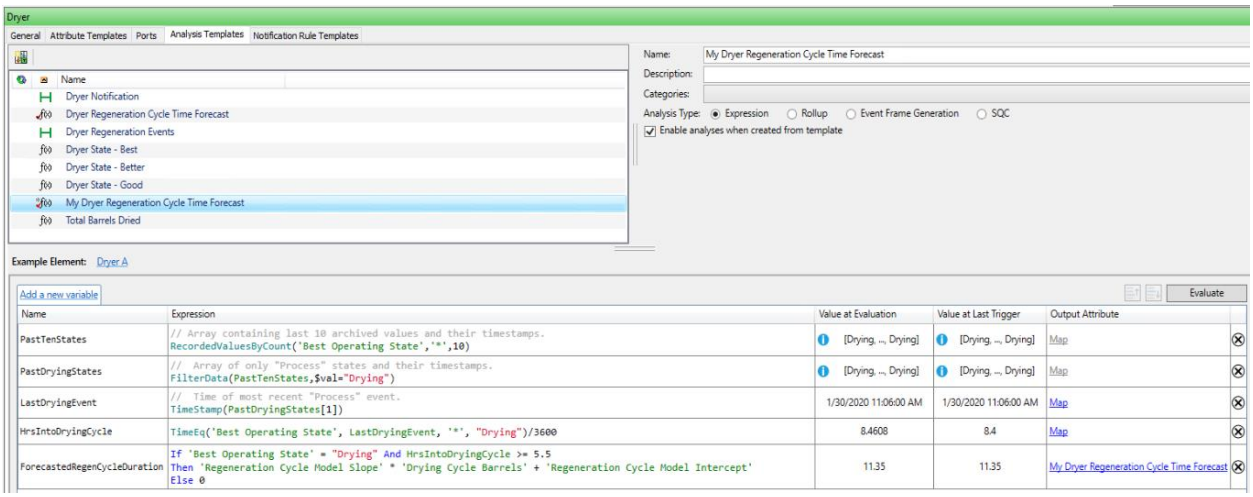
8. The Dryer template has already been configured to have an attribute named **'My Forecasted Regeneration Cycle Time Forecast'** which point to the PI tags **'Dryer A.My Dryer Regeneration Cycle Time Forecast.%ID%'** and **'Dryer B.My Dryer Regeneration Cycle Time Forecast_%ID%'** for Dryer elements **Dryer A** and **Dryer B,** respectively**.**

   To the right of the **Expression** field, under **Output Attribute**, click the **Map** link and assign the **'My Forecasted Regeneration Cycle Time Forecast'** template attribute for the **ForecastedRegenCycleDuration** variable.

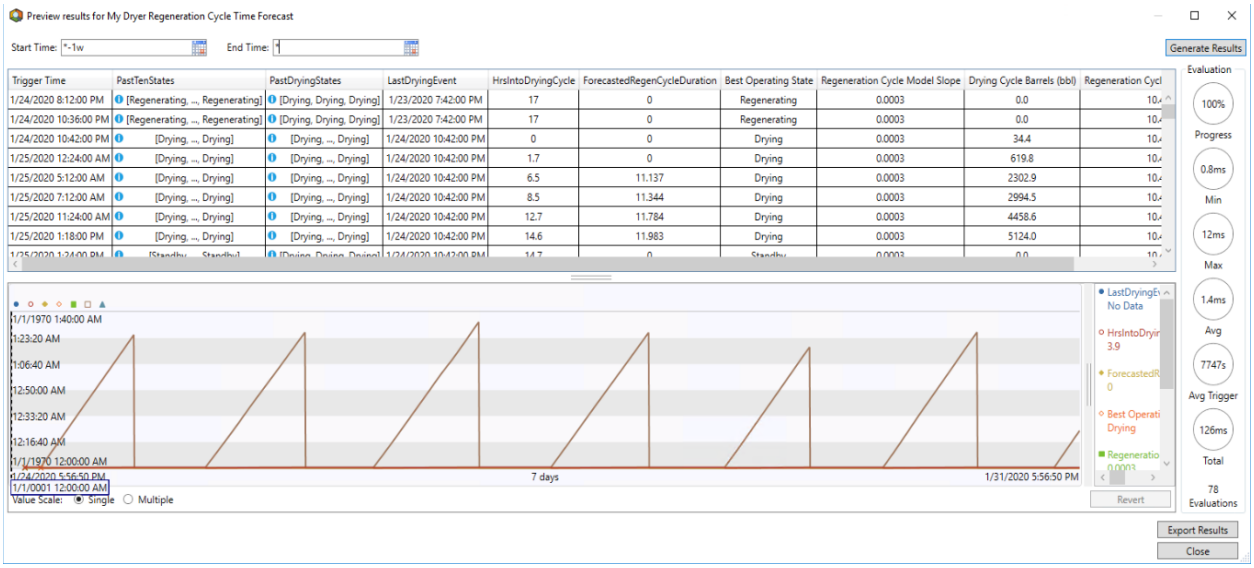
   Also note that the **Example Element** for this template has be set to **Dryer A**. These means that all evaluations and preview calculations will be done using Dryer A data. You can change to another element by clicking the link and selecting a different one, e.g. Dryer B.

