John H. Glenn Research Center at Lewis Field

Diagnostic and Predictive Maintenance Applications of PI

OSI Users Conference 2002

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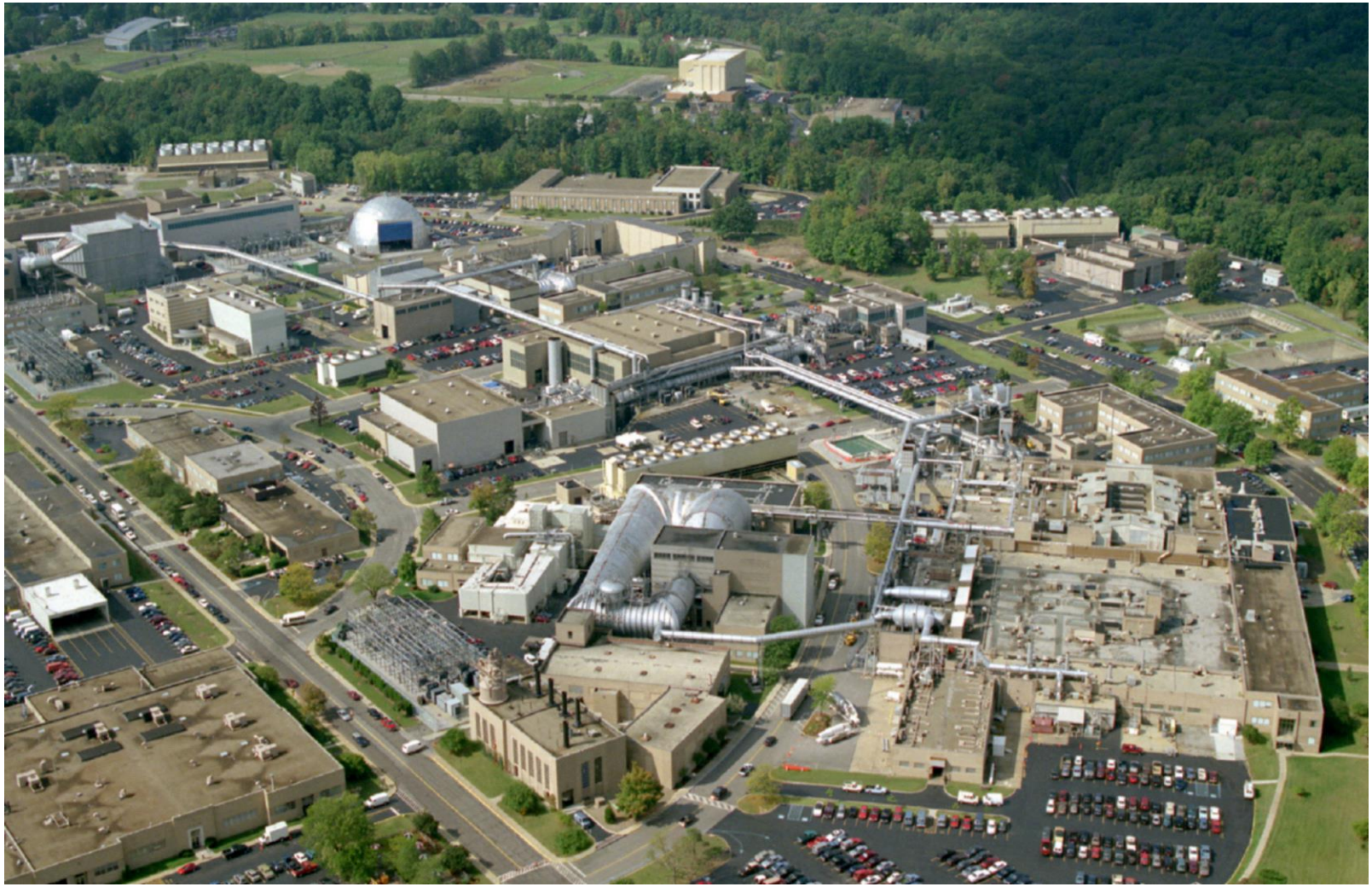


