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(12) **United States Patent**
Al-Yami et al.

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(45) **Date of Patent: Dec. 1, 2015**

(54) **SYSTEMS AND METHODS FOR DRILLING FLUIDS EXPERT SYSTEMS USING BAYESIAN DECISION NETWORKS**

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(73) Assignees: **Saudi Arabian Oil Company**, Dhahran (SA); **The Texas A&M University System**, College Station, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 296 days.

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(51) **Int. Cl.**

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G06N 7/00	(2006.01)
G06F 17/00	(2006.01)

(52) **U.S. Cl.**

CPC . ***G06N 5/02*** (2013.01); ***G06N 7/005*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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Assistant Examiner — Mikayla Chubb
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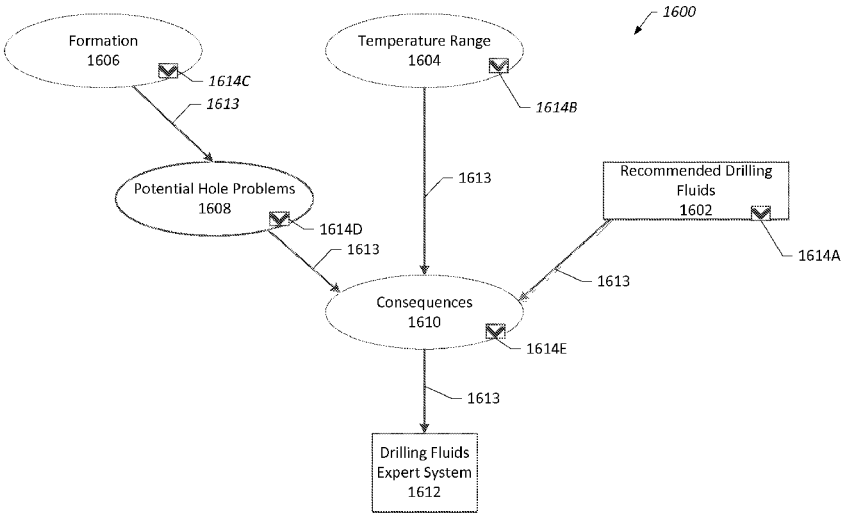
(57) **ABSTRACT**

Provided are systems and methods for drilling fluids expert systems using Bayesian decision networks to determine drilling fluid recommendations. A drilling fluids expert system includes a drilling fluids Bayesian decision network (BDN) model that receives inputs and outputs recommendations based on Bayesian probability determinations. The drilling fluids BDN model includes a temperature ranges uncertainty node, a formation uncertainty node, a potential hole problems uncertainty node, and a drilling fluids decision node.

20 Claims, 34 Drawing Sheets



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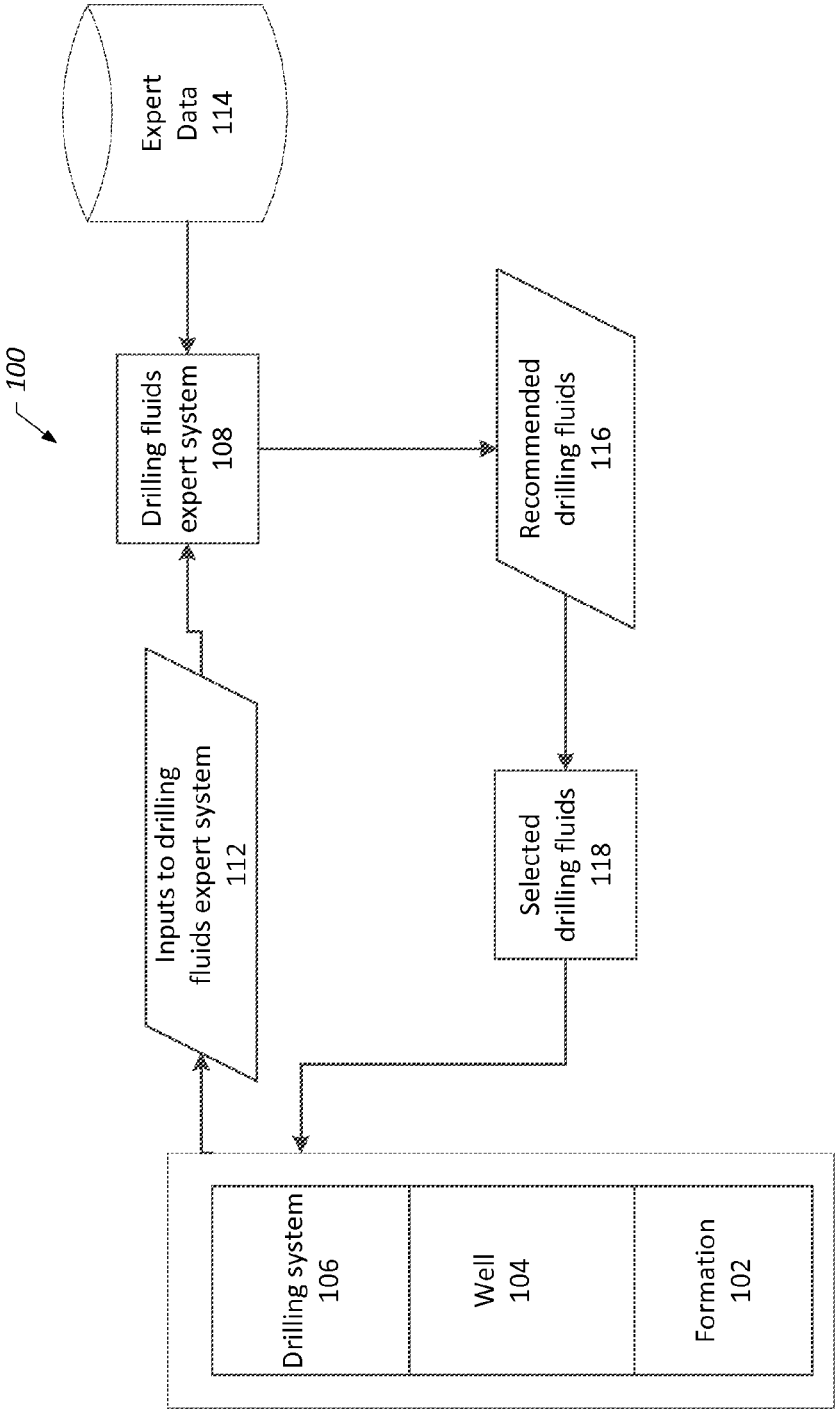
100
Expert Data 114
Drilling fluids expert system 108
Recommended drilling fluids 116
Inputs to drilling fluids expert system 112
Selected drilling fluids 118
Drilling system 106
Well 104
Formation 102

FIG. 1

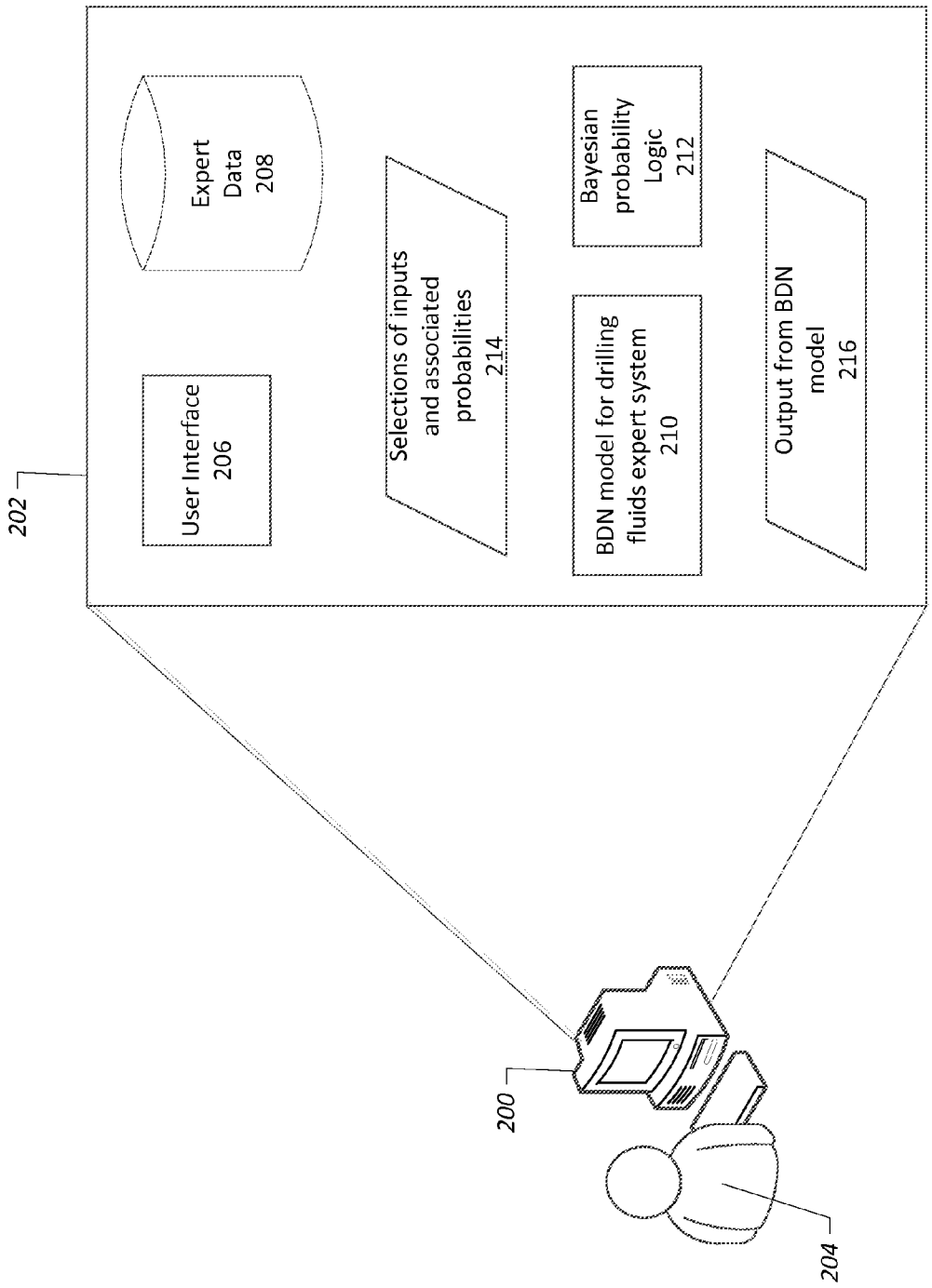
202
User Interface 206
Expert Data 208
Selections of inputs and associated probabilities 214
BDN model for drilling fluids expert system 210
Bayesian probability Logic 212
Output from BDN model 216
200
204

FIG. 2

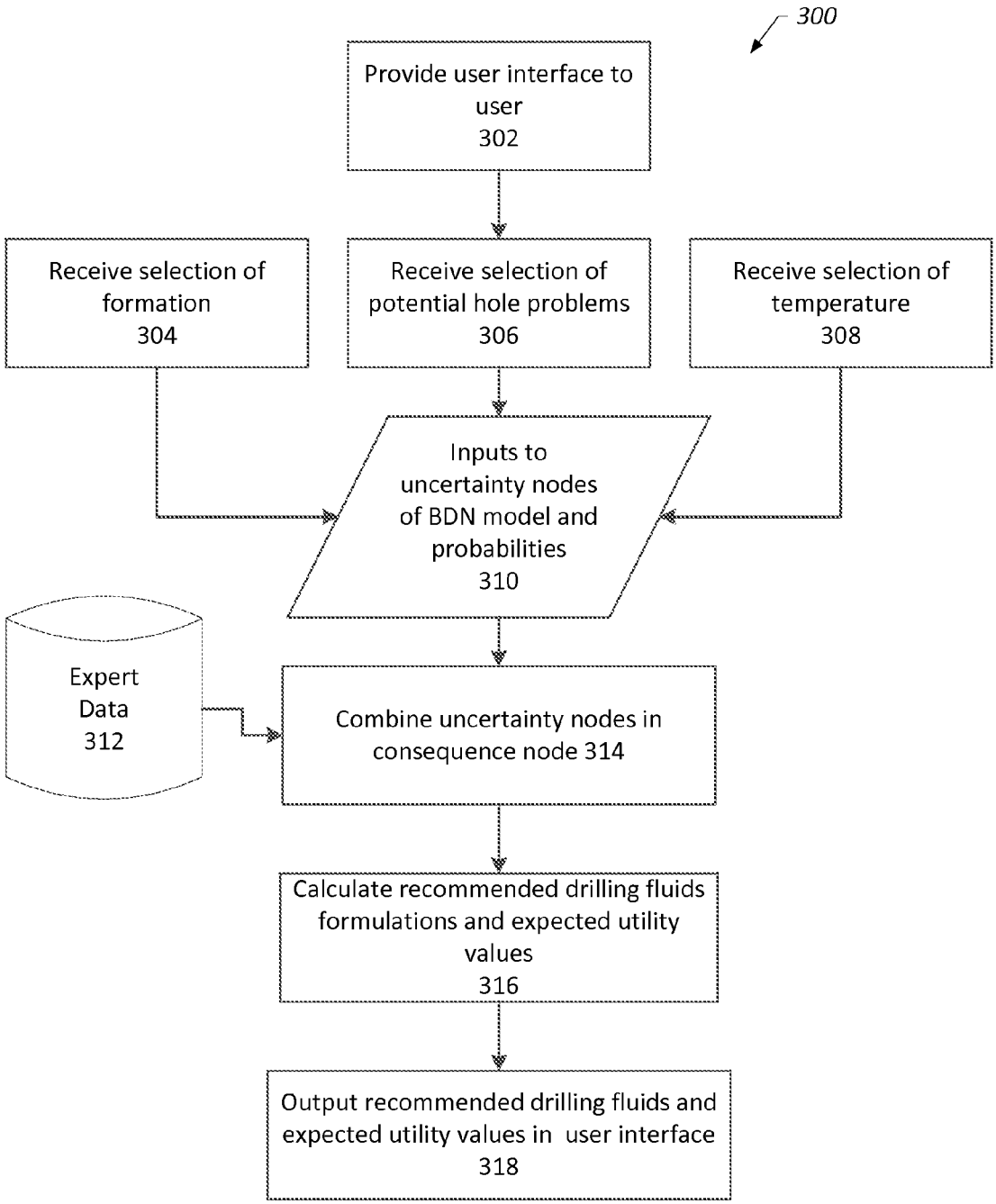
300
Provide user interface to user
302
Receive selection of formation
304
Receive selection of potential hole problems
306
Receive selection of temperature
308
Inputs to uncertainty nodes of BDN model and probabilities
310
Expert Data
312
Combine uncertainty nodes in consequence node 314
Calculate recommended drilling fluids formulations and expected utility values
316
Output recommended drilling fluids and expected utility values in user interface
318