9. Check in your changes by clicking **Check In** at the top of PI System Explorer.

10. We now have our complete analysis which is forecasting the duration of the regeneration cycle using the Drying Cycle Barrels of the preceding drying phase as a predictor. Your complete analysis should look like the one below, and should evaluate like the one below:



11. You can use the **Preview Results** feature of AF Analytics to confirm that the Analysis is functioning. Right-click on your analysis and click on **Preview Results**.



12. In the lower left-hand corner of PI System Explorer, select the **Management** view. Here is where you manage all the Asset Analytics configured for an AF Database. This includes enabling, disabling and backfilling calculations.

13. Select the **'My Dryer Regeneration Cycle Time Forecast'** analyses for the **Dryer A and B** elements. On the right-hand side under **Operations**, click **Enable**.

14. Once the  appears in the **Status** column the analyses are up and running. Again under **Operations**, click on **Queue**. This exposes the backfilling configuration dialog.

    Configure the **Start** and **End** times to be **'*-7d'** and **'*'**, respectively. And finally, click **Queue** start backfilling results for the two dryers.

5.3 Proactive Solution – PI Notifications

Now that we have a working analysis whose output will tell us the predicted duration for each regeneration phase, we want to be able to take this one step further – to notify operators when to end the drying phase for one dryer and begin regeneration (switch which dryer is active). Remember, the ultimate goal here is to balance the use of each dryer such that they will have a similar end of life – significantly reducing replacement costs and required downtime.

In this last section we will:

- Create an Event Frame analysis to store an event any time the expected Regeneration forecast is greater than or equal to 11 hours.
- Create a notification rule to send an e-mail to the student01@pischool.int account any time the expected Regeneration forecast is greater than or equal to 11 hours.

Analysis for Event Frame Generation

1. An Event Frame template has been created for you to use. After walking through its configuration, we will configure an analytic to generate the Event Frames themselves. In PI System Explorer, select the **Library** view. Under the **Templates** branch of the hierarchy, expand **Event Frame Templates** and select the **Regeneration Time Notification** template. The **Naming Pattern** is specified under the **General** tab.
2. Select the **Attribute Templates** tab at the top to see the list of attributes.