Central Process Distributed Control System (CP-DCS)

ED

CAD

CAEB

ERB

CP-DCS Customers

- Wind Tunnels (10x10, 8x6/9x15, IRT)
- Propulsion Systems Lab
- Icing Research Tunnel
- Engine Components Research Lab
- Rocket Combustion Lab
- Aeroacoustic Propulsion Lab
- Compressor, Turbine and Combustor Test Cells

Major Systems (ED & CAD)

- ED (Electrical Dispatch)
  - 13 Substations ==> 138,000V to 2400V
  - Max Power Available = 370MW
  - Base (Institutional Load) = 21MW
  - 212,000 MWHR ==>Annual Usage
- CAD (Central Air Dispatch)
  - Over 600+ Remotely Operated Valves
  - Combustion Air Distribution Piping => 16,000 Ft
  - Exhaust Distribution Piping ==> 7,000 Ft

Major Systems (CAEB)

- CAEB (Central Air Equipment Building)
  - 7 Compressors (107,000Hp)
    - 40, 150, 450 Psig
    - Flow ==> 400 lb/sec @ 150Psig
  - 8 Exhausters (106,000 Hp)
    - Altitude ==> 90,000 Ft.
    - Flow ==> 700 Lb/Sec @ 19,000 Ft.
  - 2 Variable Frequency Mg's (5000 Hp)
  - 1 Static Frequency Converter (7500 Hp)
  - 3 Turboexpanders
    - -90 Deg F

Major Systems (ERB)

- ERB
  - 9 Compressors (29,100 Hp)
    - 40, 150, 450, 1250 Psig
    - Flow ==> 88 lb/sec @ 40Psig
  - 10 Exhausters (16,900 Hp)
    - Flow ==> 35 Lb/Sec @26" Vacuum
  - 1 Turboexpander/Compressor
    - -70 Deg F
  - Variable Frequency
    - 9 Rotating Converters
      - 15,000 Hp
      - 10 Hz ==> 120 Hz

Hardware Configuration

- 3 Data Highway Rings
  - 13.5 Miles of Coaxial Data Highway Cable
- 22 Operator Control Stations
- 5 Field Operator Stations (Monitor Only)
- 1 Software Development Station
- 3 Engineering Stations
- 1 PI Central Data Archive Station

Hardware Configuration (Continued)

- 67 Remote Processors Communicating to:
  - Directly to 4050 I/O
  - 29 PLC's to 9500 I/O
  - 50 Process/Surge Avoidance Controllers
  - 23 Power Monitoring Panel Meters
  - 2 Vibration Monitoring/Analysis Systems

Growth of System I/O

- 1983 (Initial SCADA)
  - 3740 Pts
- 1992 (Upgrade to DCS)
  - 9,950 Pts
- 1996
  - 11,700 Pts
- 1999 -- PI System Installed
- 2001
  - 16,000 Pts