FIG. 3

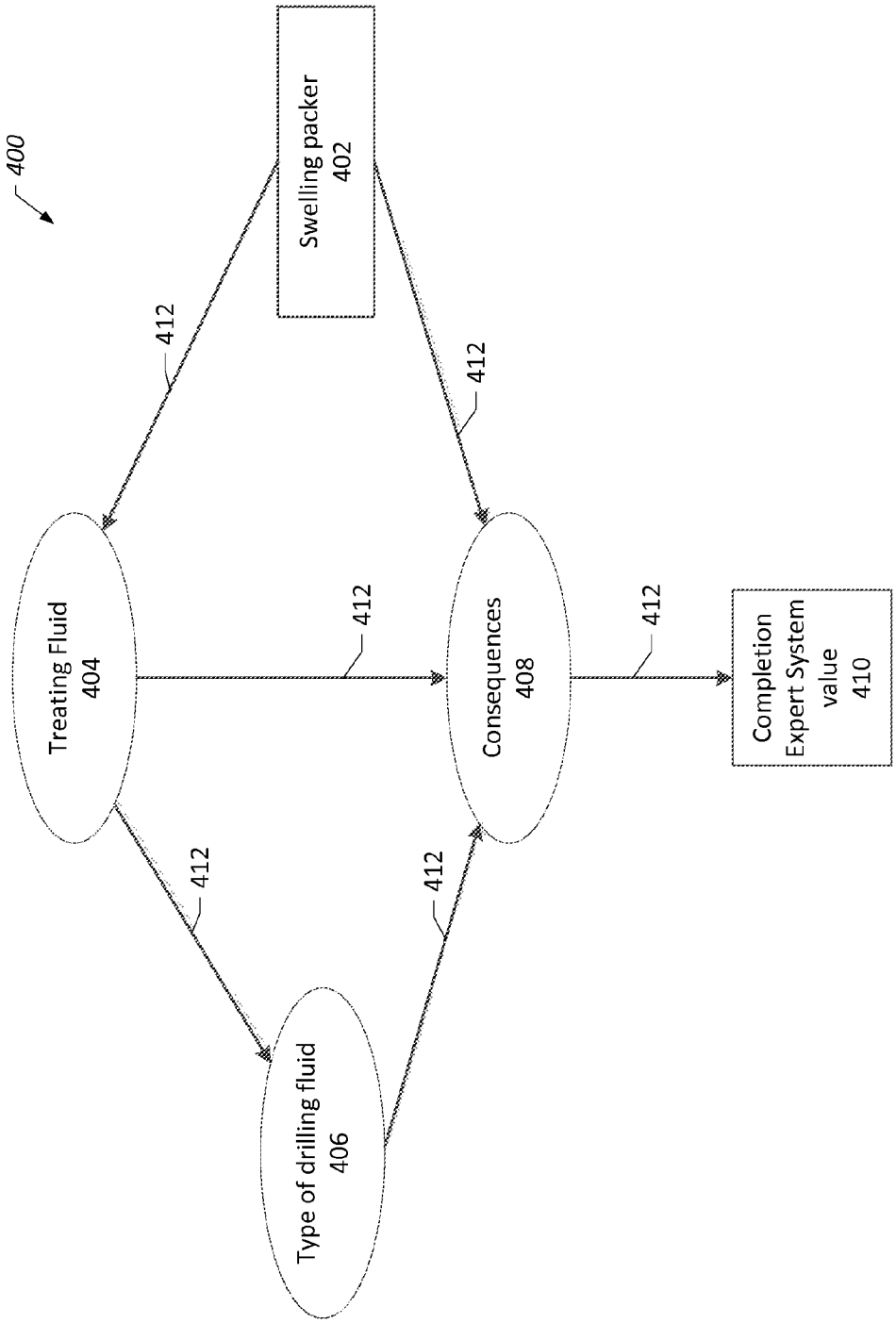
400
Swelling packer
402
412
412
Treating Fluid
404
412
Consequences
408
412
Completion
Expert System
value
410
412
412
Type of drilling fluid
406

FIG. 4

FIG. 5

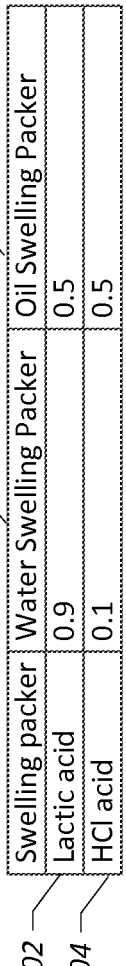

FIG. 6

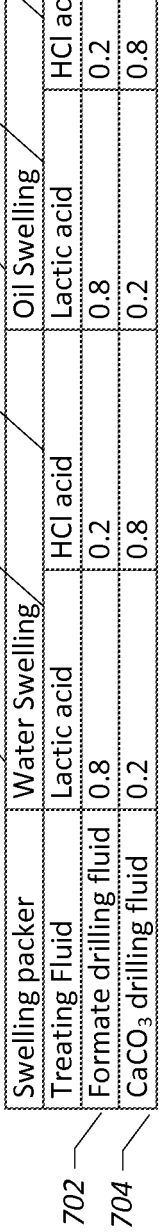

FIG. 7

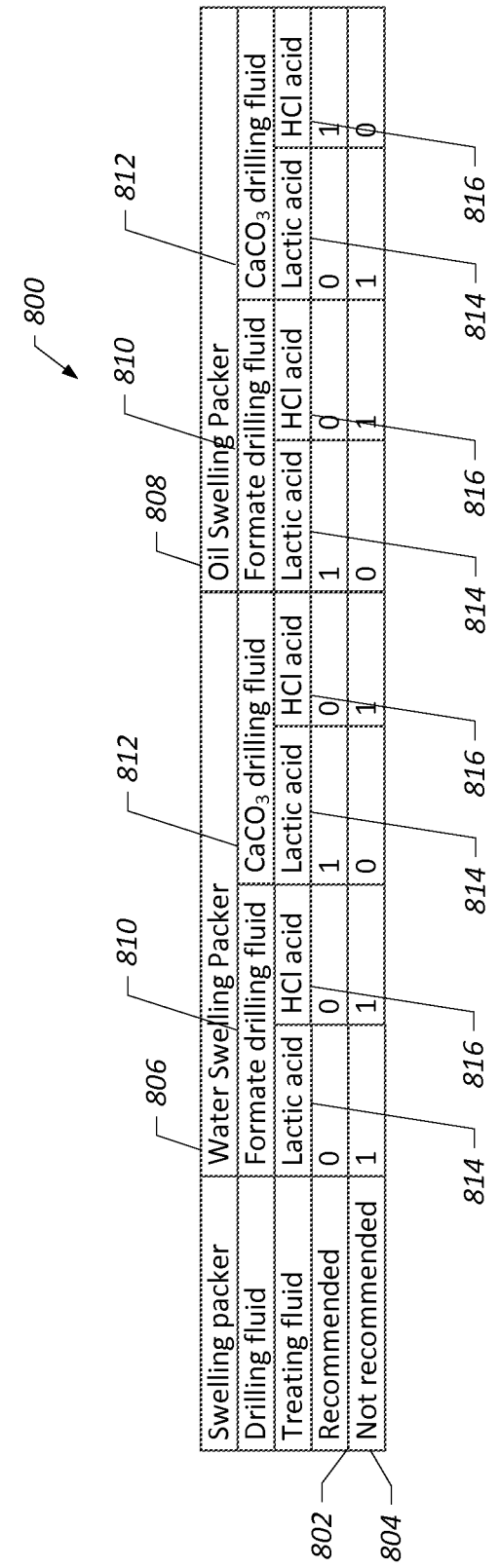
800
806
810
812
808
802
804
814
816
Swelling packer
Water Swelling Packer
Oil Swelling Packer
Drilling fluid
Formate drilling fluid
$CaCO_3$ drilling fluid
Formate drilling fluid
$CaCO_3$ drilling fluid
Treating fluid
Lactic acid
HCl acid
Lactic acid
HCl acid
Lactic acid
HCl acid
Recommended
0
0
1
0
1
0
1
Not recommended
1
1
0
1
0
1
0

FIG. 8

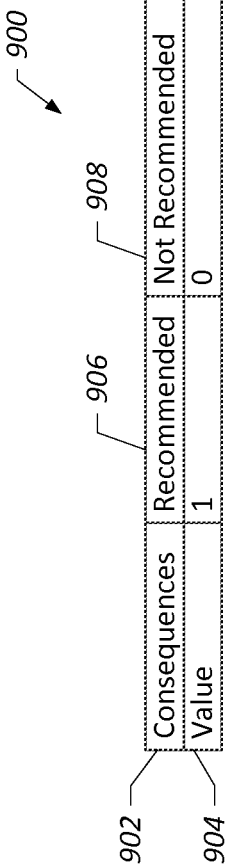
900
906
908
902
904
Consequences
Recommended
Not Recommended
Value
1
0

FIG. 9

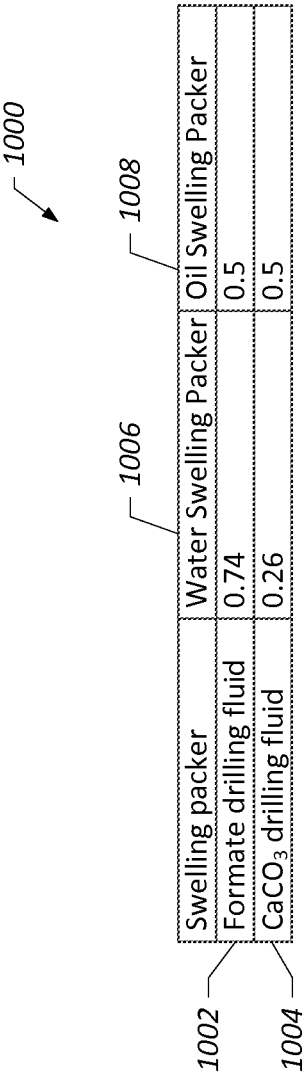
1000
1008
1006
Swelling packer
Water Swelling Packer
Oil Swelling Packer
Formate drilling fluid
0.74
0.5
$CaCO_3$ drilling fluid
0.26
0.5
1002
1004

FIG. 10

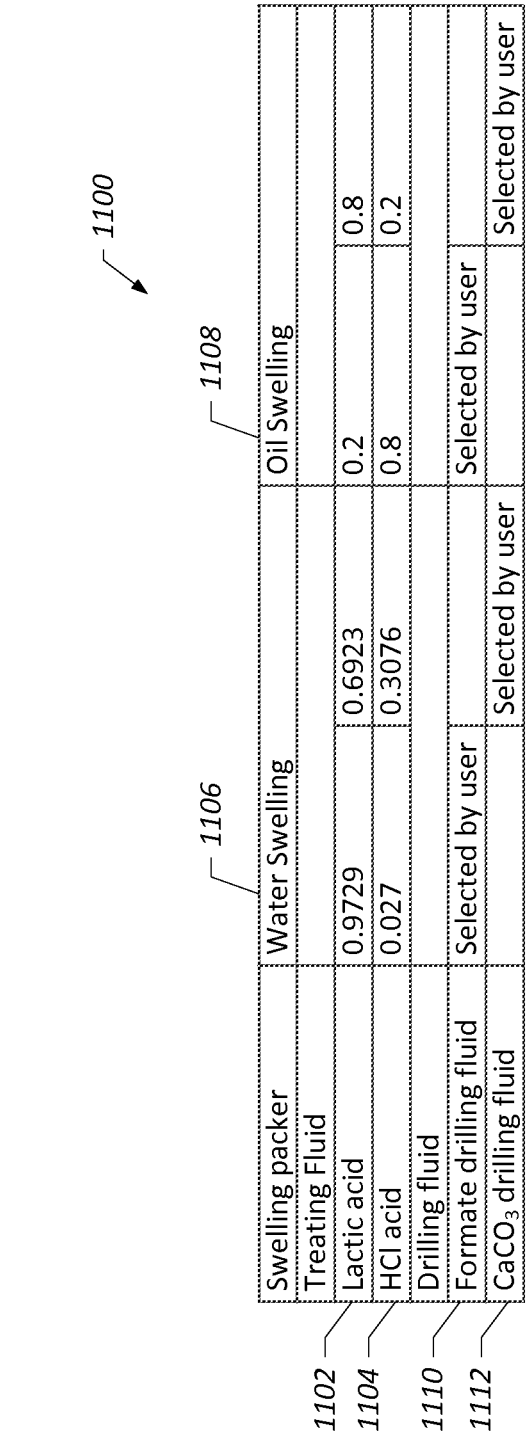
1100
1106
1108
Swelling packer
Water Swelling
Oil Swelling
Treating Fluid
Lactic acid
0.9729
0.6923
0.2
0.8
HCl acid
0.027
0.3076
0.8
0.2
Drilling fluid
Formate drilling fluid
Selected by user
Selected by user
$CaCO_3$ drilling fluid
Selected by user
Selected by user
1102
1104
1110
1112

FIG. 11

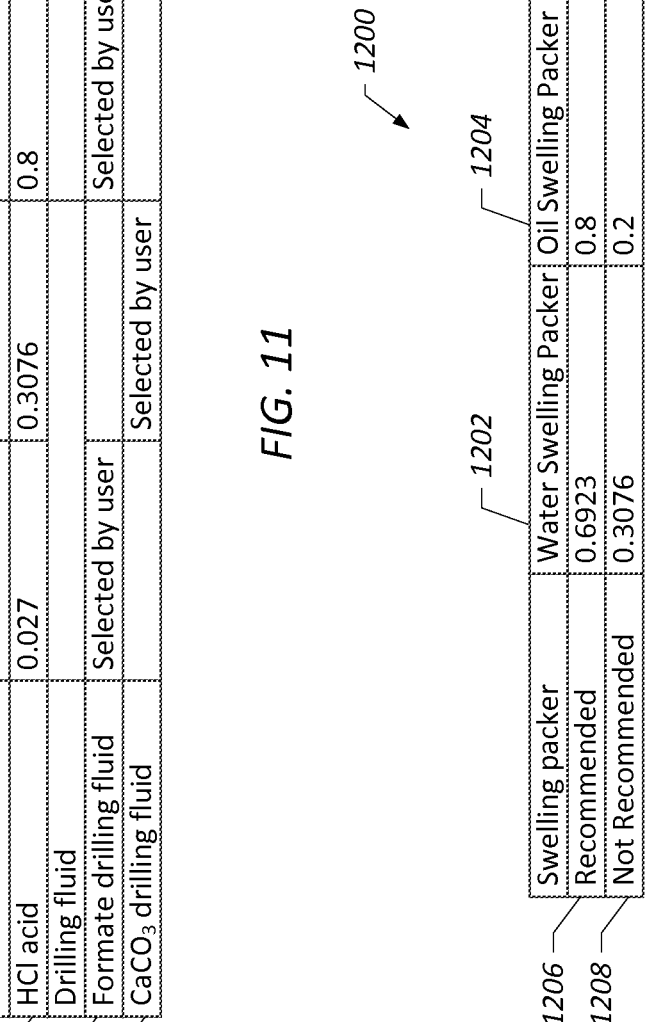
1200
1202
1204
Swelling packer
Water Swelling Packer
Oil Swelling Packer
Recommended
0.6923
0.8
Not Recommended
0.3076
0.2
1206
1208

FIG. 12

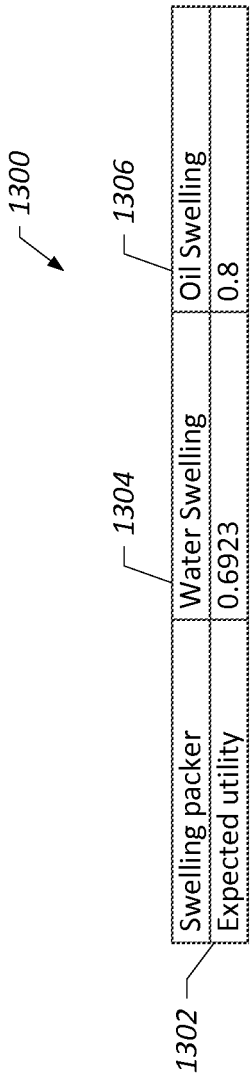
1300
1306
1304
Swelling packer
Water Swelling
Oil Swelling
Expected utility
0.6923
0.8
1302

FIG. 13

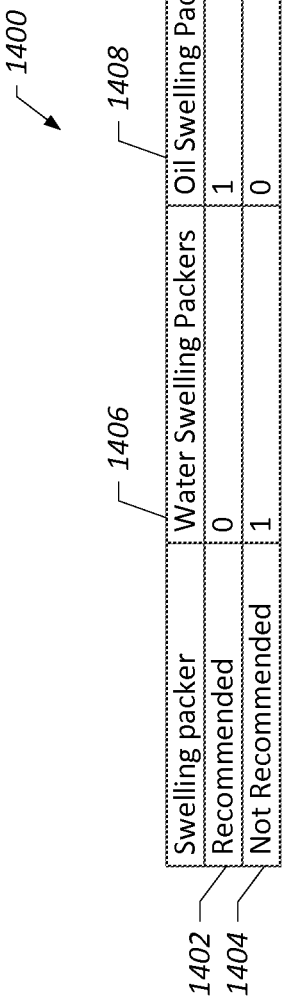
1400
1408
1406
Swelling packer
Water Swelling Packers
Oil Swelling Packers
Recommended
0
1
Not Recommended
1
0
1402
1404