   Expand the attribute configuration dialog by clicking the  along the right-hand boarder of PI System Explorer.
3. You can see that this particular template will store the **Forecasted Regeneration Cycle Time** and the **Last Drying Cycle Time.** Just like in the previous event frame, these are merely placeholders to contain the result of an Asset Analytics calculation which occurs upon the end or close of the Event Frame. We will configure this calculation in the next steps.
4. In PI System Explorer, navigate back to the **Dryer** element template in the **Library** under **Element Templates**. Click and navigate to the **Analysis Templates** tab.
5. Create a new Analysis Template by clicking  . Rename it **'My Dryer Notification'**. Set the Analysis Type to **Event Frame Generation**. Uncheck **Enable analysis when creating from template**. Assign the Event Frame Template to **Regeneration Time Notification.** Note that the Example Element has been assigned to Dryer A by default.
6. Similar to our **My Dryer Regeneration Cycle Time Forecast**, we will be using AF Analytics array functions to grab the timestamp of the latest drying event.
   a. We will be creating a multi-line analysis utilizing the multi-variable capability of AF Analytics. The first step in our analysis is to find the last drying event. We will be making use of new AF Analytics functions that allow for array calculations. Let's us the **RecordedValuesByCount** function to grab the past 10 states of the dryer. Create a variable called **PastTenStates** and input the following formula:

```
RecordedValuesByCount('Best Operating State','*',10)
```

This operation will create an array of 10 values consisting of the past 10 states the dryer has had. To view the output of the operation, click on **Evaluate** and hover your mouse over the **Blue Information Symbol** next to the evaluation.

b. We now want to filter this array to only capture the states where the dryer is in **"Drying**" mode. Create another variable called **PastDryingStates** and input the following formula:

```
FilterData(PastTenStates,$val="Drying")
```

This operation will create an array of filtered values consisting of the past "**Drying"** phases and their associated timestamps.

c. Let's grab the most recent drying event. Create a new variable called **LastDryingEvent** and input the following:

```
TimeStamp(PastDryingStates[1])
```

This operation grabs the timestamp of first value in the **PastDryingStates** array, or the most recent drying phase's associated timestamp.

7. Add a **Start Trigger** with the following logic:

```
'My Dryer Regeneration Cycle Time Forecast' >= 11
```

8. Add an **End Trigger** with the following logic:

```
'My Dryer Regeneration Cycle Time Forecast' >= 11
```

This event frame will be captured and begin and end when the predicted regeneration cycle duration is greater than or equal to 11.

9. To write to the **Forecasted Regeneration Cycle Time** and the **Last Drying Cycle Time** attributes of the Event Frame template, we will be using Output Expressions.

a. Add an output expression called **CurrentForecast** and input the following expression

```
TagVal('My Dryer Regeneration Cycle Time Forecast',
EventFrame("StartTime"))
```

This expression will output the value of the predicted regeneration time at the start time of the event frame.

Map this output expression to the **Forecasted Regeneration Cycle Time** attribute of the Event Frame Template

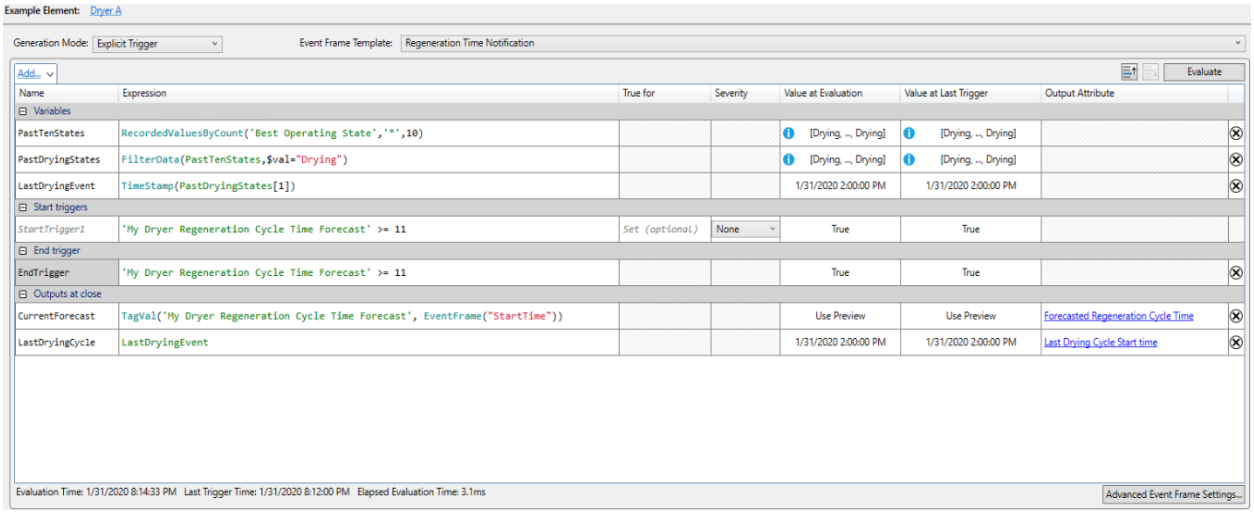
b. Add an output expression called **LastDryingCycle** and input the following expression

```
LastDryingEvent
```

This will write the value of the **LastDryingEvent** variable you created previously.

