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Eryurek et al.

(54) REMOTE ANALYSIS OF PROCESS CONTROL PLANT DATA

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Publication Classification

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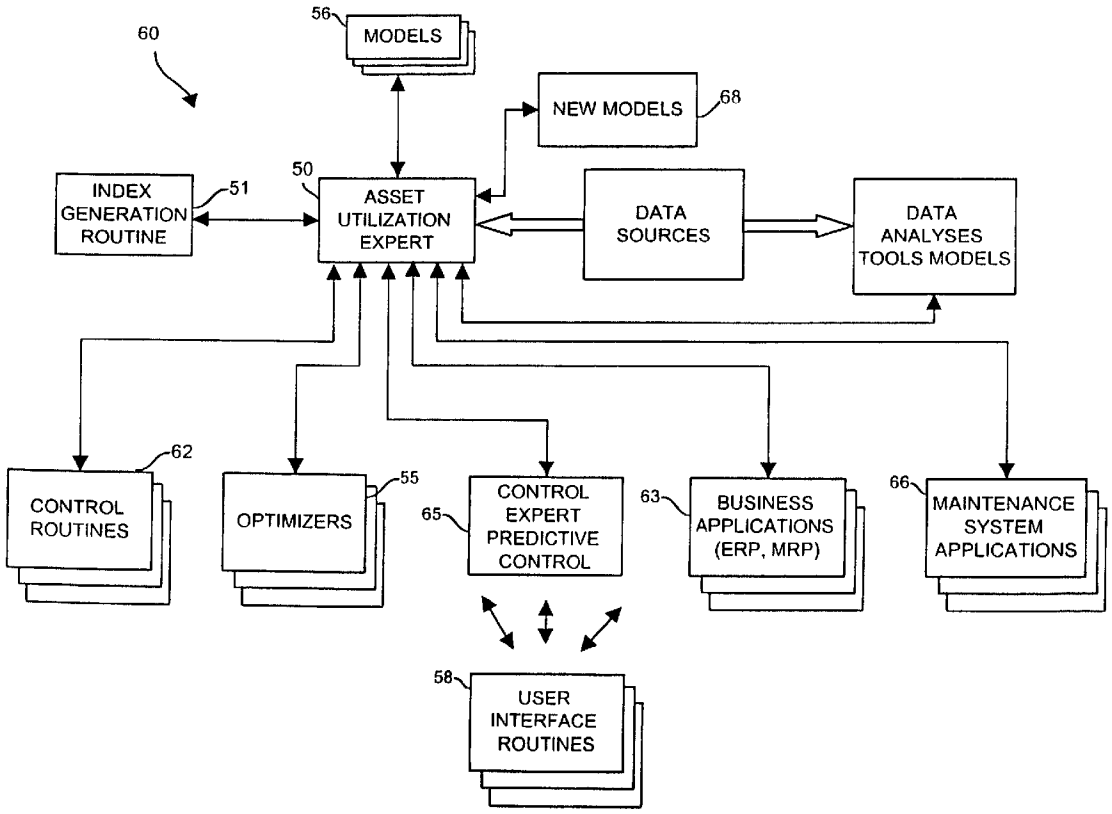
(52) **U.S. Cl.** **702/188**

(57) **ABSTRACT**

A system and method for analyzing a process collects process data within a process control plant and transmits the collected process data to a remote data processing facility. The remote data processing facility analyzes the process data using a process analysis tool such as a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and/or an accounting tool to generate analysis data. The analysis data is then transmitted to the process control plant via a communication link such as the Internet.



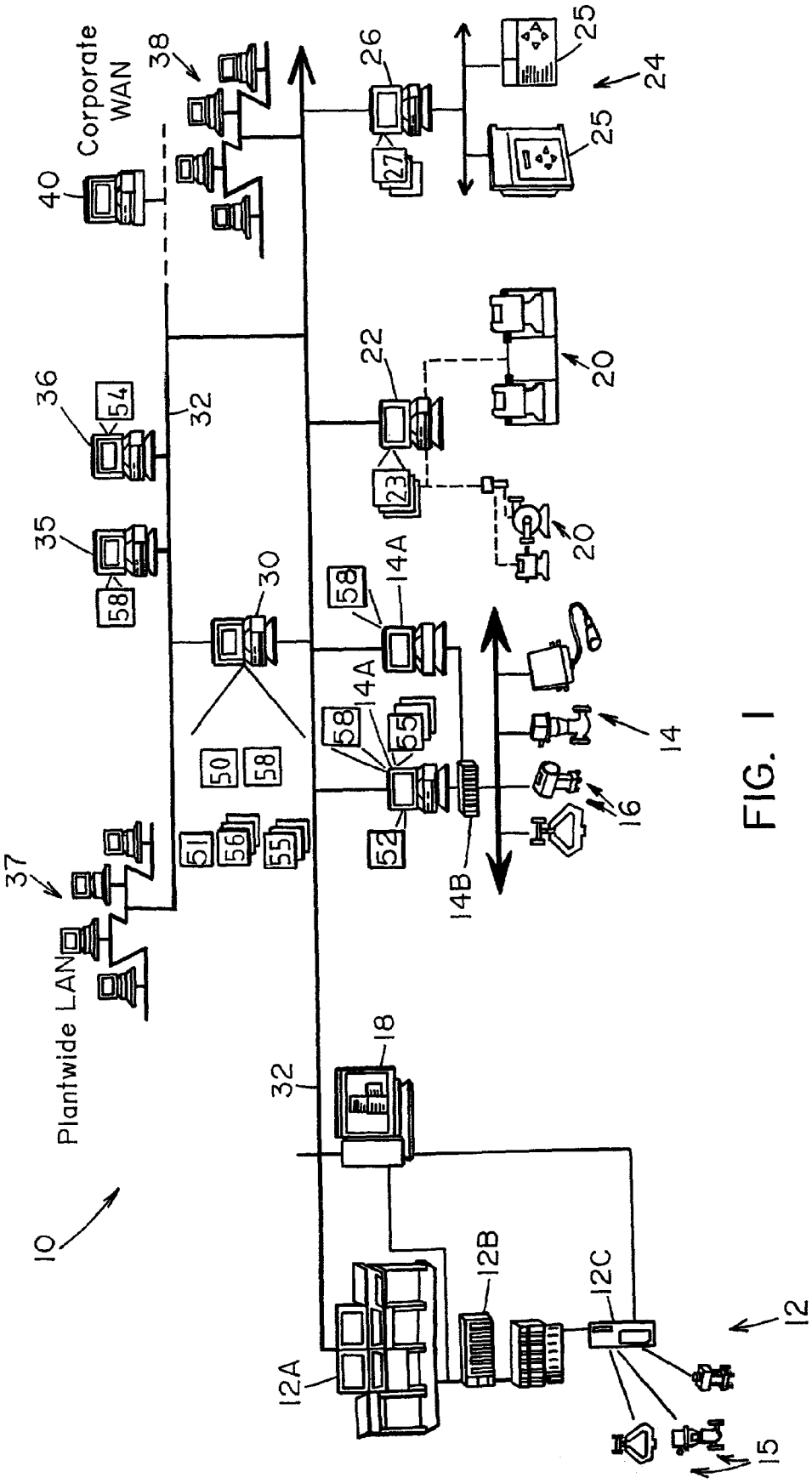

Corporate WAN
Plantwide LAN
10
12
12A
12B
12C
14
14A
14B
15
16
18
20
22
23
24
25
26
27
30
32
35
36
37
38
40
50
51
52
54
55
56
58

FIG. 1

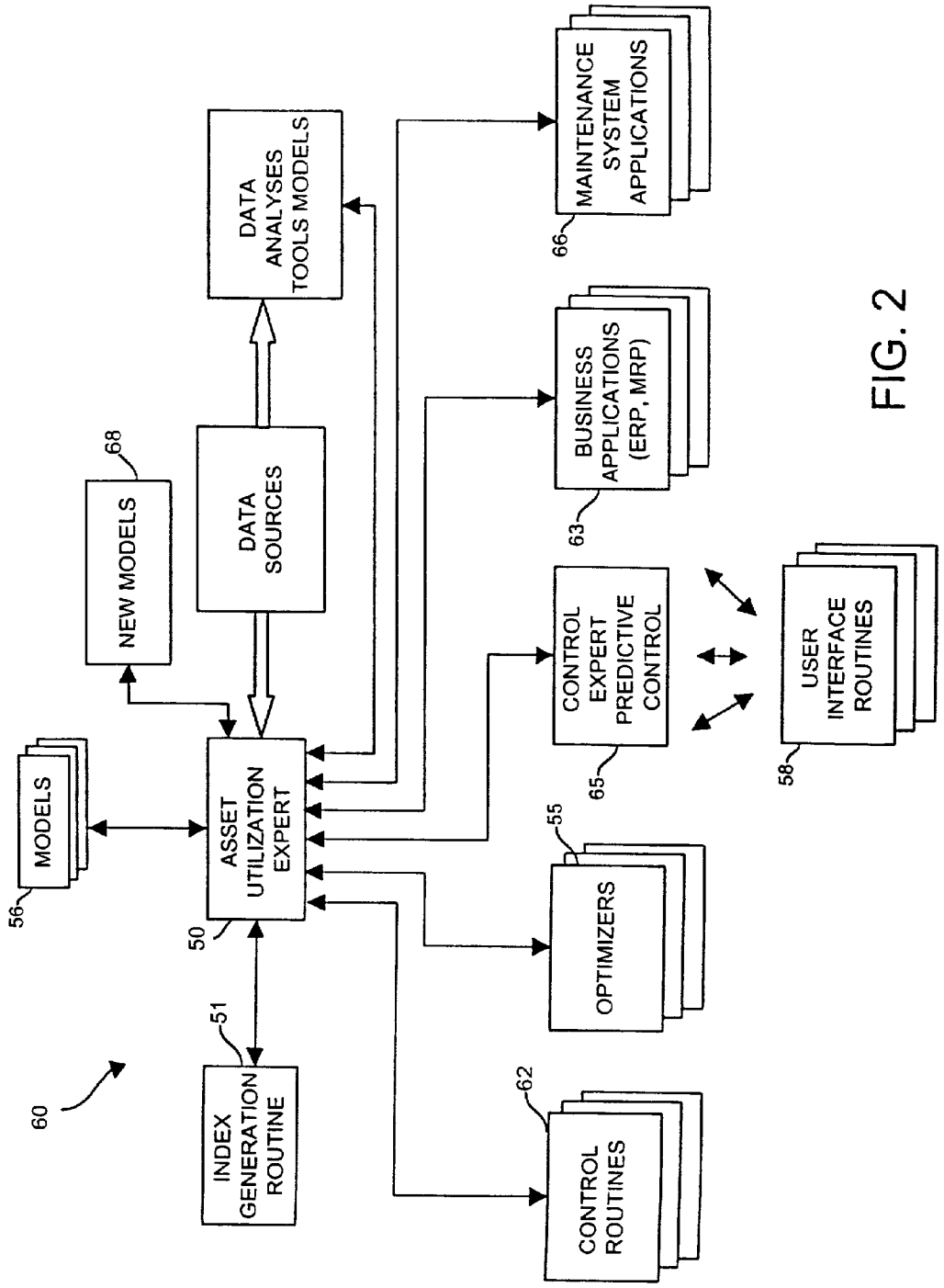

60
MODELS
56
NEW MODELS
68
INDEX GENERATION ROUTINE
51
ASSET UTILIZATION EXPERT
50
DATA SOURCES
DATA ANALYSES TOOLS MODELS
CONTROL ROUTINES
62
OPTIMIZERS
55
CONTROL EXPERT PREDICTIVE CONTROL
65
BUSINESS APPLICATIONS (ERP, MRP)
63
MAINTENANCE SYSTEM APPLICATIONS
66
USER INTERFACE ROUTINES
58

FIG. 2

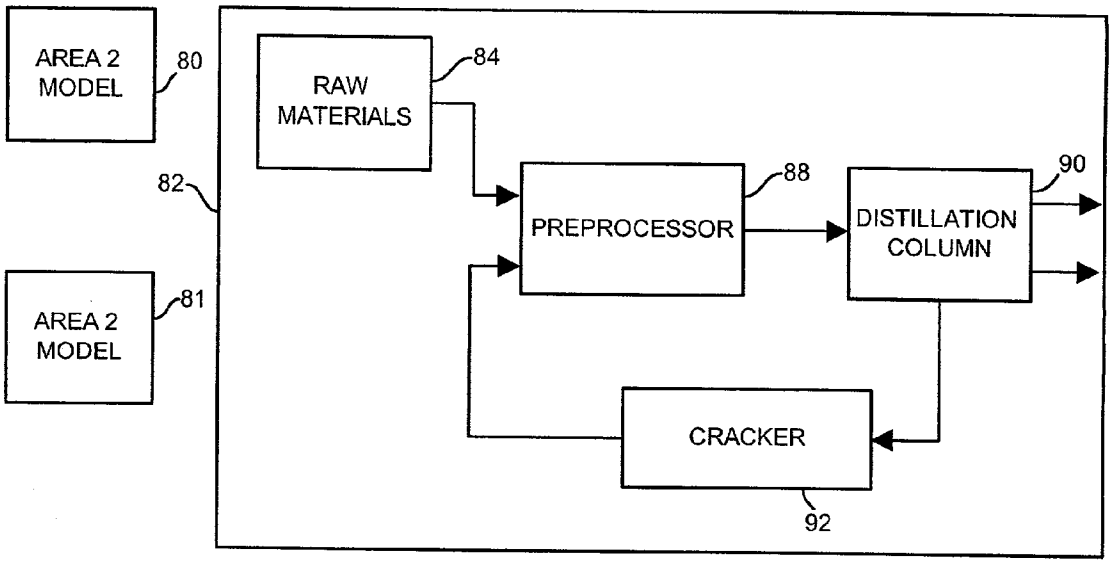

AREA 2 MODEL
80
RAW MATERIALS
84
82
PREPROCESSOR
88
DISTILLATION COLUMN
90
AREA 2 MODEL
81
CRACKER
92

FIG. 3

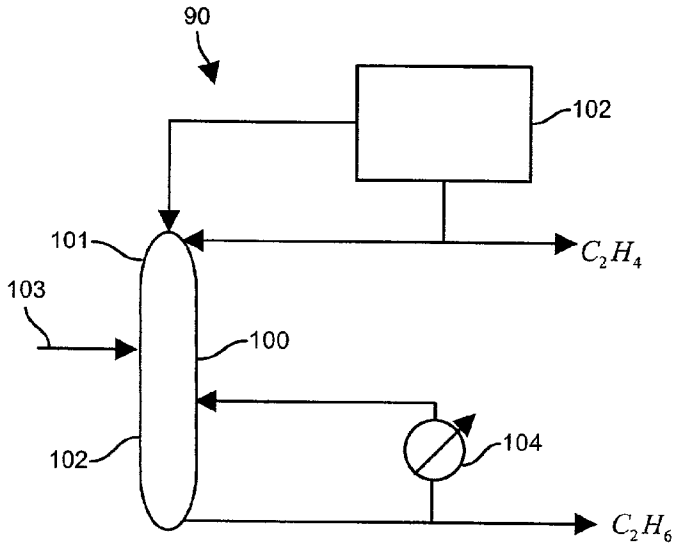

90
102
101
C_2H_4
103
100
104
102
C_2H_6

FIG. 4

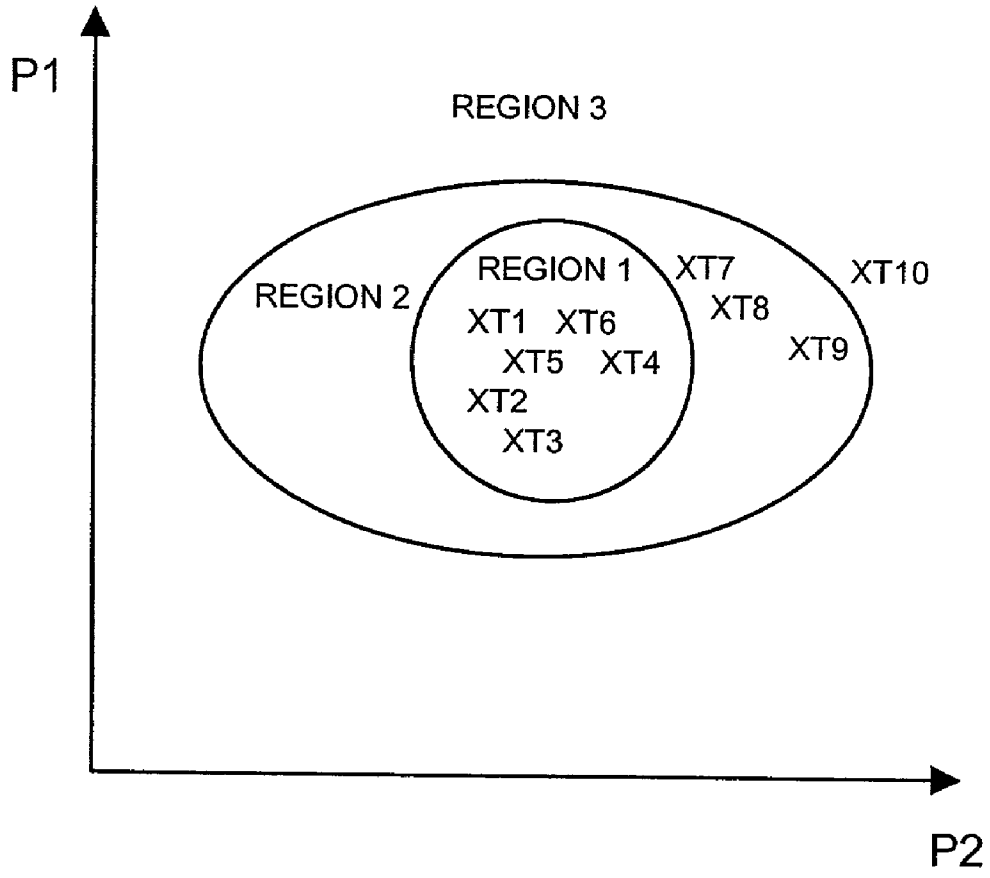

P1
REGION 3
REGION 2
REGION 1
XT1 XT6
XT5 XT4
XT2
XT3
XT7
XT8
XT9
XT10
P2

FIG. 5

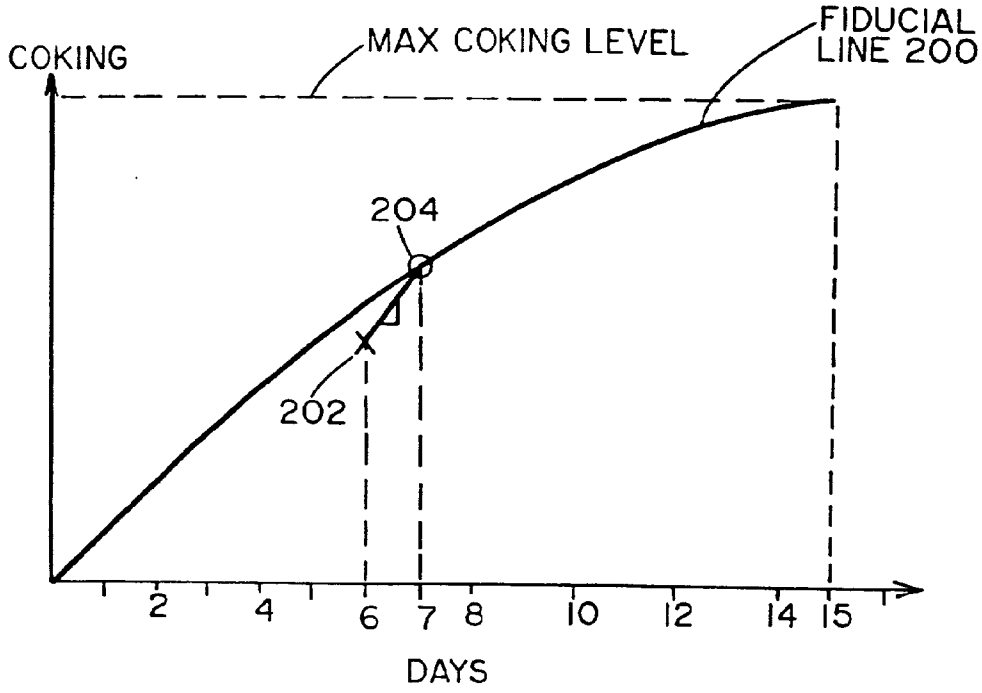

COKING
MAX COKING LEVEL
FIDUCIAL LINE 200
204
202
2
4
6
7
8
10
12
14
15
DAYS

FIG. 6

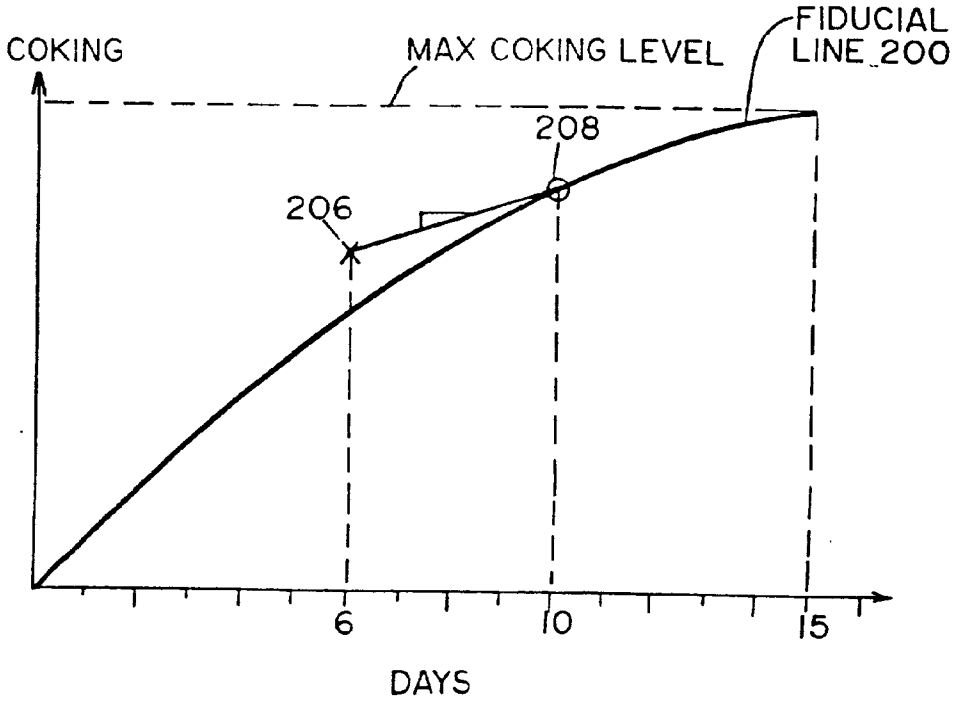
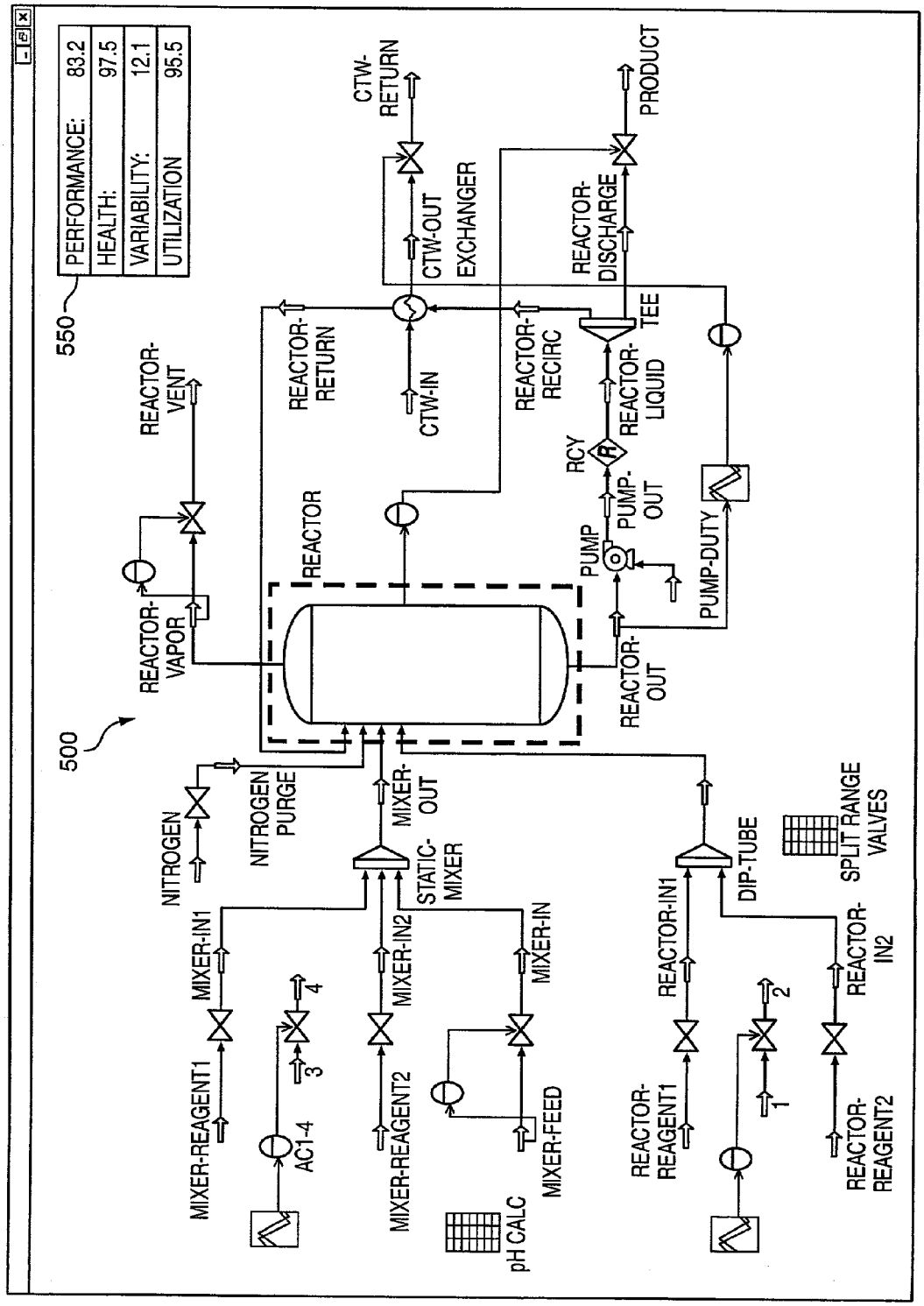

COKING
MAX COKING LEVEL
FIDUCIAL LINE 200
208
206
6
10
15
DAYS

FIG. 7

FIG. 8


PERFORMANCE: 83.2
HEALTH: 97.5
VARIABILITY: 12.1
UTILIZATION 95.5
550
500
REACTOR-VENT
REACTOR-VAPOR
REACTOR-RETURN
CTW-IN
CTW-RETURN
CTW-OUT
EXCHANGER
REACTOR-RECIRC
REACTOR-DISCHARGE
PRODUCT
REACTOR-LIQUID
TEE
RCY
PUMP-OUT
PUMP
PUMP-DUTY
REACTOR
REACTOR-OUT
NITROGEN
NITROGEN PURGE
MIXER-OUT
STATIC-MIXER
MIXER-IN1
MIXER-IN2
MIXER-IN
MIXER-REAGENT1
MIXER-REAGENT2
MIXER-FEED
AC1-4
pH CALC
REACTOR-IN1
REACTOR-IN2
DIP-TUBE
SPLIT RANGE VALVES
REACTOR-REAGENT1
REACTOR-REAGENT2

	PI	VI	HI	UI
Unit	x		x	x
Sub Unit	x		x	x
Loop		x	x	x
Device		x	x	

FIG. 9

PERFORMANCE FOR FCCU: 83.2

575

Loop Name	Index	Weight
FIC-101	88	3
TIC-111	89	3
LIC-111	88	3
FIC-111	60	3
FIC-112	80	1
TCI-222	87	1
FIC-101	88	3
TIC-111	89	3
LIC-111	88	3
FIC-111	60	3
FIC-112	80	1
TIC-222	87	1
PIC-111	87	1

FIG. 10

Device Name	INDEX	Description	Weight
FV-111	100	Leaking	3
TI-111	98	Sticktion	3
LI-111	90	40	3
MC-101	95	Will burn up in 2 weeks	2
FV-111	96	0	3

FIG. 11

FCCU Variability: 12.1

Device Name	Index	Weight
Fv-101	0	3
TI-111	2	3
LI-111	40	3
FV111	0	3
FV-112	0	1
TI-222	2	1
FI-101	7	3
TI-111	6	3
LI-111	7	3
FI-111	7	3
FI-112	7	1
TI-222	7	1
Sub unit: Reboiler RB101	15	2

FIG. 12

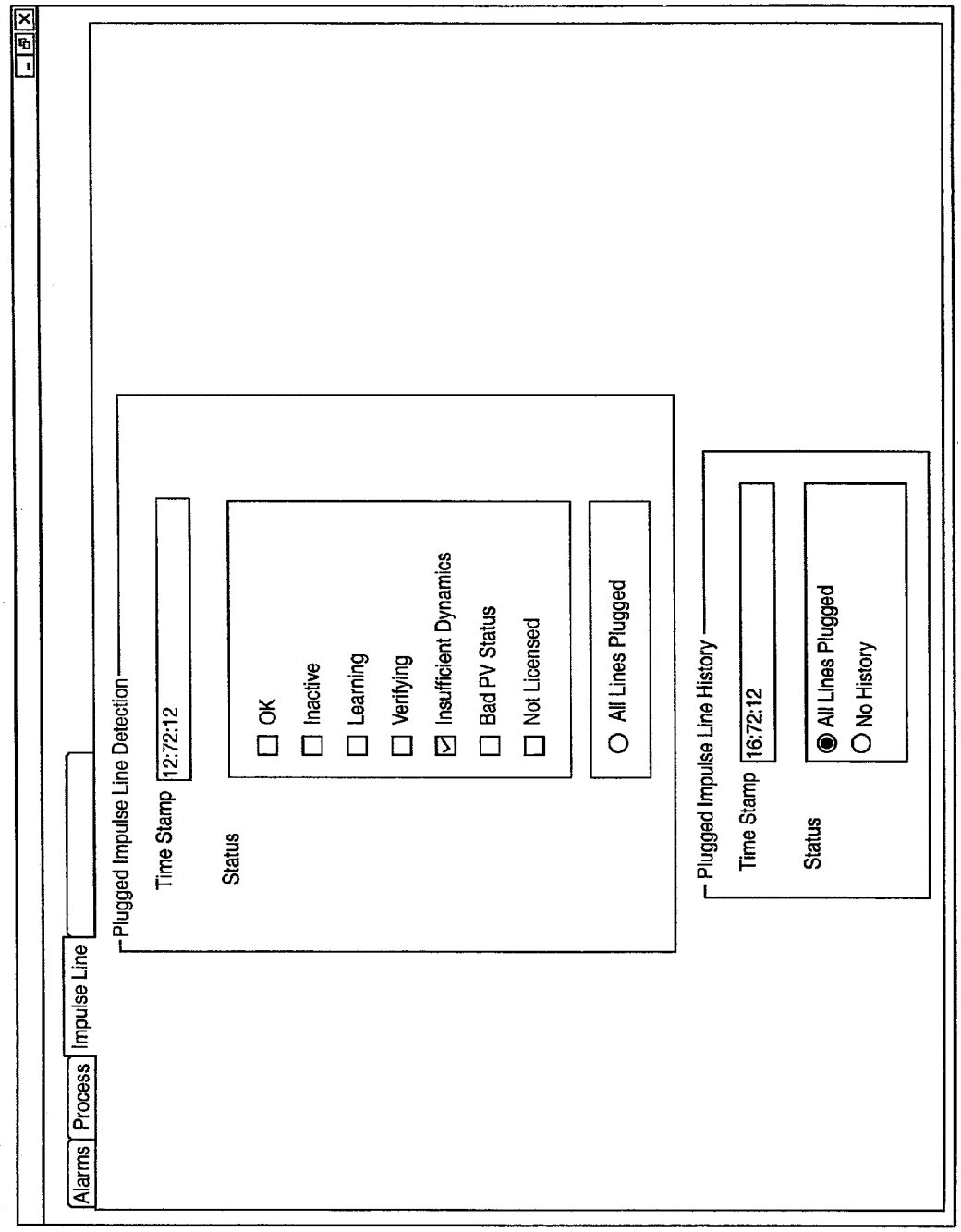
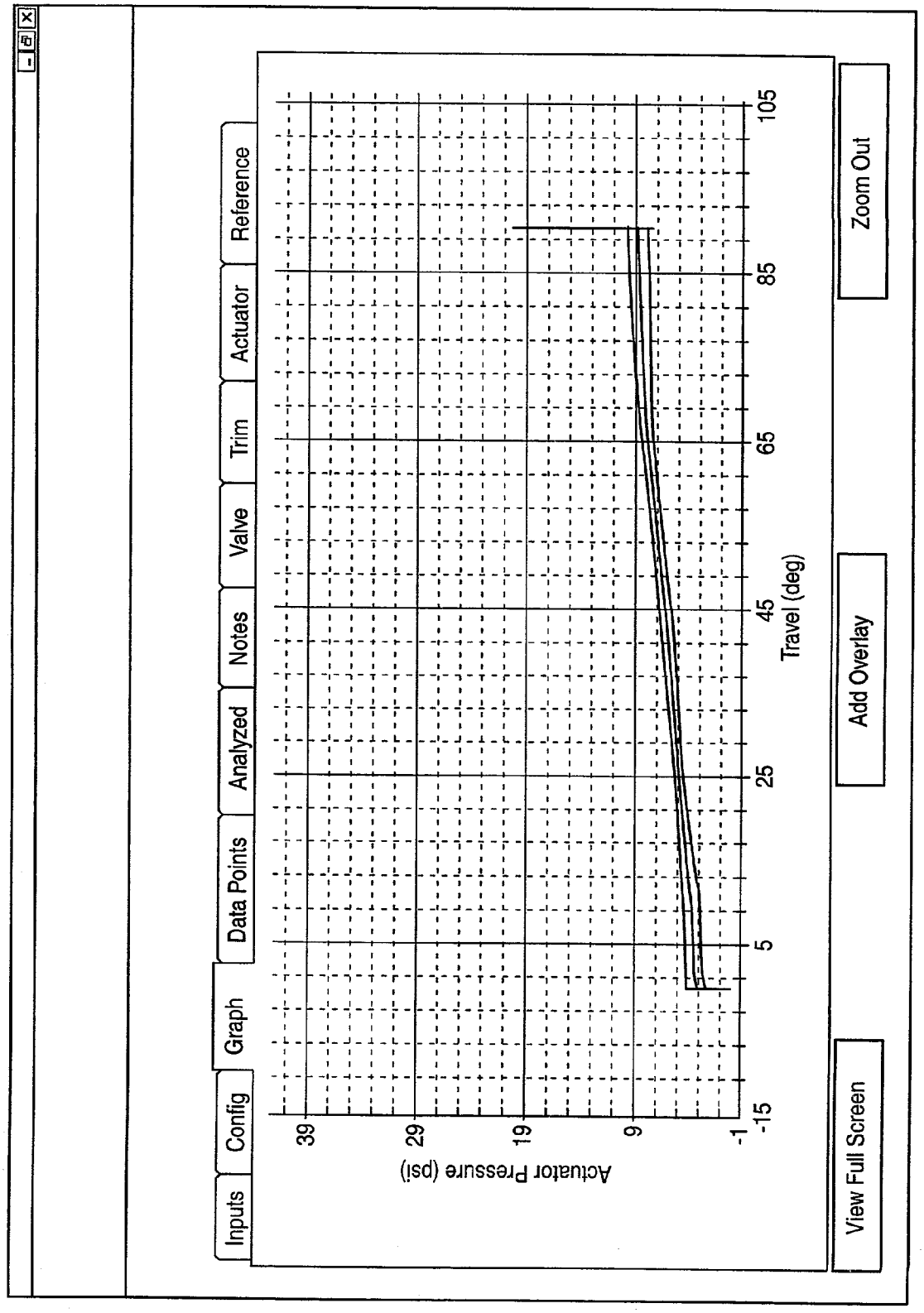