FIG. 14

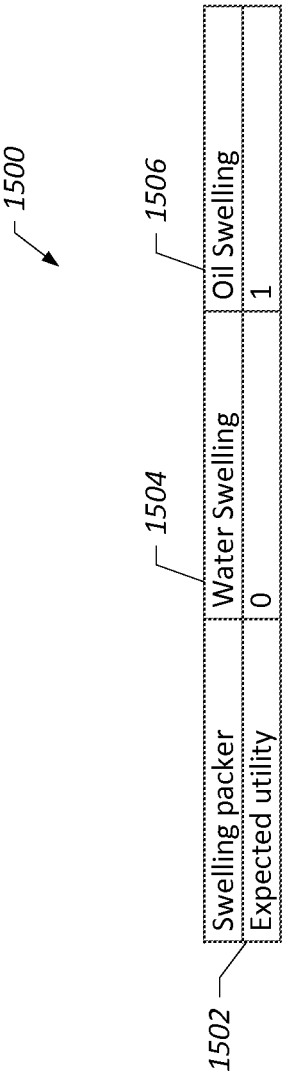
1500
1506
Oil Swelling
1
1504
Water Swelling
0
Swelling packer
Expected utility
1502

FIG. 15

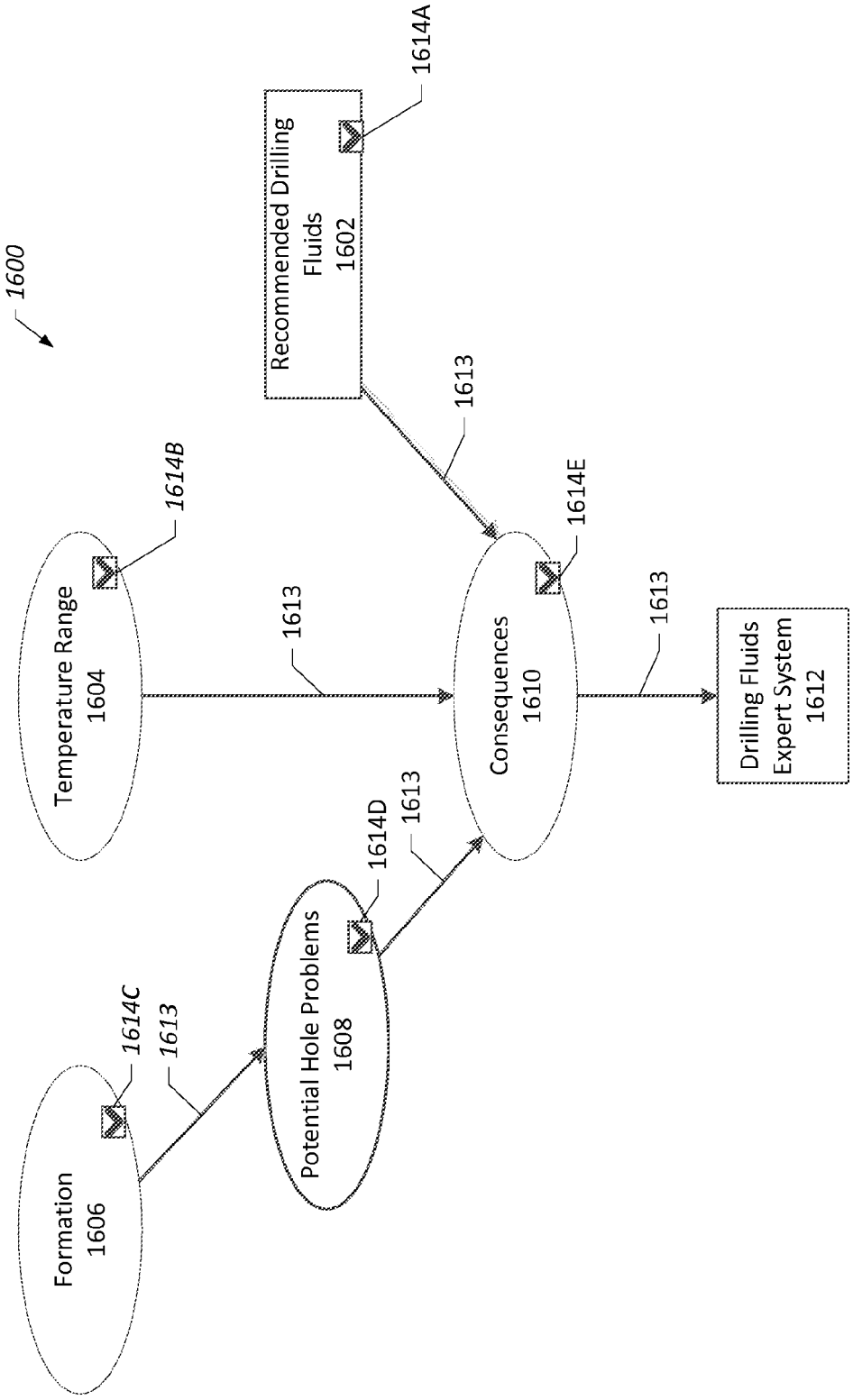
1600
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
1614B
1613
Consequences 1610
1614E
1613
Drilling Fluids Expert System 1612
1614D
1613
Potential Hole Problems 1608
1614C
1613
Formation 1606

FIG. 16A

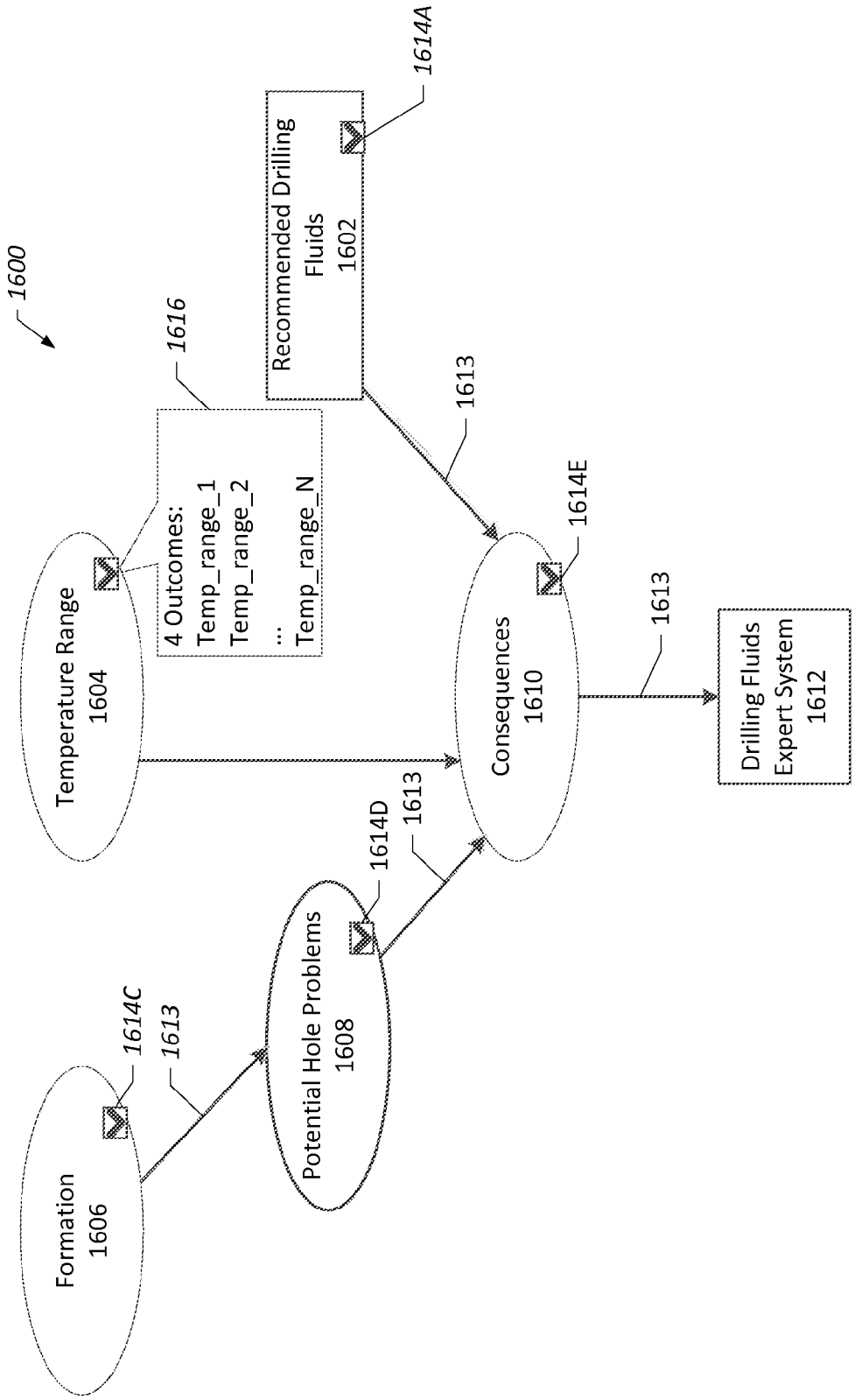
1600
1616
4 Outcomes:
Temp_range_1
Temp_range_2
...
Temp_range_N
Temperature Range
1604
Recommended Drilling
Fluids
1602
1614A
1613
1614E
Consequences
1610
1613
Drilling Fluids
Expert System
1612
1614D
1613
Potential Hole Problems
1608
1614C
1613
Formation
1606

FIG. 16B

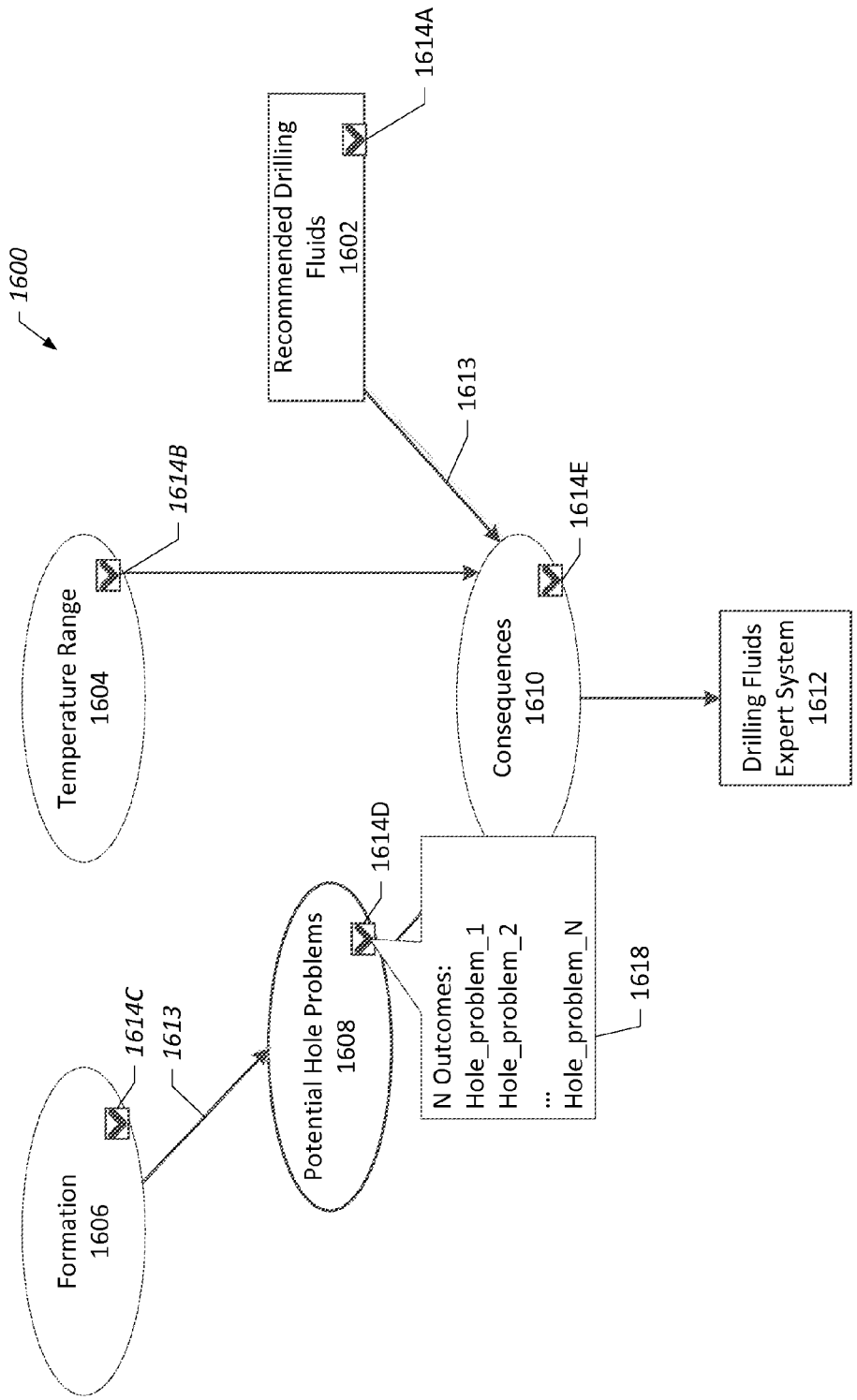
1600
Recommended Drilling Fluids 1602
1614A
1613
1614B
Temperature Range 1604
1614E
Consequences 1610
Drilling Fluids Expert System 1612
1614D
Potential Hole Problems 1608
N Outcomes:
Hole_problem_1
Hole_problem_2
...
Hole_problem_N
1618
1614C
1613
Formation 1606

FIG. 16C

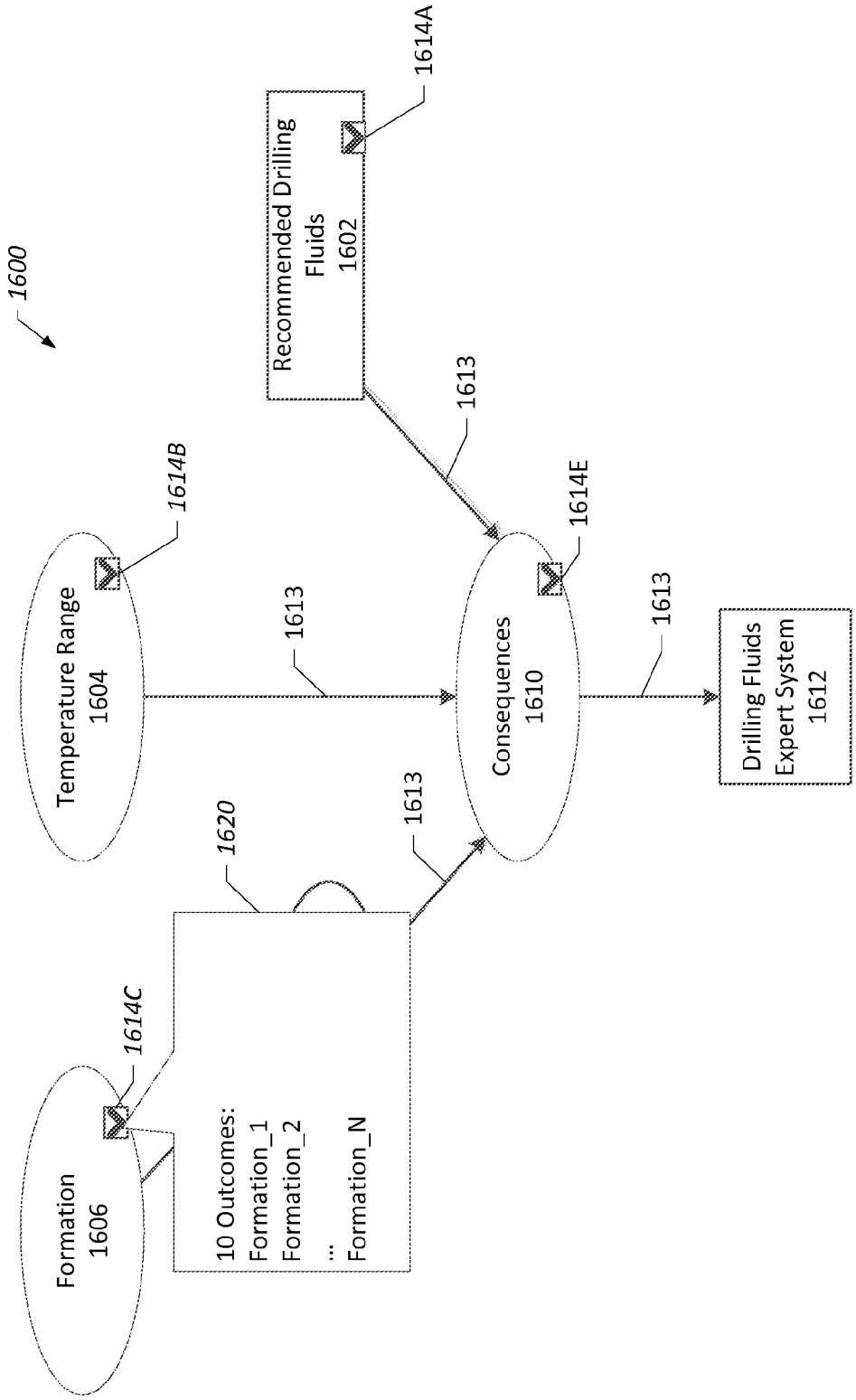
1600
Recommended Drilling Fluids 1602
1614A
1613
1614B
Temperature Range 1604
1613
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1620
1613
1614C
Formation 1606
10 Outcomes:
Formation_1
Formation_2
...
Formation_N