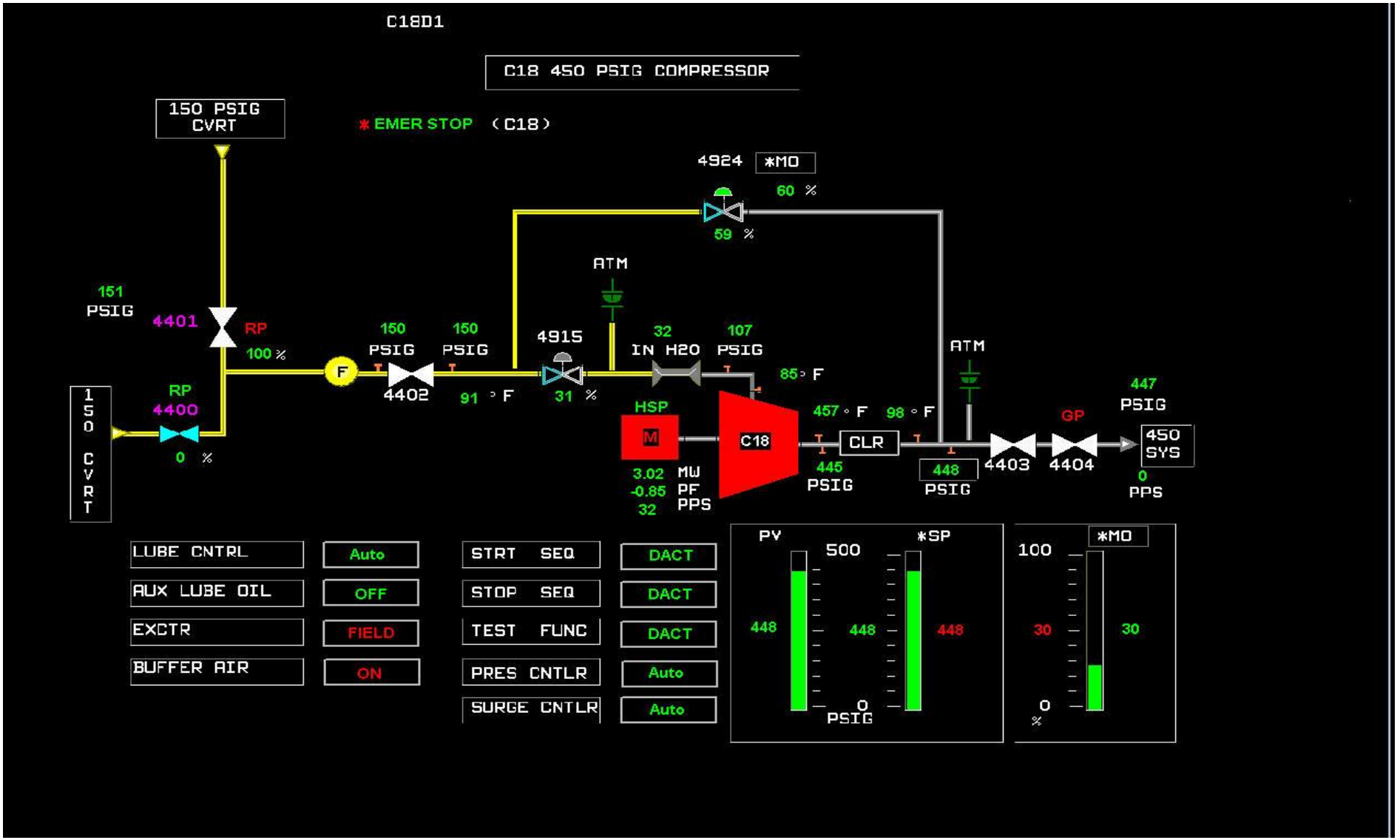
Uses of PI System

- All 12,000 Pts archived (console database)
- 3 Yr. of Data Available on Line
- Diagnostics, Operator Process Screen Playback
- Analysis
- Defense of Control System
- Machine Run Time/Start Log
- Predictive Maintenance

PI-For Diagnostics

- PI Archive Playback of Process Graphic used for Diagnostic/troubleshooting of problems/operator errors
- Process graphic uses a bit map image of the operator console graphic
- Dynamic points (Analog & Digital) populate the graphic from the PI history file.
- Future enhancement includes a method where two graphics will not have to be maintained (the operator console graphic & the archive bit map image)

PI-For Diagnostics, Archive Playback



PI--For Analysis

- Advanced Subsonic Compressor (1250 Psig) loss of outlet pressure--also compressor overheating
- Used PI trend to establish the exact time/date of transient decrease in outlet pressure
- Determined from trend of compressor inlet control valve & surge avoidance recycle valve that compressor seal had failed
- Replaced compressor seal. Modified operating sequence to extend Compressor depressurization ramp time. Modified recycle valve surge control line
- Rapid identification of problem provided cost savings of $100,000 by preventing major damage to the Compressor