Alarms
Process
Impulse Line
Plugged Impulse Line Detection
Time Stamp
12:72:12
Status
OK
Inactive
Learning
Verifying
Insufficient Dynamics
Bad PV Status
Not Licensed
All Lines Plugged
Plugged Impulse Line History
Time Stamp
16:72:12
Status
All Lines Plugged
No History

FIG. 13

FIG. 14


Inputs
Config
Graph
Data Points
Analyzed
Notes
Valve
Trim
Actuator
Reference
Actuator Pressure (psi)
39
29
19
9
-1
-15
5
25
45
65
85
105
Travel (deg)
View Full Screen
Add Overlay
Zoom Out

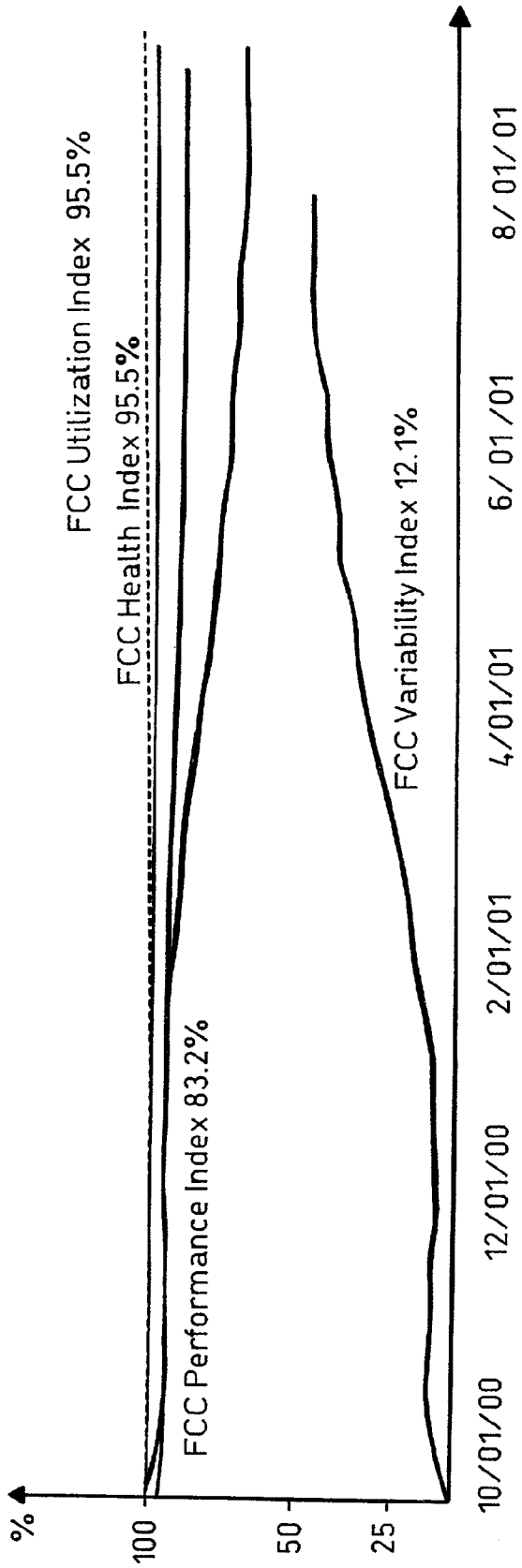

FCC Utilization Index 95.5%
FCC Health Index 95.5%
FCC Performance Index 83.2%
FCC Variability Index 12.1%
%
100
50
25
10/01/00
12/01/00
2/01/01
4/01/01
6/01/01
8/01/01

FIG. 15

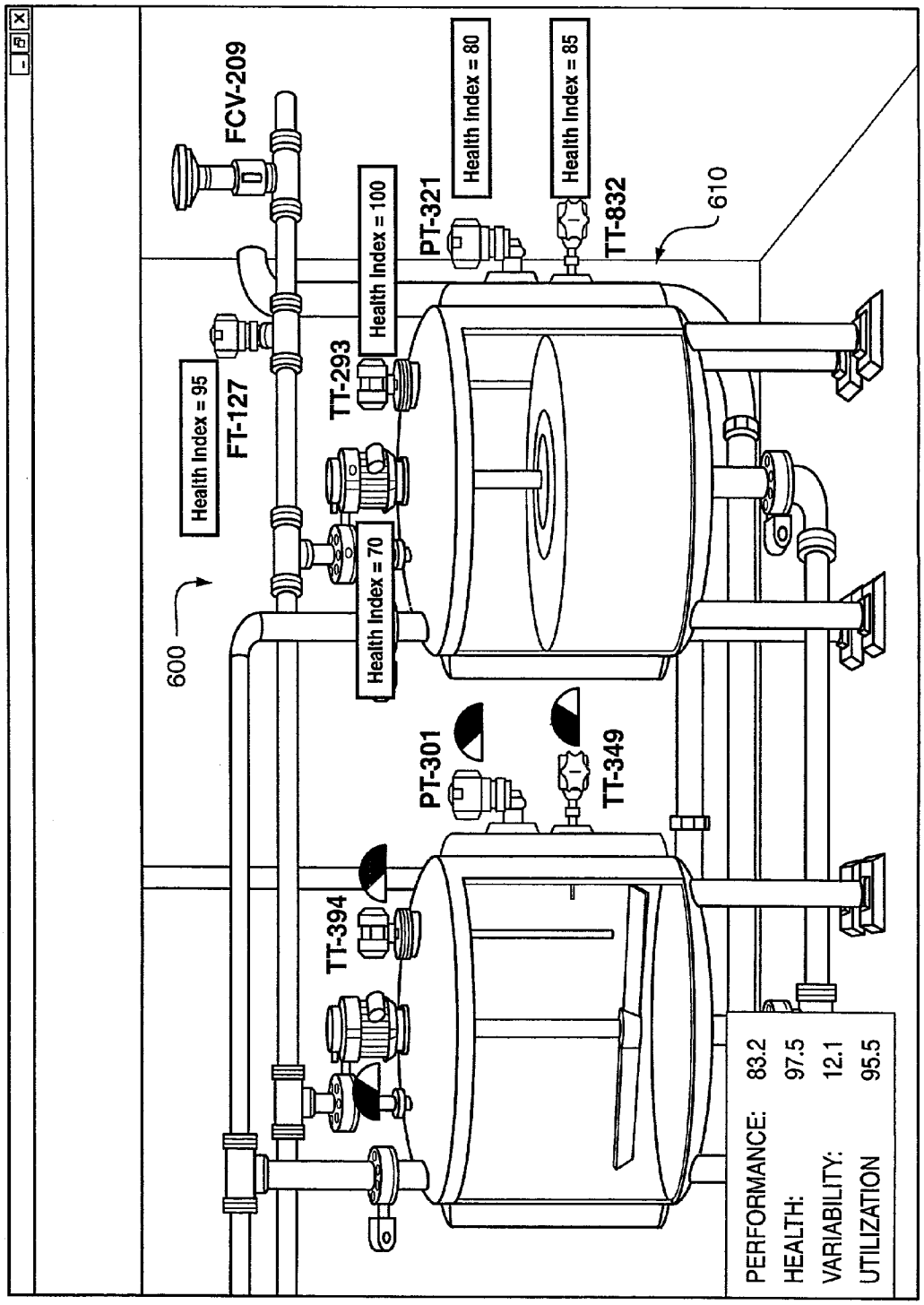

600
Health Index = 95
FT-127
FCV-209
Health Index = 100
TT-293
Health Index = 70
PT-321
Health Index = 80
Health Index = 85
TT-832
610
PT-301
TT-349
TT-394
PERFORMANCE: 83.2
HEALTH: 97.5
VARIABILITY: 12.1
UTILIZATION 95.5

FIG. 16

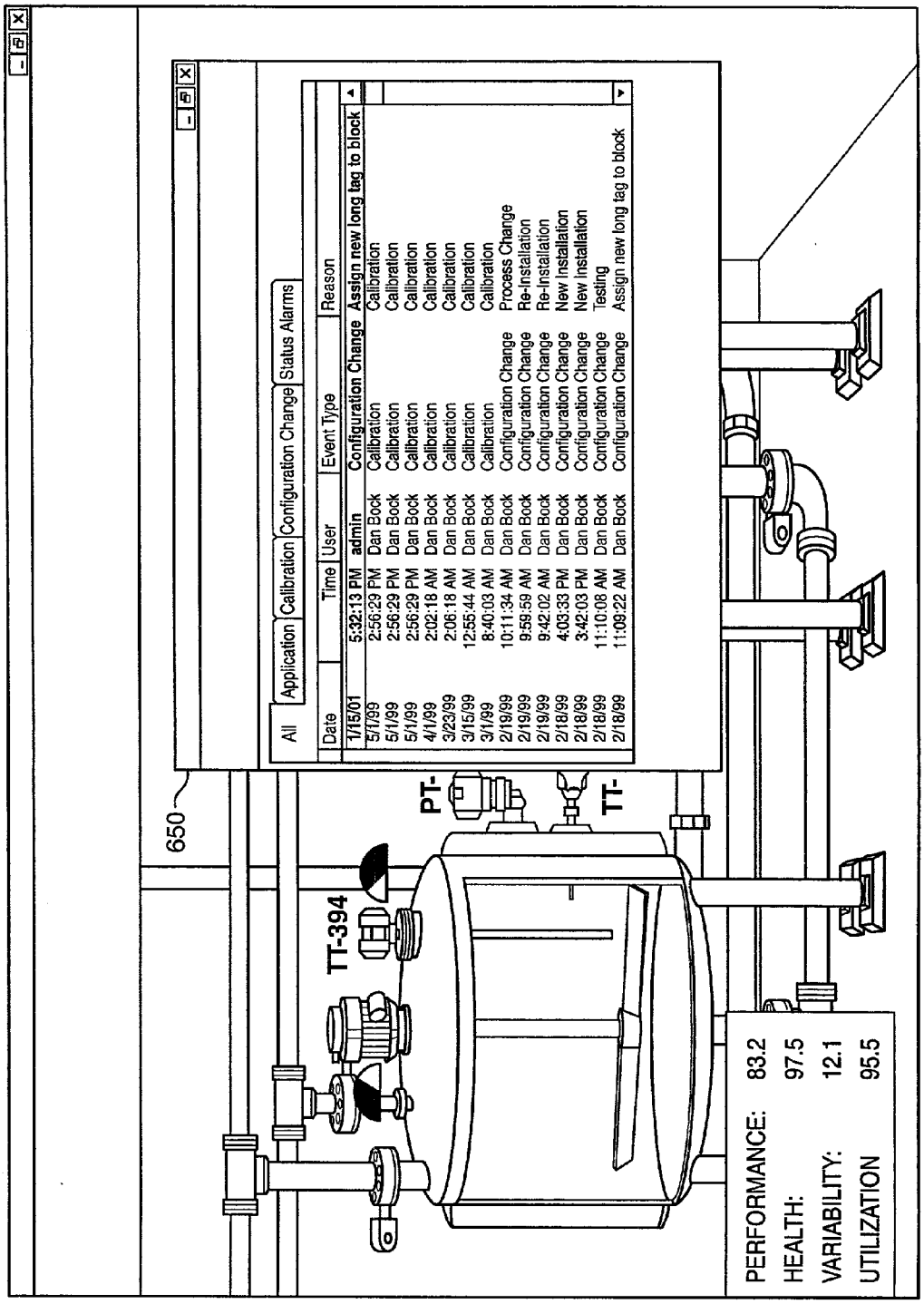

650
All
Application
Calibration
Configuration Change
Status Alarms
Date
Time
User
Event Type
Reason
1/15/01 5:32:13 PM admin Configuration Change Assign new long tag to block
5/1/99 2:56:29 PM Dan Bock Calibration Calibration
5/1/99 2:56:29 PM Dan Bock Calibration Calibration
5/1/99 2:56:29 PM Dan Bock Calibration Calibration
4/1/99 2:02:18 AM Dan Bock Calibration Calibration
3/23/99 2:06:18 AM Dan Bock Calibration Calibration
3/15/99 12:55:44 AM Dan Bock Calibration Calibration
3/1/99 8:40:03 AM Dan Bock Calibration Calibration
2/19/99 10:11:34 AM Dan Bock Configuration Change Process Change
2/19/99 9:59:59 AM Dan Bock Configuration Change Re-Installation
2/19/99 9:42:02 AM Dan Bock Configuration Change Re-Installation
2/18/99 4:03:33 PM Dan Bock Configuration Change New Installation
2/18/99 3:42:03 PM Dan Bock Configuration Change New Installation
2/18/99 11:10:08 AM Dan Bock Configuration Change Testing
2/18/99 11:09:22 AM Dan Bock Configuration Change Assign new long tag to block
PT-
TT-
TT-394
PERFORMANCE: 83.2
HEALTH: 97.5
VARIABILITY: 12.1
UTILIZATION 95.5

FIG. 17

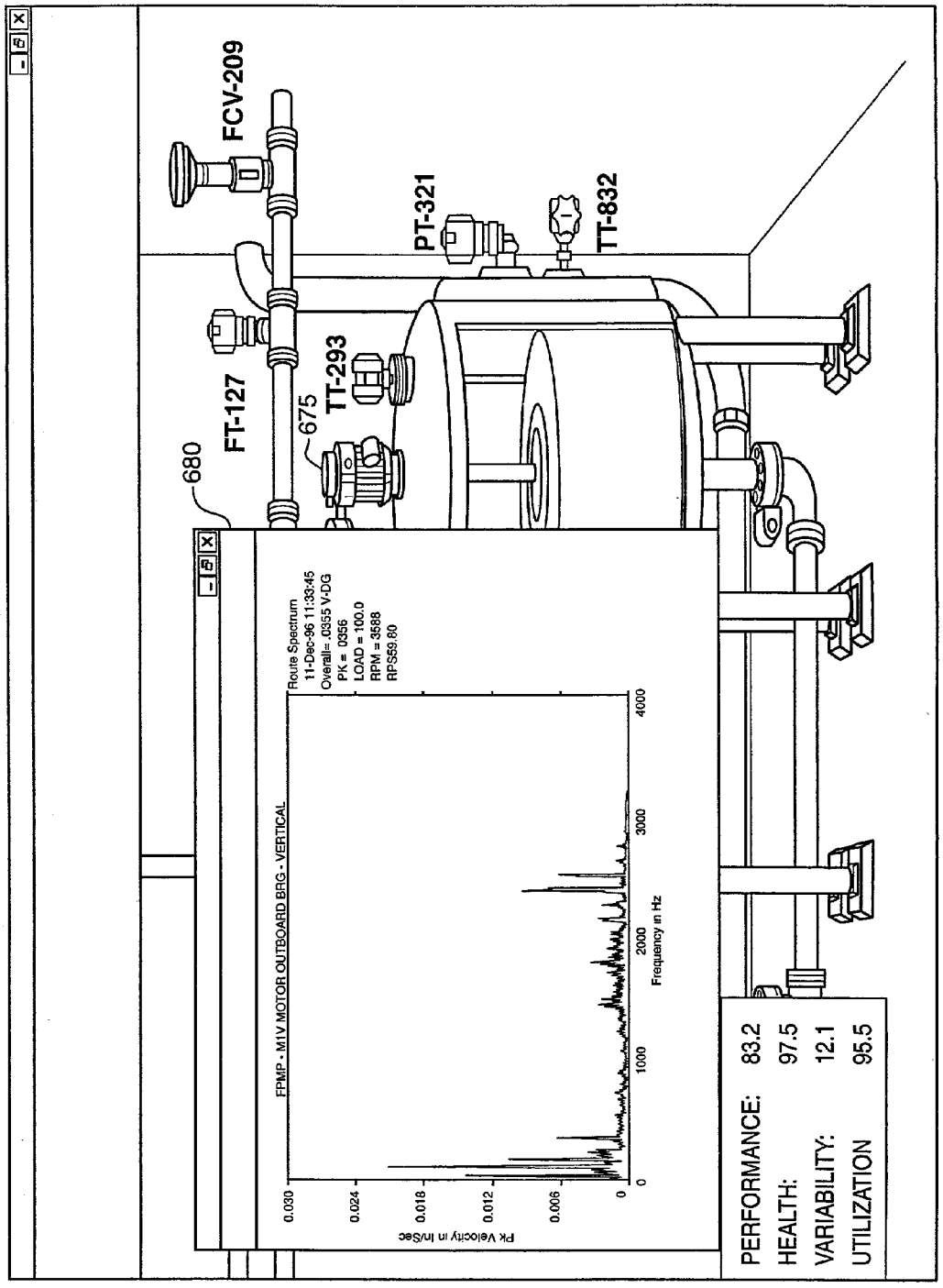

FCV-209
PT-321
TT-832
FT-127
TT-293
675
680
FPMP - M1V MOTOR OUTBOARD BRG - VERTICAL
Route Spectrum
11-Dec-96 11:33:45
Overall= .0355 V-DG
PK = .0356
LOAD = 100.0
RPM = 3588
RPS59.80
Pk Velocity in In/Sec
0.030
0.024
0.018
0.012
0.006
0
0
1000
2000
3000
4000
Frequency in Hz
PERFORMANCE: 83.2
HEALTH: 97.5
VARIABILITY: 12.1
UTILIZATION 95.5

FIG. 18

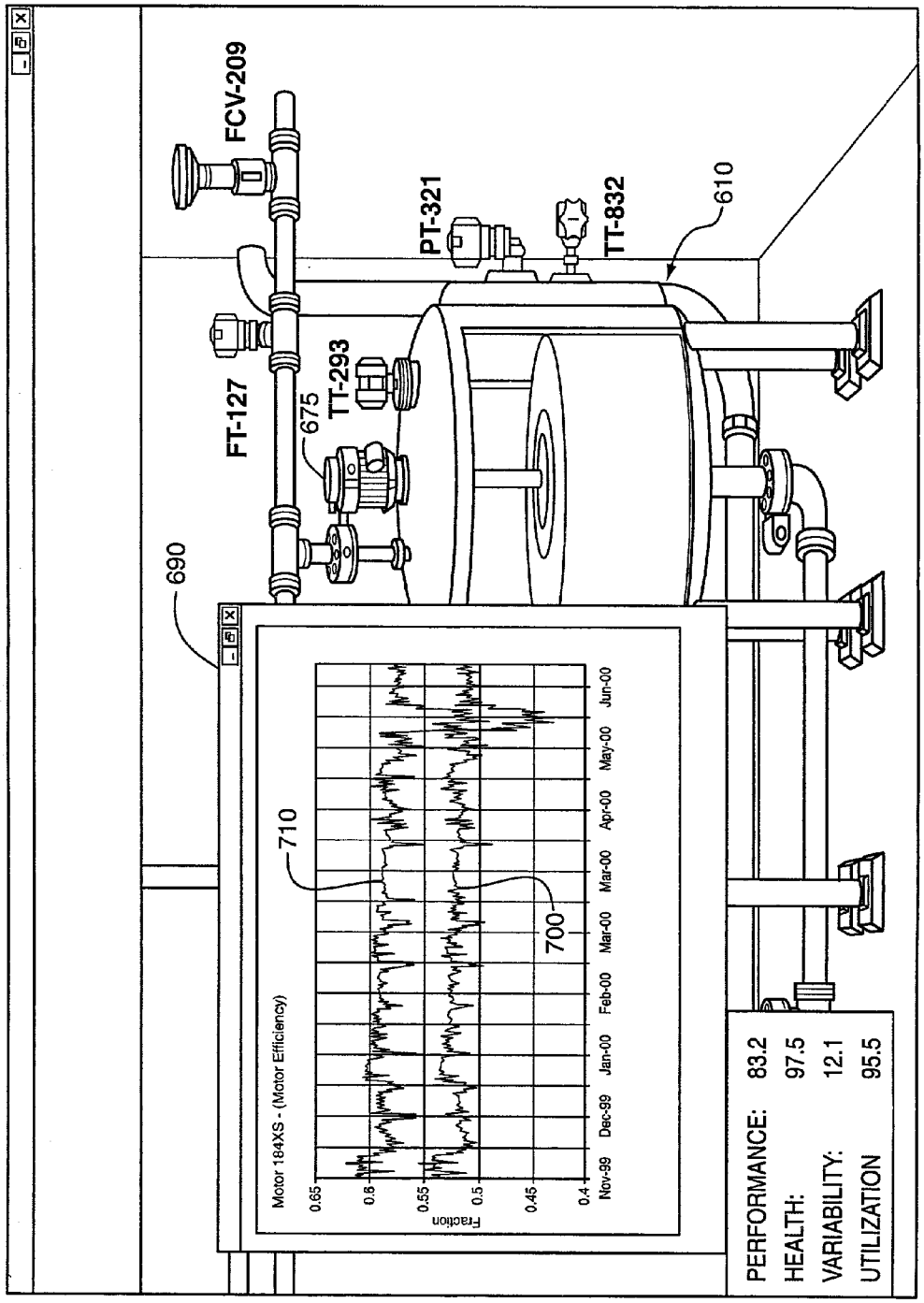

FCV-209
FT-127
675
TT-293
PT-321
TT-832
610
690
710
700
Motor 184XS - (Motor Efficiency)
Fraction
0.65
0.6
0.55
0.5
0.45
0.4
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Mar-00
Apr-00
May-00
Jun-00
PERFORMANCE: 83.2
HEALTH: 97.5
VARIABILITY: 12.1
UTILIZATION 95.5

FIG. 19

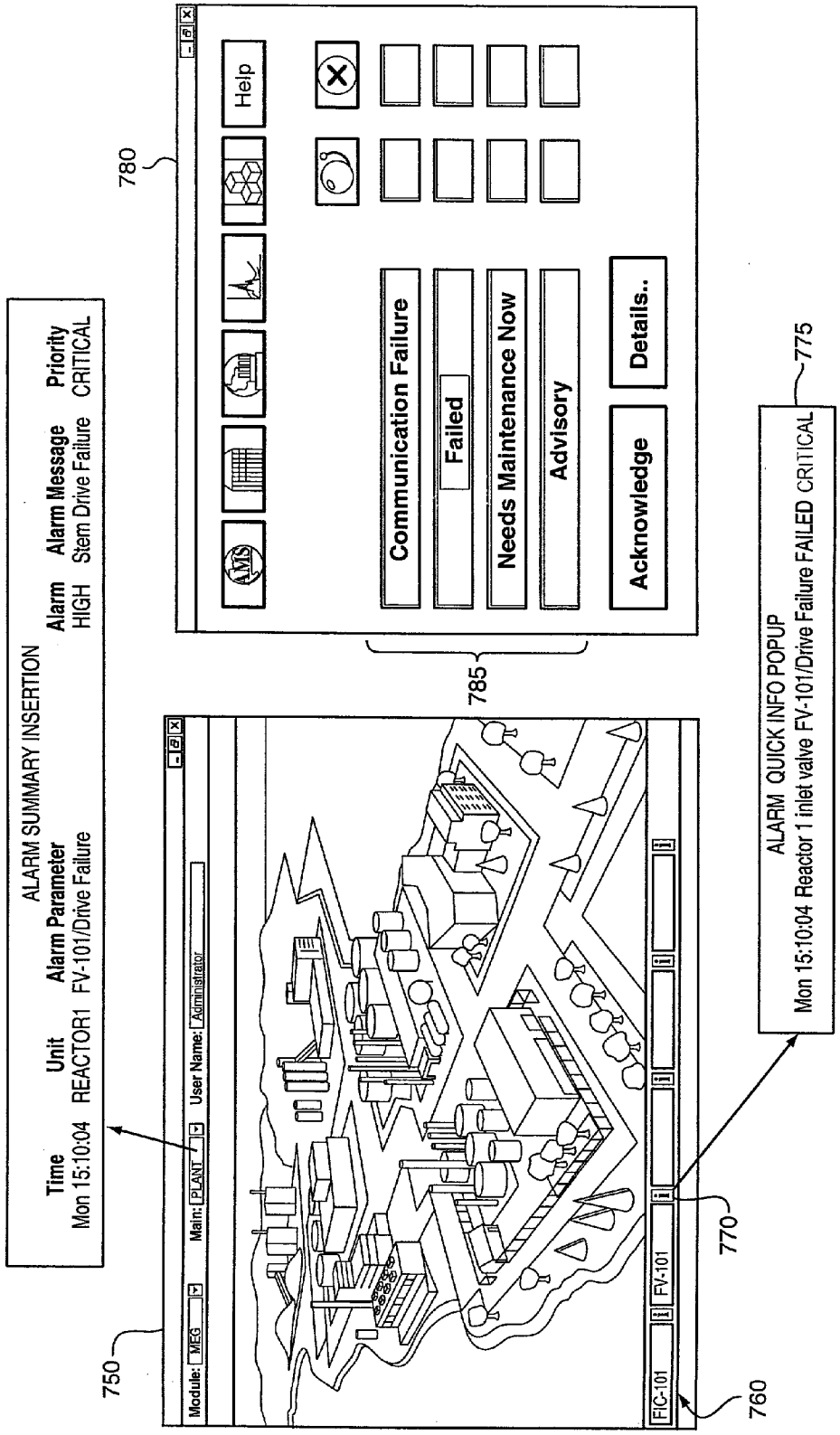

ALARM SUMMARY INSERTION
Time
Mon 15:10:04
Unit
REACTOR1
Alarm Parameter
FV-101/Drive Failure
Alarm
HIGH
Alarm Message
Stem Drive Failure
Priority
CRITICAL
Module: MEG
Main: PLANT
User Name: Administrator
FIC-101
FV-101
Help
Communication Failure
Failed
Needs Maintenance Now
Advisory
Acknowledge
Details..
ALARM QUICK INFO POPUP
Mon 15:10:04 Reactor 1 inlet valve FV-101/Drive Failure FAILED CRITICAL
750
760
770
775
780
785

FIG. 20

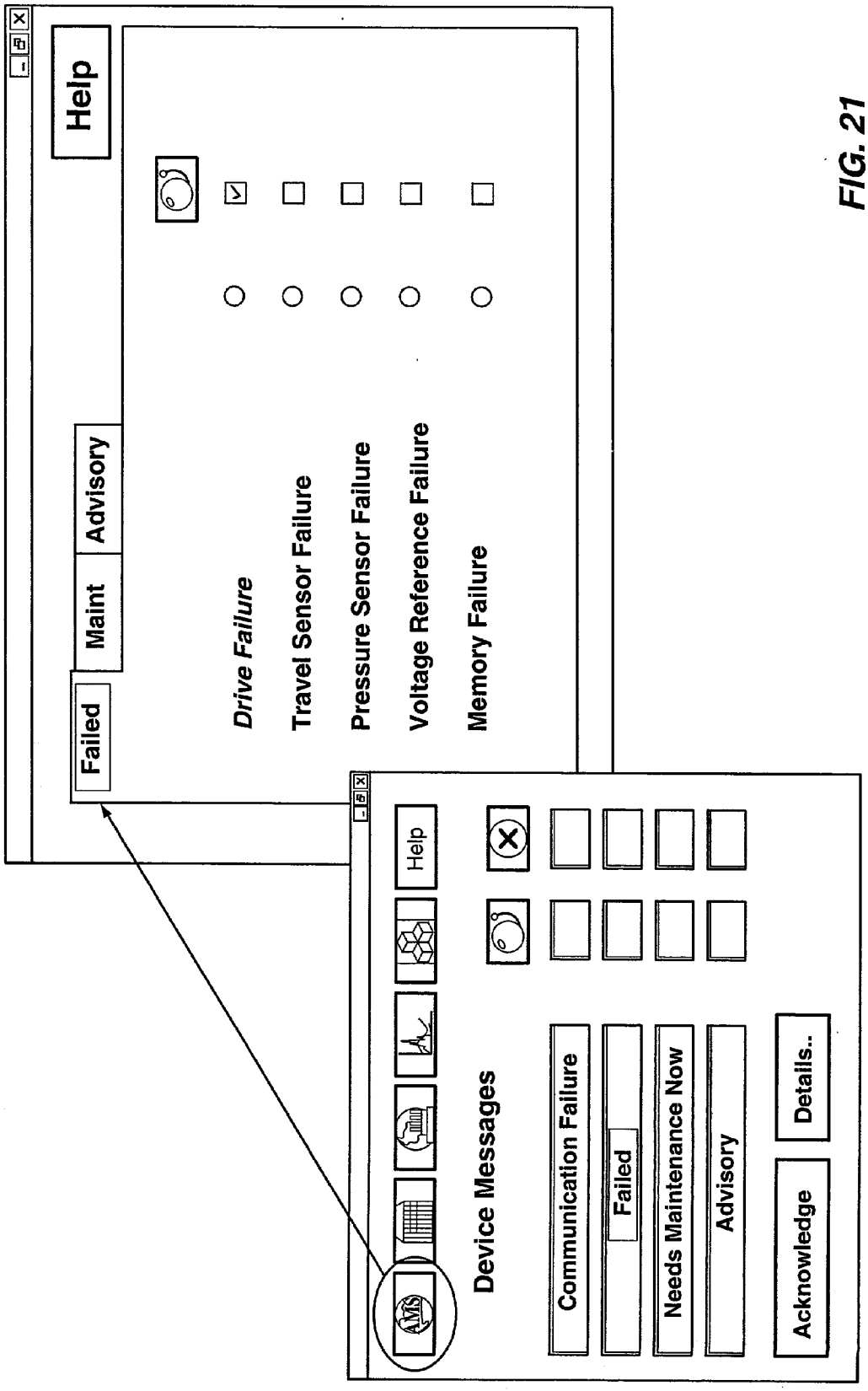

Help
Failed
Maint
Advisory
Drive Failure
Travel Sensor Failure
Pressure Sensor Failure
Voltage Reference Failure
Memory Failure
Help
Device Messages
Communication Failure
Failed
Needs Maintenance Now
Advisory
Acknowledge
Details..