FIG. 16D

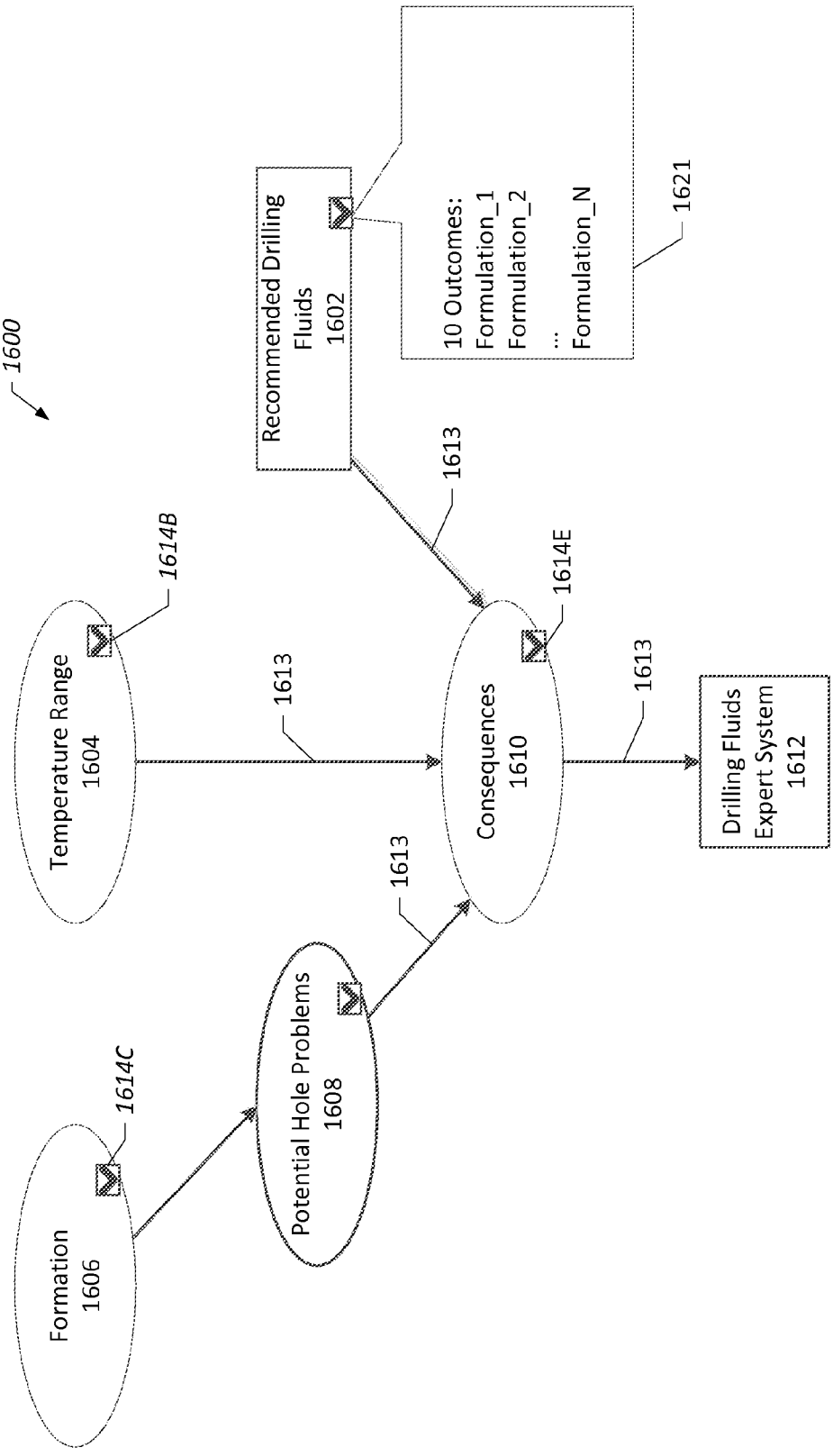
1600
Recommended Drilling Fluids 1602
10 Outcomes:
Formulation_1
Formulation_2
...
Formulation_N
1621
1613
1614B
Temperature Range 1604
1613
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1613
Potential Hole Problems 1608
1614C
Formation 1606

FIG. 16E

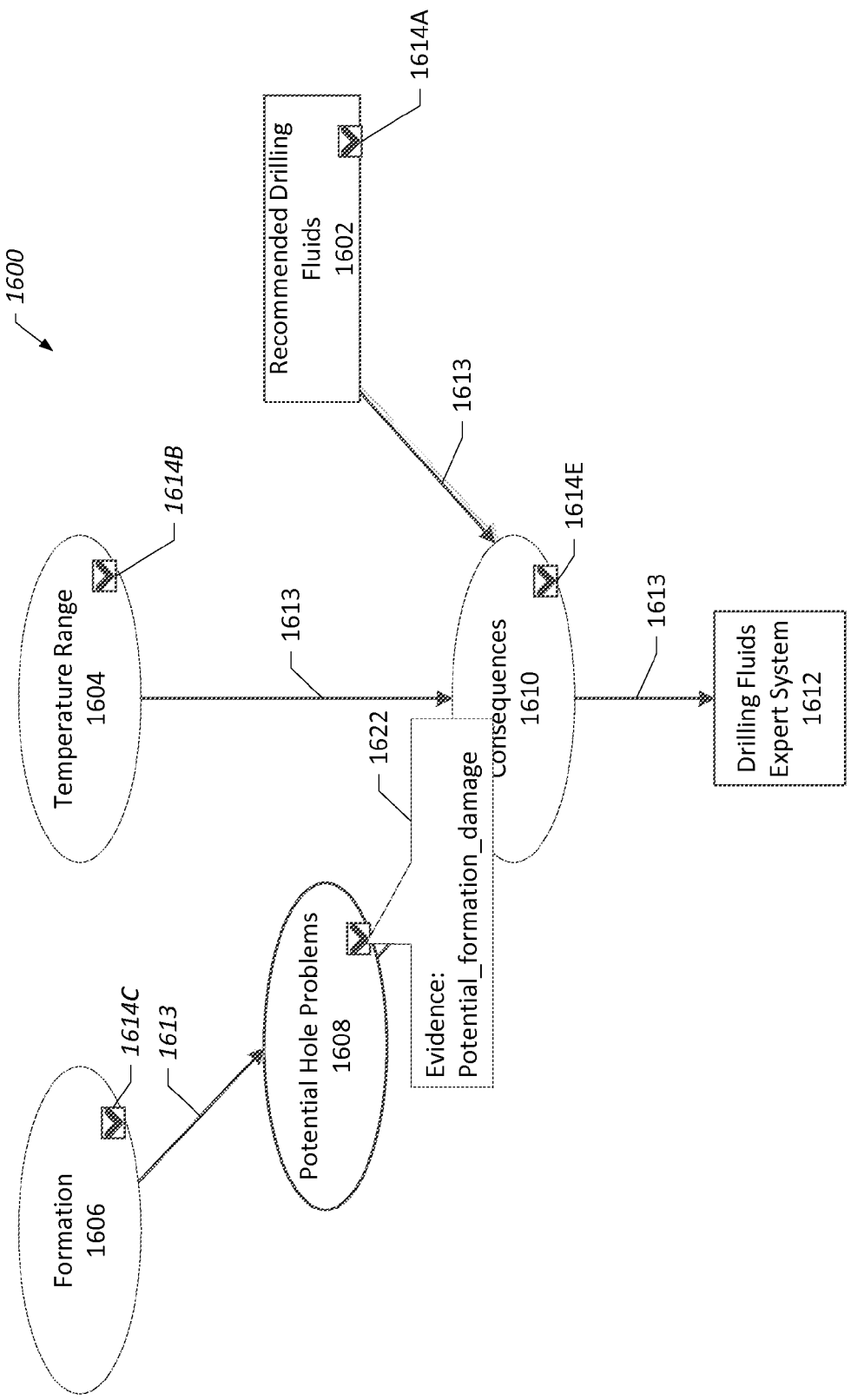
1600
Recommended Drilling Fluids 1602
1614A
1613
1614B
Temperature Range 1604
1613
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1622
Evidence: Potential_formation_damage
Potential Hole Problems 1608
1614C
1613
Formation 1606

FIG. 16F

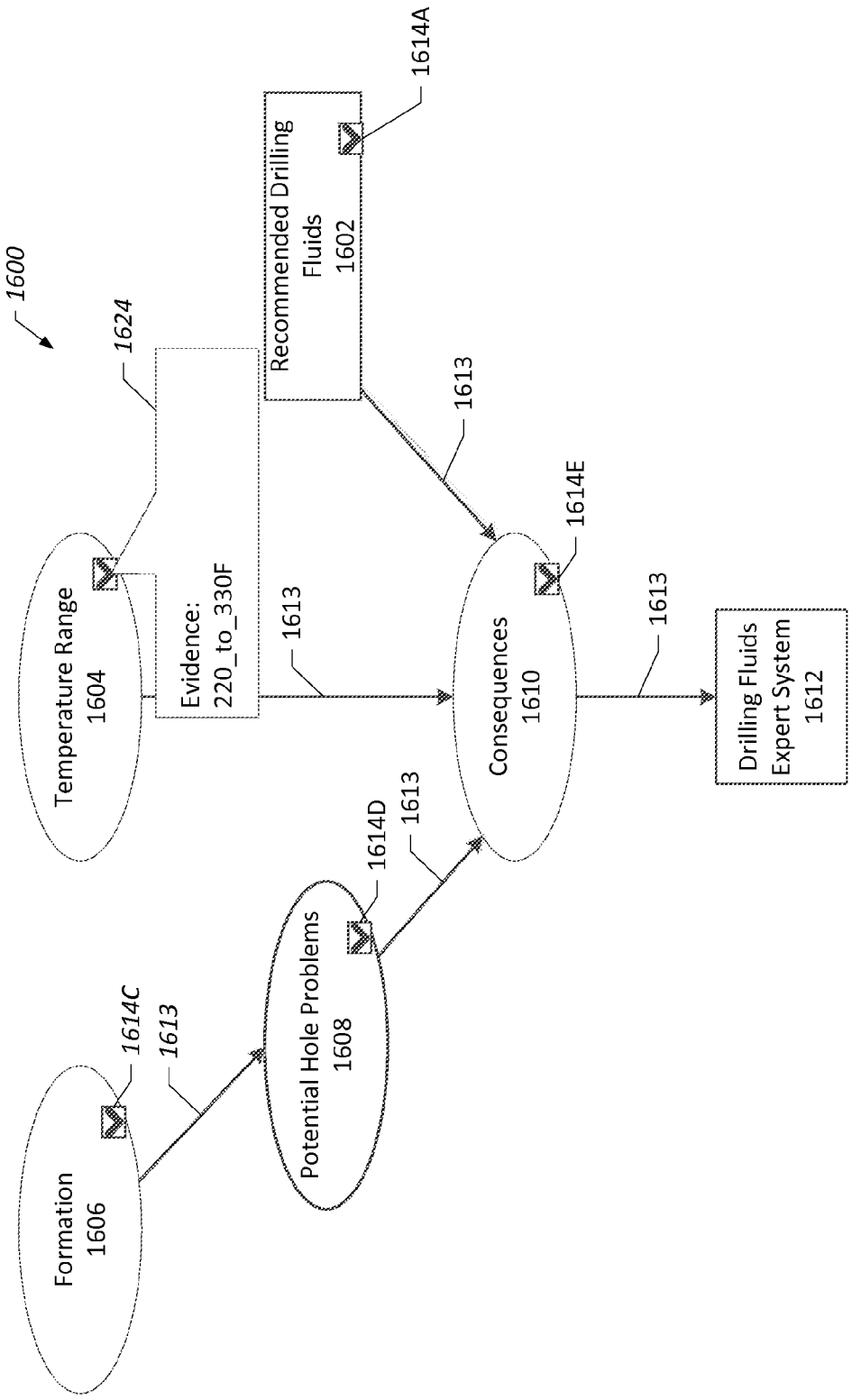
1600
1624
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
Evidence: 220_to_330F
1613
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1614D
1613
Potential Hole Problems 1608
1614C
1613
Formation 1606

FIG. 16G

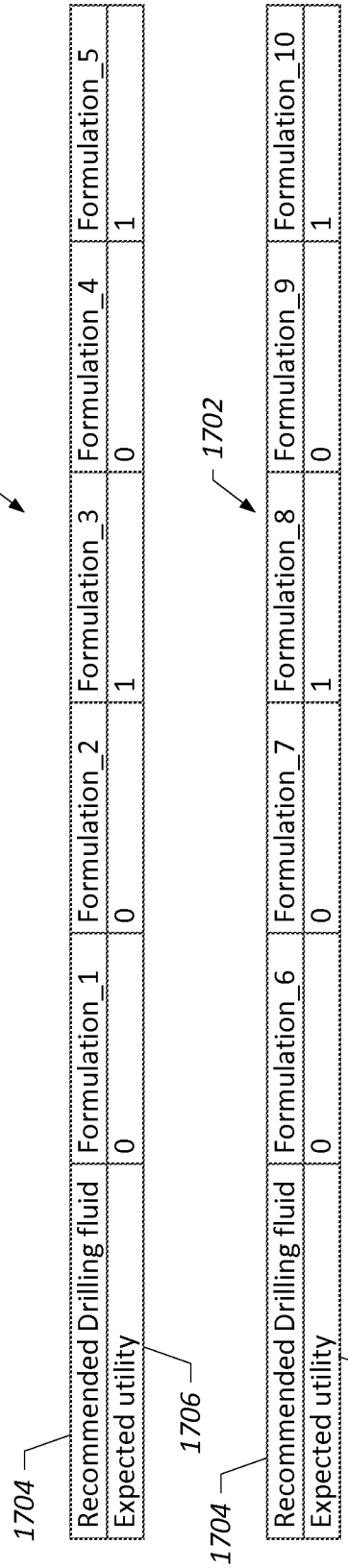
1700
1702
1704
1704
1706
1706
Recommended Drilling fluid
Formulation_1
Formulation_2
Formulation_3
Formulation_4
Formulation_5
Expected utility
0
0
1
0
1
Recommended Drilling fluid
Formulation_6
Formulation_7
Formulation_8
Formulation_9
Formulation_10
Expected utility
0
0
1
0
1