PI-For Defense

- Guide Vane Control was Suspect for Compressor Wheel failure due to Surge
  - PI archive proved compressor guide vane servo positioning system response was as designed--compressor was not operating in surge
  - After disassembly of compressor, it was determined that compressor wheel to casing clearance was not per spec--this caused wheel interference with casing and subsequent destruction
- Compressor Pressure Control Suspect in Burst Disc Rupture.
  - Control set point was 40 Psig. Burst disc rupture point was 60 Psig. PI trend proved three pressure taps located at burst disc never exceeded 47 Psig
  - Determined failure due to defective burst disc

PI-For Defense (Continued)

- Exciter suspect in loss of Field Excitation to 16,000Hp Compressor Drive Motors
  - Pi archive proved that the DC Exciter set point from the drive motor Static Frequency Converter (SFC) went erroneously to zero
  - Set point from the SFC to the Exciter was corrected and the problem was solved

Runtime Calculations

- Old system used elapsed timer blocks in Bailey function code
- New features such as Utilization and Availability were difficult to code in function blocks
- Data could be lost on download of MFP
- Backup Scheme was complex and unreliable, requiring data to be sent to multiple MFPs across the DCS data highway
- Data was available only on operator consoles

PI to the Rescue

- NASA got PI system as part of Year 2000 upgrade project
- Runtime, Availability and Utilization were much easier to track in PI system
- Motor status data was already being archived, simple Datalink Calculation could determine runtimes based on date passed to it
- Simple Performance equation points were added to track the availability and utilization
- Added check for equipment that had not run in 14 days

Sample Runtime Spreadsheet

Date	2/27/2002 10:55											
COMP		TEST RUN	DAILY	MONTHLY	YEARLY	ACCUM	SERVICE AIR		TEST RUN	DAILY	MONTHLY	YEARLY	ACCUM
C1	RUNTIME	NO	2.07	90.39	130.79	2476.54	SA20	RUNTIME	NO	0.00	147.78	233.30	6187.88
	% AVAIL		100.00	100.00	100.00			% AVAIL		100.00	96.30	74.14	
	% UTIL		0.00	44.44	36.21			% UTIL		0.00	55.56	44.83	
C2	RUNTIME	NO	0.00	49.29	68.58	1687.66	SA21	RUNTIME	NO	10.94	404.00	674.43	9687.46
	% AVAIL		100.00	100.00	100.00			% AVAIL		100.00	100.00	100.00	
	% UTIL		100.00	40.74	27.59			% UTIL		100.00	88.89	74.14	
C3	RUNTIME	NO	0.00	99.31	159.03	3359.13	SA22	RUNTIME	NO	0.00	51.87	290.34	7220.39
	% AVAIL		100.00	100.00	100.00			% AVAIL		100.00	85.19	93.10	
	% UTIL		100.00	55.56	44.83			% UTIL		100.00	40.74	48.28	
C4	RUNTIME	NO	0.00	31.52	102.81	2514.81	SA23	RUNTIME	NO	0.00	270.14	694.10	6683.67
	% AVAIL		100.00	44.44	67.24			% AVAIL		100.00	96.30	87.93	
	% UTIL		100.00	18.52	24.14			% UTIL		100.00	70.37	68.97	
C5	RUNTIME		0.00	35.57	165.43	2293.23	System Summary						
	% AVAIL	NO	100.00	85.19	93.10			% AVAIL		100.00	94.44	88.79	
	% UTIL		100.00	33.33	39.66			% UTIL		75.00	63.89	59.05	
C6	RUNTIME	YES	0.00	0.00	36.68	330.19	CHILLER			DAILY	MONTHLY	YEARLY	ACCUM
	% AVAIL		100.00	85.19	77.59		BLWER	RUNTIME		0.00	15.18	23.08	493.95
	% UTIL		0.00	0.00	6.90		1040	RUNTIME		10.93	545.31	1204.60	20349.71
System Summary								% AVAIL		100.00	100.00	100.00	
	% AVAIL		100.00	85.80	89.66			% UTIL		100.00	88.89	91.38	
	% UTIL		66.67	32.10	29.89		1050	RUNTIME		0.00	577.09	752.77	15941.14
CHILLER			DAILY	MONTHLY	YEARLY	ACCUM		% AVAIL		100.00	100.00	100.00	
1020	RUNTIME	YES	0.00	0.04	0.05	1049.80		% UTIL		0.00	96.30	56.90	
	% AVAIL		0.00	51.85	77.59		1060	RUNTIME		10.93	137.99	775.75	16913.81
	% UTIL		0.00	7.41	5.17			% AVAIL		100.00	100.00	100.00	
1030	RUNTIME	NO	0.38	75.12	101.19	928.58		% UTIL		100.00	25.93	60.34	
	% AVAIL		100.00	100.00	100.00								
	% UTIL		100.00	55.56	39.66								
System Summary													
	% AVAIL		50.00	75.93	88.79								
	% UTIL		50.00	31.48	22.41								