FIG. 21

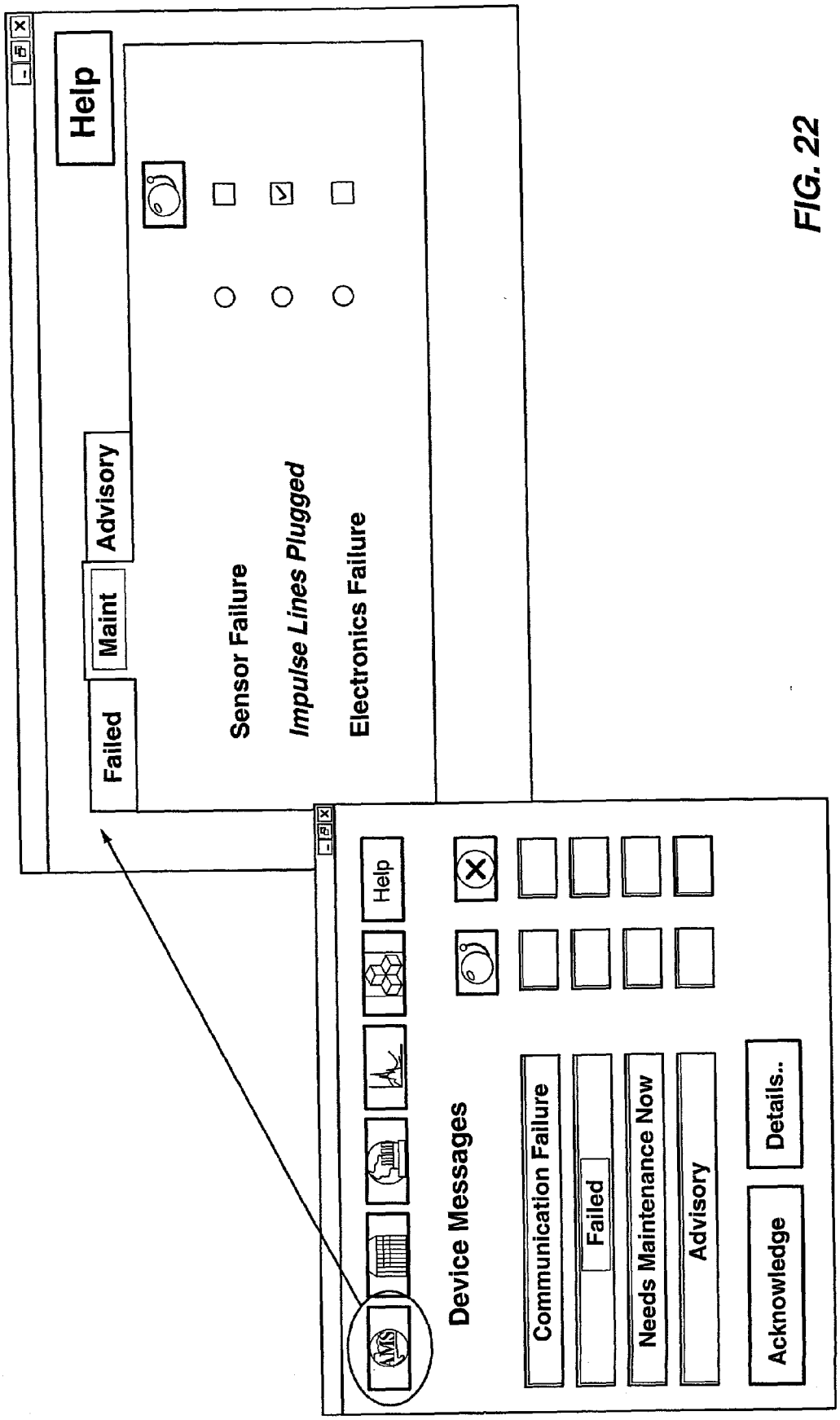

Help
Advisory
Maint
Failed
Sensor Failure
Impulse Lines Plugged
Electronics Failure
Help
Device Messages
Communication Failure
Failed
Needs Maintenance Now
Advisory
Details..
Acknowledge

FIG. 22

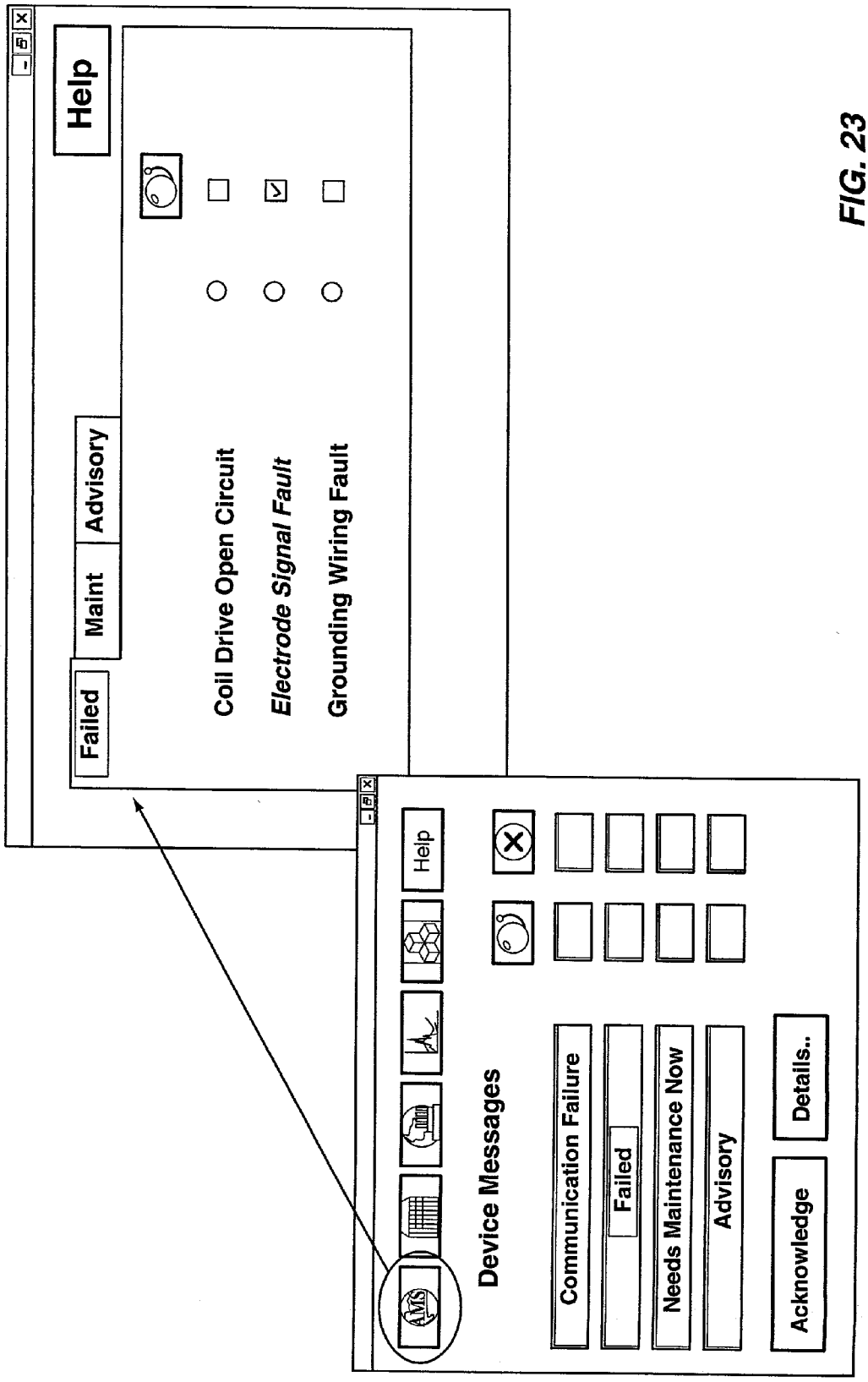

Help
Failed
Maint
Advisory
Coil Drive Open Circuit
Electrode Signal Fault
Grounding Wiring Fault
Help
Device Messages
Communication Failure
Failed
Needs Maintenance Now
Advisory
Acknowledge
Details..

FIG. 23

FIG. 24

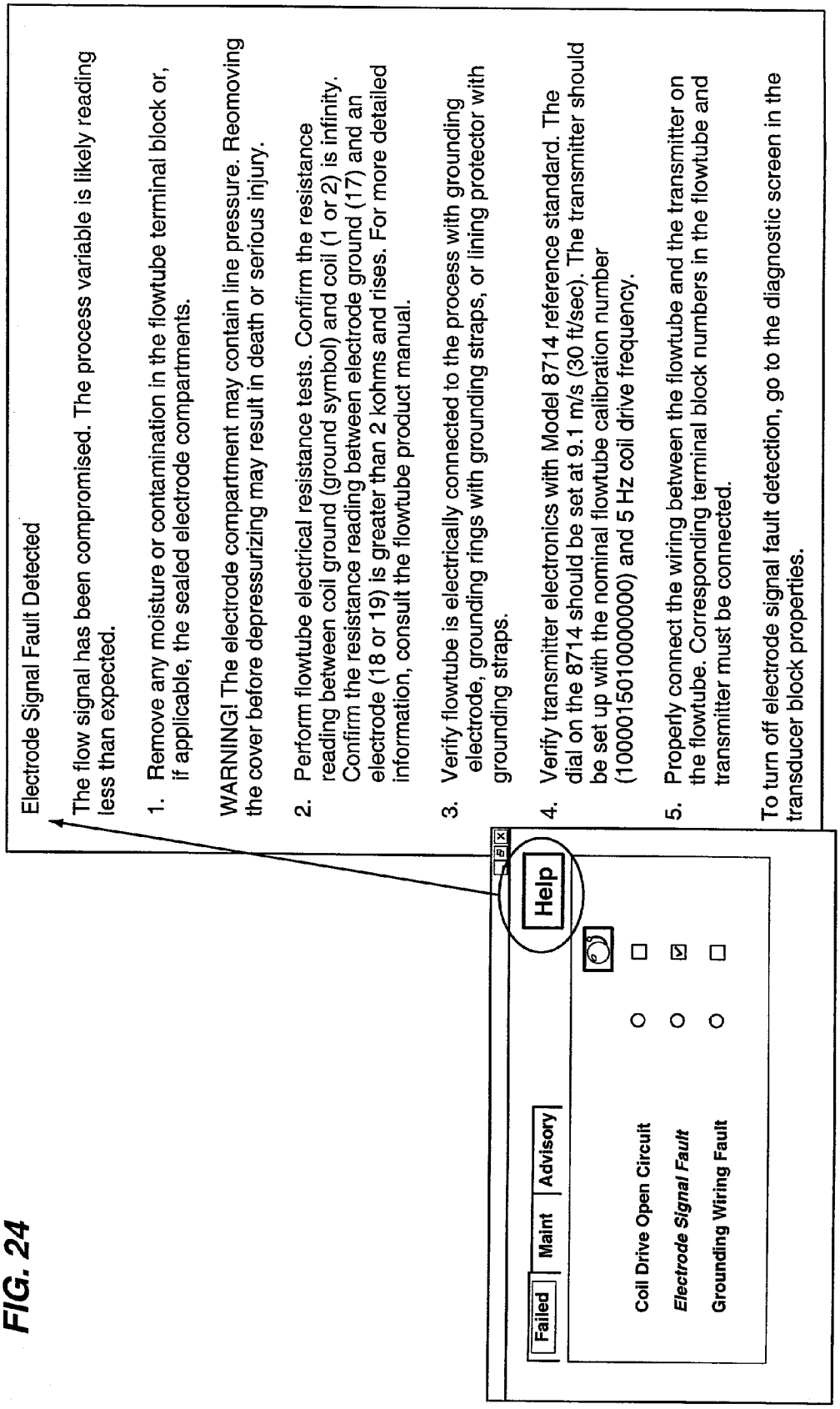
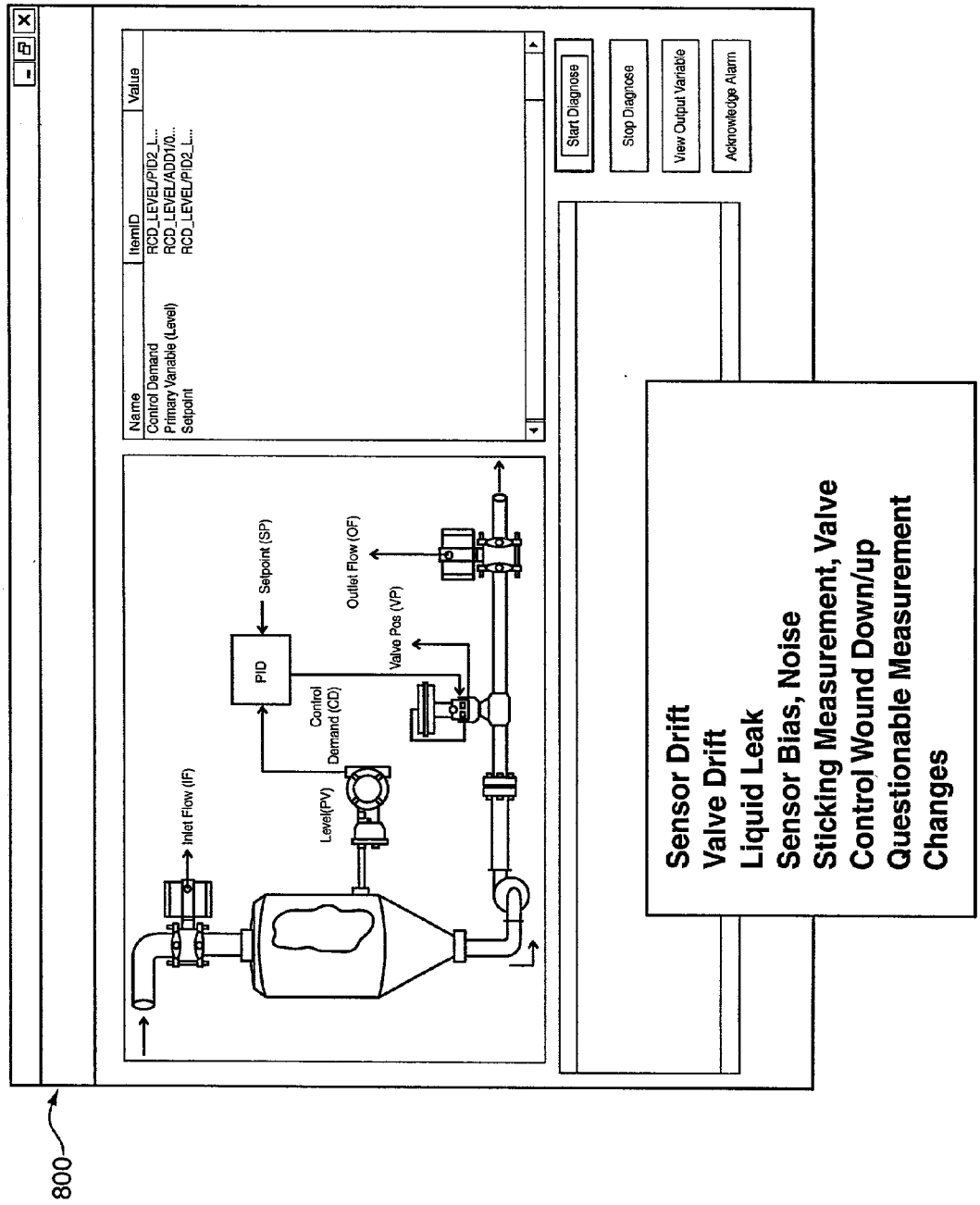

Failed
Maint
Advisory
Help
Coil Drive Open Circuit
Electrode Signal Fault
Grounding Wiring Fault
Electrode Signal Fault Detected
The flow signal has been compromised. The process variable is likely reading less than expected.
1. Remove any moisture or contamination in the flowtube terminal block or, if applicable, the sealed electrode compartments.
WARNING! The electrode compartment may contain line pressure. Reomoving the cover before depressurizing may result in death or serious injury.
2. Perform flowtube electrical resistance tests. Confirm the resistance reading between coil ground (ground symbol) and coil (1 or 2) is infinity. Confirm the resistance reading between electrode ground (17) and an electrode (18 or 19) is greater than 2 kohms and rises. For more detailed information, consult the flowtube product manual.
3. Verify flowtube is electrically connected to the process with grounding electrode, grounding rings with grounding straps, or lining protector with grounding straps.
4. Verify transmitter electronics with Model 8714 reference standard. The dial on the 8714 should be set at 9.1 m/s (30 ft/sec). The transmitter should be set up with the nominal flowtube calibration number (100001501000000) and 5 Hz coil drive frequency.
5. Properly connect the wiring between the flowtube and the transmitter on the flowtube. Corresponding terminal block numbers in the flowtube and transmitter must be connected.
To turn off electrode signal fault detection, go to the diagnostic screen in the transducer block properties.

FIG. 25


Name
ItemID
Value
Control Demand
RCD_LEVEL/PID2_L...
Primary Variable (Level)
RCD_LEVEL/ADD1/0...
Setpoint
RCD_LEVEL/PID2_L...
Start Diagnose
Stop Diagnose
View Output Variable
Acknowledge Alarm
Inlet Flow (IF)
Level(PV)
PID
Setpoint (SP)
Control Demand (CD)
Valve Pos (VP)
Outlet Flow (OF)
Sensor Drift
Valve Drift
Liquid Leak
Sensor Bias, Noise
Sticking Measurement, Valve
Control Wound Down/up
Questionable Measurement
Changes
800

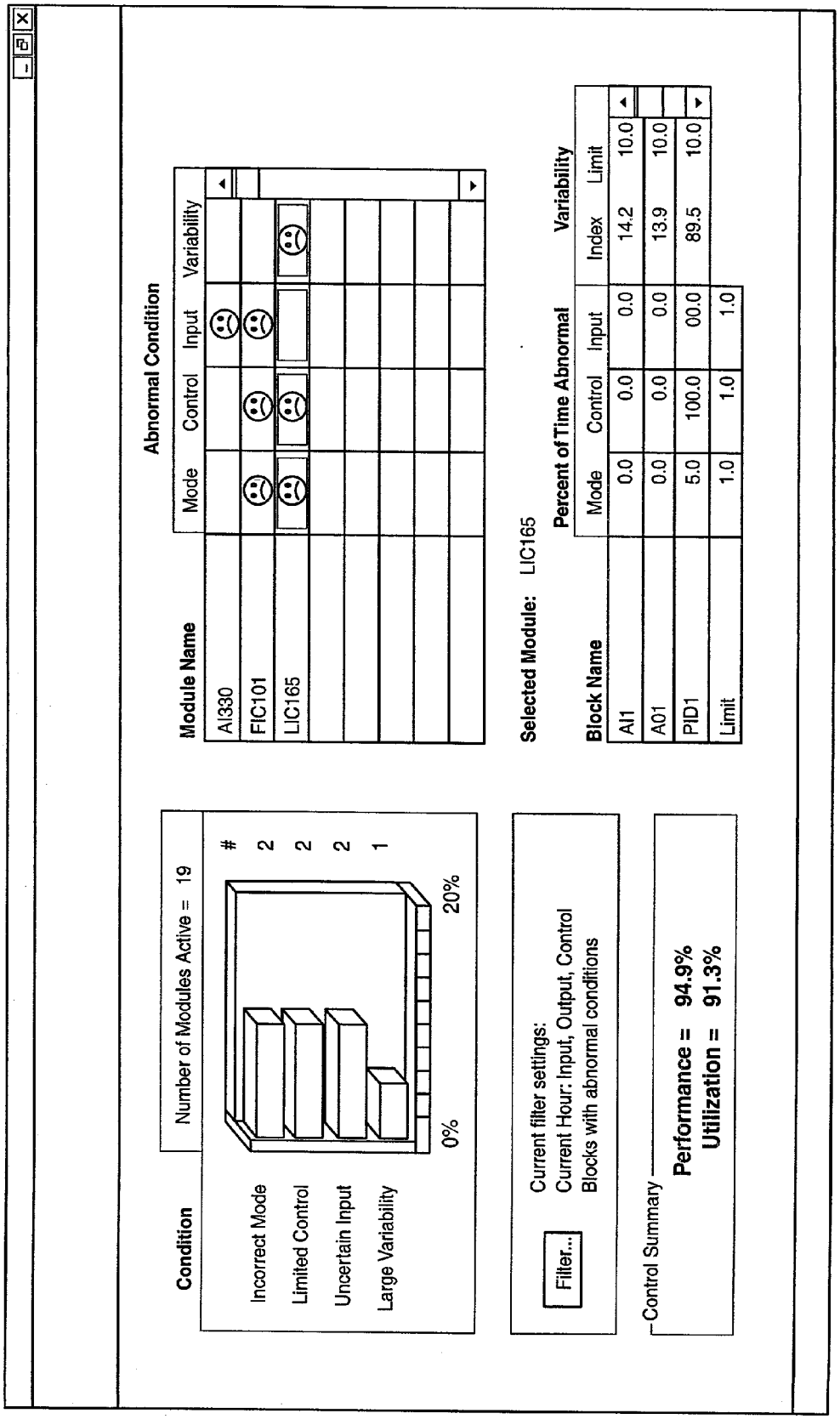

Condition
Number of Modules Active = 19
#
Incorrect Mode 2
Limited Control 2
Uncertain Input 2
Large Variability 1
0%
20%
Filter...
Current filter settings:
Current Hour: Input, Output, Control
Blocks with abnormal conditions
Control Summary
Performance = 94.9%
Utilization = 91.3%
Abnormal Condition
Module Name
Mode
Control
Input
Variability
AI330
FIC101
LIC165
Selected Module: LIC165
Percent of Time Abnormal
Variability
Block Name
Mode
Control
Input
Index
Limit
AI1 0.0 0.0 0.0 14.2 10.0
AO1 0.0 0.0 0.0 13.9 10.0
PID1 5.0 100.0 00.0 89.5 10.0
Limit 1.0 1.0 1.0

FIG. 26

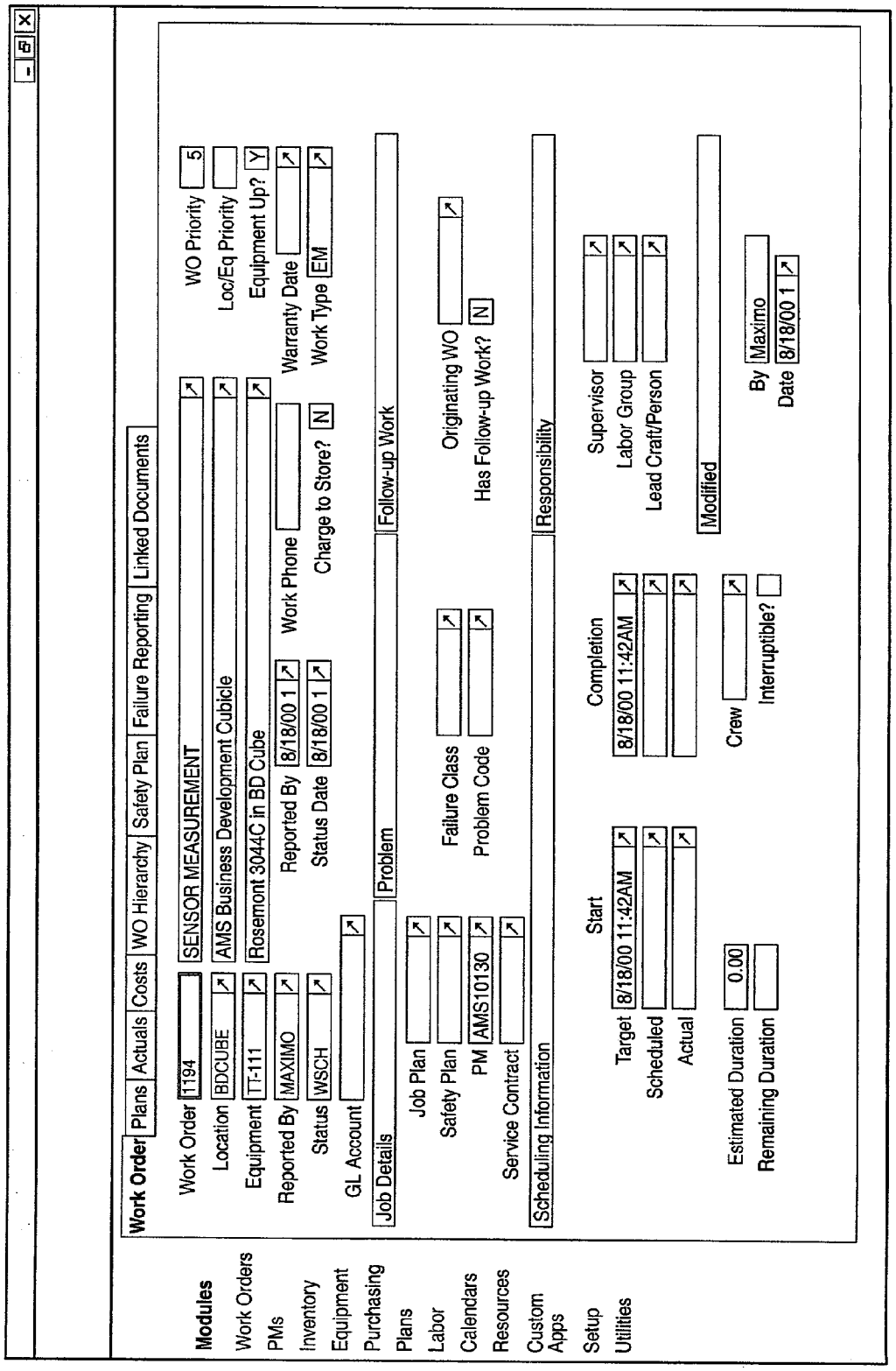

Modules
Work Orders
PMs
Inventory
Equipment
Purchasing
Plans
Labor
Calendars
Resources
Custom Apps
Setup
Utilities
Work Order
Plans
Actuals
Costs
WO Hierarchy
Safety Plan
Failure Reporting
Linked Documents
Work Order 1194
SENSOR MEASUREMENT
Location BDCUBE
AMS Business Development Cubicle
Equipment TT-111
Rosemont 3044C in BD Cube
Reported By MAXIMO
Reported By 8/18/00 1
Work Phone
Status WSCH
Status Date 8/18/00 1
Charge to Store? N
GL Account
WO Priority 5
Loc/Eq Priority
Equipment Up? Y
Warranty Date
Work Type EM
Job Details
Problem
Follow-up Work
Job Plan
Safety Plan
PM AMS10130
Service Contract
Failure Class
Problem Code
Originating WO
Has Follow-up Work? N
Scheduling Information
Responsibility
Start
Target 8/18/00 11:42AM
Scheduled
Actual
Completion
8/18/00 11:42AM
Estimated Duration 0.00
Remaining Duration
Crew
Interruptible?
Supervisor
Labor Group
Lead Craft/Person
Modified
By Maximo
Date 8/18/00 1

FIG. 27

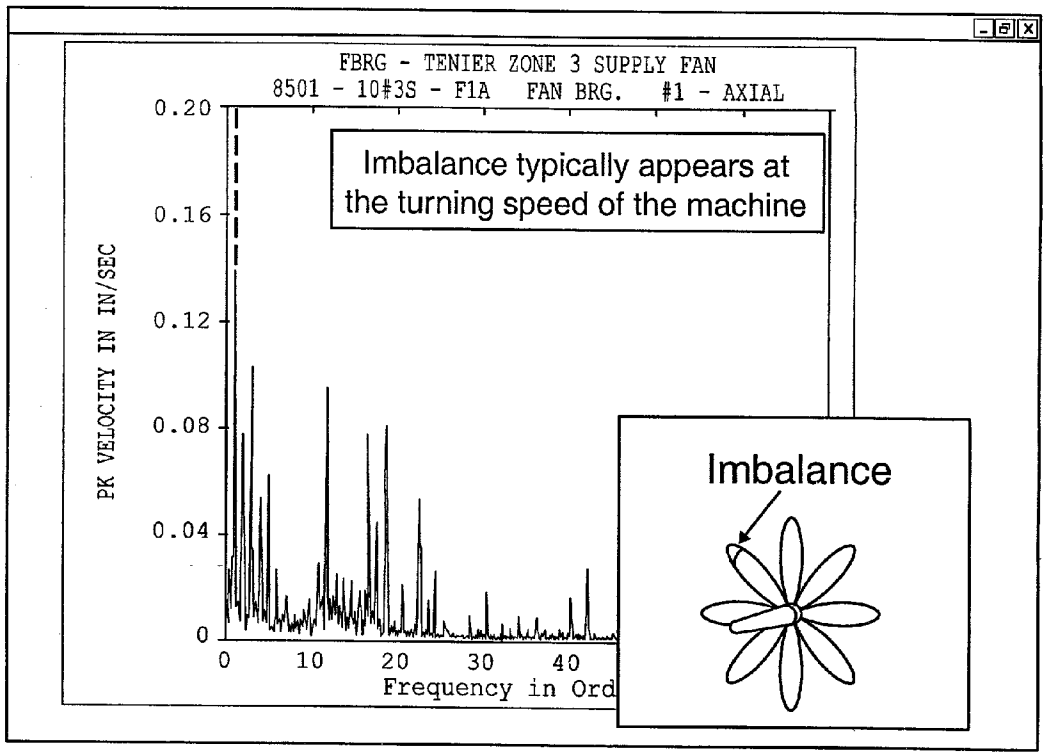

FBRG - TENIER ZONE 3 SUPPLY FAN
8501 - 10#3S - F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0 10 20 30 40
Frequency in Ord
Imbalance typically appears at the turning speed of the machine
Imbalance

FIG. 28

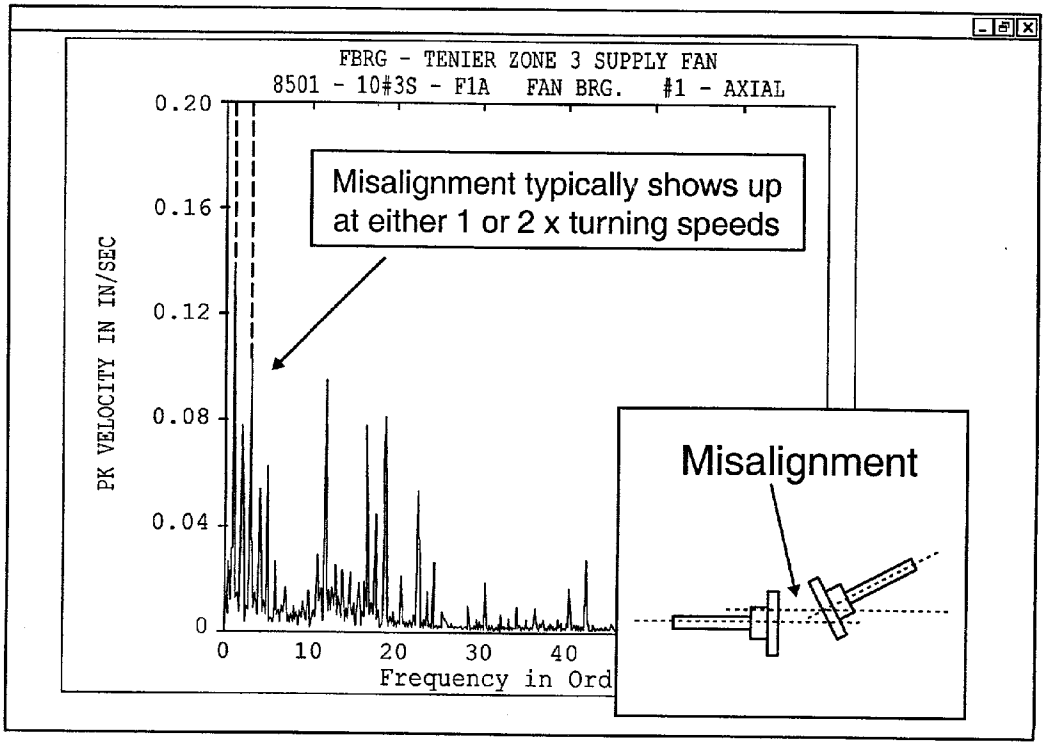

FBRG - TENIER ZONE 3 SUPPLY FAN
8501 - 10#3S - F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0 10 20 30 40
Frequency in Ord
Misalignment typically shows up at either 1 or 2 x turning speeds
Misalignment