FIG. 17

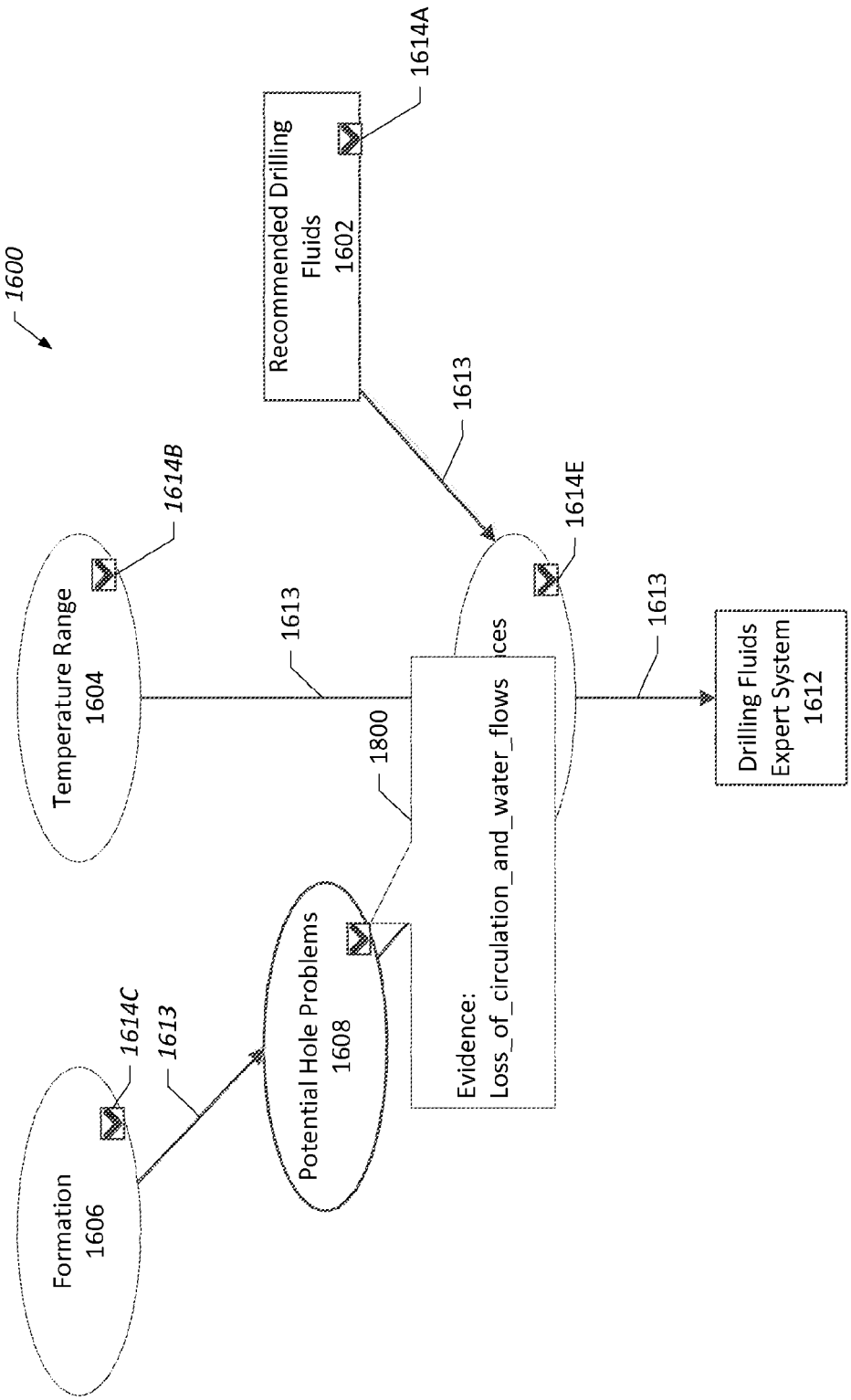
1600
Recommended Drilling Fluids 1602
1614A
1613
1614E
Temperature Range 1604
1614B
1613
1800
Evidence: Loss_of_circulation_and_water_flows ces
1613
Drilling Fluids Expert System 1612
Potential Hole Problems 1608
Formation 1606
1614C
1613

FIG. 18A

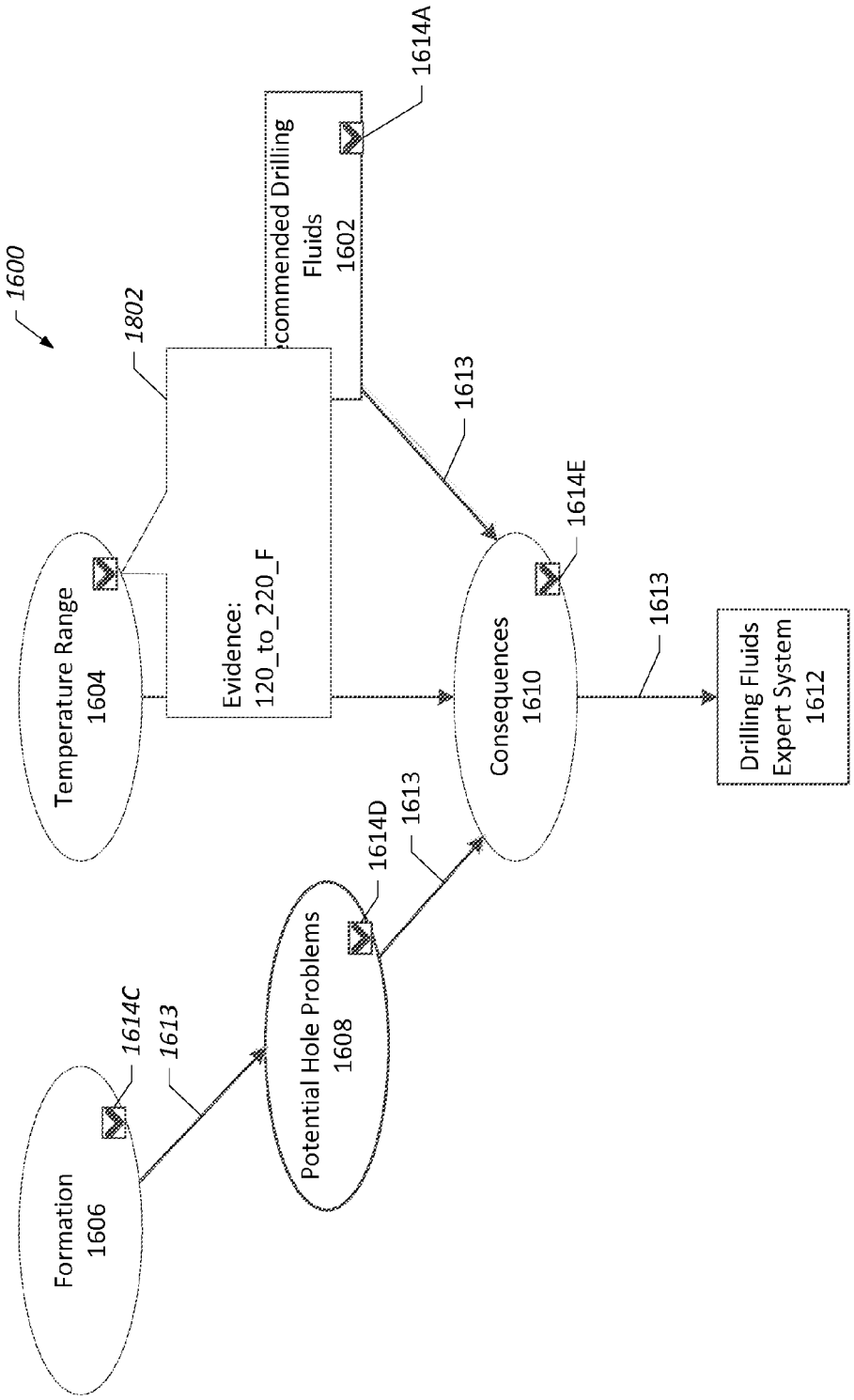
1600
1802
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
Evidence: 120_to_220_F
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1614D
1613
Potential Hole Problems 1608
1614C
1613
Formation 1606

FIG. 18B

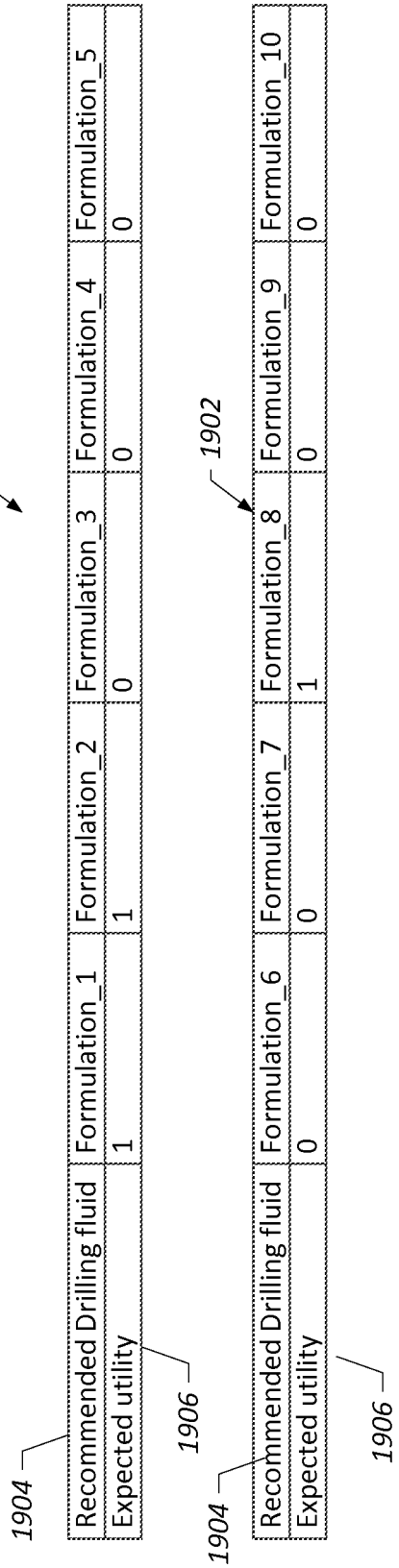
1900
1902
1904
1904
1906
1906
Recommended Drilling fluid
Formulation_1
Formulation_2
Formulation_3
Formulation_4
Formulation_5
Expected utility
1
1
0
0
0
Recommended Drilling fluid
Formulation_6
Formulation_7
Formulation_8
Formulation_9
Formulation_10
Expected utility
0
0
1
0
0

FIG. 19

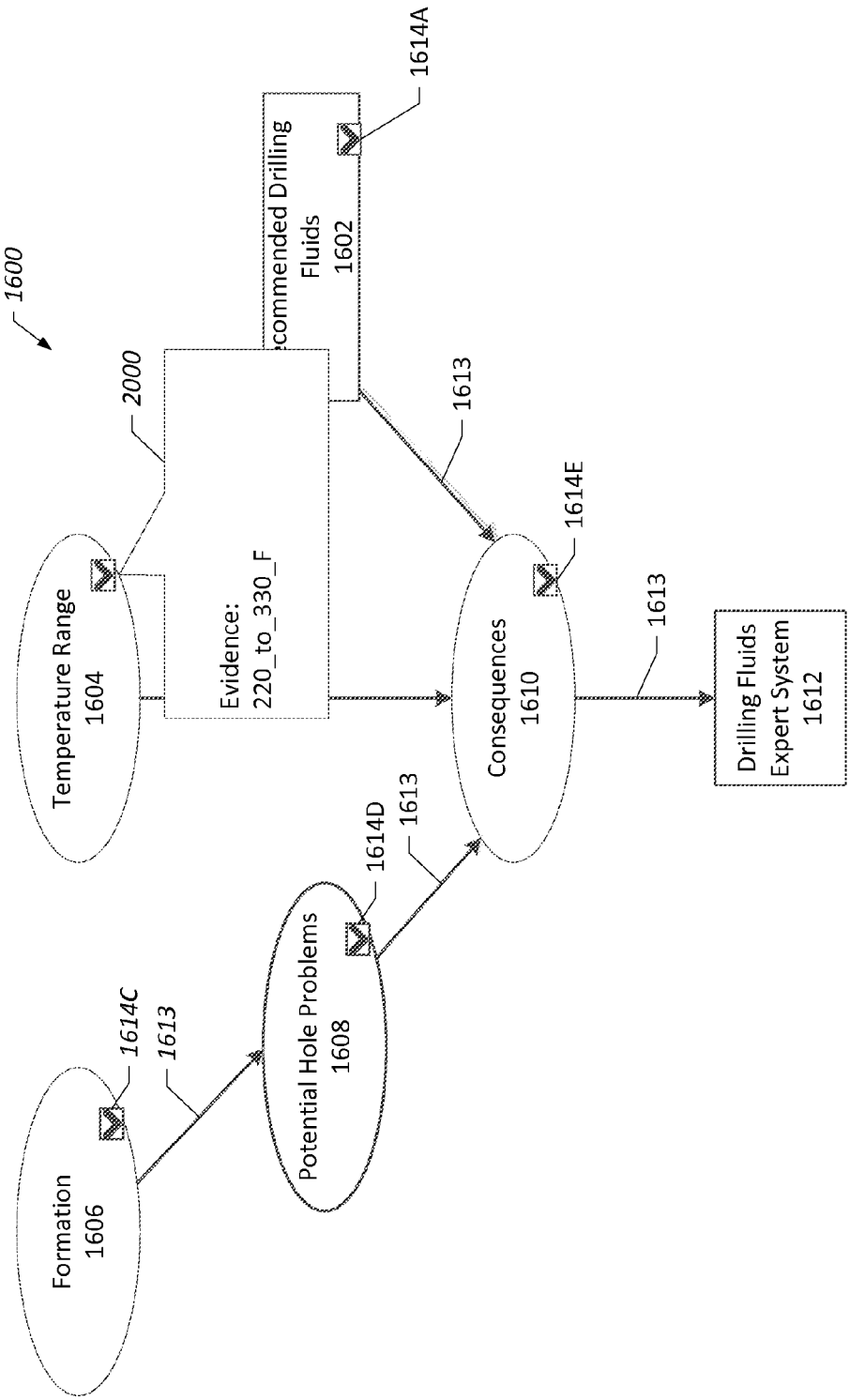
1600
2000
Temperature Range
1604
Evidence:
220_to_330_F
ecommended Drilling
Fluids
1602
1614A
1613
1614E
Consequences
1610
1613
Drilling Fluids
Expert System
1612
1614D
1613
Potential Hole Problems
1608
1614C
1613
Formation
1606

FIG. 20A

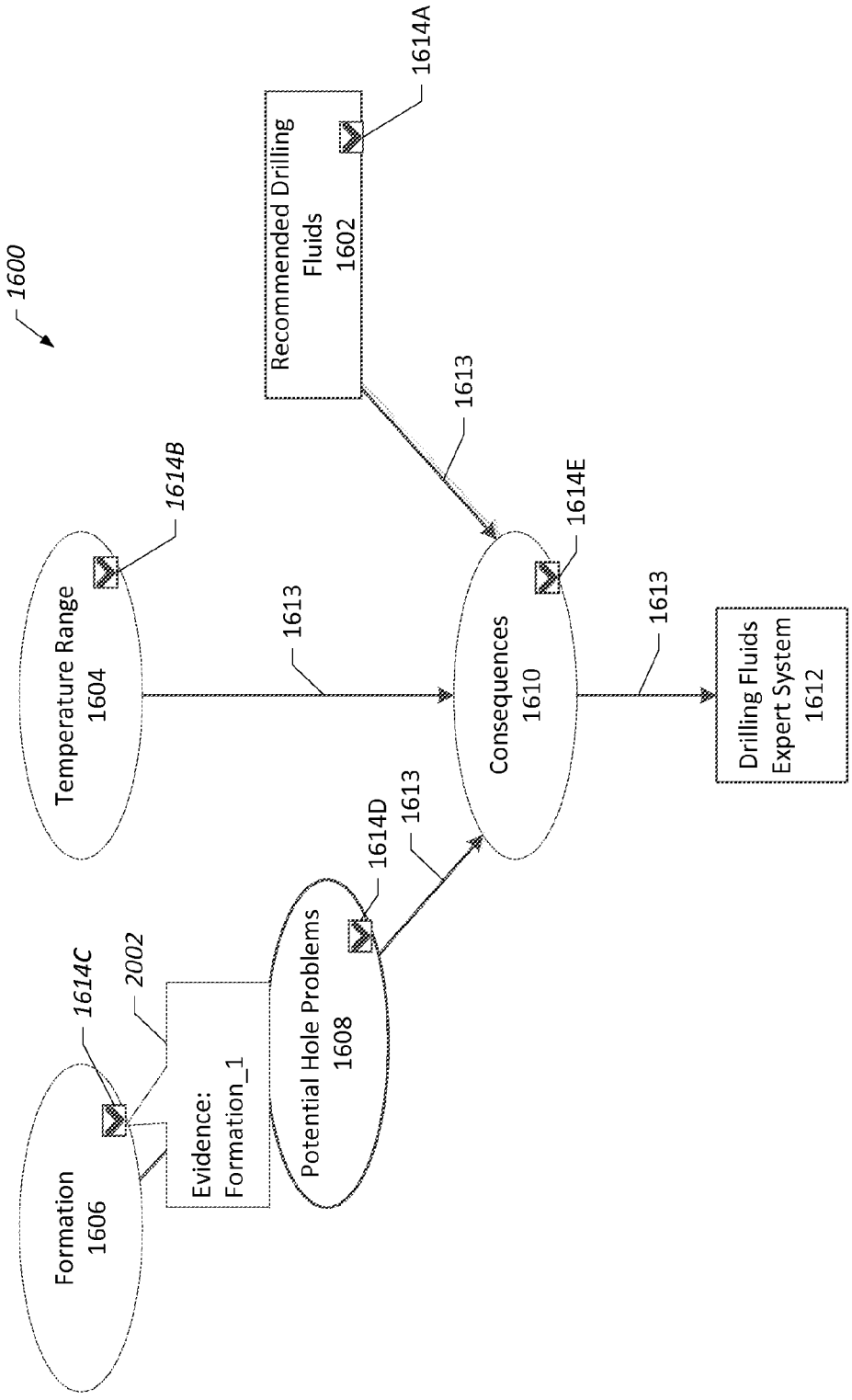
1600
Recommended Drilling Fluids 1602
1614A
1613
1614B
Temperature Range 1604
1613
1614E
Consequences 1610
1613
Drilling Fluids Expert System 1612
1614D
1613
Potential Hole Problems 1608
1614C
2002
Evidence: Formation_1
Formation 1606