Sample Runtime Formulas

daily runtime

(TIMEEQ('005-0165','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0178','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0287','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0200','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1165','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('038P0056','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"YES") * .000277778)
(TIMEEQ('005-1916','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1917','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1016','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1018','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1020','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('024-0031','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1988','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1955','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778)
(TIMEEQ('005-1957','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778)
(TIMEEQ('005-1959','27-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778)

monthly runtime

(TIMEEQ('005-0165','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0178','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0287','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-0200','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1165','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('038P0056','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"YES") * .000277778)
(TIMEEQ('005-1916','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1917','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1016','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1018','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1020','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('024-0031','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1988','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"RUN") * .000277778)
(TIMEEQ('005-1955','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778
(TIMEEQ('005-1957','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778
(TIMEEQ('005-1959','01-Feb-02 00:00:00','28-Feb-02 00:00:00',"OPEN") * .000277778

Predictive Machine Maintenance

- Previously large equipment inspection and maintenance was done every 3 years
- Machine Tear-downs are expensive, not only in financial aspects, but also with regards to research.
- PI system was utilized as a way to track Machine run hours and starts.
- Now inspections are done every 4000 hours or 600 starts.

Predictive Machine Maintenance

- System uses same types of Datalink expressions used to calculate runtimes
- Datalink function used to filter motor data and return number of starts over given period of time

```
=PICompFilDat(005-0165, 01-Jan-02 00:00:00, 01-Feb-02 00:00:00, '005-0165' ="STRT" and prevval('005-0165', 01-Feb-02 00:00:00) = "OFF" ,0,1,)
```

- Excel functions then take runtime and start data to estimate the next inspection date for each piece of equipment.
- Excel functions also used to estimate number of starts prior to installation of PI server, if the last inspection date is prior to 2/01/99. The date the PI server came online at Glenn