FIG. 29

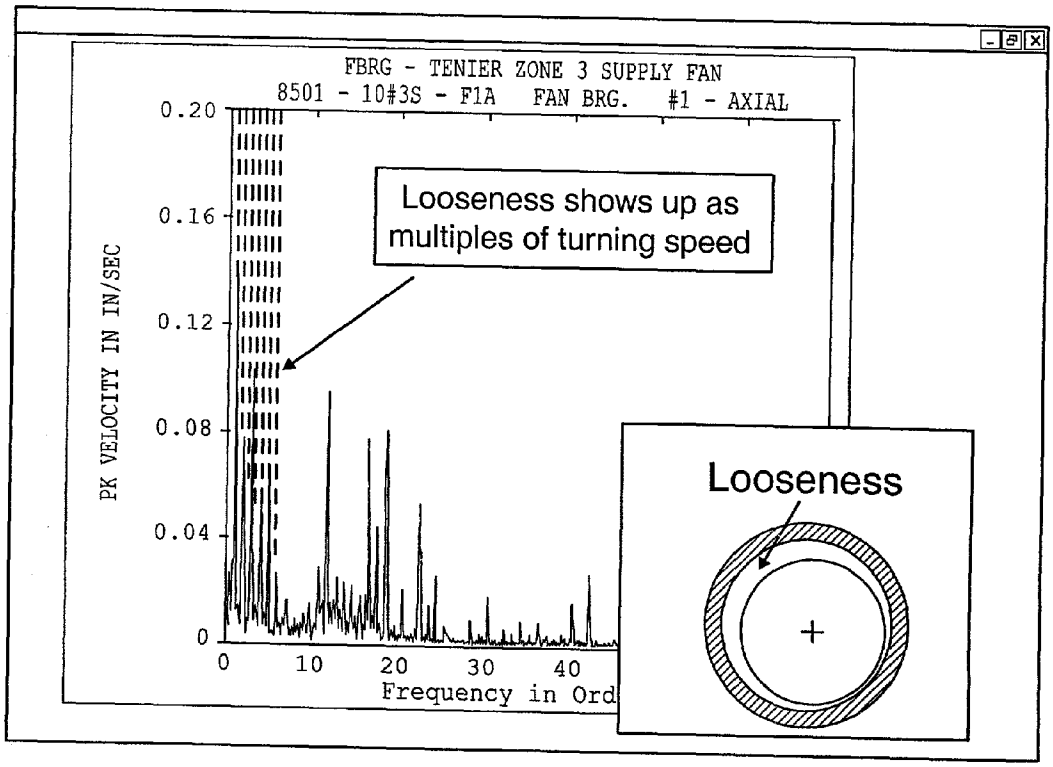

FBRG - TENIER ZONE 3 SUPPLY FAN
8501 - 10#3S - F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0
10
20
30
40
Frequency in Ord
Looseness shows up as multiples of turning speed
Looseness

FIG. 30

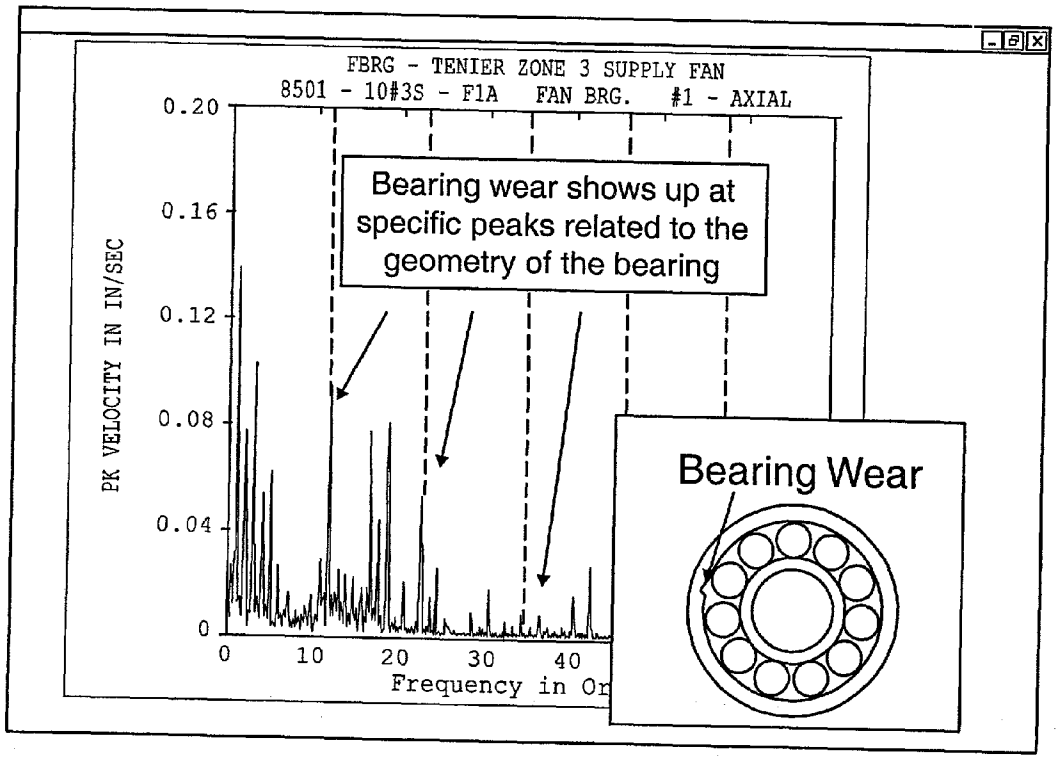

FBRG - TENIER ZONE 3 SUPPLY FAN
8501 - 10#3S - F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0
10
20
30
40
Frequency in Or
Bearing wear shows up at specific peaks related to the geometry of the bearing
Bearing Wear

FIG. 31

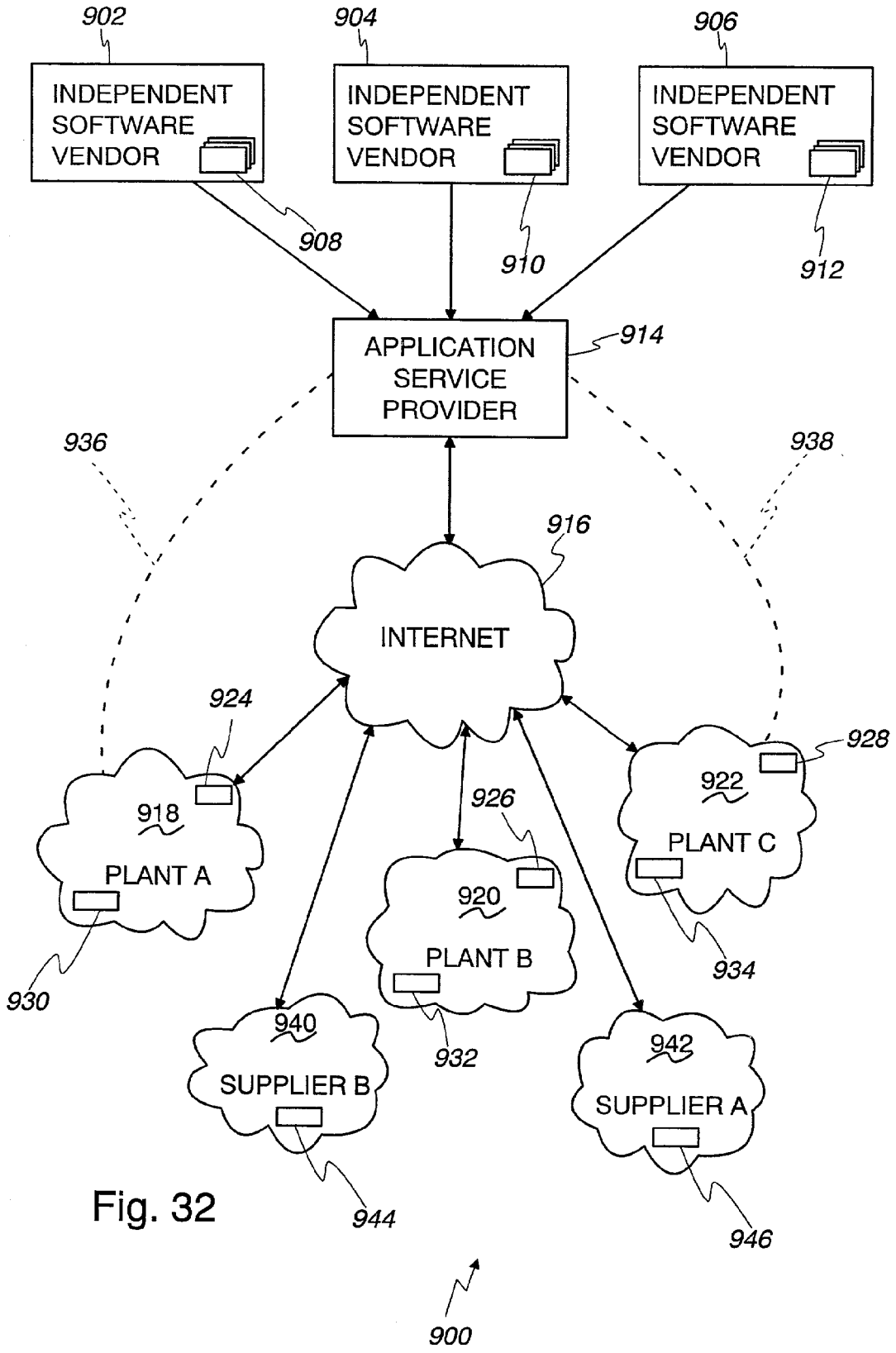

902
904
906
INDEPENDENT SOFTWARE VENDOR
INDEPENDENT SOFTWARE VENDOR
INDEPENDENT SOFTWARE VENDOR
908
910
912
APPLICATION SERVICE PROVIDER
914
936
938
916
INTERNET
924
928
918
PLANT A
926
922
PLANT C
920
PLANT B
930
934
940
SUPPLIER B
932
942
SUPPLIER A
944
946
900

Fig. 32

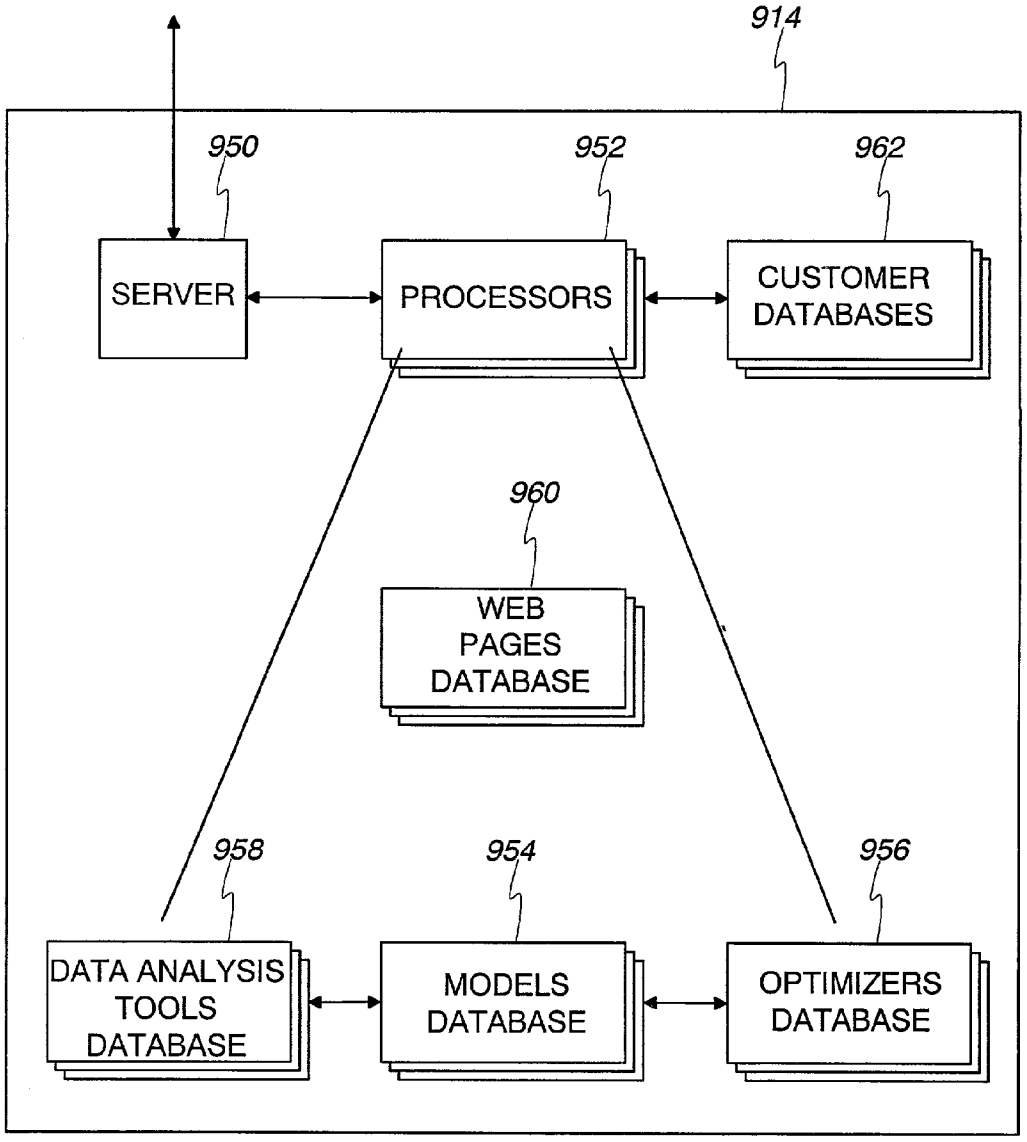

914
950
952
962
SERVER
PROCESSORS
CUSTOMER DATABASES
960
WEB PAGES DATABASE
958
954
956
DATA ANALYSIS TOOLS DATABASE
MODELS DATABASE
OPTIMIZERS DATABASE

Fig. 33

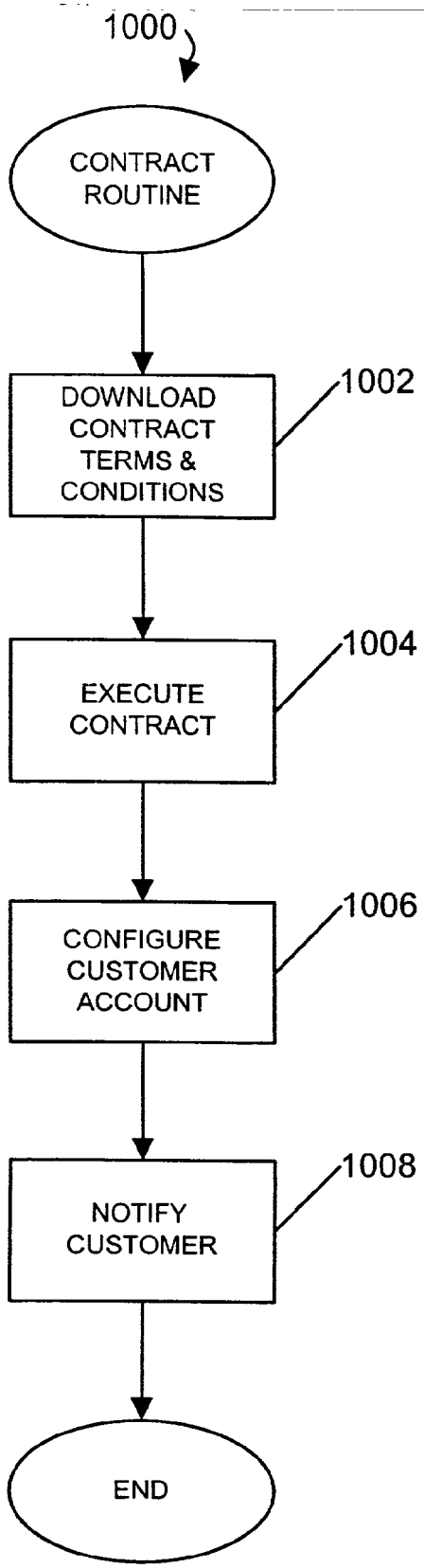

1000
CONTRACT ROUTINE
DOWNLOAD CONTRACT TERMS & CONDITIONS
1002
EXECUTE CONTRACT
1004
CONFIGURE CUSTOMER ACCOUNT
1006
NOTIFY CUSTOMER
1008
END

FIG. 34

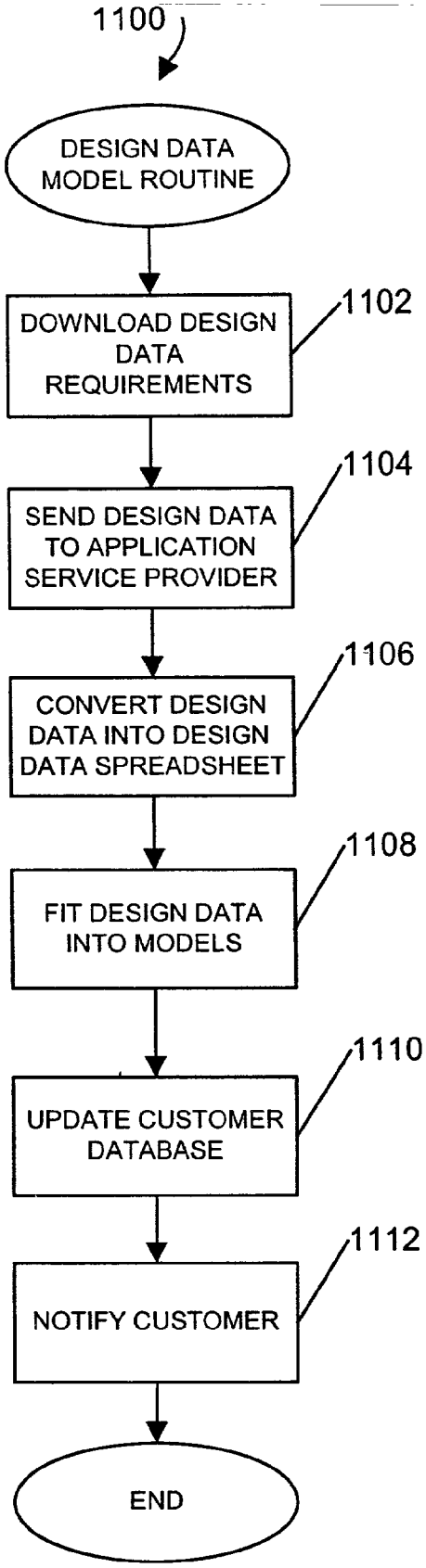

1100
DESIGN DATA MODEL ROUTINE
DOWNLOAD DESIGN DATA REQUIREMENTS
1102
SEND DESIGN DATA TO APPLICATION SERVICE PROVIDER
1104
CONVERT DESIGN DATA INTO DESIGN DATA SPREADSHEET
1106
FIT DESIGN DATA INTO MODELS
1108
UPDATE CUSTOMER DATABASE
1110
NOTIFY CUSTOMER
1112
END

FIG. 35

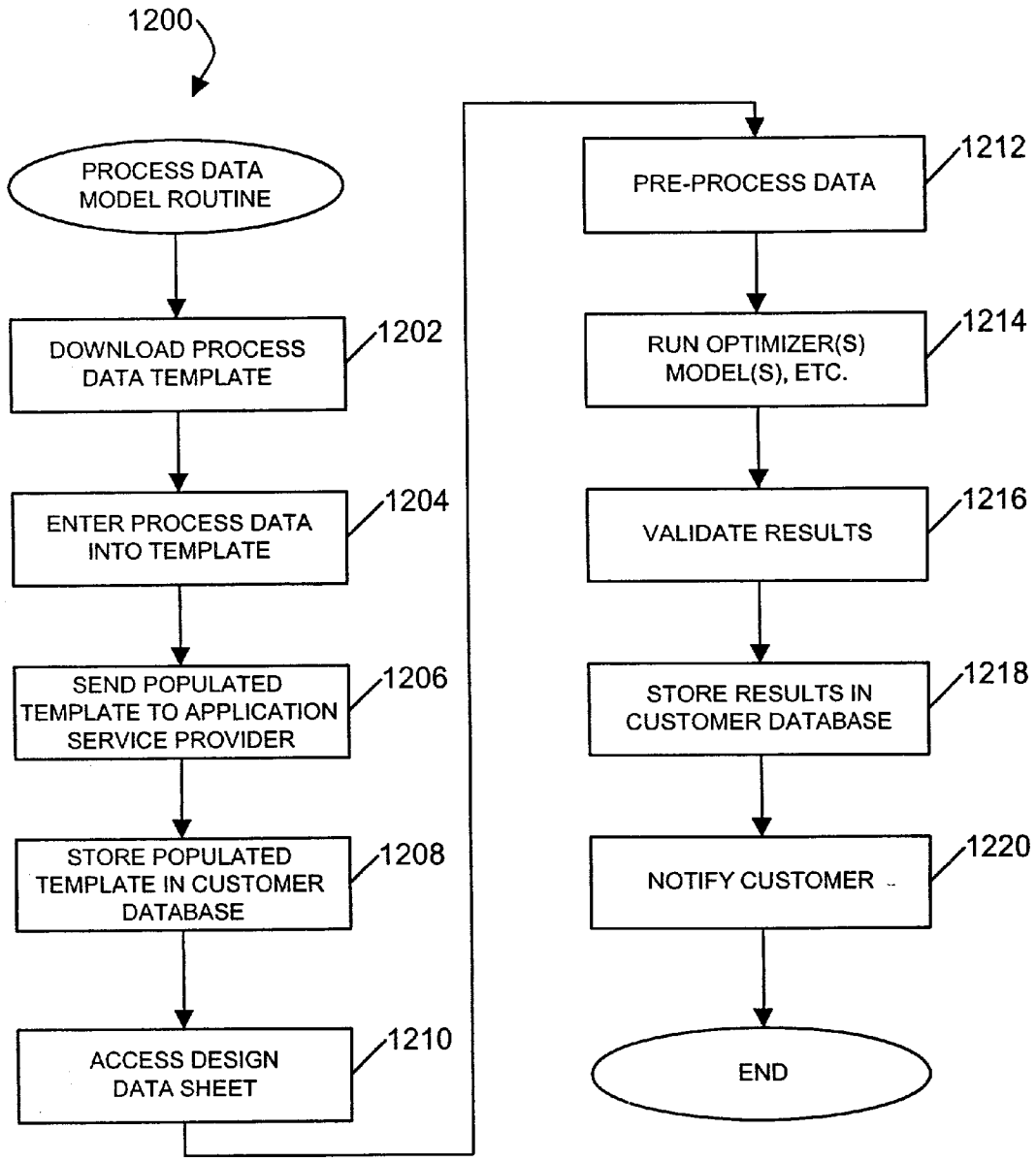
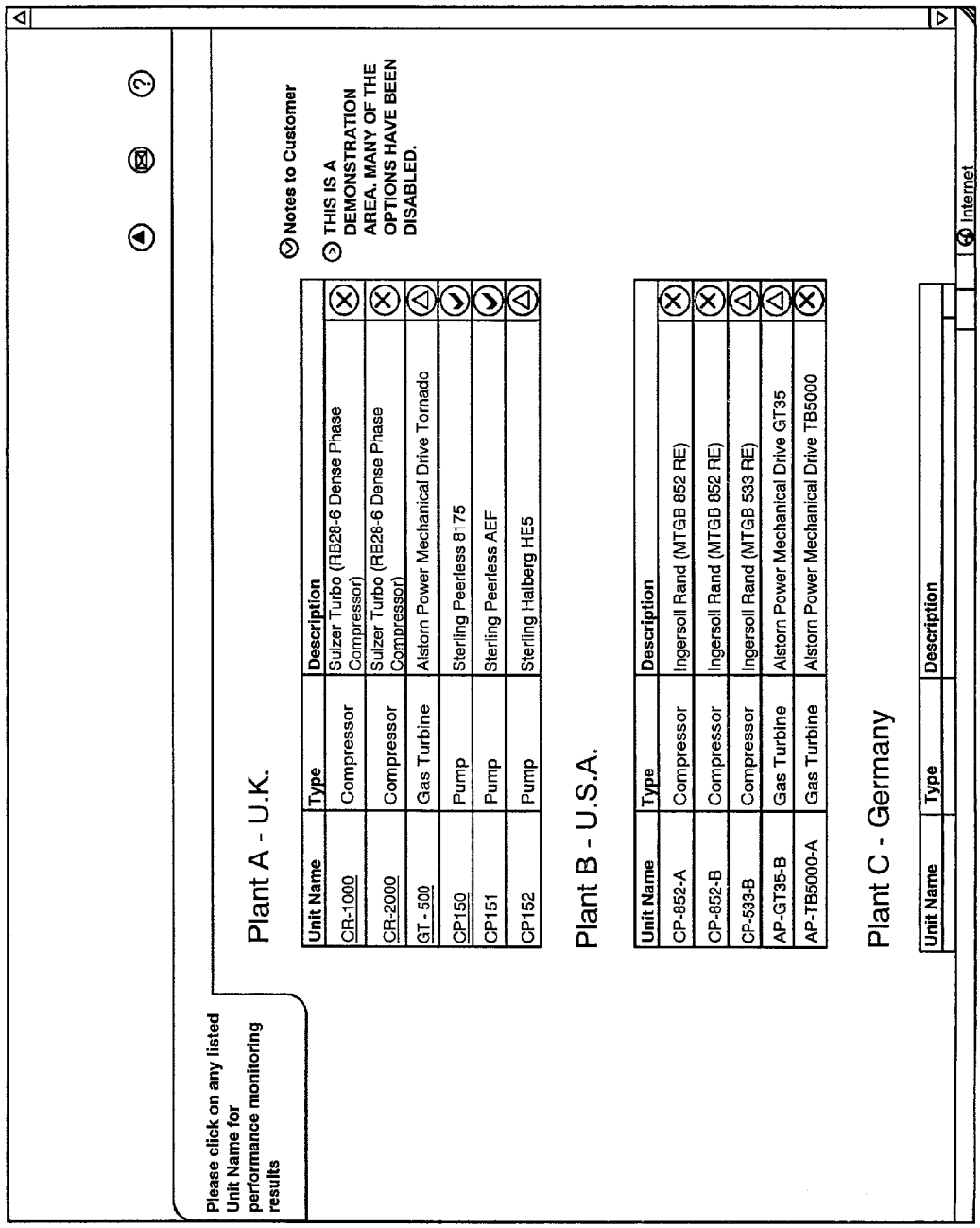

1200
PROCESS DATA MODEL ROUTINE
DOWNLOAD PROCESS DATA TEMPLATE
1202
ENTER PROCESS DATA INTO TEMPLATE
1204
SEND POPULATED TEMPLATE TO APPLICATION SERVICE PROVIDER
1206
STORE POPULATED TEMPLATE IN CUSTOMER DATABASE
1208
ACCESS DESIGN DATA SHEET
1210
PRE-PROCESS DATA
1212
RUN OPTIMIZER(S) MODEL(S), ETC.
1214
VALIDATE RESULTS
1216
STORE RESULTS IN CUSTOMER DATABASE
1218
NOTIFY CUSTOMER
1220
END

FIG. 36

Fig. 37


Please click on any listed Unit Name for performance monitoring results
Plant A - U.K.
Unit Name | Type | Description
CR-1000 | Compressor | Sulzer Turbo (RB28-6 Dense Phase Compressor)
CR-2000 | Compressor | Sulzer Turbo (RB28-6 Dense Phase Compressor)
GT - 500 | Gas Turbine | Alstorn Power Mechanical Drive Tornado
CP150 | Pump | Sterling Peerless B175
CP151 | Pump | Sterling Peerless AEF
CP152 | Pump | Sterling Halberg HE5
Plant B - U.S.A.
Unit Name | Type | Description
CP-852-A | Compressor | Ingersoll Rand (MTGB 852 RE)
CP-852-B | Compressor | Ingersoll Rand (MTGB 852 RE)
CP-533-B | Compressor | Ingersoll Rand (MTGB 533 RE)
AP-GT35-B | Gas Turbine | Alstorn Power Mechanical Drive GT35
AP-TB5000-A | Gas Turbine | Alstorn Power Mechanical Drive TB5000
Plant C - Germany
Unit Name | Type | Description
Notes to Customer
THIS IS A DEMONSTRATION AREA. MANY OF THE OPTIONS HAVE BEEN DISABLED.
Internet

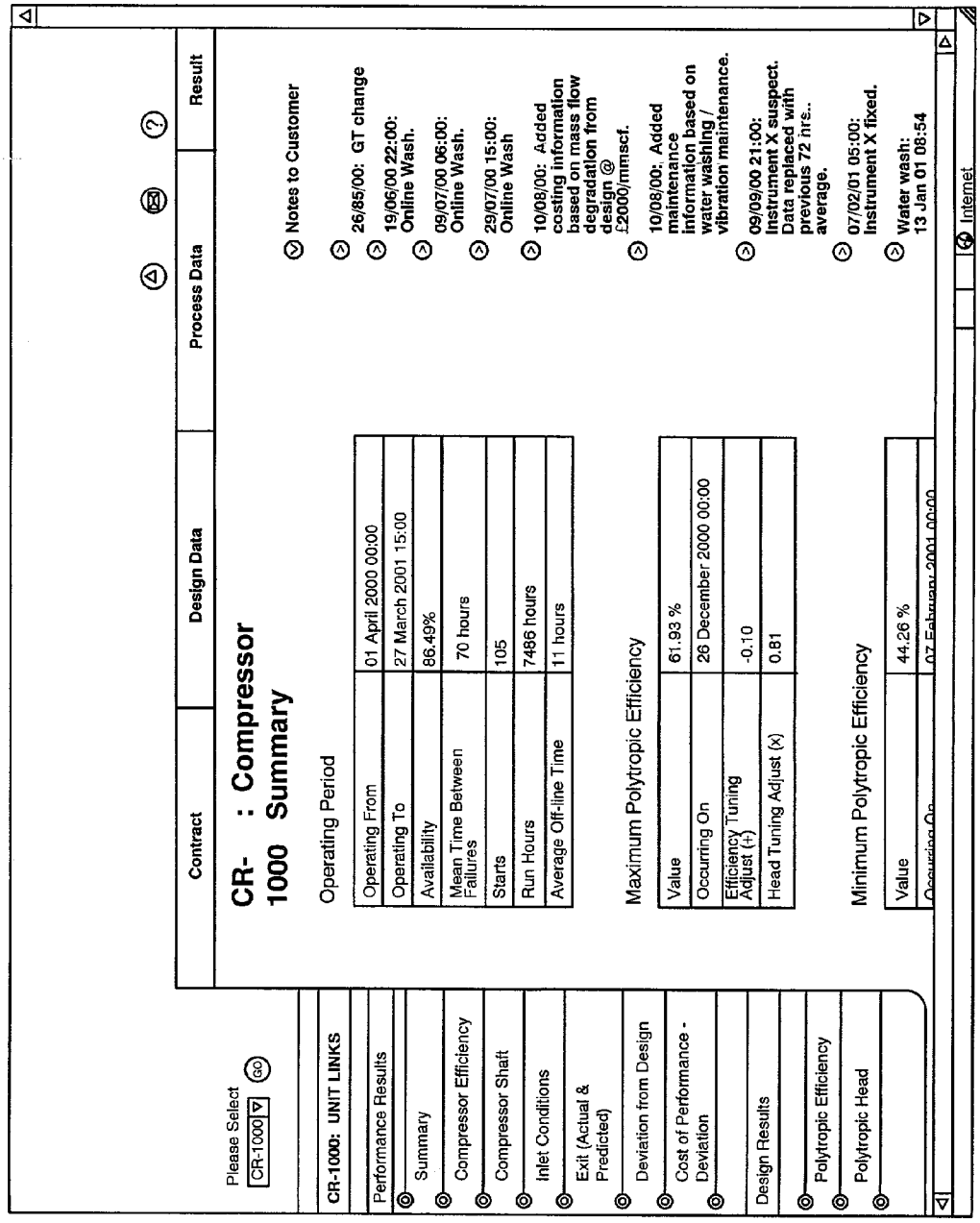
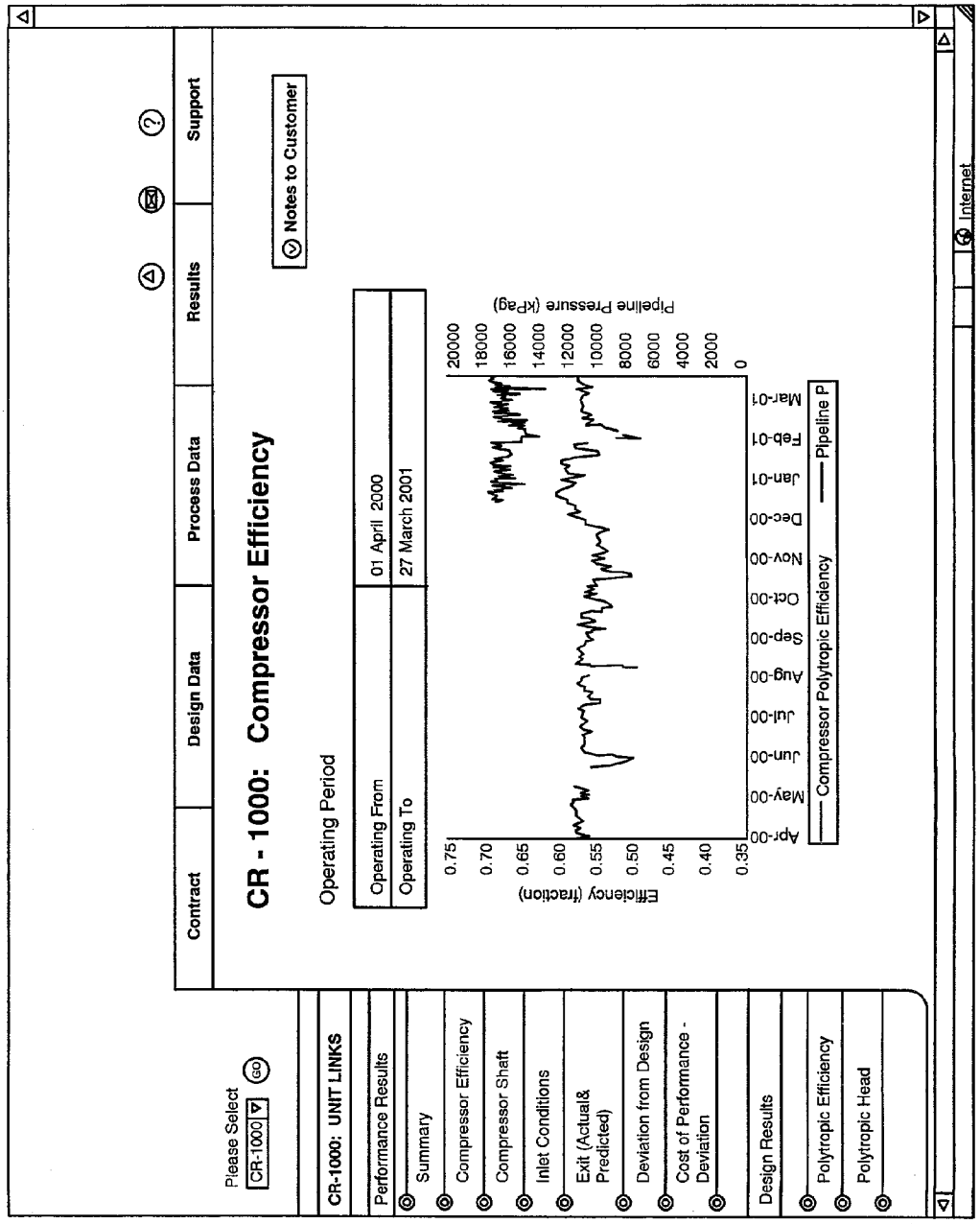