FIG. 20B

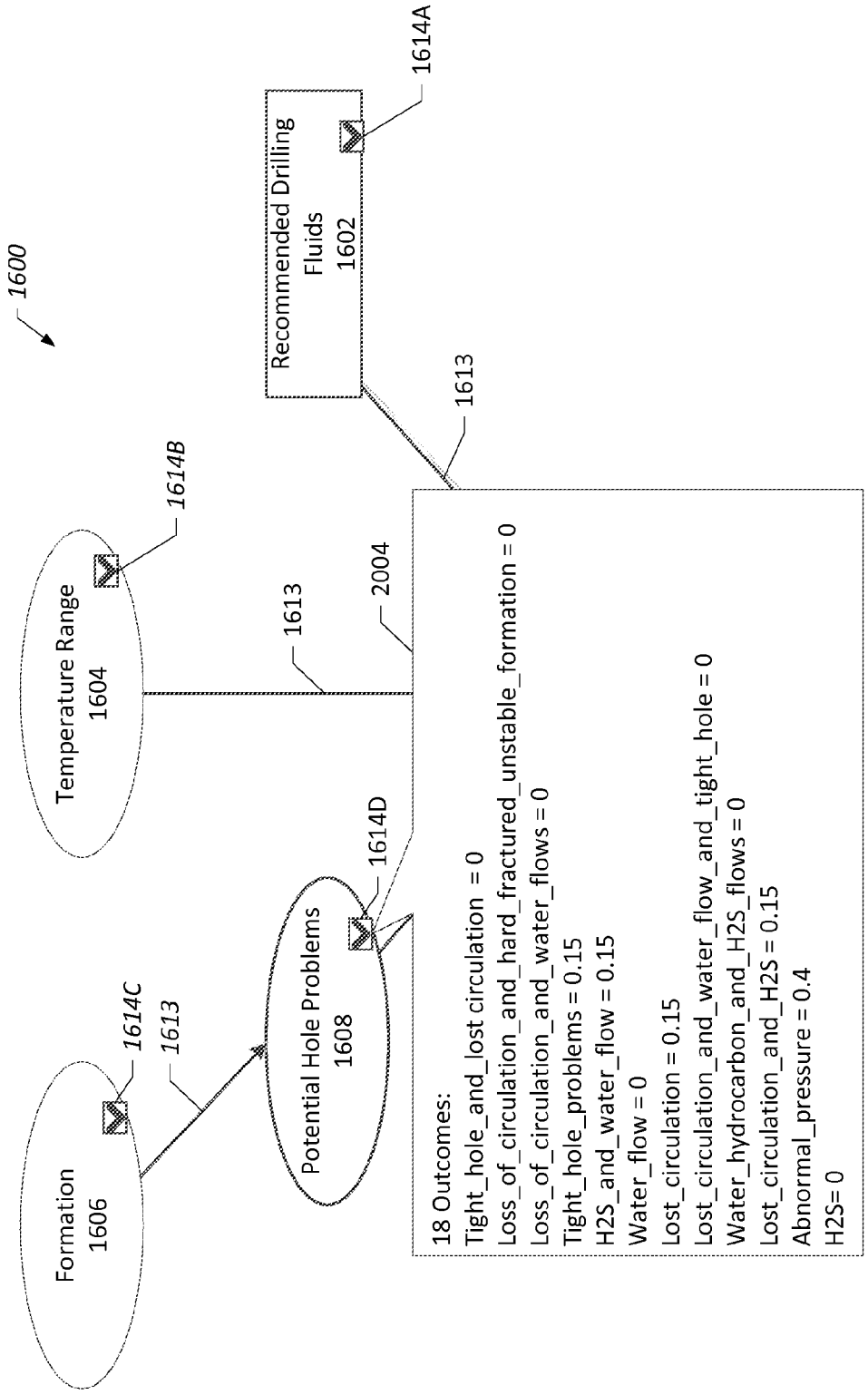
1600
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
1614B
1613
2004
Potential Hole Problems 1608
1614D
Formation 1606
1614C
1613
18 Outcomes:
Tight_hole_and_lost circulation = 0
Loss_of_circulation_and_hard_fractured_unstable_formation = 0
Loss_of_circulation_and_water_flows = 0
Tight_hole_problems = 0.15
H2S_and_water_flow = 0.15
Water_flow = 0
Lost_circulation = 0.15
Lost_circulation_and_water_flow_and_tight_hole = 0
Water_hydrocarbon_and_H2S_flows = 0
Lost_circulation_and_H2S = 0.15
Abnormal_pressure = 0.4
H2S= 0

FIG. 20C

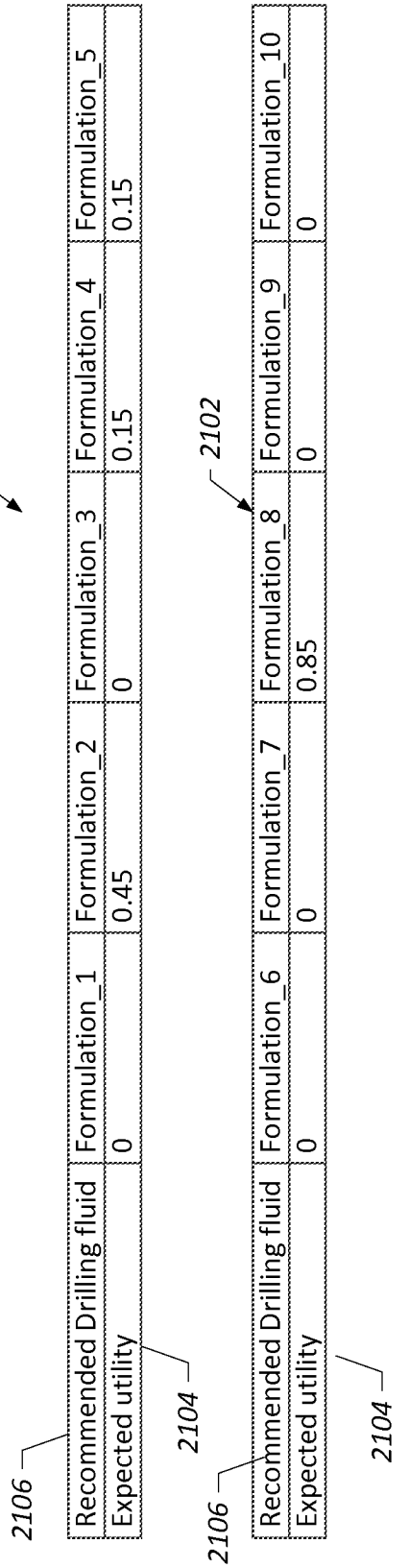
2100
2102
2106
2104
2106
2104
Recommended Drilling fluid
Formulation_1
Formulation_2
Formulation_3
Formulation_4
Formulation_5
Expected utility
0
0.45
0
0.15
0.15
Recommended Drilling fluid
Formulation_6
Formulation_7
Formulation_8
Formulation_9
Formulation_10
Expected utility
0
0
0.85
0
0

FIG. 21

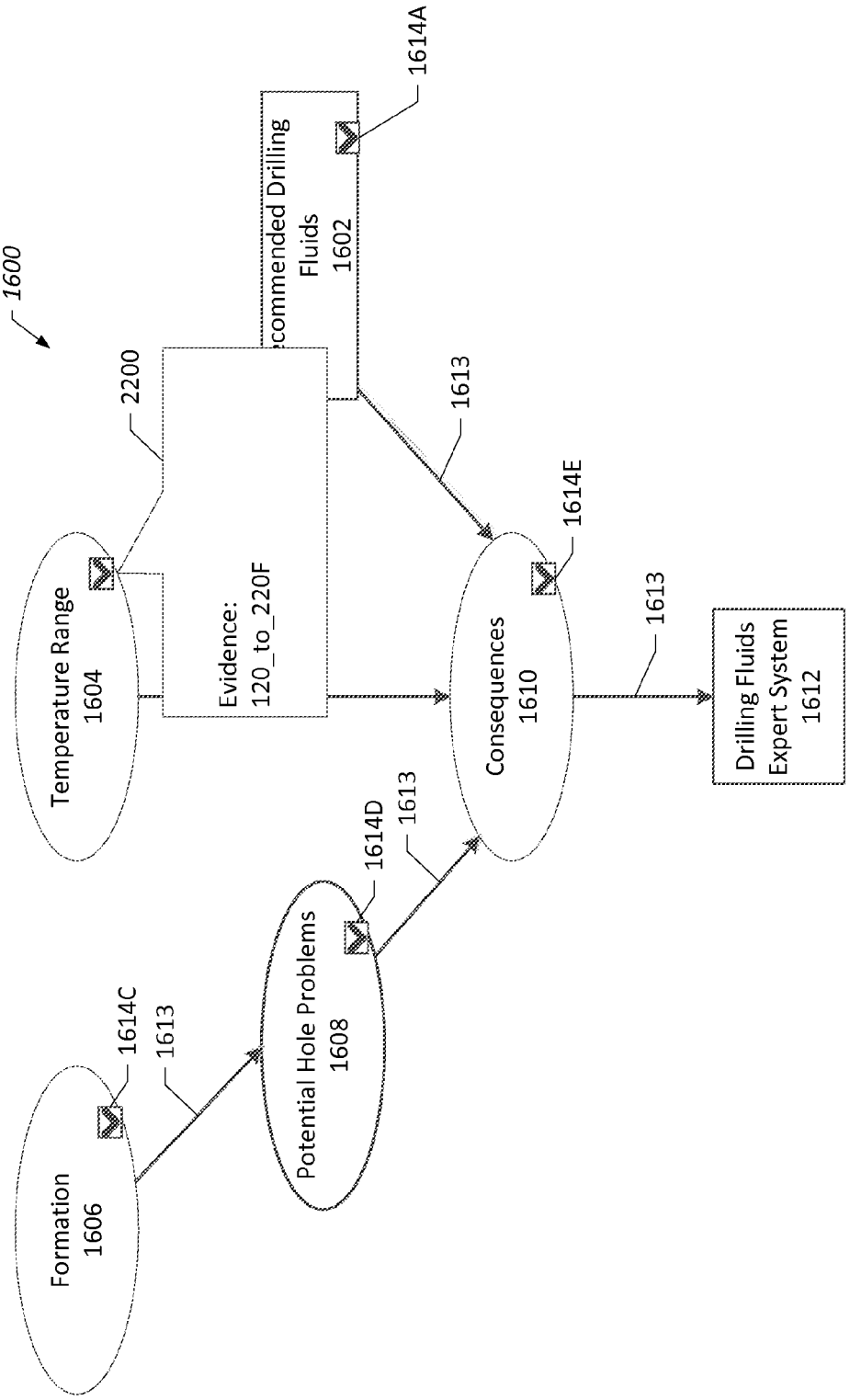
1600
2200
Evidence:
120_to_220F
Temperature Range
1604
Formation
1606
Potential Hole Problems
1608
Consequences
1610
Drilling Fluids
Expert System
1612
commended Drilling
Fluids
1602
1614A
1614C
1614D
1614E
1613
1613
1613
1613

FIG. 22A

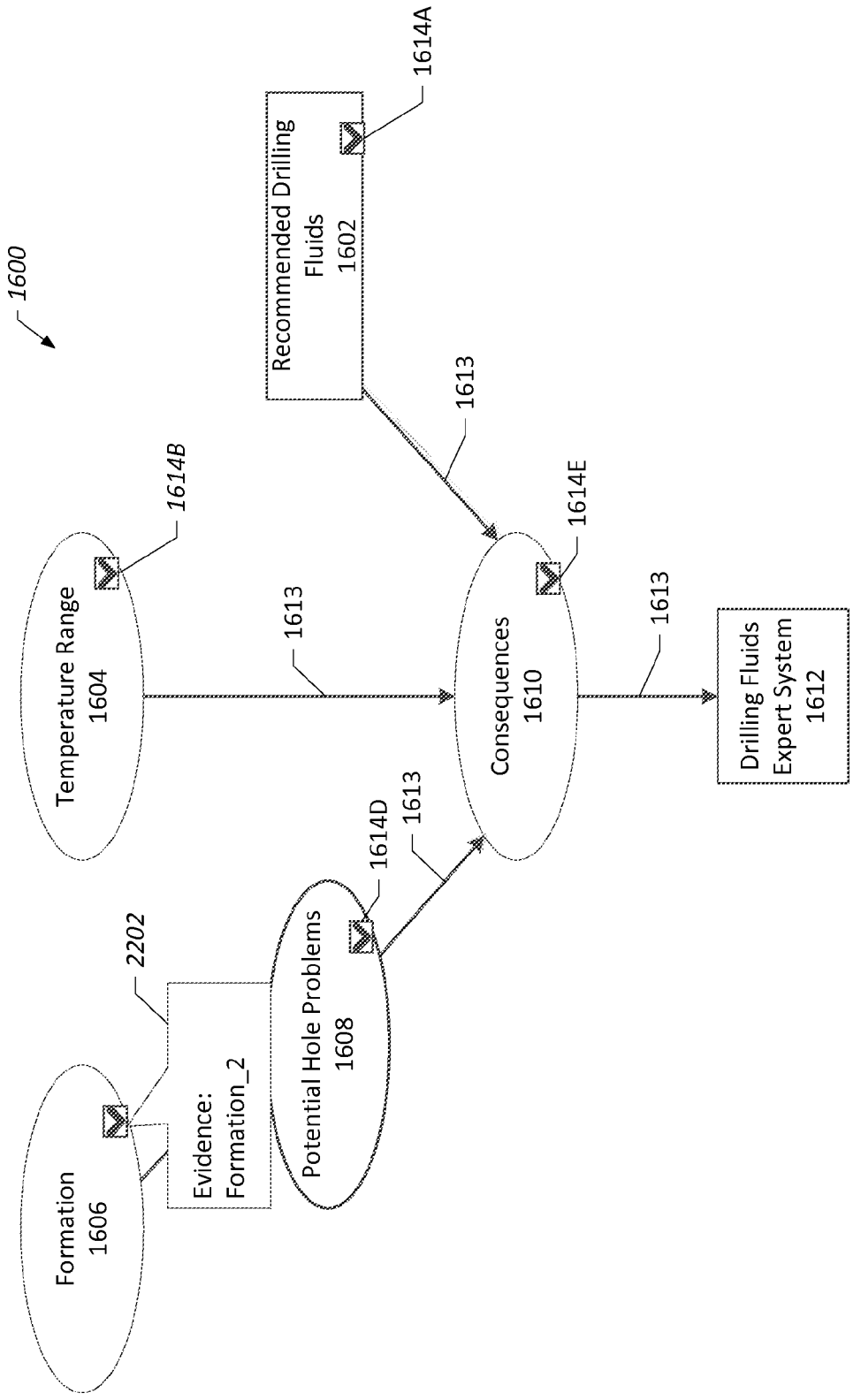
1600
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
1614B
1613
Consequences 1610
1614E
1613
Drilling Fluids Expert System 1612
1614D
1613
Potential Hole Problems 1608
2202
Evidence: Formation_2
Formation 1606