Predictive Machine Maintenance

20-FEB-02 00:00:00	MACHINE RUN HOURS						STARTS (MACHINE ROLLS)			
COMP-ERB	Monthly	Yearly	ACCSLI	ACCLT	RTSD	NID	Monthly	Yearly	ACCSLI	NID
C1	52.55	92.95	2438.70	2438.70	3/27/1998	1/5/2004	12.00	23.00	431.00	10/10/2002
C2	17.73	37.02	1656.10	1656.10	9/10/1998	4/3/2006	5.00	10.00	319.00	9/20/2004
C3	60.70	120.42	3320.52	3320.52	5/29/1998	10/1/2002	12.00	24.00	519.00	12/28/2001
C4	8.91	80.19	2492.20	2492.20	4/2/1998	11/27/2003	2.00	13.00	404.00	1/21/2003
C5	12.27	142.13		2269.93			4.00	20.00		
C6	0.00	36.68		643.15			0.00	4.00		
EXH-ERB										
DE7	2.79	3.08	1129.66	1146.53	2/22/1999	5/27/2009	2.00	2.00	239.00	6/13/2006
DE8	2.60	2.60	1182.90	1182.90	4/1/1997	1/19/2009	3.00	3.00	242.00	1/24/2007
DE9	2.37	2.37	980.99	984.42	2/27/1999	1/12/2011	2.00	2.00	190.00	3/31/2008
DE10	2.64	2.64	1343.11	1343.11	9/1/1998	11/19/2007	2.00	2.00	315.00	11/9/2004
COMP-CAEB										
C10	26.93	110.57	1522.64	1727.43	6/2/1999	4/21/2006	7.00	19.00	274.00	3/23/2005
C11	0.03	0.08	1370.17	1619.12	7/16/1999	11/9/2006	1.00	2.00	223.00	4/27/2006
C12	25.07	183.33	2610.98	2610.98	7/21/1998	9/11/2003	2.00	19.00	426.00	1/9/2003
C13	24.62	244.58	2255.43	2255.43	1/1/1999	5/25/2004	4.00	29.00	362.00	1/14/2004
C16	27.68	97.46	589.62	1648.43	5/26/2000	2/22/2008	5.00	23.00	122.00	8/12/2008
C17	40.97	214.98	1834.30	1834.30	2/1/1999	7/28/2005	8.00	29.00	354.00	3/2/2004
C18	41.34	80.17	1138.21	1190.34	4/26/1999	2/11/2009	5.00	28.00	206.00	4/11/2007
EXH-CAEB										
E40	27.67	166.20	1211.87	1282.65	4/12/1999	6/12/2008	8.00	33.00	243.00	2/21/2006
E41	18.35	130.16	851.31	1306.40	3/10/2000	2/17/2009	5.00	23.00	156.00	5/31/2007
E42	27.34	164.90	1196.44	1265.98	4/12/1999	7/25/2008	7.00	25.00	228.00	8/1/2006
E43	18.17	128.65	856.64	1296.30	3/8/2000	3/5/2009	8.00	24.00	179.00	7/10/2006
E44	20.81	155.25	2070.17	2070.17	11/28/1998	11/8/2004	6.00	23.00	492.00	9/20/2002
E45	12.09	166.99	2109.16	2109.16	11/1/1998	9/30/2004	3.00	19.00	378.00	10/15/2003
E46	20.59	154.06	2028.82	2028.82	11/28/1998	12/20/2004	2.00	17.00	366.00	12/22/2003
E47	11.86	165.26	2062.67	2062.67	11/1/1998	11/16/2004	2.00	16.00	365.00	12/18/2003

PI-ACE vs. Performance Equations

PI-ACE: What is it?

- Advanced Computing Engine
- Performance Equations on Steroids
- More advanced and complex calculations possible
- Flexible scheduling (event, clock, natural)
- Visual Basic based applications, simplify development and debugging
- Support for calculations involving tags from multiple PI servers