Map this output expression to the **Last Drying Cycle Time** attribute of the Event Frame Template.

10. Your complete **My Dryer Notification** Event Frame should look like this:



11. Click the **Evaluate** button to preview the results and make sure there are no errors. If it all looks good, **Check In** your changes.
12. Return to the **Management** view in PI System Explorer. Select the **'My Dryer Notification'** analyses for the **Dryer A and B** elements. On the right-hand side under **Operations**, click **Enable**.
13. Once the  appears in the **Status** column the analyses are up and running. Again under **Operations**, click on **Queue**. This exposes the backfilling configuration dialog.

    Configure the **Start** and **End** times to be **'*-7d'** and **'*'**, respectively. And finally, click **Queue** start backfilling Event Frames for the two dryers.

Create a Notification Rule

The next step from here is to create a **New Notification Rule Template** from this **My Dryer Notification** Event Frame.

1. Under the Analysis Details on the top right of PI System Explorer, click on the blue hyperlinked text that says **"Create a new notification rule template for My Dryer Notification"**
2. Call this new notification rule template **"My Dryer Notification"**
3. Under the **Subscriptions** section, click on **View/Edit Subscriptions**
4. Expand **student01** and drag the **E-mail** endpoint under **student01** into the **Subscriptions** section. Click OK and **Check In**.

Configure Notification Message Formatting

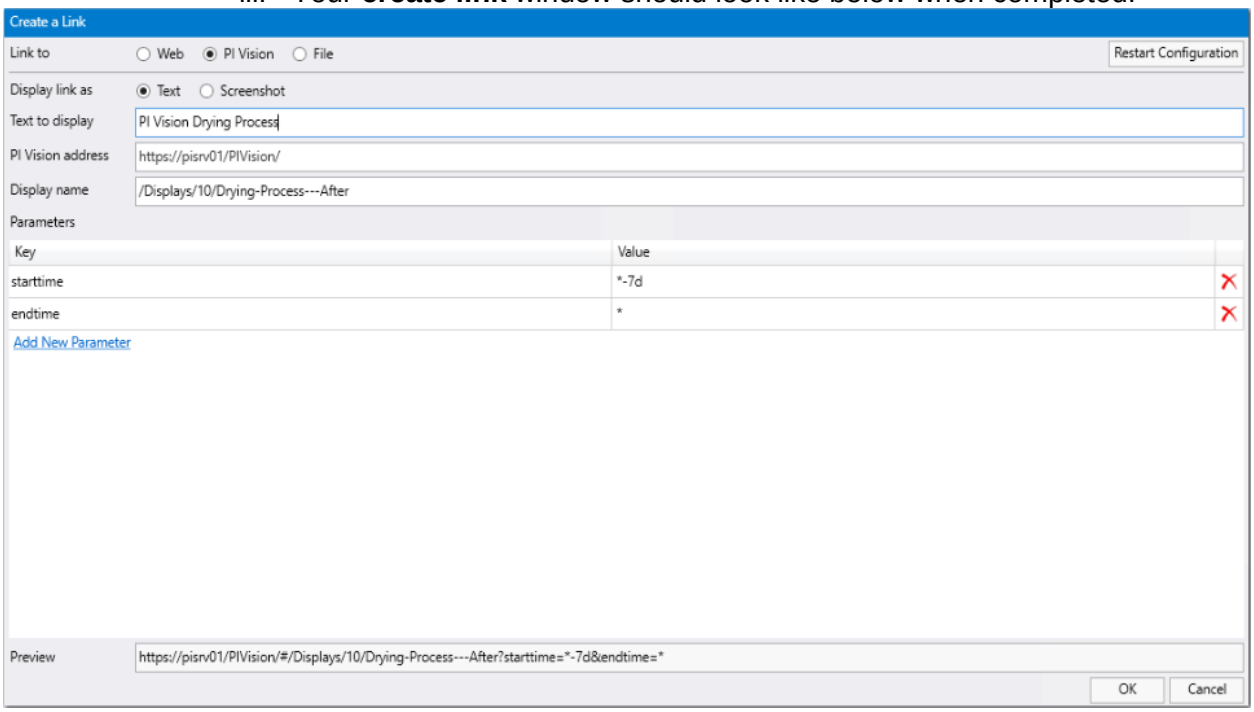
1. Click on the blue **Manage Formats** link in the **Subscriptions** section. Select the line with **Global Default Email** (color changes to light blue) and click on the Duplicate icon above. Rename the duplicated format as **My Dryer Notification Email.**
2. Change the subject of the e-mail to:

   Subject | Event Frame:Name | - High Regeneration Time Forecasted
3. Remove the items for **Server, Database,** and **Severity.**
4. Add an informative message to tell the operators the predicted regeneration time and instruct them to switch dryers. It should like similar to this:

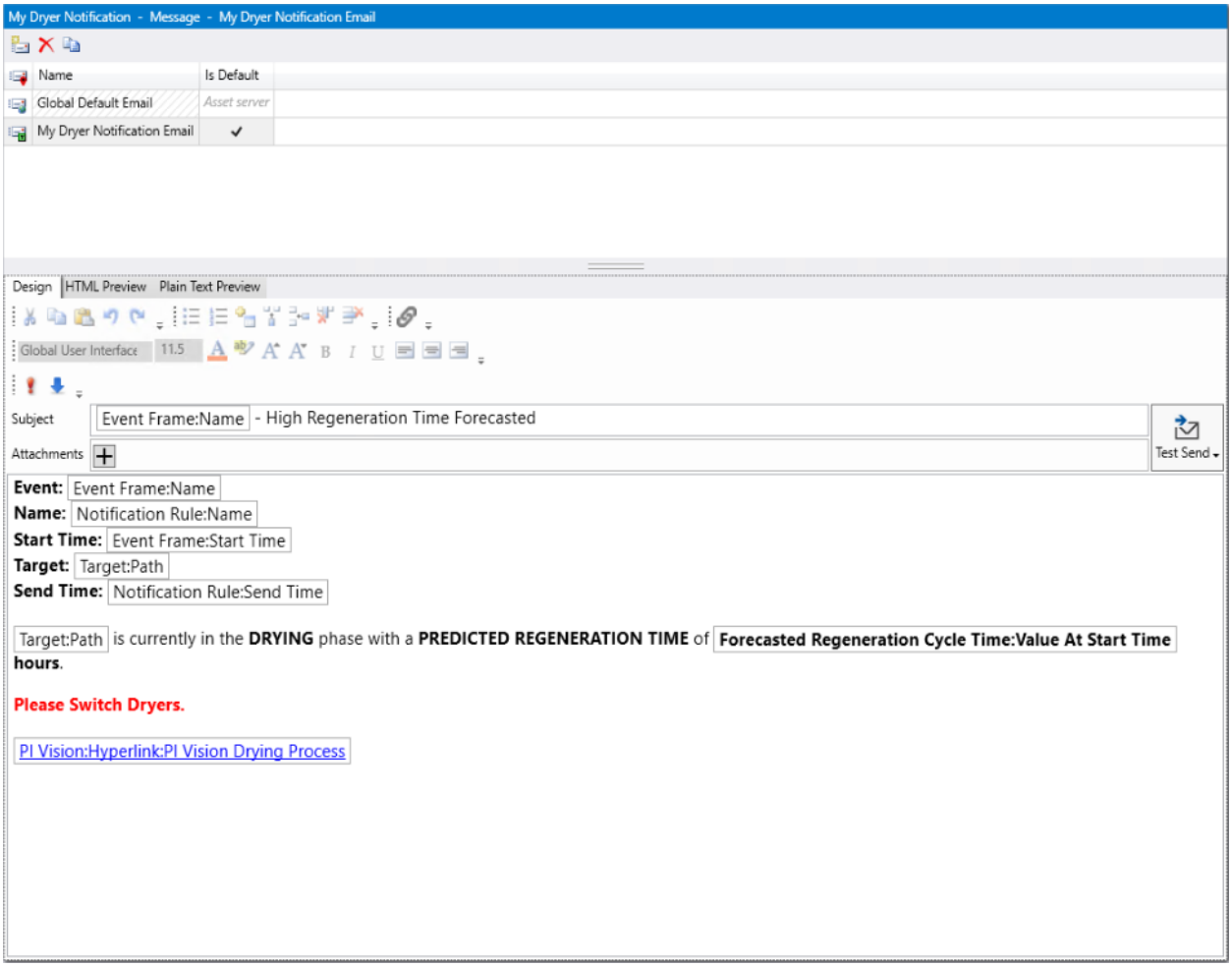
   Target:Path is currently in the **DRYING** phase with a **PREDICTED REGENERATION TIME** of **Forecasted Regeneration Cycle Time:Value At Start Time** **hours**.