FIG. 22B

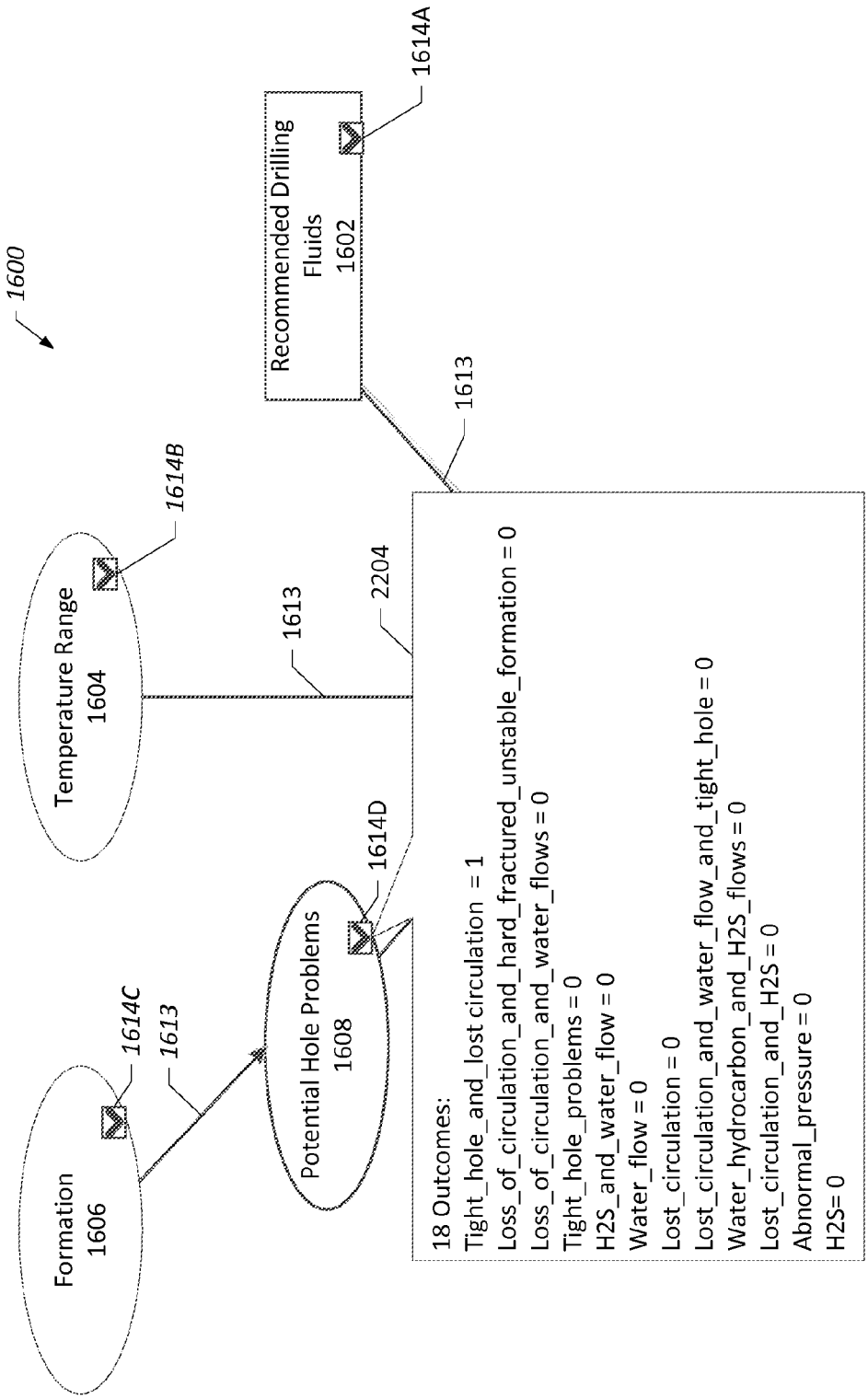
1600
Recommended Drilling Fluids 1602
1614A
1613
Temperature Range 1604
1614B
1613
2204
Potential Hole Problems 1608
1614D
Formation 1606
1614C
1613
18 Outcomes:
Tight_hole_and_lost circulation = 1
Loss_of_circulation_and_hard_fractured_unstable_formation = 0
Loss_of_circulation_and_water_flows = 0
Tight_hole_problems = 0
H2S_and_water_flow = 0
Water_flow = 0
Lost_circulation = 0
Lost_circulation_and_water_flow_and_tight_hole = 0
Water_hydrocarbon_and_H2S_flows = 0
Lost_circulation_and_H2S = 0
Abnormal_pressure = 0
H2S= 0

FIG. 22C

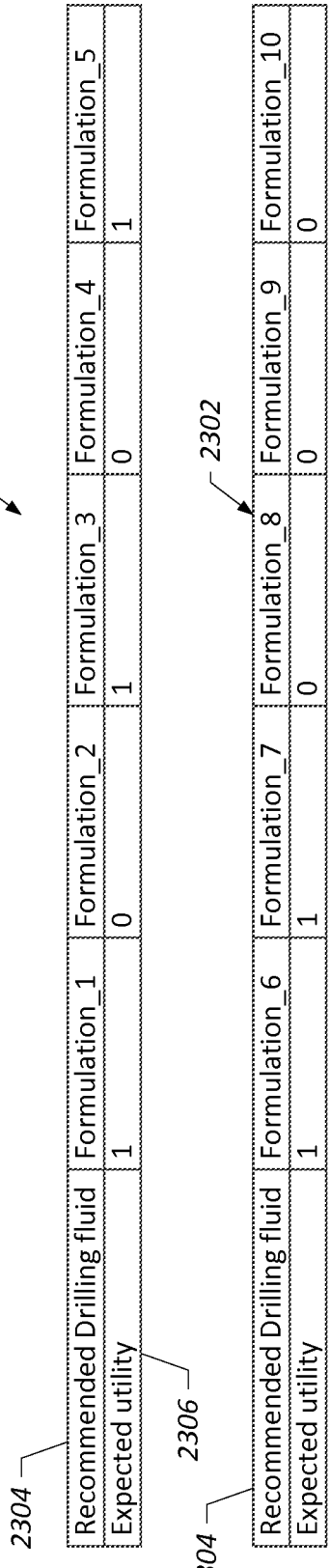
2300
2302
2304
2306
2304
2306
Recommended Drilling fluid
Formulation_1
Formulation_2
Formulation_3
Formulation_4
Formulation_5
Expected utility
1
0
1
0
1
Recommended Drilling fluid
Formulation_6
Formulation_7
Formulation_8
Formulation_9
Formulation_10
Expected utility
1
1
0
0
0

FIG. 23

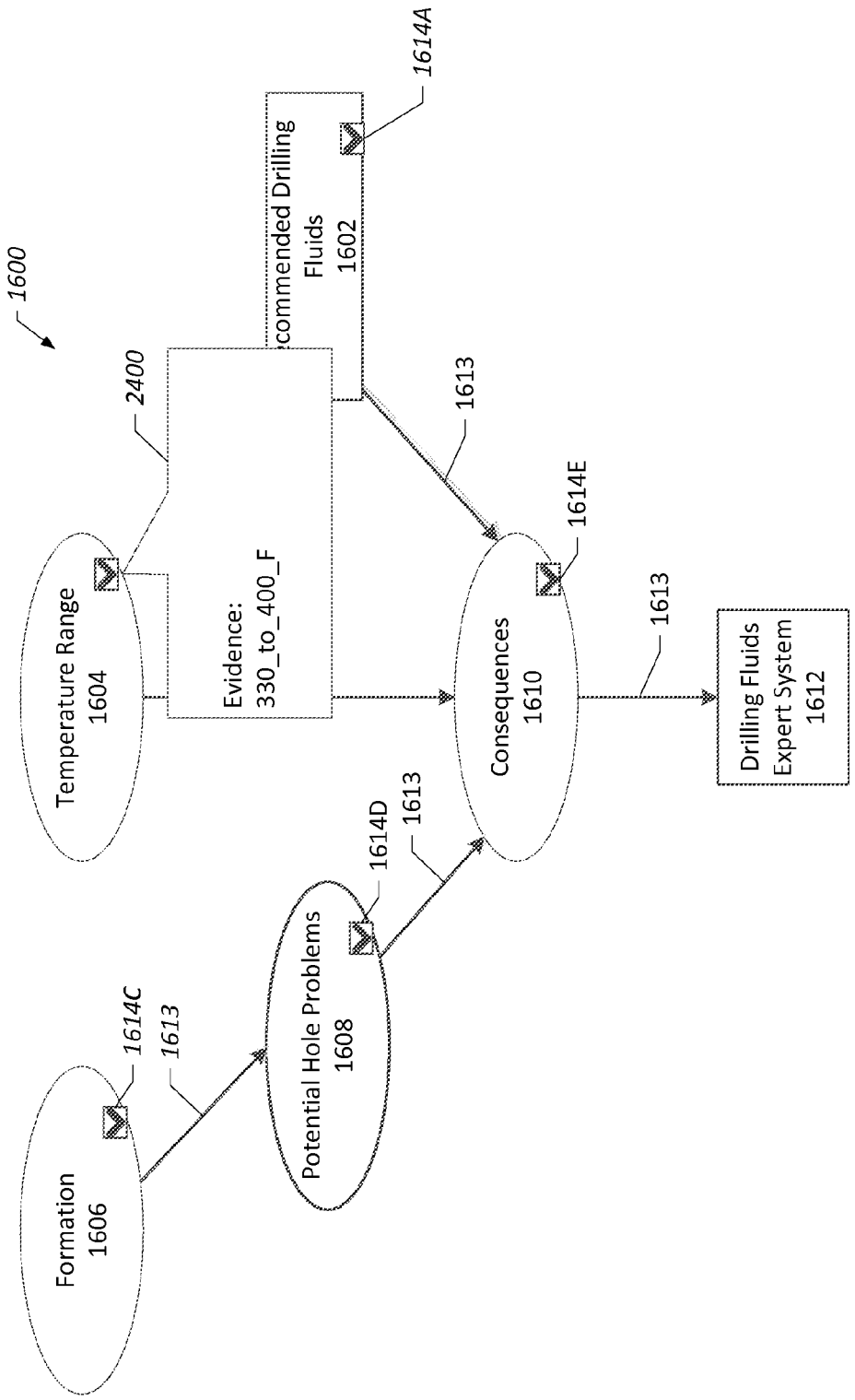
1600
2400
Temperature Range
1604
Evidence:
330_to_400_F
commended Drilling
Fluids
1602
1614A
1613
1614E
Consequences
1610
1613
Drilling Fluids
Expert System
1612
1614D
1613
Potential Hole Problems
1608
1614C
1613
Formation
1606

FIG. 24A

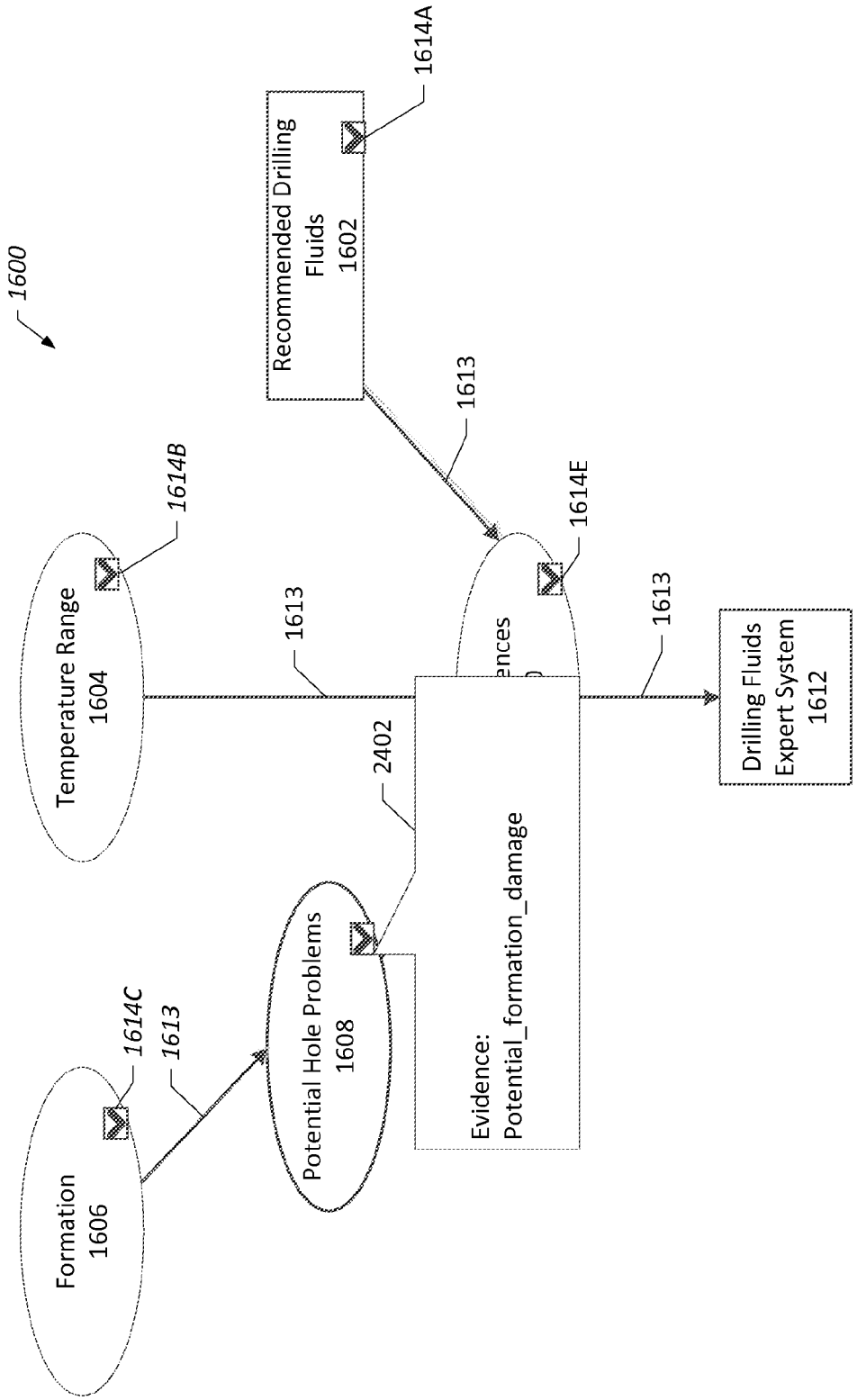
1600
Recommended Drilling Fluids 1602
1614A
1613
1614E
Temperature Range 1604
1614B
1613
1613
Drilling Fluids Expert System 1612
2402
Evidence: Potential_formation_damage
Potential Hole Problems 1608
Formation 1606
1614C
1613