PI-ACE vs Performance Equations

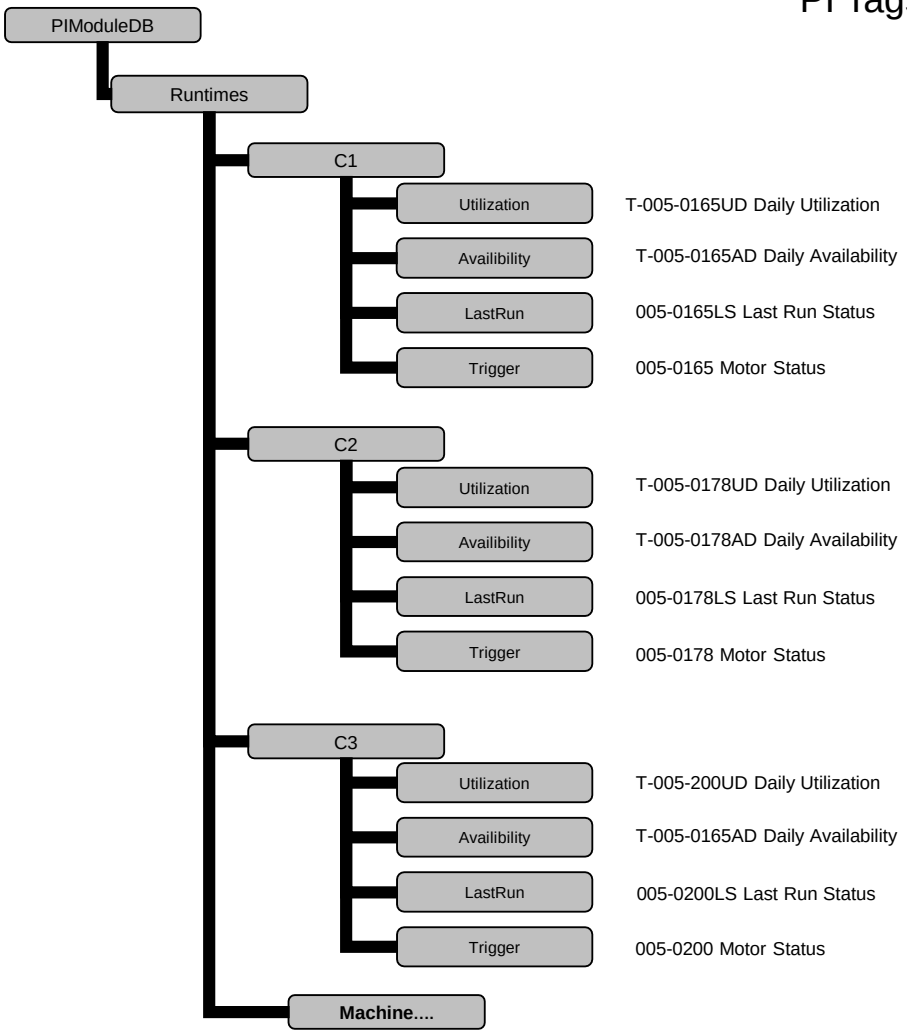
PI-ACE: What is it? (cont.)

- Support for PI module database structure, easy to organize and group points
- Support for 3rd party applications, COM Object Automation and user defined functions

PI-ACE VERSION of Runtime Equations

- Module database used to organize and group PI points
- Single PI-ACE app developed to calculate data
- Module database objects as context or parameter for the application
- New ability to launch external application to email or notify operator if system needs to run

PI Module Database Structure for Runtime points



PI-ACE and PE equation comparision

ACE Application

```
Public Sub ActualPerformanceEquations()

    Dim TimeRun, TimeInvalid As Date
    Dim mailmsg As NewMail

    If Trigger.IsGood Then
        TimeRun = Trigger.TimeEQ(Now, Now - 1, "RUN")
        TimeInvalid = Trigger.TimeEQ(Now, Now - 1, "INVL")
        If TimeRun > 0 Then
            Utilization.Value = 100
            Availability.Value = 100
        Else
            Utilization.Value = 0
            If TimeInvalid < 57600 Then
                Availability.Value = 100
            Else
                Availability.Value = 0
            End If
        End If
        'Has Machine Run in past 14 Days
        LastRun.Value = Trigger.TimeEQ(Now, Now - 14, "RUN")
        If LastRun.Value = 0 Then
            Set mailmsg = New NewMail
            mailmsg.Send "PIACE@cpdcs.grc.nasa.gov",
                        "Operations@cpdcs.grc.nasa.gov", _
                        Trigger.Desc & "Run Status", _
                        Trigger.Desc & "has not run for the past 14 Days"
        End If
        Availability.Value = 0
        Utilization.Value = 0
    End If
End Sub
```