   Please Switch Dryers.

5. At the bottom of the design window, add a link to the **'Drying Process – After'** PI Vision Display.
   a. Click on the **Insert Link** option and enter the URI of the PI Vision page showing the drying states: https://pisrv01/PIVision/#/Displays/10/Drying-Process---After. Click Continue.
   b. Enter **PI Vision Drying Process** in the **Text to Display** field.
   c. Set the time context for the PI Vision link:
      i. Enter a new **Key** for **starttime** with a value of **'*-7d'**.
      ii. Enter a new **Key** for **endtime** with a value of **'*'**.
      iii. Your **create link** window should look like below when completed:



   d. Click OK and **Check In**.
6. Your message configuration window should look like the one below when complete:



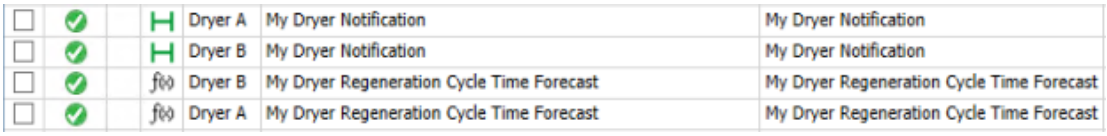
7. Click on the **Test Send** button and enter in the student01@pischool.int email address.
8. Open up **Outlook** from the Desktop or the Taskbar. You should have received the test e-mail. Open the e-mail and confirm the formatting and that the PI Vision link works.