Please Select
CR-1000
GO
CR-1000: UNIT LINKS
Performance Results
Summary
Compressor Efficiency
Compressor Shaft
Inlet Conditions
Exit (Actual & Predicted)
Deviation from Design
Cost of Performance - Deviation
Design Results
Polytropic Efficiency
Polytropic Head
Contract
Design Data
Process Data
Result
CR-1000 : Compressor Summary
Operating Period
Operating From 01 April 2000 00:00
Operating To 27 March 2001 15:00
Availability 86.49%
Mean Time Between Failures 70 hours
Starts 105
Run Hours 7486 hours
Average Off-line Time 11 hours
Maximum Polytropic Efficiency
Value 61.93 %
Occurring On 26 December 2000 00:00
Efficiency Tuning Adjust (+) -0.10
Head Tuning Adjust (x) 0.81
Minimum Polytropic Efficiency
Value 44.26 %
Notes to Customer
26/85/00: GT change
19/06/00 22:00: Online Wash.
09/07/00 06:00: Online Wash.
29/07/00 15:00: Online Wash
10/08/00: Added costing information based on mass flow degradation from design @ £2000/mmscf.
10/08/00: Added maintenance information based on water washing / vibration maintenance.
09/09/00 21:00: Instrument X suspect. Data replaced with previous 72 hrs.. average.
07/02/01 05:00: Instrument X fixed.
Water wash: 13 Jan 01 08:54
Internet

Fig. 38

Fig. 39


Please Select
CR-1000
GO
Contract
Design Data
Process Data
Results
Support
CR-1000: UNIT LINKS
Performance Results
Summary
Compressor Efficiency
Compressor Shaft
Inlet Conditions
Exit (Actual& Predicted)
Deviation from Design
Cost of Performance - Deviation
Design Results
Polytropic Efficiency
Polytropic Head
CR - 1000: Compressor Efficiency
Notes to Customer
Operating Period
Operating From
01 April 2000
Operating To
27 March 2001
Efficiency (fraction)
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
Pipeline Pressure (kPag)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Jan-01
Feb-01
Mar-01
Compressor Polytropic Efficiency
Pipeline P
Internet

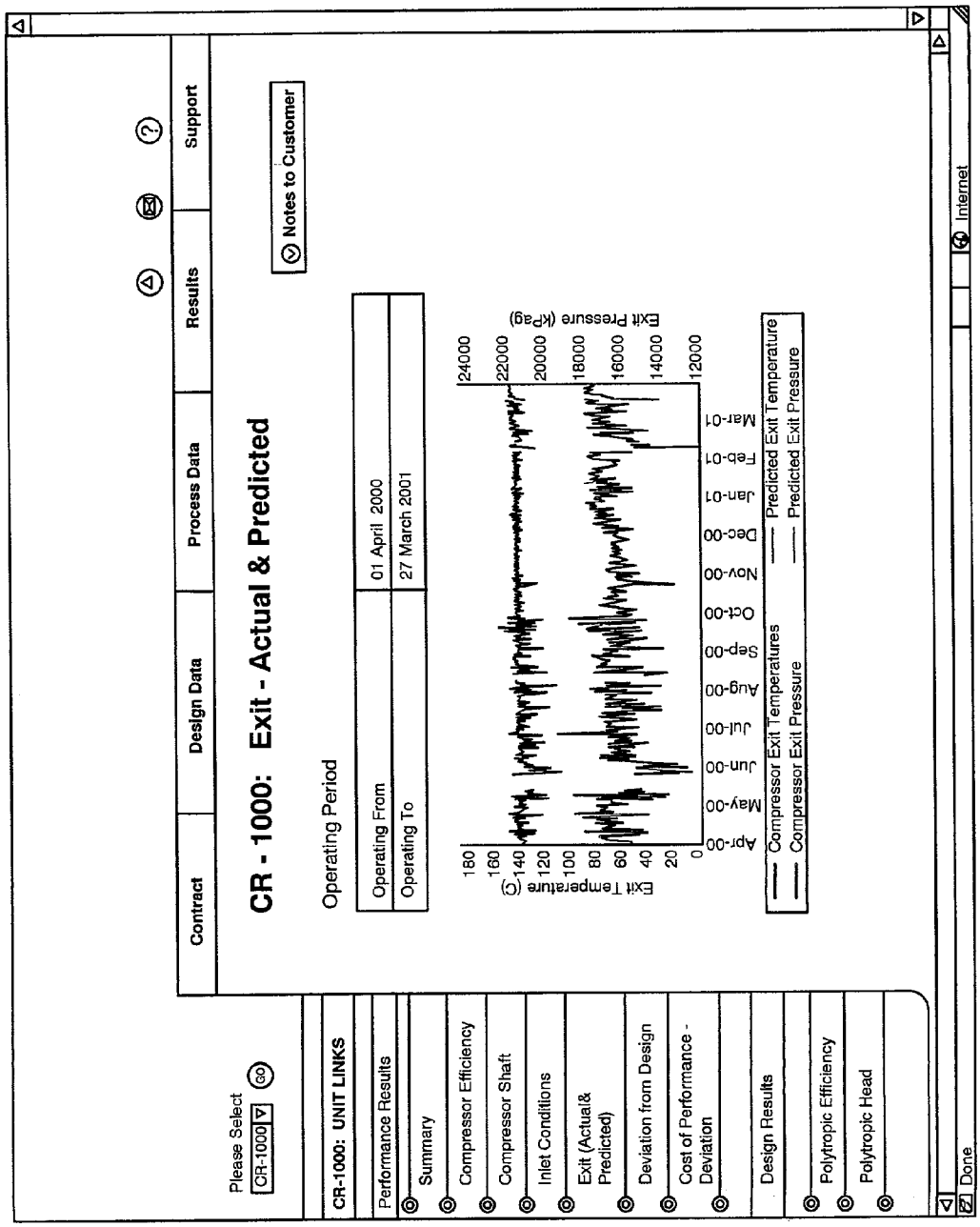
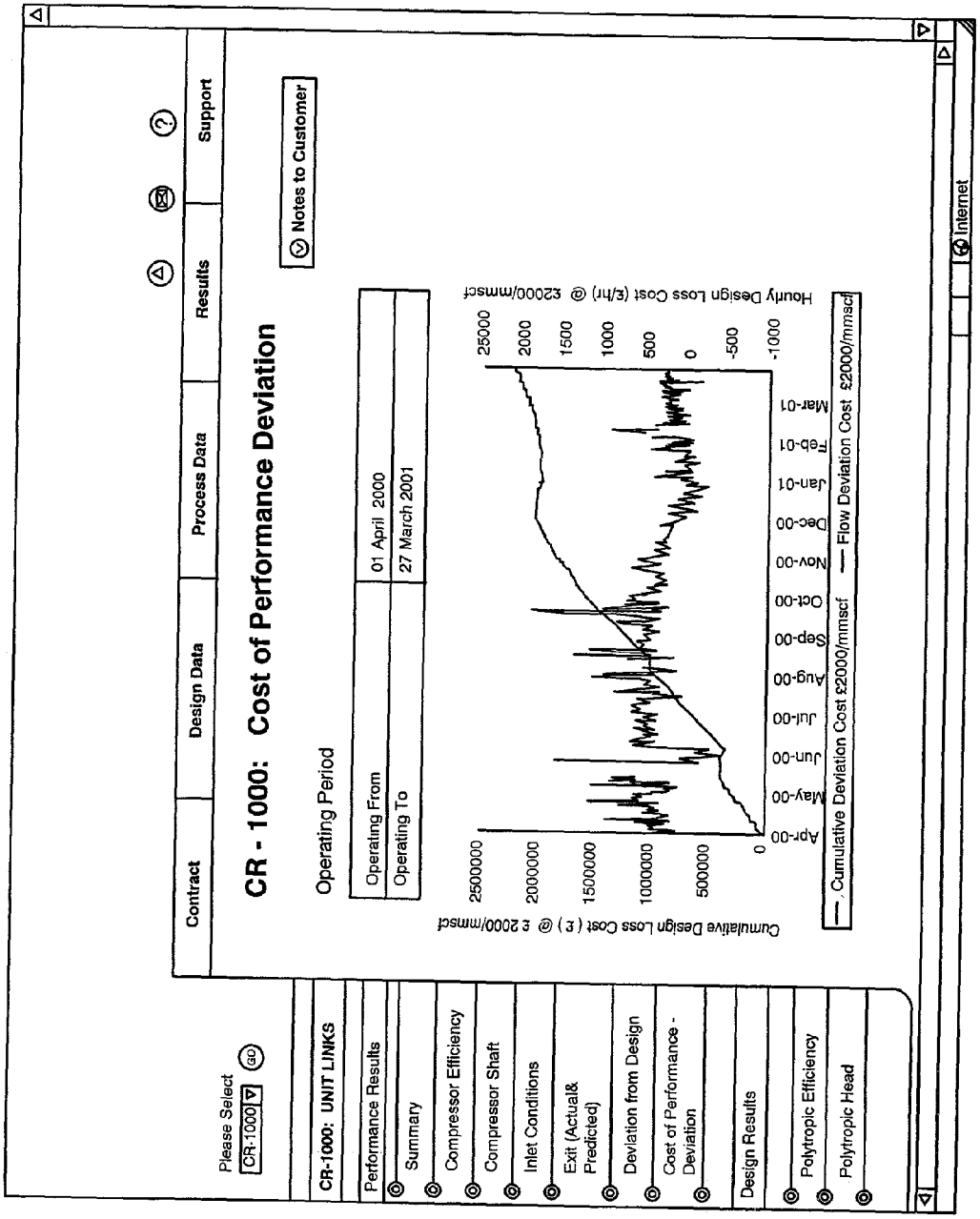

Please Select
CR-1000
GO
Contract
Design Data
Process Data
Results
Support
CR-1000: UNIT LINKS
Performance Results
Summary
Compressor Efficiency
Compressor Shaft
Inlet Conditions
Exit (Actual& Predicted)
Deviation from Design
Cost of Performance - Deviation
Design Results
Polytropic Efficiency
Polytropic Head
CR - 1000: Exit - Actual & Predicted
Notes to Customer
Operating Period
Operating From
01 April 2000
Operating To
27 March 2001
Exit Temperature (C)
Exit Pressure (kPag)
Compressor Exit Temperatures
Compressor Exit Pressure
Predicted Exit Temperature
Predicted Exit Pressure
Done
Internet

Fig. 40

Fig. 41


Please Select
CR-1000
go
Contract
Design Data
Process Data
Results
Support
CR-1000: UNIT LINKS
Performance Results
Summary
Compressor Efficiency
Compressor Shaft
Inlet Conditions
Exit (Actual& Predicted)
Deviation from Design
Cost of Performance - Deviation
Design Results
Polytropic Efficiency
Polytropic Head
CR - 1000: Cost of Performance Deviation
Notes to Customer
Operating Period
Operating From
01 April 2000
Operating To
27 March 2001
Cumulative Design Loss Cost (£) @ £ 2000/mmscf
2500000
2000000
1500000
1000000
500000
0
Hourly Design Loss Cost (£/hr) @ £2000/mmscf
25000
2000
1500
1000
500
0
-500
-1000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Jan-01
Feb-01
Mar-01
Cumulative Deviation Cost £2000/mmscf
Flow Deviation Cost £2000/mmscf
Internet

REMOTE ANALYSIS OF PROCESS CONTROL PLANT DATA

RELATED APPLICATION

[0001] This application claims the benefit of the filing date of Provisional U.S. Patent Application No. 60/273,164 entitled "Asset Utilization Expert in a Process Control Plant" filed on Mar. 1, 2001.

FIELD OF THE INVENTION

[0002] The present invention relates generally to process control systems within process plants and, more particularly, to the use of asset or process analysis tools by a remote processing facility to analyze process control plant data.

DESCRIPTION OF THE RELATED ART

[0003] Process control systems, like those used in chemical, petroleum or other processes, typically include one or more centralized or decentralized process controllers communicatively coupled to at least one host or operator workstation and to one or more process control and instrumentation devices, such as field devices, via analog, digital or combined analog/digital buses. Field devices, which may be, for example valves, valve positioners, switches, transmitters, and sensors (e.g., temperature, pressure and flow rate sensors), perform functions within the process such as opening or closing valves and measuring process parameters. The process controller receives signals indicative of process measurements or process variables made by or associated with the field devices and/or other information pertaining to the field devices, uses this information to implement a control routine and then generates control signals which are sent over one or more of the buses to the field devices to control the operation of the process. Information from the field devices and the controller is typically made available to one or more applications executed by an operator workstation to enable an operator to perform desired functions with respect to the process, such as viewing the current state of the process, modifying the operation of the process, etc.

[0004] While a typical process control system has many process control and instrumentation devices, such as valves, transmitters, sensors, etc. connected to one or more process controllers which execute software that controls these devices during the operation of the process, there are many other supporting devices that are also necessary for or related to process operation. These additional devices include, for example, power supply equipment, power generation and distribution equipment, rotating equipment such as turbines, etc., all of which are typically distributed throughout a plant. While this additional equipment does not necessarily create or use process variables and in many instances is not controlled or even coupled to a process controller for the purpose of affecting the process operation, this equipment is nevertheless important to and is ultimately necessary for proper operation of the process. In the past, process controllers were typically not aware of these other devices or the process controllers simply assumed that these devices were operating properly when performing process control.

[0005] Still further, many process plants have other computers that execute applications related to business functions or maintenance functions. For example, some plants include computers that execute applications associated with ordering raw materials, replacement parts or devices for the plant, applications related to forecasting sales and production needs, etc. Likewise, many process plants, and especially those that use smart field devices, include applications which are used to help monitor and maintain the devices within the plant, regardless of whether these devices are process control and instrumentation devices or are other types of devices. For example, the Asset Management Solutions (AMS) application sold by Fisher-Rosemount Systems, Inc. enables communication with and stores data pertaining to field devices to ascertain and track the operating state of the field devices. An example of such a system is disclosed in U.S. Pat. No. 5,960,214 entitled "Integrated Communication Network for use in a Field Device Management System." In some instances, the AMS application may be used to communicate with devices to change parameters within the device, to cause the device to run applications on itself, such as self calibration routines or self diagnostic routines, to obtain information about the status or health of the device, etc. This information may be stored and used by a maintenance person to monitor and maintain these devices. Likewise, there are other types of applications that are used to monitor other types of devices, such as rotating equipment and power generation and power supply devices. These other applications are typically available to the maintenance persons and are used to monitor and maintain the devices within a process plant.

[0006] However, in the typical plant or process, the functions associated with the process control activities, the device and equipment maintenance and monitoring activities, and the business activities are separated, both in the location in which these activities take place and in the personnel who typically perform these activities. Furthermore, the different people involved in these different functions generally use different tools, such as different applications run on different computers to perform the different functions. In many instances, these different tools collect or use different types of data associated with or collected from the different devices within the process and are set up differently to collect the data they need. For example, process control operators who generally oversee the day to day operation of the process and who are primarily responsible for assuring the quality and continuity of the process operation typically affect the process by setting and changing set points within the process, tuning loops of the process, scheduling process operations such as batch operations, etc. These process control operators may use available tools for diagnosing and correcting process control problems within a process control system, including, for example, auto-tuners, loop analyzers, neural network systems, etc. Process control operators also receive process variable information from the process via one or more process controllers which provide information to the operators about the operation of the process, including alarms generated within the process. This information may be provided to the process control operator via a standard user interface.

[0007] Still further, it is currently known to provide an expert engine that uses process control variables and limited information about the operating condition of the control routines or function blocks or modules associated with process control routines to detect poorly operating loops and to provide information to an operator about suggested

courses of action to correct the problem. Such an expert engine is disclosed in U.S. patent application Ser. No. 09/256,585 entitled "Diagnostics in a Process Control System," which was filed on Feb. 22, 1999 and in U.S. patent application Ser. No. 09/499,445 entitled "Diagnostic Expert in a Process Control System," which was filed on Feb. 7, 2000, both of which are hereby expressly incorporated by reference herein. Likewise, it is known to run control optimizers, such as real time optimizers, within a plant to optimize the control activities of the process plant. Such optimizers typically use complex models of the plant to predict how inputs may be changed to optimize operation of the plant with respect to some desired optimization variable such as, for example, profit.

[0008] On the other hand, maintenance personnel who are primarily responsible for assuring that the actual equipment within the process is operating efficiently and for repairing and replacing malfunctioning equipment, use tools such as maintenance interfaces, the AMS application discussed above, as well and many other diagnostic tools that provide information about operating states of the devices within the process. Maintenance persons also schedule maintenance activities that may require shut down of portions of the plant. For many newer types of process devices and equipment, which are generally smart field devices, the devices themselves may include detection and diagnostic tools that automatically sense problems with the operation of the device and automatically report these problems to a maintenance person via a standard maintenance interface. For example, the AMS software reports device status and diagnostic information to the maintenance person and provides communication and other tools that enable the maintenance person to determine what is happening in devices and to access device information provided by devices. Typically, maintenance interfaces and maintenance personnel are located apart from process control operators, although this is not always the case. For example, in some process plants, process control operators may perform the duties of maintenance persons or vice versa, or the different people responsible for these functions may use the same interface.

[0009] Still further, persons responsible for applications used for business applications, such as ordering parts, supplies, raw materials, etc., making strategic business decisions such as choosing which products to manufacture, what variables to optimize within the plant, etc. are typically located in offices of the plant that are remote from both the process control interfaces and the maintenance interfaces. Likewise, managers or other persons may want to have access to certain information within the process plant from remote locations or from other computer systems associated with the process plant for use in overseeing the plant operation and in making long term strategic decisions.

[0010] Because, substantially different applications are used to perform the different functions within a plant, e.g., process control operations, maintenance operations and business operations are separated, the different applications used for these different tasks are not integrated and, thus, do not share data or information. In fact, many plants only include some, but not all, of these different types of applications. Furthermore, even if all of the applications are located within a plant, because different personnel use these different applications and analysis tools and because these tools are generally located at different hardware locations within the plant, there is little if any flow of information from one functional area of the plant to another, even when this information may be useful to other functions within the plant. For example, a tool, such as a rotating equipment data analysis tool, may be used by a maintenance person to detect a poorly functioning power generator or piece of rotating equipment (based on non-process variable type data). This tool may detect a problem and alert the maintenance person that the device needs to be calibrated, repaired or replaced. However, the process control operator (either a human or a software expert) does not have the benefit of this information, even though the poorly operating device may be causing a problem that is affecting a loop or some other component which is being monitored by the process control operation. Likewise, the business person is not aware of this fact, even though the malfunctioning device may be critical to and may be preventing optimization of the plant in a manner that the business person desires. Because the process control expert is unaware of a device problem that may be ultimately causing poor performance of a loop or unit in the process control system and because the process control operator or expert assumes that this equipment is operating perfectly, the process control expert may misdiagnose the problem it detects within the process control loop or may try to apply a tool, such as a loop tuner, which could never correct the problem. Likewise, the business person may make a business decision to run the plant in a manner that will not achieve the desired business effects (such as optimizing profits) because of the malfunctioning device.

[0011] Due to the abundance of data analysis and other detection and diagnostic tools available in the process control environment, there is a lot of information pertaining to the health and performance of devices available to the maintenance person that could be helpful to process operators and business persons. Similarly, there is a lot of information available to process operators about the current operational status of the process control loops and other routines that may be helpful to maintenance persons or to business persons. Likewise, there is information generated by or used in the course of performing the business functions that could be helpful to maintenance persons or process control operators in optimizing the operation of the process. However, in the past, because these functions were separated the information generated or collected in one functional area was not used at all, or not used very well, in other functional areas, resulting in a sub-optimal use of the assets within process plants.

[0012] Furthermore, legal pressures such as, for example, increased environmental regulation and increased competition has caused improved efficiency of the process control activities within a plant to become a significant source of profit improvement. While a variety of data analysis tools such as optimization software, maintenance software, and a variety of other well known asset management methods, tools or software such as those described above are widely used within process control plants, supporting such methods, tools and software often result in a substantial cost to the plant owner.

[0013] More specifically, the efficient operation of a plant depends strongly on the condition of the equipment within the plant and the timing of maintenance on that equipment. Traditionally, equipment performance monitoring tools such as, for example, input/output algorithms, models, etc. have

been used to determine how efficiently a plant is running and/or whether a more cost effective process can be achieved through changes in maintenance procedures, replacement of worn equipment, modification of equipment, etc. Unfortunately, equipment performance monitoring requires significant expenditures for hardware and software (e.g., data analysis tools) and also typically requires skilled technicians and other specialists to support and oversee the daily performance monitoring activities. Many plant owners and operators have recognized that the high costs associated with equipment performance monitoring activities has become an important area for competitive cost reductions, particularly in the case of smaller plant operations for which economies of scale dictate greater focus on core competencies.

SUMMARY OF THE INVENTION

[0014] In accordance with one aspect of the invention, a system and method for analyzing a process collects process data within a process control plant and transmits the collected process data to a remote data processing facility. The remote data processing facility may analyze the process data to generate analysis data using one of a plurality asset or process analysis tools stored within a database of the remote data processing facility. The analysis data may then be transmitted to the process control plant.

[0015] The system and method may analyze the process data within the remote data processing facility using one of a process control tool, a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and an accounting tool. Additionally, the system and method may transmit the collected process data to the remote data processing facility via an open network.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] **FIG. 1** is an exemplary block diagram of a process control plant having an asset utilization expert configured to receive and coordinate data transfer between many functional areas of the plant;

[0017] **FIG. 2** is an exemplary data and information flow diagram with respect to the asset utilization expert within the plant of **FIG. 1**;

[0018] **FIG. 3** is an exemplary block diagram of a model used to simulate the operation of an area within a plant;

[0019] **FIG. 4** is an exemplary block diagram of a model used to simulate the operation of a unit within the area model of **FIG. 3**;

[0020] **FIG. 5** is an exemplary two-dimensional performance monitoring diagram;

[0021] **FIG. 6** is a graph illustrating an exemplary fiducial line chosen for use in a furnace and a coking rate based on this fiducial line;

[0022] **FIG. 7** is a graph illustrating the development of a new coking rate based on the fiducial line of **FIG. 6**;

[0023] **FIG. 8** is an exemplary depiction of a display representing a unit within a process control system that may be displayed by a graphical user interface;

[0024] **FIG. 9** is an exemplary table that illustrates one manner in which indexes may be generated for different levels of a system hierarchy;

[0025] **FIG. 10** is an exemplary chart depicting one manner in which a performance index for a unit may be calculated;

[0026] **FIG. 11** is an exemplary table that illustrates one manner in which index values may be used to calculate a new index value as a weighted average of the index values;

[0027] **FIG. 12** is an exemplary table that illustrates one manner in which a variability index may be calculated for a unit;

[0028] **FIG. 13** is an exemplary display that may be provided by a graphical user interface in response to an abnormal variability index;

[0029] **FIG. 14** is an exemplary display of the data used to generate a variability index;

[0030] **FIG. 15** is an exemplary graphical depiction of a display that may be provided by a graphical user interface to enable a user to monitor indexes associated with a portion of a plant;

[0031] **FIG. 16** is an exemplary graphical display that may be provided by a graphical user interface to enable a user to analyze the operational status and performance of a process area within a plant;

[0032] **FIG. 17** is an exemplary depiction of a display that may be provided by a graphical user interface to enable a user to view audit trail information;

[0033] **FIG. 18** is an exemplary depiction of a display that may be provided by a graphical user interface to enable a user to perform a more detailed analysis of data used to generate one or more indexes for a device;

[0034] **FIG. 19** is an exemplary depiction of a display that may be provided by a graphical user interface to enable a user to graphically view or monitor a performance characteristic of a device;

[0035] **FIG. 20** is yet another exemplary depiction of a display that may be provided by a graphical user interface to enable a user to quickly investigate information within a plant;

[0036] FIGS. **21-23** are exemplary pop-up windows that may be displayed by a graphical user interface to provide device status information;

[0037] **FIG. 24** is an exemplary display that may be provided by a graphical user interface to give detailed help information to a user;

[0038] **FIG. 25** is an exemplary depiction of a display that may be provided by a graphical user interface to enable a user to diagnose loop-related problems;

[0039] **FIG. 26** is yet another exemplary depiction of a display that may be provided by a graphical user interface that enables a user to analyze the performance and/or status of one or more process control loops;

[0040] **FIG. 27** is still another exemplary depiction of a display that may be provided by a graphical user interface to enable a user to track or generate work orders;

[0041] FIGS. **28-31** are exemplary displays depicting spectral plots of vibration of an element within a rotary device;

[0042] **FIG. 32** is a schematic block diagram of a system that enables one or more independently operable process control plants to remotely access models, optimizers and other data analysis tools;

[0043] **FIG. 33** is a more detailed schematic block diagram of the application service provider shown in **FIG. 32**;

[0044] **FIG. 34** is an exemplary flow diagram that illustrates a routine that may be used by a process control plant to establish a business relationship with the application service provider shown in **FIGS. 32 and 33**;

[0045] **FIG. 35** is an exemplary flow diagram of a routine that may be used by the application service provider shown in **FIGS. 32 and 33** to design a data model for a plant;

[0046] **FIG. 36** is an exemplary flow diagram of a routine that may be used by the application service provider shown in **FIGS. 32 and 33** to process and/or analyze process control data; and

[0047] FIGS. **37-41** are exemplary web pages containing analysis results that may be displayed to a customer using the system shown **FIG. 32**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0048] Referring now to **FIG. 1, a** process control plant **10** includes a number of business and other computer systems interconnected with a number of control and maintenance systems by one or more communication networks. The process control plant **10** includes one or more process control systems **12** and **14**. The process control system **12** may be a traditional process control system such as a PROVOX or RS3 system or any other DCS that includes an operator interface **12**A coupled to a controller **12**B and to input/output (I/O) cards **12**C which, in turn, are coupled to various field devices such as analog and Highway Addressable Remote Transmitter (HART) field devices **15**. The process control system **14**, which may be a distributed process control system, includes one or more operator interfaces **14**A coupled to one or more distributed controllers **14**B via a bus, such as an Ethernet bus. The controllers **14**B may be, for example, DeltaV™ controllers sold by Fisher-Rosemount Systems, Inc. of Austin, Tex. or any other desired type of controllers. The controllers **14**B are connected via I/O devices to one or more field devices **16**, such as for example, HART or Fieldbus field devices or any other smart or non-smart field devices including, for example, field devices that use any of the PROFIBUS®, WORLD-FIP®, Device-Net®, AS-Interface and CAN protocols. As is known, the field devices **16** may provide analog or digital information to the controllers **14**B related to process variables as well as to other device information. The operator interfaces **14**A may store and execute tools available to the process control operator for controlling the operation of the process including, for example, control optimizers, diagnostic experts, neural networks, tuners, etc.

[0049] Still further, maintenance systems, such as computers executing the AMS application or any other device monitoring and communication applications may be connected to the process control systems **12** and **14** or to the individual devices therein to perform maintenance and monitoring activities. For example, a maintenance computer **18** may be connected to the controller **12**B and/or to the devices **15** via any desired communication lines or networks (including wireless or handheld device networks) to communicate with and, in some instances, reconfigure or perform other maintenance activities on the devices **15**. Similarly, maintenance applications such as the AMS application may be installed in and executed by one or more of the user interfaces **14**A associated with the distributed process control system **14** to perform maintenance and monitoring functions, including data collection related to the operating status of the devices **16**.

[0050] The process control plant **10** also includes rotating equipment **20**, such as turbines, motors, etc. that are connected to a maintenance computer **22** via a permanent or temporary communication link (such as a bus, a wireless communication system or hand held devices that are connected to the equipment **20** to take readings and which are then removed). The maintenance computer **22** may store and execute known monitoring and diagnostic applications **23** provided by, for example, CSi Systems or other any other known applications used to diagnose, monitor and optimize the operating state of the rotating equipment **20**. Maintenance personnel usually use the diagnostic applications **23** to maintain and oversee the performance of the rotating equipment **20** to determine problems with the rotating equipment **20** and to determine when and if the rotating equipment **20** must be repaired or replaced.

[0051] Similarly, a power generation and distribution system **24** having power generating and distribution equipment **25** associated with the plant **10** is connected via, for example, a bus, to another computer **26** that runs and oversees the operation of the power generating and distribution equipment **25**. The computer **26** may execute known power control and diagnostics applications **27** such as those provided by, for example, Liebert, ASCO or any other company to control and maintain the power generation and distribution equipment **25**.

[0052] In the past, the various process control systems **12** and **14** and the power generating and maintenance systems **22** and **26** have not been interconnected with in a manner that enables these systems to share data generated in or collected by each of these systems in a useful manner. As a result, each of the different functions such as process control functions, power generation functions and rotating equipment functions have operated on the assumption that the other equipment within the plant, which may be affected by or have an affect on that particular function, is operating perfectly which, of course, is almost never the case. However, because the functions are so different and because the equipment and personnel that oversee these functions are different, there has been little or no meaningful data sharing between the different functional systems within the plant **10**.

[0053] To overcome this problem, a computer system **30** is provided that is communicatively connected to the computers or interfaces associated with the various functional systems within the plant **10**, including the process control functions **12** and **14**, the maintenance functions, such as those implemented in the computers **18**, **14**A, **22** and **26** and the business functions. In particular, the computer system **30** is communicatively connected to the traditional process control system **12** and to the maintenance interface **18** associated with the control system **12**, is connected to the process control and/or maintenance interfaces **14**A of the

distributed process control system **14**, is connected to the rotating equipment maintenance computer **22** and the power generation and distribution computer **26**, all via a bus **32**. The bus **32** may use any desired or suitable local area network (LAN) or wide area network (WAN) protocol to provide communications.

[**0054**] As illustrated in **FIG. 1**, the computer **30** is also connected via the same or a different network bus **32** to business system computers and maintenance planning computers **35** and **36**, which may execute, for example, enterprise resource planning (ERP), material resource planning (MRP), accounting, production and customer ordering systems, maintenance planning systems or any other desired business applications such as parts, supplies and raw materials ordering applications, production scheduling applications, etc. The computer **30** may also be connected via, for example, the bus **32**, to a plantwide LAN **37**, a corporate WAN **38** as well as to a computer system **40** that enables remote monitoring of or communication with the plant **10** from remote locations.

[**0055**] In one embodiment, the communications over the bus **32** occur using the XML protocol. In that case, data from each of the computers **12**A, **18**, **14**A, **22**, **26**, **35**, **36**, etc. is wrapped in an XML wrapper and is sent to an XML data server that may be located in, for example, the computer **30**. Because XML is a descriptive language, the server can process any type of data. At the server, if necessary, the data is encapsulated with to a new XML wrapper, i.e., this data is mapped from one XML schema to one or more other XML schemas that are created for each of the receiving applications. Thus, each data originator can wrap its data using a schema understood or convenient for that device or application, and each receiving application can receive the data in a different schema used for or understood by the receiving application. The XML data server is configured to map one schema to another schema depending on the source and destination(s) of the data. If desired, the server may also perform certain data processing functions or other functions based on the receipt of data. The mapping and processing function rules are set up and stored in the XML data server prior to operation of the system described herein. In this manner, data may be sent from any one application to one or more other applications.

[**0056**] Generally speaking, the computer **30** stores and executes an asset utilization expert **50** that collects data and other information generated by the process control systems **12** and **14**, the maintenance systems **18**, **22** and **26** and the business systems **35** and **36** as well as information generated by data analysis tools executed in each of these systems. The asset utilization expert **50** may be based on, for example, the OZ expert system currently provided by NEXUS. However, the asset utilization expert **50** may be any other desired type of expert system including, for example, any type of data mining system. Importantly, the asset utilization expert **50** operates as a data and information clearinghouse in the process plant **10** and is able to coordinate the distribution of data or information from one functional area, such as the maintenance area, to other functional areas, such as the process control or the business functional areas. The asset utilization expert **50** may also use the collected data to generate new information or data that can be distributed to one or more of the computer systems associated with the different functions within the plant **10**. Still further, the asset utilization expert **50** may execute or oversee the execution of other applications that use the collected data to generate new types of data to be used within the process control plant **10**.