PE Equations

T-005-0165AD:IF(NOT(BadVal('005-0165')) AND (TIMEEQ('005-0165','Y','T',"RUN") > 0 OR TIMEEQ('005-0165','Y','T',"INVL") < 57600)) THEN 100 ELSE 0

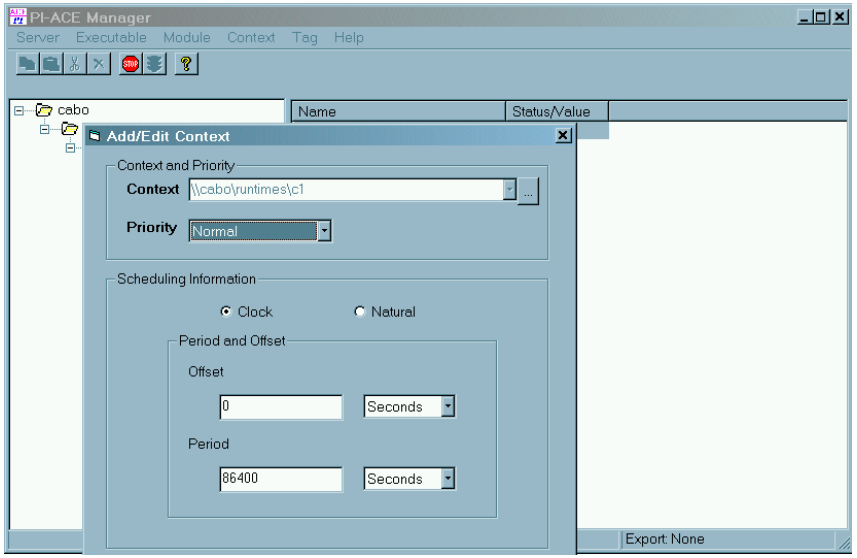
T-005-0165UD: IF(BadVal('005-0165') OR TIMEEQ('005-0165','Y','T',"RUN") <= 0) THEN 0 ELSE 100

005-0165-LS:FINDEQ('005-0165','*','01-Feb-99 00:00:00',"RUN") < '*-14D'

Schedule PI-ACE Application to run

- Add new context for each piece of equipment in the "runtime" module.
- Set offset and period for schedule

\\cabo\runtimes\C1	005-0165	C1 MTR STRT BKR
\\cabo\runtimes\C2	005-0178	C2 MTR RUN BKR
\\cabo\runtimes\C4	005-0200	C4 MTR STRT BKR
\\cabo\runtimes\C3	005-0287	C3 MTR RUN BKR
\\cabo\runtimes\RE1	005-0661	RE1 MTR
\\cabo\runtimes\RE2	005-0662	RE2 MTR
\\cabo\runtimes\RE3	005-0663	RE3 MTR
\\cabo\runtimes\RE4	005-0664	RE4 MTR
\\cabo\runtimes\RE5	005-0665	RE5 MTR
\\cabo\runtimes\RE6	005-0666	RE6 MTR



PI-ACE VERSION of Predictive Maintenance

- Again Module database could be used to organize and group PI points
- Simplify equation development and maintenance
- Current spreadsheet version takes a long time to calculate, using PI-ACE it could be scheduled at night
- PI-ACE Application could store calculated data in Access table or HTML for easy/quick viewing
- New version could calculate and evaluate Next Inspection Date, and submit a work order to the Maintenance Management System

Possible Future use for PI-ACE

- NASA is moving towards full cost accounting for Test Cell Research
- Computing Test Cell operating costs is a complex process, involving power consumption and mass flow rates for Test Cells and machines used
- Costs must be distributed against additional test cells that are using same equipment
- PI-ACE could be used to calculate time-weighted averages of flows and MW usage
- PI-ACE calculated data could be exported to NASA billing and accounting systems