Confirming Notifications

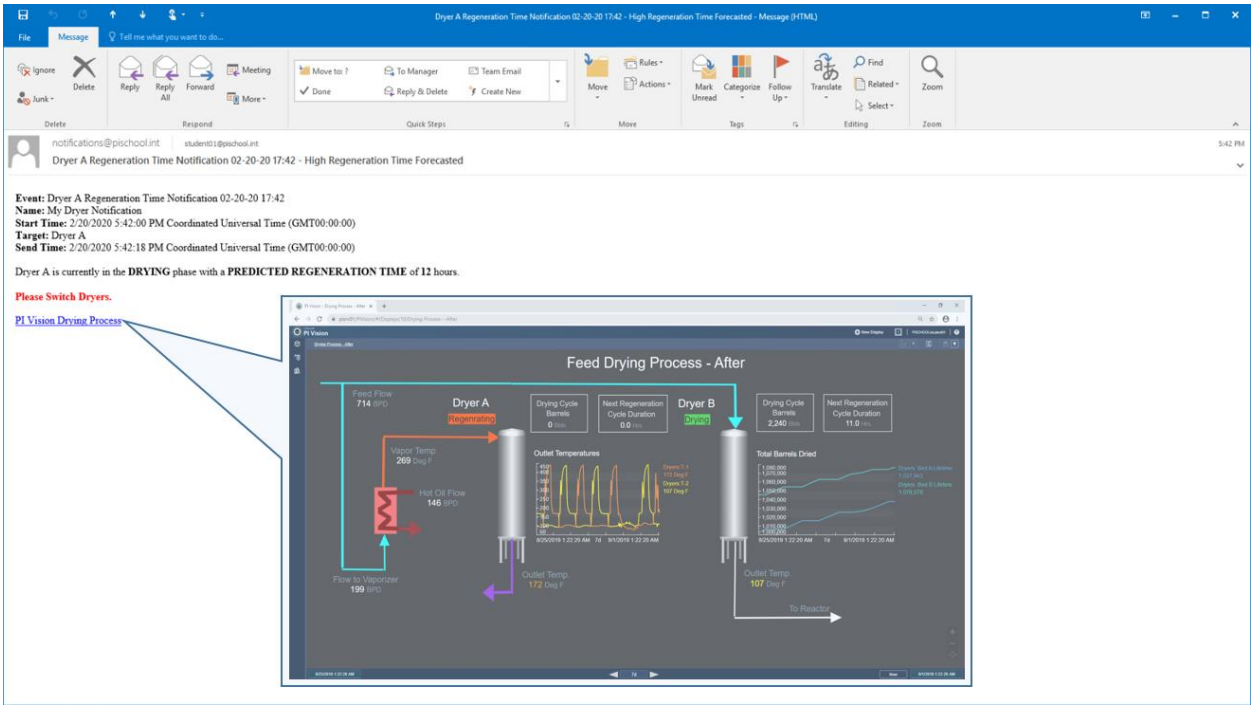
1. Return to the **Management** view in PI System Explorer. Select the **'My Dryer Notification'** analyses for the **Dryer A and B** elements. On the right-hand side under **Operations**, click **Enable**.

2. Once the  appears in the **Status** column the analyses are up and running. Again under **Operations**, click on **Queue**. This exposes the backfilling configuration dialog.

   Configure the **Start** and **End** times to be **'*-7d'** and **'*'**, respectively. And finally, click **Queue** start backfilling Event Frames for the two dryers.



You should be receiving e-mails after the analysis has been running for some time and the conditions for the Dryer Notification are met. Below is an example of what your e-mails will look like with the link to the PI Vision page:



6. Summary

6.1 Revisit Learning Objectives

Thank you for completing this lab with us! In this lab we:

- Explored features of several OSIsoft products in one lab.
- Learned how to interact with the PI System.
- Discovered how its features can work in concert to take an improvement idea and impact an actual operating problem.
- Transitioned PI Users into PI ***Power*** Users, enabling them to make a larger contribution in addressing process problems based on an improved understating of available tools and their domain expertise.