[**0057**] In particular, the asset utilization expert **50** may include or execute index generation software **51** that creates indexes associated with devices, like process control and instrumentation devices, power generation devices, rotating equipment, units, areas, etc, or indexes that are associated with process control entities, like loops, etc. within the plant **10**. These indexes may then be provided to the process control applications to help optimize process control and may be provided to the business software or business applications to provide the business persons more complete or understandable information associated with the operation of the plant **10**. The asset utilization expert **50** can also provide maintenance data (such as device status information) and business data (such as data associated with scheduled orders, timeframes, etc.) to a control expert **52** associated with, for example, the process control system **14** to help an operator perform control activities such as optimizing control. The control expert **52** may be located in, for example, the user interface **14**A or any other computer associated with the control system **14** or within the computer **30**, if desired.

[**0058**] In one embodiment, the control expert **52** may be, for example, the control expert described in U.S. patent application Ser. Nos. 09/256,585 and 09/499,445 identified above. However, these control experts may additionally incorporate and use data related to the status of devices or other hardware within the process control plant **10** in the decision making performed by the control experts. In particular, in the past, the software control experts generally only used process variable data and some limited device status data to make decisions or recommendations to the process operator. With the communication provided by the asset utilization expert **50**, especially that related to device status information such as that provided by the computer systems **18**, **14**A, **22** and **26** and the data analysis tools implemented thereon, the control expert **52** can receive and incorporate device status information such as health, performance, utilization and variability information into its decision making along with process variable information.

[**0059**] Additionally, the asset utilization expert **50** can provide information pertaining to states of devices and the operation of the control activities within the plant **10** to the business systems **35** and **36** where, for example, a work order generation application or program **54** can automatically generate work orders and order parts based on detected problems within the plant **10** or where supplies can be ordered based on work being performed. Similarly, changes in the control system detected by the asset utilization expert **50** may cause the business systems **35** or **36** to run applications that perform scheduling and supply orders using, for example, the program **54**. In the same manner, changes in customer orders can be entered into the business systems **35** or **36** and this data can be sent to the asset utilization expert **50** and sent to the control routines or control expert **52** to cause changes in the control to, for example, to begin making the newly ordered products or to implement the changes made in the business systems **35** and **36**. Of course, if desired, each computer system connected to the bus **32** may have an application therein that functions to obtain the

appropriate data from the other applications within the computer and to sends this data to, for example, the asset utilization expert **50**.

[**0060**] Additionally, the asset utilization expert **50** can send information to one or more optimizers **55** within the plant **10**. For example, a control optimizer **55** can be located in the computer **14**A and can run one or more control optimization routines **55**A, **55**B, etc. Additionally or alternatively, optimizer routines **55** could be stored in and executed by the computer **30** or any other computer, and the data necessary therefor could be sent by the asset utilization expert **50**. If desired, the plant **10** may also include models **56** that model certain aspects of the plant **10** and these models **56** can be executed by the asset utilization expert **50** or a control or other expert such as the control expert **52** to perform modeling functions, the purpose of which will be described in more detail herein. Generally speaking, however, the models **56** can be used to determine device, area, unit, loop, etc. parameters, to detect faulty sensors or other faulty equipment, as part of optimizer routines **55**, to generate indexes such as performance and utilization indexes for use in the plant **10**, to perform performance or condition monitoring, as well as for many other uses. The models **56** may be models such as those created by and sold by MDC Technology located in Teeside, England or may be any other desired types of models. There are, of course, many other applications that can be provided within the plant **10** and that can use the data from the asset utilization expert **50** and the system described herein is not limited to the applications specifically mentioned herein. Overall, however, the asset utilization expert **50** helps to optimize the use of all of the assets within the plant **10** by enabling the sharing of data and coordination of assets between all of the functional areas of the plant **10**.

[**0061**] Also, generally speaking, one or more user interface routines **58** can be stored in and executed by one or more of the computers within the plant **10**. For example, the computer **30**, the user interface **14**A, the business system computer **35** or any other computer may run a user interface routine **58**. Each of the user interface routines **58** can receive or subscribe to information from the asset utilization expert **50** and either the same or different sets of data may be sent to each of the user interface routines **58**. Any one of the user interface routines **58** can provide different types of information using different screens to different users. For example, one of the user interface routines **58** may provide a screen or set of screens to a control operator or to a business person to enable that person to set constraints or to choose optimization variables for use in a standard control routine or in a control optimizer routine. The user interface routine **58** may provide a control guidance tool that enables a user to view the indexes created by the index generation software **51** in some coordinated manner. This operator guidance tool may also enable the operator or any other person to obtain information about the states of devices, control loops, units, etc. and to easily see the information related to the problems with these entities, as that information has been detected by other software within the process plant **10**. The user interface routine **58** may also provide performance monitoring screens using performance monitoring data provided by or generated by the tools **23** and **27**, the maintenance programs such as the AMS application or any other maintenance programs, or as generated by the models in conjunction with the asset utilization expert **50**. Of course, the user interface routine **58** may provide any user access to and enable the user to change preferences or other variables used in any or all functional areas of the plant **10**.

[**0062**] **FIG. 2** is a data flow diagram illustrating some of the data flow between the asset utilization expert **50** and other computer tools or applications within the process plant **10** is provided. In particular, the asset utilization expert **50** may receive information from numerous data collectors or data sources such as multiplexers, transmitters, sensors, hand held devices, control systems, radio frequency (RF) transceivers, on-line control systems, web servers, data historians, control modules or other control applications within the process control plant **10**, interfaces such as user interfaces and I/O interfaces as well as data servers such as buses (e.g., Fieldbus, HART and Ethernet buses), valves, transceivers, sensors, servers and controllers and other plant assets such as process instrumentation, rotating equipment, electrical equipment, power generation equipment, etc. This data can take on any desired form based on how the data is generated or used by other functional systems. Still further, this data may be sent to the asset utilization expert **50** using any desired or appropriate data communication protocol and communication hardware such as the XML protocol discussed above. Generally speaking, however, the plant **10** is configured so that the asset utilization expert **50** automatically receives specific kinds of data from one or more of the data sources and so that the asset utilization expert **50** can take predetermined actions with respect to that data.

[**0063**] Also, the asset utilization expert **50** receives information from (and may execute) data analysis tools such as typical maintenance data analysis tools that are currently provided today, performance tracking tools, such as those associated with devices, as well as performance tracking tools for process control systems like that described in U.S. patent application Ser. Nos. 09/256,585 and 09/499,445 identified above. The data analysis tools may also include, for example, a root cause application which detects root causes of certain types of problems, event detection such as that described in U.S. Pat. No. 6,017,143, regulatory loop diagnostics such as that disclosed in U.S. patent application Ser. No. 09/303,869 (filed May 3, 1999), which is hereby expressly incorporated by reference herein, impulse line plugging detection applications, such as that described in U.S. patent application Ser. No. 09/257,896 (filed Feb. 25, 1999), which is hereby expressly incorporated by reference herein, other plugged line detection applications, device status applications, device configuration applications and maintenance applications, device storage, historian and information display tools, such as AMS, Explorer applications and audit trail applications. Still further, the expert **50** can receive data and any information from process control data analysis tools such as the advanced control expert **52**, model predictive control process routines such as those described in U.S. patent application Ser. Nos. 09/593,327 (filed Jun. 14, 2000) and 09/412,078 (filed Oct. 4, 1999), which are hereby expressly incorporated by reference herein, tuning routines, fuzzy logic control routines and neural network control routines, as well as from virtual sensors such as that described in U.S. Pat. No. 5,680,409, which may be provided within the process control system **10**. Still further, the asset utilization expert **50** may receive information from data analysis tools related to rotating equipment such as on-line vibration, RF wireless sensors and hand-held data collection units, oil analysis associated

with rotating equipment, thermography, ultra-sonic systems and laser alignment and balancing systems, all of which may be related to detecting problems or the status of rotating equipment within the process control plant **10**. These tools are currently known in the art and so will not be described further herein. Still further, the asset utilization expert **50** may receive data related to power management and power equipment and supplies such as the applications **23** and **27** of **FIG. 1**, which may include any desired power management and power equipment monitoring and analysis tools.

[**0064**] In one embodiment, the asset utilization expert **50** executes or oversees the execution of mathematical software models **56** of some or all of the equipment within the plant **10**, such as device models, loops models, unit models, area models, etc., which are run by, for example, the computer **30** or any other desired computer within process plant **10**. The asset utilization expert **50** may use the data developed by or associated with these models for a number of reasons. Some of this data (or the models themselves) may be used to provide virtual sensors within the plant **10**. Some of this data, or the models themselves, may be used to implement predictive control or real time optimal control within the plant **10**. Some of the data generated by the models **56** may be used by the index generation routine **51** to generate indexes which are used in other applications, such as business and process control applications. The use of the models **56** for these and other purposes will be described in more detail below.

[**0065**] The asset utilization expert **50** receives data as it is generated or at certain periodic times over, for example, the bus **32** or other any communication network within the process control plant **10**. Thereafter, periodically or as needed, the asset utilization expert **50** redistributes the data to other applications or uses that data to generate and provide other information useful in different aspects of the control or operation of the process plant **10** to other function systems within the plant **10**. In particular, the asset utilization expert **50** may supply data to cause the index generation routine **51** to create a series of composite indexes such as a performance index, a utilization index, a health index and a variability index associated with one or more of the devices, units, loops, areas, or other entities within the process control plant **10**. The generation and use of these indexes will also be discussed in more detail herein.

[**0066**] The asset utilization expert **50** may also provide data to and receive data from control routines **62** that may be located in process controllers or interfaces associated with those controllers, optimizers **55**, business applications **63**, maintenance applications **66**, etc.

[**0067**] Furthermore, a control expert **65** (which may include a predictive process controller), that in the past simply assumed the devices it was controlling either worked properly or not at all, can receive information from the asset utilization expert **50** related to the status or health of the devices it is controlling, such as the utilization, variability, health or performance indexes mentioned above or other information related to the operating status of devices, loops, etc. that can be taken into account when trying to control a process. The predictive controller **65**, as well as the optimizers **55** may provide additional information and data to user interface routines **58**. The predictive controller **65** or optimizer **55** may use the status information pertaining to actual current status of the devices in the network, as well as take into account goals and future needs such as those identified by business solution software provided from the asset utilization expert **50** as defined by, for example, business applications **63**, to optimize control based on predictions within the control system.

[**0068**] Still further, the asset utilization expert **50** may provide data to and receive data from enterprise resource planning tools such as those typically used in business solutions or business computers **35** and **36**. These applications may include production planning tools which control production planning, material resource planning, the work order generation tool **54**, which automatically generates part orders, work orders, or supply orders for use in the business applications, etc. Of course, the part order, work order and supply order generation may be completed automatically based on information from the asset utilization expert **50**, which decreases the time required to recognize that an asset needs to be fixed as well as the time is takes to receive the parts necessary to provide corrective action with respect to maintenance issues.

[**0069**] The asset utilization expert **50** may also provide information to the maintenance system applications **66**, which not only alert maintenance people to problems immediately, but also take corrective measures such as ordering parts, etc. that are needed to correct a problem. Still farther, new models **68** may be generated using types of information that are available to the asset utilization expert **50** but that were previously unavailable to any single system. Of course, it will be understood from **FIG. 2** that the asset utilization expert **50** receives information or data from the data models and the analysis tools and also receives information from enterprise resource tools, maintenance tools and process control tools.

[**0070**] Moreover, one or more coordinated user interface routines **58** may communicate with the asset utilization expert **50** as well as any other applications within the plant **10** to provide help and visualization to operators, maintenance persons, business persons, etc. The operators and other users may use the coordinated user interface routines **58** to perform or to implement predictive control, change settings of the plant **10**, view help within the plant **10**, or perform any other activities related to the information provided by the asset utilization expert **50**. As discussed above, the user interface routines **58** may include an operator guidance tool that receives information from the predictive controller **65** as well as information related to the indexes, which can be used by an operator or other user to help perform many functions such as viewing the status of a process or devices within the process, to guide the predictive controller **65** or to perform predictive or optimized control. Still further, the user interface routines **58** may be used to view data or to obtain data from any of the tools in the other parts of the process control plant **10** via, for example, the asset utilization expert **50**. For example, managers may want to know what is happening in the process or may need high level information related to the process plant **10** to make strategic plans.

[**0071**] As mentioned above, the asset utilization expert **50** can execute or oversee the execution of one or more mathematical or software models **56** that model the operation of a particular plant or entities within the plant, such as devices,

units, loops, areas, etc. These models may be hardware models or they may be process control models. In one embodiment, to generate these models, a modeling expert divides the plant into component hardware and/or process control parts and provides a model for the different component parts at any desired level of abstraction. For example, the model for a plant is implemented in software and is made up of or may include a set of hierarchically related, interconnected models for the different areas of the plant. Similarly, the model for any plant area may be made up of individual models for the different units within the plant with interconnections between the inputs and outputs of these units. Likewise, units may be made up of interconnected device models, and so on. Of course, area models may have device models interconnected with unit models, loop models, etc. In this example model hierarchy, the inputs and outputs of models for the lower level entities, such as devices, may be interconnected to produce models for higher level entities, such as units, the inputs and outputs of which may be interconnected to create still higher level models, such as area models, and so on. The way in which the different models are combined or interconnected will, of course depend on the plant being modeled. While a single, complete mathematical model for the whole plant could be used, providing different and independent component models for different portions of or entities within the plant, such as areas, units, loops, devices, etc. and interconnecting these different models to form larger models may be useful for a number of reasons. Furthermore, it is desirable to use component models that can be run independently of one another as well as together with other component models as part of a larger model.

[**0072**] While highly mathematically accurate or theoretical models (such as third or fourth order models) may be used for the entire plant or for any or all of the component models, the individual models need not necessarily be as mathematically accurate as possible and could be, for example, first or second order models or other types of models. These simpler models can generally be executed more quickly in software and can be made more accurate by matching the inputs and outputs of the models with actual measurements of inputs and outputs made within the plant in a manner described herein. In other words, the individual models may be tuned or tweaked to accurately model the plant or the entities within the plant based on actual feedback from the plant.

[**0073**] The use of hierarchical software models will now be described in connection with **FIGS. 3 and 4**. **FIG. 3** illustrates models for multiple areas **80**, **81** and **82** within a refining plant. As illustrated in **FIG. 3**, the area model **82** includes a component model of a raw material source **84** that feeds raw material such as crude oil to a pre-processor model **88**. The pre-processor model **88** provides some refining to the raw material and provides an output, such as crude oil, to a distillation process **90** for further refining. The distillation process **90** outputs C_2H_4, usually a desired product, and C_2H_6 which, generally speaking, is a waste product. The C_2H_6 is fed back to a C_2 cracker **92** which provides its output to the pre-processor **88** for further processing. The feedback from the distillation process **90** through the C_2 cracker **92** is a recycling process. Thus, the model for the area **82** may include separate models for the raw material source **84**, the pre-processor **88**, the distillation process **90** and the C_2 cracker **92** having inputs and outputs interconnected as illustrated in **FIG. 3**. That is, each component model may be tied to the inputs and outputs of other component models in the manner illustrated in **FIG. 3** to form the model for the area **82**. Of course, the models for the other areas **80** and **81** could have other component models having interconnected inputs and outputs.

[**0074**] Referring now to **FIG. 4**, the component model for the distillation process **90** is illustrated in more detail and includes a distillation column **100** having a top portion **100**T and a bottom portion **100**B. The input **103** to the distillation column **100** is an indication of pressure and temperature which may be tied to the output of the model for the pre-processor **88** shown in **FIG. 3**. However, this input could be set by an operator or be set based on actual measured inputs or variables within the plant **10**. Generally speaking, the distillation column **100** includes a number of plates disposed therein and fluid moves between the plates during the distillation process. C_2H_4 is produced out of the top **100**T of the column **100** and a reflux drum **102** feeds back some of this material to the top **100**T of the column **100**. C_2H_6 generally comes out of the bottom of the column **100** and a reboiler **104** pumps polypropylene into the bottom **100**B of the column **100** to aid in the distillation process. Of course, if desired, the model for the distillation process **90** may be made up of component models for the distillation column **100**, the reflux drum **102** and the reboiler **104**, etc. and the inputs and outputs of these models may be connected as illustrated in **FIG. 4** to form the component model for the distillation process **90**.

[**0075**] As noted above, the component model for the distillation process **90** may be executed as part of a model for the area **82** or may be executed separately and apart from any other models. In particular, the input **103** to the distillation column **100** and/or the outputs C_2H_4 and C_2H_6 can actually be measured and these measurements may be used within the model of the distillation process **90** in a number of ways as described below. In one embodiment, the inputs and outputs of the model of the distillation process **90** may be measured and used to determine other factors or parameters associated with the model of the distillation process **90** (such as the distillation column efficiency, etc.) to cause the model of the distillation process **90** to more accurately match the operation of the actual distillation column within the plant **10**. The model of the distillation process **90** may then be used with the calculated parameters as part of a larger model, such as an area or plant model. Alternatively or additionally, the model of the distillation process **90** with the calculated parameters may be used to determine virtual sensor measurements or to determine if actual sensor measurements within the plant **10** are in error. The model of the distillation process **90** with the determined parameters may also be used to perform control or asset utilization optimization studies, etc. Still further, component models may be used to detect and isolate developing problems in the plant **10** or to see how changes to the plant **10** might affect the selection of optimization parameters for the plant **10**.

[**0076**] If desired, any particular model or component model may be executed to determine the values of the parameters associated with that model. Some or all of these parameters such as efficiency parameters may mean something to an engineer within the context of the model but are generally unmeasurable within the plant **10**. More particularly, a component model may be generally mathematically

described by the equation Y=F(X, P), wherein the outputs Y of the model are a function of the inputs X and a set of model parameters P. In the example of the distillation column model of the distillation process **90** of **FIG. 4**, an expert system may periodically collect data (e.g., every hour, every ten minutes, every minute, etc.) from the actual plant indicative of the actual inputs X to and the outputs Y from the entity to which the model pertains. Then, a regression analysis such as a maximum likelihood, least squares or any other regression analysis may be periodically performed using the model and multiple sets of the measured inputs and outputs to determine a best fit for the unknown model parameters P based on the multiple sets of measured data. In this manner, the model parameters P for any particular model may be determined using actual or measured inputs and outputs to reconcile the model with the entity being modeled. Of course, this process can be performed for any and all component models used within the plant **10** and can be performed using any appropriate number of measured inputs and outputs. Preferably, the asset utilization expert **50** collects the data associated with the appropriate inputs and outputs for a model over a period of time from the process control network and stores this data for use by the models **56**. Then, at the desired times, such as every minute, hour, day, etc., the asset utilization expert **50** may execute the regression analysis using the most recently collected sets of data to determine the best fit for the model parameters using the collected data. The sets of measured input and output data that are used in the regression analysis may be independent of or may overlap with the sets of data used in a previous regression analysis for that model. Thus, for example, a regression analysis for a particular model may be run every hour but may use input and output data collected every minute for the last two hours. As a result, half of the data used in any particular regression analysis may overlap with the data used in a previous regression analysis. This overlapping of data used in the regression analysis provides for more continuity or consistency in the calculation of the model parameters.

[**0077**] Similarly, a regression analysis can be performed to determine if sensors making measurements within the process **10** are drifting or have some other error associated therewith. Here, the same data or potentially different data pertaining to the measured inputs and outputs of the entity being modeled are collected and stored by, for example, the asset utilization expert **50**. In this case, the model can be generally mathematically expressed as Y+dY=F(X+dX, P), wherein dY are the errors associated with the measurements of the outputs Y, and dX are the errors associated with measurements of the inputs X. Of course, these errors could be any types of errors, such as bias, drift, or non-linear errors and the model may recognize that the inputs X and outputs Y may have different kinds of errors associated therewith, with the different kinds of possible errors having different mathematical relationships to the actual measured values. In any event, a regression analysis, such as a maximum likelihood least squares or any other regression analysis may be performed using the model with the measured inputs and outputs to determine a best fit for the unknown sensor errors dY and dX. Here, the model parameters P may be based on the parameters P calculated using a previous regression analysis for the model or may be treated as further unknowns and may be determined in conjunction with this regression analysis. Of course, as the number of unknowns used within regression analysis increases, the amount of data required increases and the longer it takes to run the regression analysis. Furthermore, if desired, the regression analysis for determining the model parameters and the regression analysis for determining the sensor errors may be run independently and, if desired, at different periodic rates. This different periodicity may be beneficial when, for example, the time frame over which measurable sensor errors are likely to occur is much different, either greater than or less than, the time frame over which changes in the model parameters are likely to occur.

[**0078**] In any event, using these component models, the asset utilization expert **50** can perform asset performance monitoring by plotting the values of the determined model parameter(s) (and/or model inputs and outputs) versus time. Still further, the asset utilization expert **50** can detect potentially faulty sensors by comparing the determined sensor errors dY and dX to thresholds. If one or more of the sensors appears to have a high or an otherwise unacceptable error associated therewith, the asset utilization expert **50** can notify a maintenance person and/or a process control operator of the faulty sensor.

[**0079**] It will be understood from this discussion that the component models may be executed independently for different purposes at different times and, in many cases, may be executed periodically to perform the above described performance monitoring activities. Of course, the asset utilization expert **50** can control the execution of the appropriate models for the appropriate purposes and use the results of these models for asset performance monitoring and optimization. It will be understood that the same model may be run by the asset utilization expert **50** for different purposes and for calculating different parameters or variables associated with the model.

[**0080**] As noted above, the parameters, inputs, outputs or other variables associated with any particular model may be stored and tracked to provide performance monitoring for a device, a unit, a loop, an area or any other entity of a process or a plant. If desired, two or more of these variables may be tracked or monitored together to provide a multi-dimensional plot or measure of the performance of the entity. As part of this performance modeling, the location of the parameters or other variables within this multi-dimensional plot may be compared to thresholds to see if the entity, as defined by the coordinated parameters being monitored, is within a desired or acceptable region or is, instead, outside of that region. In this manner, the performance of an entity may be based on one or more parameters or other variables associated with that entity. **FIG. 5** illustrates a two-dimensional plot of the operating region of an entity, such as the distillation column of **FIG. 4**, as defined by the values of the parameters P1 and P2 for this entity. Here, the parameters P1 and P2 (which may be determined using the model regression analysis described above or in any other desired manner) are plotted in a two-dimensional manner and the points on the plot (each being defined by a value for P1 and a value for P2) are determined for different times illustrated as T1-T10. Thus the point XT1 represents the point defined by the values for the parameters P1 and P2 at time T1. The points XT1 to XT10 on the plot of **FIG. 5** illustrate that the entity was operating within a desired region (region **1**) between the times T1 and T6, entered a less desirable but acceptable region (region **2**) at time T7 and entered an

unacceptable or failing region (region **3**) at time T**10**. Of course, the boundaries of these different regions are determined beforehand by, for example, an expert and are stored in the computer **30** for access by the asset utilization expert **50** at any desired time. While **FIG. 5** illustrates a two-dimensional parameter performance monitoring technique, this same technique could be applied in one dimension or in three or more dimensions to effect performance monitoring. Furthermore, the regions or other information about the location of the entity in the n-dimensional plot may be used by, for example, the index generation routine **51**, to generate a performance index.

[**0081**] It will be understood that the asset utilization expert **50** can monitor one or more entities using the monitoring technique described above based on model parameters or other model variables and can report the operating states or performance measures of these entities to any other desired persons, functions or applications within the process control plant **10**, such as to a process control expert system, a maintenance person, a business application, a user interface routine **58**, etc. Of course, it will also be understood that the asset utilization expert **50** may perform performance or condition monitoring on any desired entity, based on one, two, three or any other desired number of parameters or variables for each entity. The identity and number of variables or parameters to be used in this performance monitoring will generally be determined by an expert familiar with the process and will be based on the type of entity being monitored.

[**0082**] If desired, the asset utilization expert **50** may also define a performance index or plot by comparing one or more of the parameters determined by the models as described above with the same parameter determined by the model run in accordance with the design parameters of the entity being modeled. In particular, the asset utilization expert **50** may execute a model using the design parameters of the entity within the plant **10** to which the model pertains to determine what the designed performance of the entity would be if it was operating according to the current state of the process and using the actual inputs to the entity as measured within the plant **10**. This design performance can then be compared to the actual performance of the entity as determined by the component model for that entity or as determined by the measured inputs and outputs of the entity to generate a measure of the performance of the entity.

[**0083**] Thus, for example, the efficiency of an entity may be determined using the component model that estimates the parameters of the entity (one of which may be efficiency) based on the regression analysis described above. At the same time, a model of the entity may be run using the parameters that would result according to the design criteria of the entity, but based on the actual inputs to and/or outputs from the entity. Thus, for example, if a different raw material was being input to the entity, the design model would be run using the efficiency that would result from the change in raw materials. The performance of the entity in both cases may be compared to determine a performance index which indicates how far from the possible or designed operation the actual entity is operating. This performance index can then be reported to and used by other applications or users of the system, such as a process control, a maintenance or a business person or application.

[**0084**] The component models **56** may also be used to perform process optimization. In particular, the asset utilization expert **50** may use one or more of the optimization routines **55** that execute the individual component models to optimize the operation of the plant in terms of some optimization criteria provided by, for example, a process control operator or a business person via a business application. The optimizer **55** can be a real time optimizer that operates in real time to optimize the plant **10** based on the actual state of the plant **10** at that time. Alternatively or additionally, an optimizer **55** may determine changes to be made to the plant **10**, such as bringing certain devices or units back on line, that will provide the greatest optimization of the plant **10**. Of course, other types of optimization routines **55** may be executed instead of or in addition to those mentioned here.

[**0085**] In one embodiment, the RTO+ real time optimization routine, which is provided by MDC Inc., may be used as a real time optimizer and may be executed at various or periodic times during operation of the plant **10**, such as every 3-5 minutes, every 10-15 minutes, every hour, etc. Of course, other known or later developed optimizer routines which perform optimization less frequently, such as every 3 or 4 hours or every 3 to 4 days could be used instead.

[**0086**] The RTO+ optimizer implements three general phases each time it is executed to perform real time optimization. The RTO+ optimization routine first executes an input phase during which the routine checks to determine whether the variables that were previously indicated at the design of the optimizer as being variables which could be manipulated by the optimizer to perform optimization, such as set points or other inputs of various devices, units, etc., can actually be manipulated at the current time. This information may be available to the optimizer from the asset utilization expert **50**, which obtains this information from the process control system and stores this information within any desired database. Thus, during the input phase, the optimizer actually determines, based on the data provided to it from the asset utilization expert **50**, whether each of the possible manipulated inputs is still available to be changed. In many instances, one or more of the potential manipulated inputs may not be available for change due to the fact that, for example, a device which provides that input is not operating or has been taken off-line or the device is being run in a mode other than the designed mode thereby preventing the controller from changing inputs to the device.

[**0087**] As part of the input phase, the real time optimizer may also determine if the variables that were supposed to change during the last run of the optimizer were actually changed to and reached the suggested or calculated values from the last run of the optimizer, i.e., the values to which they were supposed to be changed. If a variable that was supposed to change to a particular value did not reach that value, the optimizer recognizes that there is a problem that is preventing the change from occurring and effectively removes the option of changing this variable to that value during the next run of the optimizer. Detecting the failure of a variable to reach a value which it should have theoretically reached may also cause the optimizer to indicate to an operator that there may be a problem within the system that needs to be addressed.

[**0088**] Next, during the input phase, the optimizer performs a quick execution of each of the individual component

models that make up the entire model using, for example, the actual inputs and outputs measured from the plant **10**. The calculated outputs of each component model are then reviewed to see if there is any problem with any particular component model that will prevent the entire model from running accurately. Here, the optimizer may use the actual measured inputs for each entity (which have previously stored) to see if the individual component parts of the model work for these actual inputs to produce realistic outputs.

[**0089**] Assuming that each of the component models can be executed, the optimizer may look for discrepancies in the models that may effect the ability of the optimizer to optimize. For example, the optimizer may determine if a measurement made by a real device is the same as predicted by the component model using the actual inputs to the device. If the model (using the most recently calculated model parameters) predicts an output that deviates from the actual measurement of the output, such as if the model predicts a flow rate of eighteen and a flow rate meter reads twenty, then the optimizer may reset a constraint associated with the flow rate at two below the previously defined constraint. Thus, if the constraint associated with that flow rate was originally set at twenty-five, the optimizer may use a constraint of twenty-three because the optimizer recognizes that its model is in error by two with respect to this variable. Of course, the optimizer may look for other inconsistencies or deviations between models and the actual measurements of the plant to reset, update or tweak constraints or other variables within the optimization routine.

[**0090**] In the next phase, known generally as the optimization phase, the optimizer runs the individual models in a predetermined order using the outputs from one component model as inputs to one or more of the other component models making up the entire model. Using the entire model, the constraints provided by the user and the new constraints determined by the input phase, as well as the optimization criteria, the optimizer determines the changes to be made to the input or manipulated variables that have been detected as currently being capable of manipulation, which will optimize the plant over the time window in which the optimizer runs. This time window may be 3-4 minutes, 3-4 hours, etc., and is generally the periodic rate at which the optimizer runs. The use of optimization software is well known and any desired optimization software for this purpose could be used. Thus, in one example, a refining plant may be optimized to operate a C_2 cracker to make as much profit as possible based on the possible output products that can be produced by the C_2 cracker as determined by the current prices and lots of production associated with each of those possible outputs. A constraint, however, may be that the C_2 cracker has to produce a certain amount of one product because there is a business contract to provide that amount of that product which must be fulfilled no matter what the current price of that product happens to be. In another example, an optimization criteria may be to maximize the use of one particular raw material because the cost of keeping excess amounts of that raw material at the plant overshadows other costs or price concerns, such as products that have the highest current price.

[**0091**] It will be seen that the determination of the optimization criteria, which is typically performed by a business person or a business application, is very critical to the operation of the optimizer and thus, ultimately, to the operation of the plant **10**. As a result, the asset utilization expert **50** may provide the business person, via the user interface routines **58**, a systematic set of choices of what the optimization criteria will be at any particular time and may provide the choices made by the operator or any other user to the optimization routine. In fact, there are many optimization variables that can be selected and the choice of these different criteria may be provided to the operator or business person via the user interface to allow the operator or business person to choose different optimization criteria in any desired manner.

[**0092**] Next, the optimization routine enters an output phase in which implementation of the results of the optimizer may be accomplished. In particular, after computing the suggested changes to the manipulated variables, the optimizer may determine if the manipulated variables or inputs to be changed are still available because one or more of the devices which were available at the time the optimizer began the optimization phase may have gone off-line or may have otherwise become unavailable, which will prevent the suggested changes in the input variables from being implemented. However, if all of the manipulated variables to be changed can still be changed, the suggested changes may be provided to an operator via, for example, a user interface (e.g., a graphical user interface). The operator may be able to simply press a button and have the changes to the manipulated variables initiated or downloaded to the process control routine automatically, such as changing set points, etc. in a matter determined by the optimizer. In another embodiment or in later stages of operation, for example, when the process is running properly, the optimizer may automatically implement the suggested changes if the operator does not prevent the instantiation of the these changes within a particular time window. Thus, the output of the optimizer may be used every time the optimizer executes unless the operator intervenes to prevent the changes from the optimizer from being used. As part of this operation, one or more of the user interface routines **58** may provide a screen to the operator indicating the suggested changes to be made and a button or bar which the operator uses to install the changes or to prevent the changes from being installed. If, in one embodiment, the user pushes a button to install the changes, all of the changes are sent to the appropriate controllers where they are checked for limits and then implemented.

[**0093**] The real time optimizer, such as that described above, may be executed relatively frequently compared to most optimizers for a number of reasons. First, the real time optimizer uses fitness for purpose component models, which typically run much faster than the highly theoretical models that are typically used to design a plant. These component models are accurate, however, because one or more parameters of the models are being tweaked or altered (using the regression analysis described above) based on actual inputs and outputs of the plant **10**. That is, the real time optimizer uses the model parameters provided by the last run of the regression analysis on the model to reconcile the model with the actual operation of the plant **10**. Still further, the optimizer described above is faster than conventional optimizers because it uses restricted optimization steps. That is, the optimizer only tries to optimize over the time period between individual runs of the optimizer, which reduces the amount of processing performed by the optimization routine. Additionally, the real time optimizer may be configured

to recognize the occurrence of one or more significant events, which may trigger the real time optimizer to restart as these events may make previous recommendations unfeasible or undesirable.

[0094] While the use of a closed loop real time optimizer has been discussed above, other types of optimizers **55** that use the same or different component models could also be executed by the asset utilization expert **50** in conjunction with or separately from the real time optimizer. These other optimizers could be executed less frequently and for other reasons. For example, a wideband optimizer may be used to look at or determine where the final optimal operating point of a process may ultimately be, even though the real time optimizer may not be able to drive the plant **10** to that point for some time. This wideband optimizer may enable the business person to make long term predictions about the plant **10** or may enable the operator to determine if the operation of the plant **10** is headed toward a desirable region. If the wideband optimizer determines that the ultimately achievable optimization point is still not acceptable, the operator may decide to change the configuration or other operating parameters of the plant **10**.