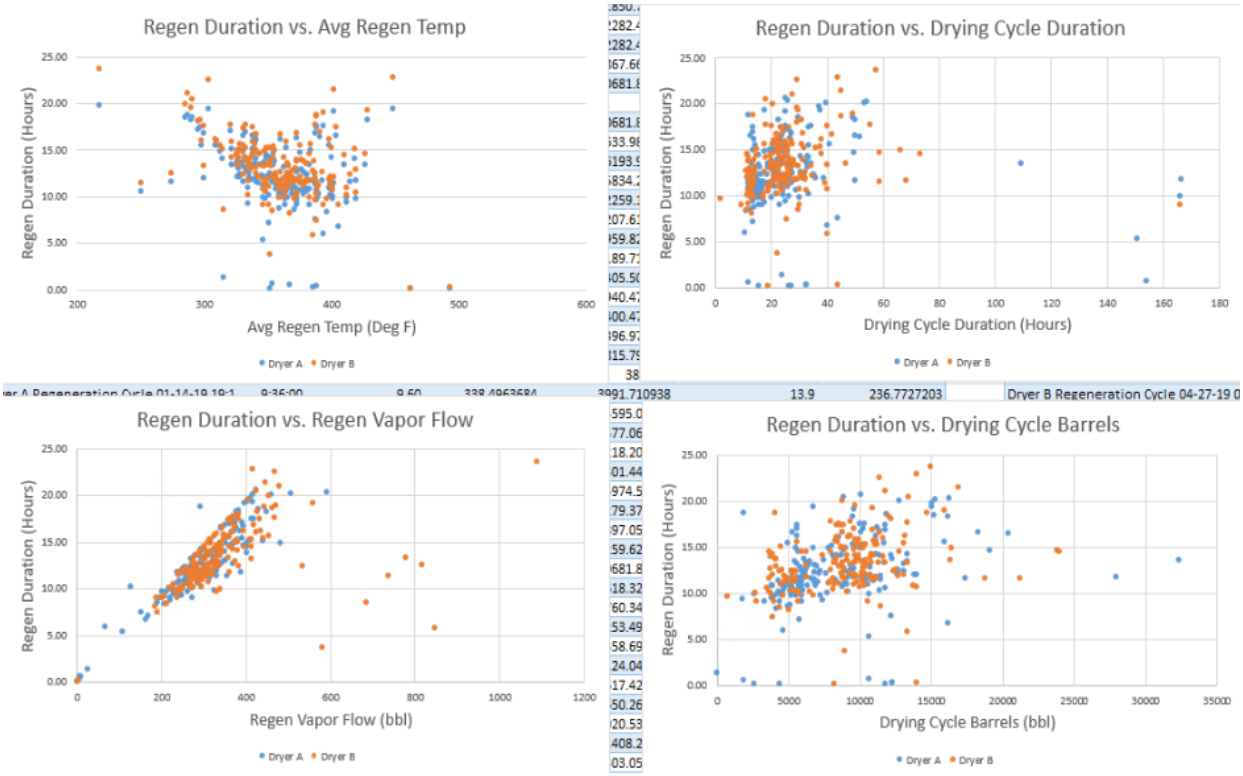
7. Appendix

7.1 Predictive Model Development and Variable Selection

There is a hidden sheet in the **'PI World Dryer Regen Duration.xlsx'** Excel file on the lab VM desktop that has been built out for you. If you right click on the sheet ribbon and click **Unhide > 'Regen** Variables' you will be able to see this sheet. This sheet plots event frame duration (or the Regeneration cycle duration) as a function of key variables.

The purpose of this sheet is to identify an appropriate variable to use that will be a good predictor of the time it takes the dryer to regenerate. The variables we have are:

- Average Regen Temp (the average temperature of the dryer throughout the regeneration phase)
- Regen Vapor Flow (the total flow of regeneration vapor throughout the regeneration phase)
- Drying Cycle Duration (the duration of the drying phase preceding the regeneration phase)
- Drying Cycle Barrels (the amount of barrels processed during the drying phase preceding the regeneration phase)



Avg Regen Temp and Regen Vapor Flow appear to be good indicators of Regen Duration – meaning there definitely appears to be a correlation between these

variables and the regeneration duration. Would these variables be a good choice for predicting the regeneration time?

The answer is of course, no. The reason being is that these variables are collected during the regeneration phase itself, and thus cannot be used to predict the duration of the regeneration phase. This is important to know for this analytics project and this lesson can be taken to other analytics projects as well.


Tip

Having the domain knowledge on the process to know which variables are appropriate to use for modeling and forecasting is extremely important.

A common story we hear from analytics and data science projects is that the end results often propose "obvious" answers or suggestions. This highlights the importance of working with, or including Subject Matter Experts throughout the course of your analytics projects.

So that leaves us with two variables: Drying Cycle Duration and Drying Cycle Barrels. Drying Cycle Duration seems like a potentially good candidate, however the drawback with simply using duration as our predictor is that the flow or the speed of the barrels processed during the drying phase is extremely variable and unknown. For example, one drying phase might have a shorter duration but process more feed because of a higher flow than another drying phase. Given that knowledge, the **Drying Cycle Barrels is the best option we have to use as a variable for our predictive model for regeneration duration**.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