[0095] Other optimizers, such as selection optimizers, may determine whether changes in the process configuration that need to be performed by the operator or maintenance person could better optimize the process. For example, in some cases, a selection optimizer may recognize that certain units or other manipulated inputs that are supposed to be available to the real time optimizer are no longer available for some reason, e.g., the devices associated with these inputs are down or are off-line. The selection optimizer runs one or more optimization tests assuming that one or more of these devices, units, etc. are available to determine how much better the plant **10** would operate (i.e., how much more optimal the plant **10** could be with respect to some optimization criteria) if these entities were put back into operation. This optimizer may, for example, tell the operator or business person how much more money the plant **10** could make by getting certain units or devices online, or could tell the operator or business person which devices or units to focus on getting back into operation first. Such a selection optimizer may also try to optimize by turning particular pumps or valves on or off, by replacing other devices that are running in sub-optimal modes, etc. to determine which critical changes to the process or to the assets thereof could be made to make the process more profitable or optimal. The selection optimizer might use inputs from the operator or business person and/or might use other branch and bound techniques which are common in data processing or data mining routines to select the way in which to adjust the optimization variables. Other selection techniques could also be used, such as providing the selection optimizer with a series of rules to apply in a particular order to determine how to change the process or to determine which changes to the process, if implemented, would provide improvements or the most improvement to the plant **10**.

[0096] As a result of the above discussion, it can be seen that the use of models provides many new types of data or information for the business applications, process control applications and asset maintenance and monitoring applications. In particular, the models can be used to perform performance monitoring and to produce a performance index which indicates the relative performance of a device, unit, area, etc. within a plant. This performance index may be a measure of the performance of an entity with respect to the possible performance of that entity. Furthermore, while device and unit models have been discussed above, similar models could be made and executed for process control entities, such as loops, to provide performance measures and optimization criteria for these types of entities as well. Also, as indicated above, models may, in some cases, be used to measure or indicate the health of certain devices or other entities and to provide a health index indicative of these entities. For example, the error measurements of certain input and output sensors as determined by the regression analysis used on certain models may be used as or converted into an indication of the health of those devices. Also, other information not otherwise available to the process controller, such as model parameters and virtual sensor measurements based on the models could be provided to the process controllers or to the business persons for use in numerous manners.

[0097] Besides performance and health indexes, the asset utilization expert **50** can assist the index generation routine **51** in creating other types of indexes such as a utilization index and a variability index. A variability index indicates how much some signal into or out of, or some other parameter associated with a device, loop, unit, etc. varies in comparison to how much this signal or parameter is expected to vary. The data needed to create this variability index may be collected by the asset utilization expert **50** and provided to the index generation routine **51** at any desired or convenient times. Of course, the normal amount of variation of a signal or parameter may be set by a manufacturer, engineer, operator or maintenance person familiar with the entity or may be based on a statistical measure (such as an average, standard deviation, etc.) associated with that or other similar entities within the plant and this normal or expected variation may be stored by or updated within the index generation routine **51**.

[0098] The utilization index may be used to track or reflect the utilization of individual devices, units, loops, or other entities and may provide some indication as to whether an entity is being over utilized or under utilized based on previously determined bench marks or operational goals. A utilization index can be generated based on measured uses of the actual device. For example, a device may be measured to determine how often it is being used within a process or is being left idle and this index may be compared to a desired utilization for that entity to determine if the entity is being over or under utilized. The utilization index might identify devices, units, loops, etc. that are not being utilized as often as they could be or should be or, on the other hand, which are being utilized too much and, thus, are being over used.

[0099] In some instances, a utilization index might be determined based on the business decisions made regarding the appropriate or desired use of a particular device. For example, many processing or refinery plants use furnaces that are subject to the problem of coking and, as a result, must be periodically cleaned. Generally speaking, coking occurs in furnaces that are used in petroleum industries where it is desirable to rapidly heat a petroleum based fluid in a short amount of time. Such a furnace might have an input tube that travels through the interior of the furnace so that fluid traveling within the tube is rapidly heated to a high temperature, such as 1400° F. In some cases, to get the fluid

at the center of the tube to such a high temperature, it may be necessary to heat the outside of the tube to about 1700° F. However, because the fluid traveling through the tube is petroleum based, some of the material forms carbon or other kinds of viscous or particulate material that is deposited on the inside surfaces of the tubes which, in turn, reduces the heat transfer efficiency of the furnace over time. The deposition of this material is generally called coking. The greater the amount of fluid flowing through the tube, the more coking that occurs and, thus, the lower the efficiency of the furnace. At some point, the efficiency of the furnace becomes so low that the furnace must be taken off-line and cleaned. This cleaning process is time consuming and requires a great deal of manpower and resources, including steam cleaning equipment. As a result, the cleaning of these furnaces must generally be scheduled in advance to assure that the manpower and necessary equipment is available.

[**0100**] A business person or process control operator, knowing the fact that particular furnaces within the plant **10** will experience coking, may attempt to obtain the most efficient use of those furnaces by specifying how coking is to occur within each furnace over time. Thus, for example, a business person might decide to operate a particular furnace for a period of 15 days and wants to get the most use out of that furnace in that time period by running the furnace to its maximum coking level at the end of the 15 day period. If the furnace reaches its maximum coking level too soon, i.e., before the end of the 15 day period, the furnace must be taken off-line but still cannot be cleaned until the end of the 15 day period because that is when the cleaning manpower and machinery becomes available (i.e., has been scheduled). This early removal of the furnace may adversely affect the process operation. However, if the furnace does not reach its maximum allowable coking level by the end of the 15 day period, the furnace must still be taken off-line and cleaned because, again, that is the only time that the manpower and machinery is available. However, the furnace has been under utilized, which means that an opportunity has been lost because the costs of cleaning an under utilized furnace are the same as the costs of cleaning a fully utilized furnace. Furthermore, as a result of this under utilization other furnaces were probably being overused and subject to more coking than necessary.

[**0101**] To plan the best utilization of the furnace over a given time period, such as the 15 day period discussed above, the operator or business person may draw a fiducial line which defines the desired amount of coking for the furnace over time. An exemplary fiducial line **200** in a plot of coking of a furnace versus time is illustrated in **FIG. 6**. The fiducial line **200** specifies how the business person or operator desires to use the furnace with respect to coking over a period of 15 days (after which time this furnace will be cleaned). The coking of the furnace is directly related to the heat transfer efficiency of the furnace. As can be see from **FIG. 6**, at the end of the 15 day period, if the use of the furnace follows the fiducial line **200**, the furnace will reach its maximum coking level, which corresponds to the minimum allowable heat transfer efficiency of the furnace. Of course, it will be understood that the fiducial line **200** of **FIG. 6** is but one of many possible fiducial lines that could be selected.

[**0102**] Unfortunately, it is impossible, due to the high temperatures within the furnace, to measure the coking in the furnace at any particular time. However, a measure of coking within the furnace may be made, instead, with the use of one or more models for the furnace constructed according to the principles discussed above. Here, coking may be a parameter of the model which is determined from other variables within the model, from inputs to and outputs from the model or from using a regression analysis as described above. The asset utilization expert **50** may then run this model periodically to obtain, as a virtual senor measurement or as a model parameter, the amount of coking in the furnace. The equations for this determination are well known in the art and will not be discussed herein. Furthermore, if desired, an optimizer may use the coking value defined by the fiducial line **200** of **FIG. 6** (or the coking rate defined by the slope of this line at any point) as an optimization criteria and set the manipulated variables of the plant in an attempt operate the furnace so that the coking within the furnace, as measured by the model for this furnace, follows the fiducial line **200** of **FIG. 6**.

[**0103**] Now, in the example of **FIG. 6**, it is assumed that the asset utilization expert **50**, running the models for the furnace, determines that at day six the coking of the furnace is at point **202**, which is substantially below the desired coking amount as defined by fiducial line **200** at day six. The fact that the coking estimate for the furnace at day six is below that defined by the fiducial line **200** means that the furnace is being under utilized according to the fiducial line **200**. As a result, the asset utilization expert **50** may make this fact known to, for example, an operator or business person, such as by providing a utilization index for the furnace that identifies, in some desired or convenient manner, that the furnace is being under utilized according to previously defined utilization criteria.

[**0104**] Based on this utilization index, the business person or operator may recognize that there is an opportunity to use the furnace more because, after the period of 15 days, the furnace will be shut down anyway whether or not the maximum amount of coking has occurred within the furnace. To get the coking parameter back on to the fiducial line **200** within a certain period of time such as, for example, by day seven (which is marked as point **204** in **FIG. 6**), and to get the best utilization out of the furnace, the operator or the asset utilization expert **50** may define a line between the points **202** and **204**. The slope of this line defines a rate of coking that is greater than the rate of coking allowed by the fiducial line **200** between days six and seven. The operator or optimization routine may then run the furnace more to obtain the rate of coking defined by the slope of the line between the points **202** and **204**. This higher rate of coking may, for example, be used as a constraint, or even as an optimization parameter, within an optimization routine which controls the operation of the plant **10** or of the furnace. For example, it is well known that the amount or rate of coking can be adjusted by adjusting any of a number of parameters associated with the furnace, such as the speed that material is provided through the furnace (the faster the speed, the less coking that takes place), the exit temperature of the material out of the furnace (the higher the exit temperature, the more coking that takes place) and the amount of steam injected into the fluid sent through the furnace (typically, the more steam that is used, the less coking that takes place). The optimizer may use the desired rate of coking to adjust one or more of these parameters to obtain the new coking rate. In any event, the measurement

of the utilization of the furnace based on the actual coking of the furnace compared to the desired coking of the furnace indicates, in this example, that the furnace is being under utilized and that greater optimization of the plant **10** can occur if the furnace is used more.

[**0105**] Referring now to **FIG. 7**, if the coking of the furnace at day six is measured or determined by the models for the furnace to be above the fiducial line **200**, such as at the point **206**, then the furnace is being over utilized and the rate of use of the furnace should be reduced to enable the furnace to last 15 days. In this case, there may be another furnace that could be brought online or that is already online that could be used to compensate for the reduction in use of the furnace. Similar to the example of **FIG. 6**, an operator or business person may be informed of the over utilization of the furnace using, for example, a utilization index reflecting, for example, some indication of the difference between the actual coking amount and the desired coking amount. Thereafter, the operator or business person may determine that it is desirable to get the coking parameter of the furnace back onto the fiducial line by day **10** because the coking value of the furnace may already be greater than the value allowed for day seven or eight. A line can be drawn between the point **206** and the point **208**, which is the point on the fiducial line at day ten and the slope of this newly drawn line may define the rate of coking that is allowed or desired for use between days seven and ten. Of course, the operator or an optimizer or other control routine can implement control strategies to force the coking rate of the furnace to be the rate defined by the slope of the line between the points **206** and **208**.

[**0106**] Other business decisions may be used to change the utilization index of the furnace. For example, at day six, even though the furnace may be running at or around the fiducial line in terms of the coking parameter, a business person may decide that it is necessary to get five more days use out of the furnace and thereby increase the life of the furnace to twenty days before it is cleaned. This may be done because the cleaning equipment will not be available until twenty days anyway. In this case, the fiducial line between day six and day twenty may be redrawn and the control routine or optimizer may attempt to follow the new fiducial line. However, if the entire fiducial line is redrawn, what was previously defined as 100% utilization or exact utilization at day six for a fifteen day fiducial line may now be over utilization for a twenty day fiducial line. In this case, the asset utilization expert **50** may provide a new rate of coking as an optimization or constraint to an optimizer or to a process control routine to attempt to get the utilization index back to 100%. Similarly, if the furnace is to be shut down early such as at the end of twelve days, the furnace may now be under utilized based on a twelve day fiducial line and an optimizer or a process control routine may use a new coking rate in an attempt to get the utilization index back to 100%.

[**0107**] It should be noted that a business decision to run the furnace on a particular fiducial line in conjunction with the use of models for the furnace that measure or estimate the coking amount of the furnace at any particular time can be used to indicate whether a particular entity, such as the furnace, is being over utilized or under utilized during actual process runs. Furthermore, changes to the control of the process can be made to use the furnace more or less based on the utilization index.

[**0108**] The utilization index for the furnace example given above can be calculated or expressed in any desired manner, such as one based on the difference between or a ratio of the actual coking value and the desired coking value, the new allowable coking rate, the difference between or a ratio of the desired coking rate as defined by the fiducial line and the new allowable coking rate, or any other measure of utilization. Of course, while one manner of determining a utilization index for a furnace has been described herein, there are many other manners of determining or defining utilization indexes for furnaces, as well as for other devices, units, loops, etc. within a process control plant. In particular, utilization indexes for different entities can be measured in any desired manner and in different manners for different types of entities. In one example, the utilization index may be expressed as a percent, where 100% means that the entity is being used the correct or desired amount, a value over 100% means that the entity is being over utilized and a value under 100% means that the entity is being under utilized. Of course, other ways of measuring and expressing utilization could also be used within the context of different kinds of devices.

[**0109**] One important aspect of the system of **FIG. 1** is the user interface routines **58** which provide a graphical user interface (GUI) that is integrated with the asset utilization expert **50** described herein to facilitate a user's interaction with the various asset utilization capabilities provided by the asset utilization expert **50**. However, before discussing the GUI in greater detail, it should be recognized that the GUI may include one or more software routines that are implemented using any suitable programming languages and techniques. Further, the software routines making up the GUI may be stored and processed within a single processing station or unit, such as, for example, a workstation, a controller, etc. within the plant **10** or, alternatively, the software routines of the GUI may be stored and executed in a distributed manner using a plurality of processing units that are communicatively coupled to each other within the asset utilization system.

[**0110**] Preferably, but not necessarily, the GUI may be implemented using a familiar graphical windows-based structure and appearance, in which a plurality of interlinked graphical views or pages include one or more pull-down menus that enable a user to navigate through the pages in a desired manner to view and/or retrieve a particular type of information. The features and/or capabilities of the asset utilization expert **50** described above may be represented, accessed, invoked, etc. through one or more corresponding pages, views or displays of the GUI. Furthermore, the various displays making up the GUI may be interlinked in a logical manner to facilitate a user's quick and intuitive navigation through the displays to retrieve a particular type of information or to access and/or invoke a particular capability of the asset utilization expert **50**.

[**0111**] Generally speaking, the GUI described herein provides intuitive graphical depictions or displays of process control areas, units, loops, devices, etc. Each of these graphical displays may include numerical status and performance indexes (some or all of which may be generated by the index generator routine **51** described above) that are associated with a particular view being displayed by the GUI. For example, a display depicting a process control area may provide a set of indexes reflecting the status and

performance of that area (i.e., a particular portion of the process control system at a particular level of the equipment hierarchy). On the other hand, a display depicting a loop may provide a set of status and performance indexes associated with that particular loop. In any event, a user may use the indexes shown within any view, page or display to quickly assess whether a problem exists within any of the devices, loops, etc. depicted within that display.

[0112] Additionally, the GUI described herein may automatically, or may in response to a request by a user, provide maintenance information to the user. The maintenance information may be provided by any portion of the asset utilization expert **50**. Similarly, the GUI may display alarm information, process control information, etc., which may also be provided by the asset utilization expert **50**. Still further, the GUI may provide messages to the user in connection with a problem that has occurred or which may be about to occur within the plant **10**. These messages may include graphical and/or textual information that describes the problem, suggests possible changes to the system which may be implemented to alleviate a current problem or which may be implemented to avoid a potential problem, describes courses of action that may be pursued to correct or to avoid a problem, etc.

[0113] **FIG. 8** is an exemplary depiction of a display representing a unit **500** within a process control system that may be displayed by the GUI. As illustrated in **FIG. 8**, the unit **500** includes a plurality of devices such as, for example, valves, pumps, temperature transmitters, etc., all of which may be depicted graphically as shown. Additionally, the display may further include lines arrows, and any other indicia to represent logical and physical interconnections between the various devices. Of course, such graphical representations of process control systems (or portions of process control systems) are well known in the art and, thus, the manner of implementing these graphical representations or displays will not be described in further detail herein.

[0114] Importantly, the GUI display shown in **FIG. 8** also includes a plurality of index names and values **550**. In particular, the index names and values **550** include a performance index, a health index, a variability index and a utilization index, all of which have been discussed above in connection with the asset utilization expert **50** and the index generation routine **51**. The index names and values **550** may be displayed in a tabular format as shown or in any other desired format. The index names and values **550** are representative of the performance and status of the entire unit **500** and, thus, the index values shown are preferably, but not necessarily, composed of the index values associated with each of the sub-units and/or devices that make up the unit **500**.

[0115] Before discussing the GUI and the manner in which asset information, process control information, maintenance information, diagnostic information or any other type of information is displayed to a user thereby, a brief discussion of the manner in which the performance and status indexes are generated is provided below. Also, it should be recognized that while a performance index, a health index, a variability index and a utilization index are described in detail herein in connection with the various displays of the GUI, additional and/or different indexes may be generated by the asset utilization expert **50** and displayed via the GUI without departing from the scope of the invention.

[0116] In general, each of the indexes generated by the index generator routine **51** and displayed via the GUI may be calculated for individual devices, for logical and/or physical groupings of devices, for logical processes (e.g., control loops), for logical groupings of devices such as units and areas, etc. In other words, the indexes may, in principal, be calculated at each level of the equipment and logical hierarchy of a process control system or, more generally, an asset utilization system, which may include one or more process control systems. However, the meaning of a particular index may depend on the context (i.e., whether the index corresponds to a logical or a physical grouping of devices and/or parameters) in which the index is generated and displayed and may depend on the level of the hierarchy at which it is displayed. For example, at the lowest level of the equipment hierarchy, indexes correspond to physical devices such as valves, temperature sensors, actuators, etc. Thus, each device may have a unique set of indexes that may be generated within the device or for the device based on information stored within the device at the time the device is manufactured. Accordingly, each device may generate and provide its indexes to higher levels of the hierarchy and to the asset utilization expert **50** as needed.

[0117] Similarly, units or loops, each of which is composed of one or more devices or function blocks, may each have a unique set of indexes. However, the index values for each unit or loop may be generated by mathematically combining the index values for the individual devices or function blocks used within the unit or loop. Thus, if a unit or loop is composed of a pressure transmitter, a valve and a pump (or function blocks associated with the operation of these devices), the index values for the unit or loop may be based on various mathematical combinations of the index values generated for or by each of those devices or function blocks making up the unit or the loop. Likewise, because sub-unit and unit levels of the hierarchy are composed of one or more loops which, in turn, are composed of devices, the index values for each sub-unit and unit may be generated by mathematically combining loop or device index values. Still further, area indexes may be determined as combinations of the index values associated with the units, loops, devices, etc. within the area.

[0118] As discussed in greater detail below, the mathematical combination of device index values to form index values for loop, sub-unit, unit and area levels of the hierarchy may use weighted summations or averages, or any other suitable mathematical combination. Of course, the calculation of one or more of the performance, health, variability and utilization indexes may not be appropriate, required or useful for every level of the logical and equipment hierarchies. **FIG. 9** is an exemplary table that illustrates one manner in which the performance index (PI), the health index (HI), the variability index (VI) and the utilization index (UI) may or may not be generated for the device, loop, sub unit and unit levels of the system hierarchy. As shown in **FIG. 9**, the PI may be generated for the unit and sub unit levels. At the unit and sub unit levels, the PI may be calculated by comparing a model (such as one of the models **56**) of the unit or sub unit to the actual performance of the unit or sub unit or in any other desired manner. In particular, the PI in this context (i.e., at the unit and sub unit levels of the hierarchy) may be, for example, an efficiency with respect to a theoretical maximum or, alternatively, with respect to an empirically derived maximum efficiency based

on actual system performance. The table shown in **FIG. 9** also indicates that the PI need not be calculated for individual devices or loops. However, in some applications it may be desirable to calculate a PI for loops and devices. For example, in the case of calculating a PI for a device, the device manufacturer may store performance information within the device so that during operation the device may calculate a PI based on a comparison of an actual performance characteristic (such as, for example, an operating efficiency) to stored performance information, which may include a theoretical maximum device efficiency. Of course, the index generation routine **51** may also perform this function. In the case of calculating a PI for a loop, the system may, for example, compare the maximum or average loop error (i.e., the steady state error signal) to some predetermined minimum error value which, ideally, may be zero. In this manner, a small loop error may correspond to a PI value that is indicative of good performance.

[**0119**] **FIG. 9** also illustrates that the VI may be calculated at the loop and device levels of the hierarchy. At the device level, the VI may be calculated by comparing the changes or deviations in a device output to an expected or desired amount of change or variation. An excessively high or an excessively low VI value may be indicative of a device failure or malfunction or possibly an imminent failure or malfunction. Likewise, at the loop level, excessively frequent or large magnitude changes in the output of a loop may be indicative of a problem. In any case, the VI for loops and devices may be based on a comparison of actual parameter variability to expected parameter variability, which may be determined theoretically or empirically. Although **FIG. 9** shows that the VI may not be calculated for the unit and sub unit levels, in some applications, it may nevertheless be desirable to generate a VI for these levels.

[**0120**] Further, **FIG. 9** shows that the HI is calculated for the device, loop, sub unit and unit levels. The HI for a device may be based on historical usage of the device. In particular, the device manufacturer may store information relating to the life cycle of the device within the device and, based on the usage of the device and the environmental impacts imparted to the device during its operation (e.g., temperature variations, shocks, etc.), the device may determine to what extent the device has moved along its life cycle curve (i.e., aged). The manufacturer may program a device to provide an HI value which is indicative of the current status of the life cycle of the device. For example, a stroke type valve may have an expected useful operating life cycle of 250,000 full stroke cycles and the manufacturer of the stroke valve device, which is typically a smart field device, has stored in its memory the expected number of lifetime operating strokes along with the current number strokes that the valve has completed. Thus, in the case where an HI value may range from between zero and ten (where zero represents poor health and ten represents perfect health), the HI value generated by the valve may range from zero to ten as the number of strokes rises from zero to 250,000. Of course, the precise relationship between the HI values and the life cycle characteristic (e.g., strokes) may not be linear. To the contrary, many life cycle characteristics follow an exponential characteristic, whereby failure and degradation in device performance/operation progresses more rapidly as time passes, as strokes are completed, etc. Of course, there are many other manners of defining or computing an HI for a device, based on the current detected state of the device and how well it is operating. For example, if the device has two detected minor problems, its HI may decrease.

[**0121**] The HI for a loop, on the other hand, is preferably, but not necessarily, a mathematical combination (such as, for example, a weighted summation or average) of the HI values for the individual devices or functions blocks that make up the loop. Likewise, the HI values for the sub unit and unit levels may also be a mathematical combination of the underlying HI values for loops and sub units. Thus, ultimately, the HI values hierarchy for levels above the device level are based on one or more HI values for devices that have been formed into composite values.

[**0122**] As is also shown in **FIG. 9**, the UI may be calculated for the loop, sub unit and unit levels, but may not necessarily be calculated for the device level. Generally speaking, the UI represents the degree to which a particular asset (e.g., a loop, a sub unit or a unit) is being exploited in comparison to its capacity or desired utilization. For example, the UI value may be based on the amount of time for which a unit, sub unit or loop is being used to perform control or produce outputs. Additionally or alternatively, the UI value may be based on the amount of material which is being processed by the loop, sub unit and/or unit in comparison to the maximum amount that may be processed by that loop, sub unit, unit, etc.

[**0123**] **FIG. 10** is an exemplary chart depicting one manner in which the PI for the unit **500** shown in **FIG. 8** may be calculated. As shown in **FIG. 10**, each of a plurality of loops **575** that make up the unit **500** has its own PI and weighting coefficient, which may be user selected or defined based on the relative importance of that particular loop to the overall operation of the unit **500**. The indexes and weights for the loops **575** may then be mathematically combined using a weighted average to arrive at a PI value of 83.2 for unit **500**.

[**0124**] In a similar manner, the HI for the unit **500** may be calculated as a weighted average of the HI values for all of the devices (and/or loops) that make up the unit **500**. A table such as that shown in **FIG. 11** may be used to represent the values to be included in the weighted average. As is also shown in **FIG. 11, a** textual description may be associated with particular devices and index values. These textual descriptions may provide diagnostic information, maintenance information, etc. based on the HI value and the particular device associated with that HI value.

[**0125**] **FIG. 12** is an exemplary table that illustrates one manner in which the VI may be calculated for a unit, such as the unit **500** shown in **FIG. 8**. As with the HI, the VI calculated for the unit **500** of **FIG. 8** is based on a weighted average of the VI values for the individual devices, loops and/or sub units that make up the unit **500**. Of course, the GUI may provide a user with the ability to see the weighted average data such as that illustrated in FIGS. **10-12** and may enable the user to change the weights.

[**0126**] **FIG. 13** is an exemplary display that may be provided by the GUI in response to an excessive VI value associated with a device and/or loop. As shown in **FIG. 13**, the display may provide one or more possible explanations for an excessively high or an excessively low VI value associated with a particular device. In particular, the display may automatically, or may at the request of the user, indicate

that impulse lines associated with the device have become plugged, that the process is changing, that cavitations are present in an upstream pump, etc. This information may be made available to the GUI by the asset utilization expert **50** based on data analysis tools that detected these conditions. Similarly, as shown in **FIG. 14**, the VI for a valve may be explored further via the GUI by enabling the user to request the display of a graphical representation of the data used to generate the VI for that valve. Additionally, the GUI may display textual messages, either within a graphical display such as that shown in **FIG. 14** or within any other display of the GUI, that indicate one or more possible causes for an excessively high (or possibly an excessively low) VI value. Such causes may be provided by the asset utilization expert **50** based on the data available to it from all of the data sources and data analysis tools. For example, in the case of a valve demonstrating an excessive VI value, the GUI may indicate via textual messages that the valve is sticking, that cavitation may be occurring within the valve, etc.

[**0127**] **FIG. 15** is an exemplary graphical depiction of a display that may be provided by the GUI to enable a user to monitor the performance of a unit, sub unit, loop, device, etc. within the plant **10**. As shown in **FIG. 15**, the values of the various indexes may be plotted as a function of time, thereby enabling a user to more intuitively analyze any trends or any other time-based changes that may be indicative of a problem. Further, such a graphical depiction may also reveal important correlations or relationships between changes in the various indexes. For example, a user may be able to more easily identify a relationship between a decreasing or poor HI value and an increasing or excessively high VI value.

[**0128**] Still further, the GUI may also provide textual messages within the graphical display shown in **FIG. 15** or in some other display or page that indicate to the user current or potential problems, which may be related to the displayed index values or changes thereof. These textual messages may identify possible solutions to the problems which have been identified. Although the graphical information depicted within **FIG. 15** has been scaled so that the indexes are expressed as percentages and the time axis is labeled in units of months, any other units and display resolution may be used instead. For example, in the case where indexes may be or could be changing rapidly, the GUI may enable the user to display index values on an hourly basis, minute by minute, every few seconds, or more frequently (i.e., at a higher time resolution) if desired.

[**0129**] **FIG. 16** is an exemplary graphical display that may be provided by the GUI to enable a user to quickly analyze the operational status and performance of a process area within the plant **10**. As shown in **FIG. 16**, the GUI may graphically depict the physical equipment (and the interconnections therebetween) within a process area **600**. Of course, it should be recognized that although a process area is depicted within the GUI display shown in **FIG. 16**, any other portion of the plant **10** such as, for example, a unit, sub unit, loop, device, etc. may be shown instead to achieve the same or similar results. In any event, the process area **600** is depicted as having a pair of tanks, a plurality of temperature transmitters, pressure transmitters, flow transmitters, etc. and pipes, all of which may be interconnected as shown in **FIG. 16**. Further, each of the physical devices may be displayed along with an associated alphanumeric identifier (e.g., TT-394) that uniquely identifies that device within the plant **10** and may also be displayed along with a graphic meter or gauge (i.e., the partially shaded semi-circular features) that enables a user to quickly determine the status of the sensing parameter associated with that device. For example, the GUI may display a graphic meter or gauge associated with a temperature transmitter and may shade more or less of the meter based on the temperature currently being sensed by the temperature transmitter. Importantly, one or more of the VI, HI, UI and PI values may be displayed for one or more of the devices shown within the area **600**. By way of example only, the HI values for several of the devices that are connected to a tank **610** within the area **600** are displayed. However, more or fewer HI values could be displayed if desired. Additionally, different index values or groups of index values may be displayed for any of the devices that appear within the area **600** as desired. As can be appreciated from the display shown in **FIG. 16, a** user can quickly ascertain whether an area is performing properly and will continue to perform properly. Further, a user can also quickly identify those devices, units, sub units, etc. that may need attention and/or which may be causing a particular problem.

[**0130**] It will also be understood that a user may view successively lower and lower entities within a plant and be provided information about the indexes associated with each of these different entities or views. Thus, for example, a user may look at a view of the plant and see a particular set of indexes for the plant. The user may then focus on one area, such as by clicking on one of the areas within the plant view, and see the indexes associated with that area. Similarly, by clicking on units within the displayed area, the indexes for different units may be viewed. Likewise, indexes for loops, sub units, devices etc. may then be viewed by focusing on these different entities from a view of an entity in which these entities are located. In this manner, a user can quickly find the cause of a lower than (or higher than) expected index at any point or level of the plant.

[**0131**] **FIG. 17** is an exemplary depiction of a display that may be provided by the GUI to enable a user to view audit trail information in connection with any device used within the area **600**. By way of example, a user may use a mouse to click on a given device or its alphanumeric identifier or, alternatively, may enter the identifier via a keyboard, to request a pop-up audit trail window **650** for that device. In this manner, a user can use the audit trail information to determine whether an improper or unacceptable index value may be related to a failure to calibrate the device properly or in a timely manner, whether a device has been configured properly or at all, etc.

[**0132**] **FIG. 18** is an exemplary depiction of a display that may be provided by the GUI to enable a user to perform a more detailed analysis of the data which may be used in generating one or more of the indexes for a particular device within the area **600** or to perform condition monitoring. By way of example only, a vibration analysis for a motor **675** may be displayed in a pop-up window **680**. A user may request such a pop-up window in response to an abnormally high or an abnormally low index value for the unit affected by the motor **675** and/or may request the window if an index value associated with the motor is indicative of a possible problem. Furthermore, if desired, the GUI may automatically provide such pop-up windows containing a detailed

data analysis for those devices, units, etc. that have one or more abnormal index values. Similarly, **FIG. 19** is an exemplary depiction of a display that may be provided by the GUI to enable a user to graphically view or monitor a performance characteristic of a device within the area **600**. By way of example, a pop-up window **690** including a graph of the efficiency of the motor **675** is provided in response to a user request or, alternatively, in response to an automatic request by the asset utilization expert **50**. Such a pop-up window may be requested or needed if one or more of the index values associated with the portion of the process being carried out by the tank **610** is abnormal. In particular, in this example, the user may recognize that the motor **675** has a poor PI value and/or that the area **600** has a poor PI value. As a result, the user may request more detailed information, such as that contained within the pop-up window **690** to determine whether a problem exists with the motor **675**. Also, in this example, the pop-up window may contain a graph of the efficiency of the motor **675** over time where actual efficiency data **700** is graphed against theoretical or empirically derived maximum efficiency data **710**. As discussed above, these two sets of efficiency data may also be used to calculate a PI value over time for the motor **675** by, for example, using the ratio of actual efficiency and theoretical maximum efficiency as the PI value.

[**0133**] **FIG. 20** is yet another exemplary depiction of a display that may be provided by the GUI to enable a user to quickly investigate alarm information, conditions, etc. within the plant **10**. A high level graphical view **750** of the plant **10** may include an alarm banner **760** having one or more pending alarms. Each of the alarms within the alarm banner may be represented using an alphanumeric indicator that is uniquely associated with the device which generated the alarm or event. Additionally, each of the alarms within the banner **760** may also include an information button **770**, which may be selected by a user to generate a pop-up window **775** containing more detailed information relating to that particular alarm. Further, the user may also select the alphanumeric designator for the device causing a particular alarm to investigate the possible reasons for the alarm. When the alphanumeric designator is selected, a pop-up window **780** may be provided by the GUI. The pop-up window **780** may provide one or more response categories **785**, which may facilitate the user's understanding of how a particular alarm should be addressed and within what time frame the alarm should be addressed. By way of example, the pop-up window **780** may indicate that a particular device is no longer communicating, that the device has failed, that the device needs maintenance immediately, or that the device requires maintenance or some other attention soon. Of course more, fewer and/or different response categories may be used instead. The alarm display generated by the GUI at this point may be the integrated display disclosed in U.S. patent application Ser. No. 09/707,580 (filed Nov. 7, 2000) which is hereby expressly incorporated by reference herein. Generally, this alarm display may show process alarms and alerts as well as other types of alarms like maintenance alarms and alerts. Furthermore, information about the alarm, such a specific information provided in the field **775** of the alarm banner may be sent to the GUI or to the asset utilization expert **50** along with the alarm.

[**0134**] FIGS. **21-24** are exemplary depictions of displays that may be provided by the GUI in response to a user's further investigation of an alarm, alert or any other event associated with, for example, a device. Generally speaking, a user may request device status information from a pop-up window such as the pop-up window **780** shown in **FIG. 20**. This detailed status information may provide one or more possible diagnoses of problems that may be responsible for the alarm condition (i.e., failed communication, failed device, needs maintenance now, advisory, etc.). Furthermore, as shown in **FIG. 24, a** user may request detailed help from any status window. This detailed help may provide step by step instructions to guide the user or some other person in rectifying the problem diagnosed by the system. This information may be made available to the GUI from the asset utilization expert **50** and/or from devices themselves, from the process control diagnostic expert **65**, from other analysis tools, etc.

[**0135**] **FIG. 25** is an exemplary depiction of a display that may be provided by the GUI to enable a user to diagnose loop-related problems. A display such as that shown in **FIG. 25** may be provided by the GUI in response to a user's further investigation of an abnormal index value. For example, a user may recognize and/or the system may automatically recognize, that a PI value for particular loop is abnormally low and, in response, may provide a pop-up window **800**. A user may then focus the diagnostic investigation on the devices displayed within the window **800** by clicking on or selecting one or more of the devices to generate additional pop-up windows such as those described above that provide more detailed device status and performance information. Additionally, the asset utilization expert **50** may provide various possible diagnostic solutions that are displayed as text by the GUI within the window **800**. Also, the asset utilization expert **50** may provide predictive diagnostic information via the display **800** that may be used to avoid a potential problem and/or to work around a potential or current problem.

[**0136**] **FIG. 26** is yet another exemplary depiction of a display that may be provided by the GUI that enables a user to analyze the performance and/or status of one or more process control loops. Various parameters and characteristics of one or more loops may be monitored. For example, the operating mode of a loop, whether or not the control of the loop is limited, to what extent a loop input is uncertain, the variation of the loop, etc. may all be monitored simultaneously. Additionally, a control summary that provides a performance indication and a utilization indication may be provided as well. However, for the display shown in **FIG. 26**, the performance indication and the utilization indication may be, but are not necessarily, the same as the PI and UI values for the loop being monitored. The display of **FIG. 26** may be generated by a diagnostic control routine such as that disclosed in the U.S. patent application Ser. Nos. 09/256,585 and 09/499,445 identified previously.

[**0137**] **FIG. 27** is still another exemplary depiction of a display that may be provided by the GUI that enables a user to track work orders which may have been automatically generated by the work order generation routine **54**. The asset utilization expert **50** may provide data to the work order generator routine **54** which causes that routine to automatically generate work orders in response to a problem or potential problem discovered or recognized by the asset utilization expert **50** and/or a user working with the asset utilization expert **50** via the GUI. For example, the asset utilization expert **50** may receive diagnostic information,

maintenance requests, etc. and, in response, may cause the maintenance system to generate a work order that requests a maintenance person to attend to one or more problems in connection with the diagnostic information. Of course, the specifics of the work order generated will depend on the type of problem or situation detected and the standard forms used to correct the problem, such as ordering parts, supplies, etc.

[**0138**] Still further, the work order generation routine **54** could include a business to business communication function that, based on detected actual or predicted problems within the plant **10**, will automatically communicate with a supplier or other business to order parts, supplies, etc. with or without operator or maintenance person intervention. More particularly, the routine **54** can receive notifications of current problems or predicted future problems with devices or other assets based on data provided by or predictions made by the asset utilization expert **50** or any of the data analysis tools, such as the rotating equipment analysis tools. The routine **54** then automatically contacts a supplier via, for example an internet, telephone or other communication connection and orders the parts, equipment or supplies to be delivered to the plant **10** before the device needs to be replaced. In this manner, the work order generation routine **54** limits the down time or helps to assure that there is little or no down time caused by the need to wait for parts, equipment or supplies to fix the problem when it actually occurs. This fact, then makes the plant **10** more efficient.

[**0139**] Referring now to FIGS. **28-31**, the GUI can provide other screens to a user to indicate current or future problems, such as predicted problems, which can be detected by the asset utilization expert **50** or any of the data analysis tools within the plant **10**. In particular, FIGS. **28-31** illustrate displays showing spectral plots of vibration of an element, such as a shaft, within a rotary device performed by the vibration analysis programs **23** of **FIG. 1** and conditions or problems detected by the analysis tool based on these plots. For example, **FIG. 28** illustrates a detected imbalance condition, **FIG. 29** illustrates a detected misalignment condition, **FIG. 30** illustrates a detected looseness condition and **FIG. 31** illustrates a detected worn bearing condition. Of course other conditions for rotary or other devices based on the results of data analysis tools can also be displayed. Still further, the results of these tools can be used to cause the work order generation routine **54** to automatically order replacement parts.

[**0140**] **FIG. 32** is a schematic block diagram of a system **900** that enables one or more independently operable process control plants to remotely access models, optimizers and other data analysis tools such as equipment performance monitoring tools. As shown in **FIG. 32**, the system includes a plurality of independent software vendors (ISVs) **902**, **904** and **906**, each of which provides one or more software applications **908**, **910** and **912** to an application service provider (ASP) **914**. The software applications **908-912** may include a variety of data analysis tools, equipment performance monitoring tools, etc. such as those described above that, preferably, but which do not necessarily, enable plant operators to achieve improved operational efficiencies. The ISVs **902-906** may send the software applications to the ASP **914** via electronic communication links so that the ASP **914** can locally store and execute the software applications **908-912**. Additionally or alternatively, the ISVs **902-906** may provide access to the various software applications **908-912** by the ASP **914** so that the ASP **914** can remotely instantiate one or more of the applications **908-912** locally at the ISVs **902-906**. Still further, the ISVs **902-906** may physically send electronic copies of the applications **908-912** via the mail (i.e., post), for example, and the ASP **914** can locally store and execute the applications **908-912**. As is also shown in **FIG. 32**, the ASP **916** is communicatively coupled to the Internet **916** via any suitable communication link.

[**0141**] The system **900** shown in **FIG. 32** also includes a plurality of independently operable process control plants **918**, **920** and **922** that are communicatively coupled to the Internet **916** via respective servers **924**, **926** and **928**. Each of the process control plants **918-920** may be associated with a different business entity or, alternatively, multiple ones of the process control plants **918-920** may be grouped within a single business entity. The process control plants **918-922** also include respective data historians **930**, **932** and **934** that collect historical process control data and which are well known in the art and, thus, will not be described in further detail herein. Additionally, one or more of the process control plants **918-922** may be communicatively coupled to the ASP **914** via one or more direct communication links, such as links **936** and **938**, which may be implemented using any suitable communication links. Still further, the system **900** includes component, material and/or service suppliers **940** and **942** that are communicatively coupled to the Internet **916** via respective servers **944** and **946**. Of course, while **FIG. 32** shows the ASP **914**, the process control plants **918-922** and the suppliers **940** and **942** as being communicatively coupled via the Internet **916**, it is important to recognize that any other similar open communication network could be used instead without departing from the scope and the spirit of the invention.

[**0142**] Generally speaking, the ASP **914** functions as a remote data processing facility that provides pre-packaged central software infrastructure, customization and support services on a subscription basis to a client or customer, such as, for example, one or more of the plants **918-922**, via the Internet **916**. In this manner, the ASP **914** can provide an outsourced or third party equipment performance monitoring service that enables its customers to reduce net operating costs because the overhead typically associated with equipment performance monitoring software, hardware and technical support staff (e.g., technicians) are not needed. In other words, the customer does not own the software, hardware, etc. or the management responsibilities associated with equipment performance monitoring. Instead, only the results of running the applications provided by the ASP **914** need to be managed by the client. In practice, the ASP **914** may have relatively short term nonexclusive software licensing agreements with the ISVs **902-906**, and the ISVs **902-906** may use the amount of application run time, the number of transactions, screen clicks, or any other suitable metric to determine the fees to be charged to any particular customer.

[**0143**] **FIG. 33** is a more detailed schematic block diagram of the ASP **914** shown in **FIG. 32**. As shown in **FIG. 33**, the ASP **914** includes a server **950** that enables the ASP **914** to communicate with the process control plants **918-922** via the Internet **916**. The ASP **914** also includes one or more processors **952** that are in communication with one or more databases which may be used to store and execute a number of process monitoring applications and tools. In particular,

each of the processors **952** may have access to and execute models **954**, such as the component models (e.g., models of devices, units, areas, loops, etc.) described herein, which may have been created to model one or more of the systems, devices, components or any other entities within the process control plants **918-922**. For example, the models **954** may be used to model the operational characteristics of various types of equipment such as gas turbines, compressors, heat exchanges, pumps, furnaces, steam turbines, expansion turbines, hydraulic turbines, boilers, etc. The models **954** may further include different models for each of the process control plants **918-922** and these models **954** may be altered or changed by persons in the plants **918-922** via communications with the ASP **914** to, for example, reflect changes within the plants **918-922**. The processors **952** may also execute real time optimizers **956**, such as, for example, RTO+ noted above, or any other kinds of optimizers, which can be implemented as described herein with respect to **FIGS. 1 and 2** using data from the process control plants **918-922**. Still further, the processors **952** may have access to and execute other data analysis tools **958**, including, for example, any of the applications or tools within any of the computer systems of **FIG. 1**, such as any of the process control tools, process monitoring tools, equipment or device monitoring tools, index generation tools, work order generation tools, business or other tools or applications described herein. In one example, the process monitoring tool described in U.S. patent application Ser. Nos. 09/256,585 and 09/499,445 may be used to monitor process parameters. Still further, as discussed in greater detail below in connection with FIGS. **37-41**, the processors **952** may generate various reports for customers that may be accessed by these customers via a web site hosted by the ASP **914**. Still further, the processors **952** may have access to web pages **960** that may be used, as described in detail below, to provide a graphic interface to users at the plants **918-922** to the services provided by the ASP **914** such as, for example, the reports and other data analysis described herein. In addition, the processors **952** may store and retrieve process control data and other information pertaining to the plants **918-922** from one or more customer databases **962**.

[**0144**] Each of the process control plants **918-922** may periodically collect data pertaining to the plant and then send that data to the ASP **914** via the Internet **916** and/or one or more of the direct communication links **936** and **938**. Upon receiving process control data from a plant, the ASP **914** may, using an appropriate one of the processors **952**, store that data in one or more of the customer databases **962**. The processors **952** may then access that stored data and execute the appropriate process monitoring and condition monitoring tools for that plant to detect problems within the plant based on the collected data, to provide condition, plant or process monitoring for the plant, and/or to perform optimization for the plant. Of course, the data collected at the plant and sent to the ASP **914** is data previously determined to be necessary to run the desired models **954**, optimizers **956** or other data analysis tools **958** and is collected and sent to the ASP **914** at a periodic or non-periodic rate that is appropriate for the tools or models being executed. Thus, for the optimizers **956**, data may need to be collected and sent at a different rate than for the models **954** or for the performance, process or asset monitoring tools **958**. Of course, as part of an optimization or performance, condition or process monitoring exercise any appropriate models or other tools may be executed and the execution of these models or other tools generally follows the principles discussed above with respect to these same tools in the plant **10** of **FIG. 1**.

[**0145**] In any event, after executing the models **954**, data analysis or optimizer tools **958** and **956**, the processors **952** store the analysis results in the customer databases **962**, where these results can be accessed by the appropriate one of the plants **918-922** via the Internet **916** at any desired time. Alternatively or additionally, these results may be sent directly to the appropriate one of the plants **918-922** via one or more of the direct communication links **936** and **938**. The data resulting from the analysis can be any desired performance modeling data, plots or charts including, for example, those described above with respect to the user interface routines or GUI routine **58**. The results may also be suggestions by, for example, an optimizer for making changes to the plants, indexes for the plants, or any other results capable of being provided by these types of tools.

[**0146**] In one embodiment, a real time optimizer, such as that described above, may be executed on a real time basis, assuming that the plants **918-922** provide sufficient data in a timely periodic manner to enable the proper execution of this optimizer. If desired, the servers **924-928** may automatically collect and send the appropriate data to enable proper operation of the optimizer. In one embodiment, the plants **918-922** may include the asset utilization expert **50** described herein or any other expert data collection tools for use in assuring that the proper data is sent to the ASP **914** in a timely or periodic manner. Thus, the ASP **914** can function as a remote monitoring or data processing facility that can execute the software for asset, performance, condition and process monitoring as well as executing one or more optimizers for different plants. As a result, the process control plants **918-922** do not need to include processing power or applications for these purposes.

[**0147**] If desired, each of the plants **918-922** may update the models **954** stored within the ASP **914** applicable to those plants by sending new or updated models to the ASP **914** via the Internet **916** using any suitable communication format such as XML, HTML, etc. Still further, the ASP **914** may include generic templates for different process plants, areas, units, devices, loops, etc. that may be downloaded to each of the plants **918-922** and these templates may be altered at the plants **918-922** to reflect the actual operation of those plants. The updated models may then be sent back to the ASP **914** as models to be implemented in asset, condition or process monitoring or in the optimizers for the plant. In this manner, changes to the plants **918-922** may be adequately or accurately reflected within the ASP **914**.

[**0148**] Additionally, if desired, the ASP **914** may be used to perform maintenance and purchasing activities for one of the process control plants **918-922**. In particular, the ASP **914** may analyze process control information received from a plant and may, based on the results of the analysis, schedule maintenance activities via the Internet **916** or some other communication link. For example, the ASP **914** may schedules a maintenance outage based within a process control plant based on the analysis results. Alternatively or additionally, the ASP **914** may order a replacement part needed to perform some scheduled maintenance activity from one of the suppliers **940** and **942** via the Internet **916**, thereby eliminating the need for a process control plant to perform these functions directly.

[0149] **FIG. 34** is an exemplary flow diagram that illustrates a routine **1000** that may be used by a process control plant (such as any of the plants **918-922**) to establish a business relationship with the ASP **914** shown in **FIGS. 32 and 33**. Block **1002** enables a user at one of the plants **918-922** shown in **FIG. 32** to download contract terms and conditions via the Internet **916** from the ASP **914**. The ASP **914** may send contract templates containing standard terms and conditions as wells as prequalification information to a requesting plant using any suitable electronic document format such as, for example, Microsoft Word, Adobe PDF, etc. Alternatively, however, the requested electronic documents may be sent to the requesting plant within an electronic mail (i.e., an email) format and, if desired, the electronic contract documentation requested in block **1002** may be sent from the ASP **914** to one of the plants **918-922** using one of the direct communication links **936** and **938**.

[0150] In block **1004**, the potential customer (which is typically a plant owner or operator) wanting to establish a business relationship with the ASP **914** to use the data analysis and other services offered by the ASP **914** may execute the contract by signing the contract and returning the executed contract to the ASP **914**. The contract may be signed by hand and returned in hard copy form to the ASP **914** via facsimile, mail service, etc. or, alternatively, the contract may be executed electronically (i.e., using an electronic signature) and returned to the ASP **914** via the Internet **916**, via one or more of the direct communication links **936** and **938**, or using any other communication link. Of course, the final terms and conditions agreed to in the contract may be any desired contract provisions such as, for example, the customer (i.e., plant owner) may agree to share a portion of the profits and/or losses of the plant based on the use of the tools at the ASP **914** and the implementation of the results of those tools in the plant.

[0151] Upon receipt of the executed contract, block **1006** configures a customer account for the customer requesting the services offered by the ASP **914**. The configuration of a customer account preferably, but not necessarily, includes the formation of a web account that includes a plurality of web pages, some of which may be customized specifically for the customer that, as described in greater detail below, may be accessed by the customer to view data analysis results, to change account information or to use any of the services offered by the ASP **914**. Additionally, the ASP **914** creates a customer record or account within one or more of the customer databases **962**, which includes, amongst other information, details pertaining to the equipment, processes, etc. that are being used within the customer's process control plant. After the customer accounts and records have been established by block **1006**, block **1008** notifies the customer that the contracting process is complete. Preferably, but not necessarily, the ASP **914** sends this notification via email to the customer. However, any other form of communication to notify the customer may be used instead.

[0152] **FIG. 35** is an exemplary flow diagram of a routine **1100** that may be used by the ASP **914** shown in **FIGS. 32 and 33** to design a data model for a customer (i.e., a plant or group of plants). In block **1102**, a customer (e.g., one of the plants **918-922**) downloads design data requirements or specifications from the ASP **914** by communicating via the Internet **916** and interacting with one or more web pages (within a web site) provided by the ASP **914**. The design data requirements may pertain to a particular type or piece of equipment being used within the customer's plant and may include various operating parameters or curves, performance characteristics, or any other features or specifications associated with operation of the equipment. In block **1104**, the customer sends the required design data, as specified by the design data requirements sent in block **1102**, to the ASP **914**. The required design data may be sent by the customer to the ASP **914** via hard copy form using conventional mail, via facsimile, via email, or using any other desired transmission method. Alternatively, the ASP **914** may obtain the required design data from a third party, such as, for example, one of the suppliers **944** and **946** shown in **FIG. 32**. In that case, the customer may download the design data requirements in block **1102** and may provide only a portion of the required design data, such as, for example, a device type manufacture model number etc. Then, in block **1104** the customer may send the design data to the ASP **914** which, in turn, obtains the missing design data from one of the suppliers **944** and **946** via the Internet **916**. In this manner, the customer does not have to store the design data associated with all of the components, devices, systems, etc. distributed throughout its plant. Instead, the ASP **914** can obtain the required design data directly from the component supplier or manufacturer. In some cases, the supplier or manufacturer may provide a web site, including a number of web pages, that may provide the design data information required by the ASP **914**.

[0153] In block **1106**, the ASP **914** converts received design data into a design data spreadsheet or template using, for example, Microsoft Excel or any other spreadsheet generation program. In block **1108**, the ASP **914** fits the design data in the design data template to an appropriate model, which may be selected from the models **954** that are stored within the ASP **914** and, in block **1110**, the ASP **914** updates the customer databases **962** to reflect the fact that the model fitting has been completed. In block **1112**, the ASP **914** sends an electronic mail (e.g., an email) via the Internet **916** to the customer to notify the customer that the model fitting is complete and to explain to the customer how to download a template that, as described below, enables process data be submitted to the ASP **914** for analysis by the data analysis tools **958** and/or the optimizers **956**.

[0154] **FIG. 36** is an exemplary flow diagram of a routine **1200** that may be used by the ASP **914** shown in **FIGS. 32 and 33** to process and/or to analyze process control data. In block **1202**, a user may download a design data template or spreadsheet, which may have been created using the method shown in **FIG. 35**, from the ASP **914** via the Internet **916** or, alternatively, via one of the direct communication links **936** and **938**. In block **1204**, the user may populate the design data spreadsheet or template with appropriate process data, which may, for example, be retrieved from one of the data historians **930-934**. By way of example only, the design data template or spreadsheet may contain model parameters pertaining to a single unit or device within a process control plant and, thus, the template requires actual measured process control data associated with the corresponding physical unit or device within the process control system. For instance, a particular design data template may pertain to a boiler unit within the plant **918**, and a user at the plant **918** may download that particular template and populate the template (i.e., fill-in the template or spreadsheet) with actual parameter values associated with that boiler unit.

[0155] Block **1206** sends the populated template to the ASP **914** via one of the direct links **936** and **938** or, if desired, via the Internet **916** and block **1208** stores the populated design data template in an appropriate one of the customer databases **962**. Block **1210** retrieves a copy of the stored populated design data template from the one of the customer databases **962**, and block **1212** pre-processes the data within the template. The pre-processing performed by block **1212** may use data reconciliation and validation techniques such as, for example, those provided by the commercially available real time optimizer system RTO+ described above. In general, the data reconciliation and validation performed by block **1212** pre-processes process control data to eliminate aberrant data values, which may result from a device that is providing intermittent operation due to faulty wiring, for example. Further, the pre-processing performed by block **1212** may recognize and correct process data that is biased due to, for example, sensor drift, miscalibration, etc. and may also reject aberrant values and/or interpolate between valid data to fill-in missing or rejected aberrant values. In any event, block **1212** may use any desired data pre-processing techniques without departing from the scope and the spirit of the invention.

[0156] Block **1214** processes the pre-processed populated design data template using one or more of the data analysis tools **958**, the models **954** and the optimizers **956** discussed in greater detail above and which are shown by way of example in **FIG. 33**. Block **1216** then validates the results of block **1214** and block **1218** stores the validated results in an appropriate one of the customer databases **962**. Block **1220** may then notify the customer via email, facsimile, or using any suitable messaging method that the data analysis results are available.

[0157] Once data analysis results for a particular customer have been stored in one of the customer databases **962**, the ASP **914** may generate a hypertext markup language (HTML) results report file or web pages for that customer. The HTML results report file may contain analysis results in the form of an Excel spreadsheet, for example, and may be accessed and viewed via the Internet **916** by the customer locally from a plant (e.g., any of the plants **918-922**) using any suitable Internet browser.

[0158] FIGS. **37-41** are exemplary web pages containing reports and analysis results that may be displayed to a customer. In particular, **FIG. 37** is an exemplary depiction of a web page containing summary tables of the plants and the equipment within those plants that is being monitored or analyzed by the ASP **914**. **FIG. 38** is an exemplary depiction of a web page containing a summary of data analysis results for a particular piece of equipment (i.e., compressor CR-1000) within one of the customer's plants that is being monitored by the ASP **914**. The data analysis results may include, for example, efficiency parameters, costs of degradation, actual values versus predicted values, historical trending of equipment characteristics, deviation from design parameters, etc. **FIG. 39** is an exemplary depiction of a web page containing an efficiency analysis of a particular piece of equipment (i.e., compressor CR-1000) being monitored by the ASP **914**, **FIG. 40** is an exemplary depiction of a web page containing an analysis of an actual operational characteristic of the compressor CR-1000 versus the predicted operational characteristic, which in this example is exit temperature, and **FIG. 41** is an exemplary depiction of a web page containing an analysis of the cost of performance deviation due to the compressor CR-1000. Of course, each customer may have Internet access to a number of web pages stored within the ASP **914** and, preferably, but not necessarily, each customer may access these web pages (i.e., those pages containing data analysis results) via a secured area within the web site provided by the ASP **914**.

[0159] While the asset utilization expert **50** and other process elements have been described as preferably being implemented in software, they may be implemented in hardware, firmware, etc., and may be implemented by any other processor associated with the process control system **10**. Thus, the elements described herein may be implemented in a standard multi-purpose CPU or on specifically designed hardware or firmware such as an application-specific integrated circuit (ASIC) or other hard-wired device as desired. When implemented in software, the software routine may be stored in any computer readable memory such as on a magnetic disk, a laser disk, or other storage medium, in a RAM or ROM of a computer or processor, in any database, etc. Likewise, this software may be delivered to a user or a process control plant via any known or desired delivery method including, for example, on a computer readable disk or other transportable computer storage mechanism or over a communication channel such as a telephone line, the internet, etc. (which are viewed as being the same as or interchangeable with providing such software via a transportable storage medium). Also, while the expert **50** is described as possibly being a rule-based expert, other types of expert engines could be used as well, including those which use other known data mining techniques.

[0160] Thus, while the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, it will be apparent to those of ordinary skill in the art that changes, additions or deletions may be made to the disclosed embodiments without departing from the spirit and scope of the invention.

What is claimed is:

1. A method of analyzing a process, comprising the steps of:

collecting process data within a process control plant;

transmitting the collected process data to a remote data processing facility;

analyzing the process data within the remote data processing facility to generate analysis data using one of a plurality asset or process analysis tools stored within a database of the remote data processing facility; and

transmitting the analysis data to the process control plant.

2. The method of claim 1, wherein the step of analyzing the process data within the remote data processing facility to generate analysis data using the one of the plurality of asset or process analysis tools includes the step of using one of a process control tool, a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and a business tool.

3. The method of claim 1, wherein the step of transmitting the collected process data to the remote data processing facility includes the step of transmitting the collected process data via an open network.

4. The method of claim 3, wherein the step of transmitting the collected process data via the open network includes the step of transmitting the collected process data using the Internet.

5. The method of claim 1, wherein the step of analyzing the process data within the remote data processing facility to generate analysis data using the one of the plurality of asset or process analysis tools includes the step of using a model of a portion of the process control plant.

6. The method of claim 5, wherein the step of using the model of the portion of the process control plant includes the step of using one of a device model, a loop model and a unit model.

7. The method of claim 1, wherein the step of analyzing the process data within the remote data processing facility to generate analysis data using the one of the plurality of asset or process analysis tools includes the step of using an optimization tool.

8. The method of claim 1, wherein the step of transmitting the analysis data to the process control plant includes the step of transmitting one of problem data, condition data, plant data, process data, device data and optimization data.

9. The method of claim 1, wherein the step of transmitting the analysis data to the process control plant includes the step of transmitting one of a health index value, a performance index value, a utilization index value and a variability index value that is associated with a portion of the process control plant.

10. The method of claim 1, wherein the step of collecting the process data within the process control plant includes the step of collecting a predetermined set of process data for use by the plurality of asset or process analysis tools.

11. The method of claim 1, wherein the step of collecting the process data within the process control plant includes the step of repeatedly collecting the process data at a predetermined rate.

12. The method of claim 1, further comprising the step of transmitting update information from the process control plant to the remote data processing facility to update the one of the plurality of asset or process analysis tools.

13. The method of claim 12, wherein the step of transmitting the update information from the process control plant to the remote data processing facility to update the one of the plurality of asset or process analysis tools includes the step of transmitting updated model information.

14. The method of claim 12, wherein the step of transmitting the update information from the process control plant to the remote data processing facility to update the one of the plurality of asset or process analysis tools includes the step of using a communication format based on a markup language.

15. A system for analyzing process data, comprising:

a server that has a processor and that is communicatively coupled to a remote process control plant;

a database that is communicatively coupled to the server; and

a plurality of asset or process analysis tools stored within the database, wherein the processor is programmed to use one of the plurality of asset or process analysis tools to analyze the process data received from the remote process control plant to generate analysis data and to send the analysis data to the remote process control plant.

16. The system of claim 15, wherein the server is communicatively coupled to the remote process control plant via an open network.

17. The system of claim 16, wherein the open network is the Internet.

18. The system of claim 15, wherein the plurality of asset or process analysis tools includes one of a process control tool, a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and an accounting tool.

19. The system of claim 15, wherein the one of the plurality of asset or process analysis tools includes a model of a portion of the remote process control plant.

20. The system of claim 19, wherein the model of the portion of the remote process control plant includes one of a device model, a loop model and a unit model.

21. The system of claim 15, wherein the one of the plurality of asset or process analysis tools includes an optimization tool.

22. The system of claim 15, wherein the analysis data includes one of problem data, condition data, plant data, process data, device data and optimization data.

23. The system of claim 15, wherein the analysis data includes one of a health index value, a performance index value, a utilization index value, and a variability index value that is associated with a portion of the remote process control plant.

24. The system of claim 15, wherein the processor is further programmed to receive update information from the remote process control plant for updating the one of the plurality of asset or process analysis tools.

25. The system of claim 24, wherein the update information includes updated model information.

26. The system of claim 25, wherein the processor is further programmed to send the analysis data to the process control plant using a communication format based on a markup language.

27. A system that analyzes process data, comprising:

a computer readable medium; and

a first routine stored on the computer readable medium and adapted to be executed by a processor that receives process data from a remote process control plant;

a second routine stored on the computer readable medium and adapted to be executed by the processor that analyzes the process data received from the remote process control plant to generate analysis data; and

a third routine stored on the computer readable medium and adapted to be executed by the processor that sends the analysis data to the remote process control plant.

28. The system of claim 27, wherein the third routine is further adapted to send the analysis data to the remote process control plant via the Internet.

29. The system of claim 27, wherein the plurality of asset or process analysis tools includes one of a process control tool, a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and a business tool.

30. The system of claim 27, wherein the plurality of asset or process analysis tools includes an optimization tool.

31. The system of claim 27, wherein the analysis data includes one of a health index value, a performance index

value, a utilization index value and a variability index value that is associated with a portion of the remote process control plant.

32. A method of analyzing asset utilization, comprising the steps of:

receiving process data from a remote process control plant via the Internet;

analyzing the process data to generate analysis data using one of a plurality of asset or process analysis tools stored within a database; and

transmitting the analysis data to the remote process control plant via the Internet.

33. The method of claim 32, wherein the step of analyzing the process data using one of the plurality of asset or process analysis tools includes the step of using one of a process control tool, a process monitoring tool, an equipment monitoring tool, a device monitoring tool, an index generation tool, a work order generation tool and an accounting tool.

34. The method of claim 32, wherein the step of analyzing the process data using the one of the plurality of asset or process analysis tools includes the step of using a model of a portion of the remote process control plant.

35. The method of claim 32, wherein the step of analyzing the process data using the one of the plurality of asset or process analysis tools includes the step of using an optimization tool.

36. The method of claim 32, wherein the step of transmitting the analysis data to the remote process control plant includes the step of transmitting one of problem data, condition data, plant data, process data, device data and optimization data.

37. The method of claim 32, wherein the step of transmitting the analysis data to the remote process control plant includes the step of transmitting one of a health index value, a performance index value, a utilization index value and a variability index value that is associated with a portion of the remote process control plant.

38. A method of analyzing process control data, comprising the steps of:

sending a first data template to a customer associated with a process control plant;

receiving a second data template that is formed using the first data template and process control information generated within the process control plant;

analyzing the process control information within the second data template to produce analysis results; and

notifying the customer of the availability of the analysis results via an internet.

39. The method of claim 38, wherein the step of sending the first data template to the customer includes the step using the internet to send the first data template in response to a request from the customer received via a web site associated with an application service provider.

40. The method of claim 38, wherein the step of receiving the second data template that is formed using the first data template and process control information generated by the process control plant associated with the customer includes the step of receiving process control information associated with a particular piece of equipment within the process control plant.

41. The method of claim 38, wherein the step of analyzing the process control information within the second data template to produce the analysis results includes the step of using one of a data analysis tool, a model and an optimizer to analyze the process control information.

42. The method of claim 38, wherein the step of notifying the customer of the availability of the analysis results via the internet includes the step of using one of an electronic mail and a web page to notify the customer.

43. The method of claim 38, further comprising the step of storing the second data template and the analysis results in a customer database.

44. The method of claim 38, further comprising the steps of pre-processing the process control information using a data reconciliation routine and validating the analysis results prior to notifying the customer of the availability of the analysis results.

45. The method of claim 38, further comprising the step of displaying a web page to the customer containing a report based on the analysis results, wherein the report includes one of performance information, cost information and historical information associated with a particular piece of equipment within the process control plant.

46. A system for use in analyzing process control data, the system comprising:

a computer readable medium;

a first routine stored on the computer readable medium and adapted to be executed by a processor that enables a customer to contract with an application service provider;

a second routine stored on the computer readable medium and adapted to be executed by the processor that designs a data model based on design data received from the customer and a model stored by the application service provider; and

a third routine stored on the computer readable medium and adapted to be executed by the processor that processes the data model using process control data received from the customer and that provides analysis results to the customer via an internet communication link.

47. The system of claim 46, wherein the first routine is further adapted to download contract terms and conditions to the customer via the internet communication link.

48. The system of claim 46, wherein the first routine is further adapted to configure a customer account in response to receiving an executed contract from the customer.

49. The system of claim 46, wherein the second routine is further adapted to download design data requirements to the customer via the internet communication link.

50. The system of claim 46, wherein the second routine is further adapted to use the design data received from the customer to form a design data spreadsheet and to fit the design data into the model stored by the application service provider.

51. The system of claim 46, wherein the third routine is further adapted to download a process data template to the customer via the internet communication link.

52. The system of claim 46, wherein the third routine is further adapted to pre-process the process control data using a data reconciliation routine.

53. The system of claim 46, wherein the third routine is further adapted to use one of a data analysis tool and an optimizer to process the data model.

54. The system of claim 46, wherein the third routine is further adapted to store the analysis results in a customer database and to notify the customer via the internet communication link of the availability of the analysis results.

55. The system of claim 46, wherein the third routine is further adapted to display a web page to the customer containing a report based on the analysis results, wherein the report includes one of performance information, cost information and historical information associated with a particular piece of equipment within a process control plant associated with the customer.

56. A system for use analyzing process control data, the system comprising:

a server that is communicatively coupled to an internet communication link; and

a processor communicatively coupled to the server and to a plurality of databases, wherein the processor is programmed to download a process control data template to a customer via the internet communication link and wherein the processor is further programmed to use one of an optimizer and a data analysis tool to analyze a populated design data template that is formed using the process control data template and process data generated within a process plant associated with the customer.

57. The system of claim 56, wherein the plurality of databases includes one of a data analysis tools database, a models database, an optimizers database, a web pages database and a customer database.

58. A method of maintaining a process control system, comprising the steps of:

sending a first data template to a customer associated with a process control plant;

receiving a second data template that is formed using the first data template and process control information generated within the process control plant;

analyzing the process control information within the second data template to produce analysis results; and

scheduling maintenance activities for the process control plant based on the analysis results via an internet communication link.

59. The method of claim 58, wherein the step of scheduling maintenance activities for the process control plant based on the analysis results via an internet communication link includes the step of scheduling a maintenance outage within the process control plant based on the analysis results.

60. The method of claim 58, wherein the step of scheduling maintenance activities for the process control plant based on the analysis results via an internet communication link includes the step of ordering a part from a supplier via the internet communication link based on the analysis results.

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