FIG. 24B

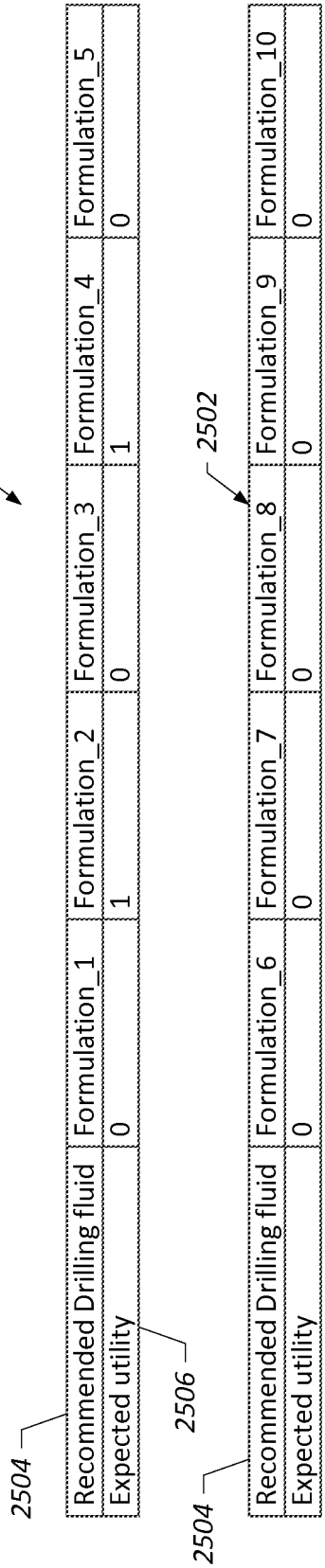
2500
2502
2504
2504
2506
2506
Recommended Drilling fluid
Formulation_1
Formulation_2
Formulation_3
Formulation_4
Formulation_5
Expected utility
0
1
0
1
0
Recommended Drilling fluid
Formulation_6
Formulation_7
Formulation_8
Formulation_9
Formulation_10
Expected utility
0
0
0
0
0

FIG. 25

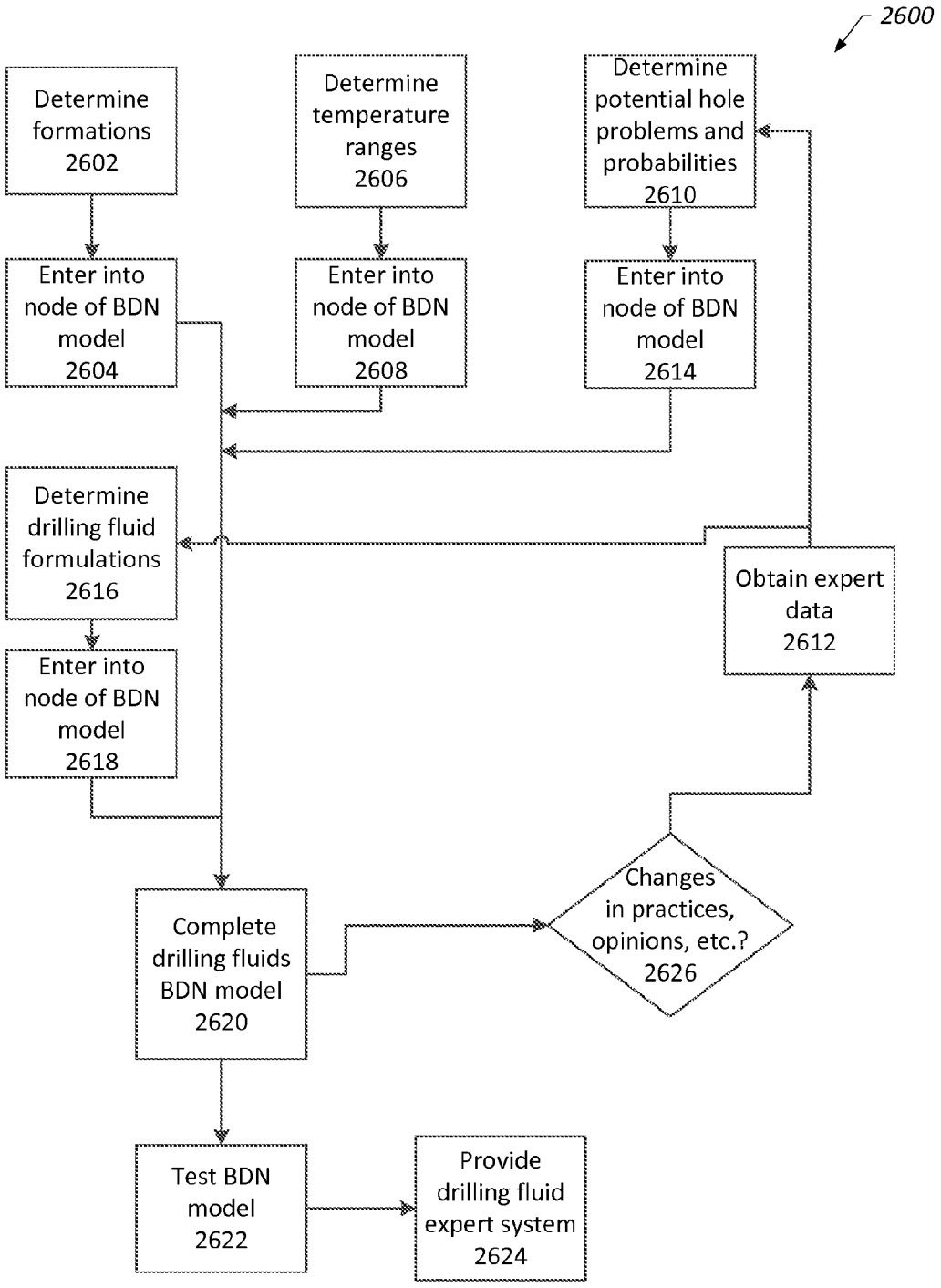
2600
Determine formations 2602
Determine temperature ranges 2606
Determine potential hole problems and probabilities 2610
Enter into node of BDN model 2604
Enter into node of BDN model 2608
Enter into node of BDN model 2614
Determine drilling fluid formulations 2616
Obtain expert data 2612
Enter into node of BDN model 2618
Changes in practices, opinions, etc.? 2626
Complete drilling fluids BDN model 2620
Test BDN model 2622
Provide drilling fluid expert system 2624

FIG. 26

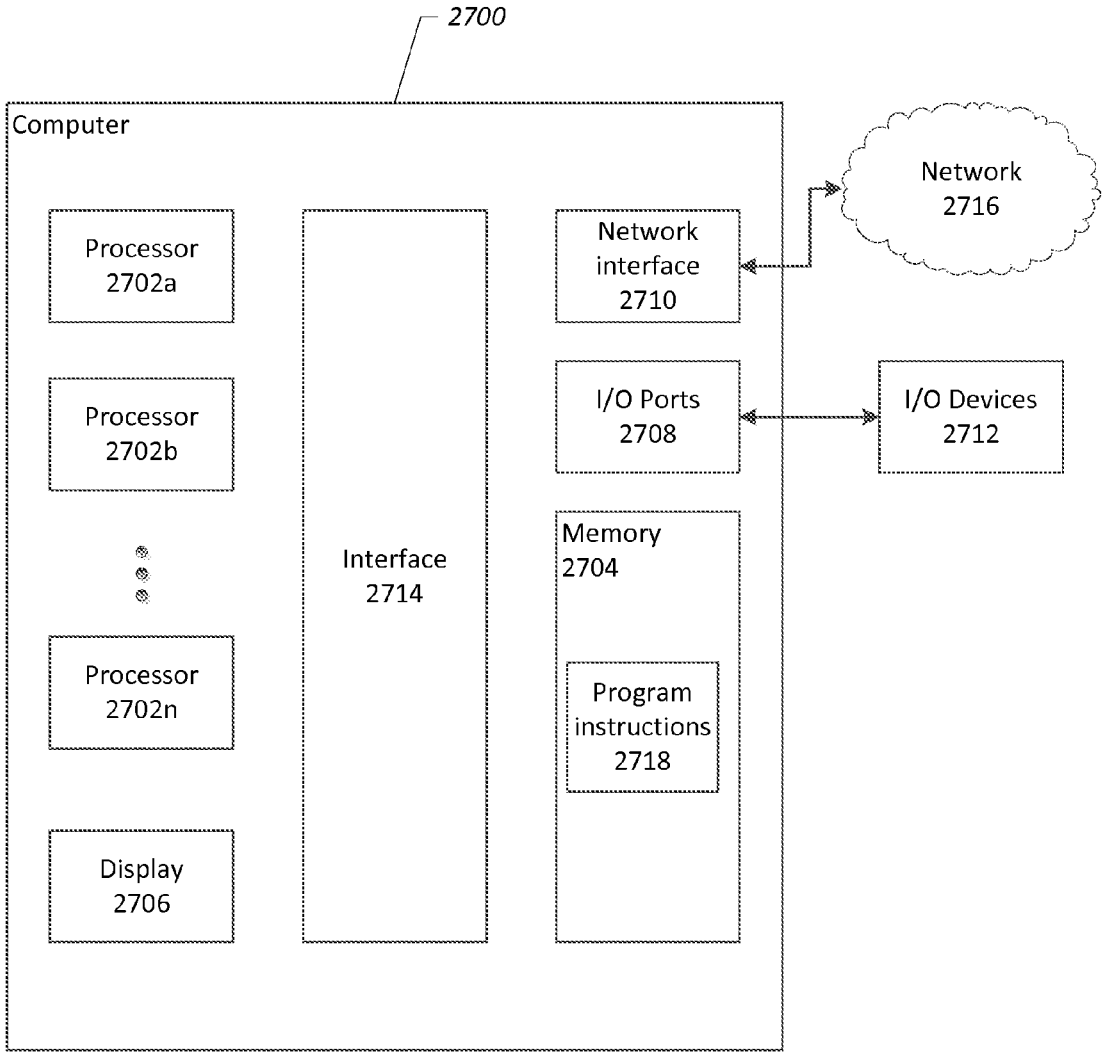
2700
Computer
Processor
2702a
Processor
2702b
Processor
2702n
Display
2706
Interface
2714
Network
interface
2710
I/O Ports
2708
Memory
2704
Program
instructions
2718
Network
2716
I/O Devices
2712

FIG. 27

SYSTEMS AND METHODS FOR DRILLING FLUIDS EXPERT SYSTEMS USING BAYESIAN DECISION NETWORKS

PRIORITY CLAIM

This application claims priority to U.S. Provisional Patent Application No. 61/722,039 filed on Nov. 2, 2012, entitled "Systems and Methods for Drilling Fluids Expert Systems Using Bayesian Decision Networks," the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to the drilling and extraction of oil, natural gas, and other resources, and more particularly to evaluation and selection of drilling fluids.

2. Description of the Related Art

Oil, gas, and other natural resources are used for numerous energy and material purposes. The search for extraction of oil, natural gas, and other subterranean resources from the earth may cost significant amounts of time and money. Once a resource is located, drilling systems may be used to access the resources, such as by drilling into various geological formations to access deposits of such resources. The drilling systems rely on numerous components and operational techniques to reduce cost and time and maximize effectiveness. For example, drill strings, drill bits, drilling fluids, and other components may be selected to achieve maximum effectiveness for a formation and other parameters that affect the drilling system. Typically, many years of field experience and laboratory work are used to develop and select the appropriate components for a drilling system. However, these techniques may be time-consuming and expensive. Moreover, such techniques may produce inconsistent results and may not incorporate recent changes in practices and opinions regarding the drilling systems.

SUMMARY OF THE INVENTION

Various embodiments of systems and methods for drilling fluids expert systems using Bayesian decision networks are provided herein. In some embodiments, a system is provided that includes one or more processors and a non-transitory tangible computer-readable memory. The memory includes drilling fluids expert system executable by the one or more processors and configured to provide one or more drilling fluids recommendations based on one or more inputs. The drilling fluids expert system includes a drilling fluids Bayesian decision network (BDN) model. The drilling fluids BDN model includes temperature ranges uncertainty node configured to receive one or more temperature ranges from the one or more inputs, a formations uncertainty node configured to receive one or more formations from the one or more inputs, a potential hole problems uncertainty node dependent on the formations uncertainty node and configured to receive one or more potential hole problems from the one or more inputs, and a drilling fluids decision node configured to receive one or more drilling fluids from the one or more inputs. The drilling fluids BDN model also includes a consequences node dependent on the temperature ranges uncertainty node, the potential hole problems uncertainty node, and the drilling fluids decision node and configured to output the one or more drilling fluids recommendations based on one or more Bayesian probabilities calculated from the one or more temperature ranges, the one or more potential hole problems, and the one or more drilling fluids.

A computer-implemented method for a drilling fluids expert system having a drilling fluids Bayesian decision network (BDN) model is also provided. The method includes receiving, at one or more processors, one or more inputs and providing, by one or more processors, the one or more inputs to one or more nodes of the drilling fluids BDN model. The one or more nodes include a temperature ranges uncertainty node, a formations uncertainty node, a potential hole problems uncertainty node dependent on the formations uncertainty node, a drilling fluids decision node, and a consequences node dependent on the temperature ranges uncertainty node, the potential hole problems uncertainty node, and the drilling fluids decision node. The method also includes determining, at one or more processors, one or more drilling fluids recommendations at the consequences node of the drilling fluids BDN model by calculating of one or more Bayesian probabilities based on the one or more inputs and providing, by one or more processors, the one or more drilling fluids recommendations to a user.

Additionally, a computer-implemented method for determining a drilling fluid formulation for a drilling system is provided. The method includes receiving, at one or more processors, an input from a user, the input comprising a temperature range, a formation, a potential hole problem, or any combination thereof, and providing, by one or more processors, the input to a drilling fluids Bayesian decision network (BDN) model configured to receive one or more drilling fluid formulations. The method also includes determining, by one or more processors, an expected utility value for the one or more drilling fluid formulations based on the input by calculating of one or more Bayesian probabilities for the one or more drilling fluid formulations based on the input and providing, by one or more processors, an output from the drilling fluids BDN model. The output includes one or more recommended drilling fluid formulations selected from the one or more drilling fluid formulations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram that illustrates a system in accordance with an embodiment of the present invention;

FIG. **2** is a schematic diagram of a computer and a drilling fluids expert system in accordance with an embodiment of the present invention;

FIG. **3** is a block diagram of a process of a drilling fluids expert system in accordance with an embodiment of the present invention;

FIG. **4** is a schematic diagram of an example of a Bayesian decision network model for the selection of a swelling packer in accordance with an embodiment of the present invention;

FIGS. **5-8** are tables of the probability states associated with the nodes of the Bayesian decision network model of FIG. **4**;

FIG. **9** is a table of input utility values assigned to a consequences node of the Bayesian decision network model of FIG. **4**;

FIG. **10** is a table of total probability calculations for drilling fluid types of the Bayesian decision network model of FIG. **4**;

FIG. **11** is a table of Bayesian probability determinations for the Bayesian decision network model of FIG. **4**;

FIG. **12** is a table of consequences based on the Bayesian probability determinations depicted in FIG. **11**;

FIG. **13** is a table of expected utilities based on the consequences depicted in FIG. **12**;

FIG. **14** is a table of table of consequences based on the probability states depicted in FIG. **8**;

FIG. **15** is a table of expected utilities based on the consequences depicted in FIG. **14**;

FIGS. **16**A-**16**G depicts a drilling fluids Bayesian decision network (BDN) model and various user selected inputs to the drilling fluids BDN model in accordance with an embodiment of the present invention;

FIG. **17** is a table of expected utilities based on the consequences output by the drilling fluids BDN model of FIG. **16**A in accordance with an embodiment of the present invention;

FIGS. **18**A and **18**B depict the drilling fluids BDN model of FIG. **16**A and various user selected inputs in accordance with an embodiment of the present invention;

FIG. **19** is a table of expected utilities based on the consequences output by the drilling fluids BDN model of FIG. **16**A in accordance with an embodiment of the present invention;

FIGS. **20**A-**20**C depict the drilling fluids BDN model of FIG. **16**A and various user selected inputs in accordance with an embodiment of the present invention;

FIG. **21** is a table of expected utilities output by the drilling fluids BDN model of FIG. **16**A based on the selected inputs FIGS. **20**A-**20**C in accordance with an embodiment of the present invention;

FIGS. **22**A-**22**C depict the drilling fluids BDN model of FIG. **16**A and various user selected inputs in accordance with an embodiment of the present invention;

FIG. **23** is a table of expected utilities output by the drilling fluids BDN model of FIG. **16**A based on the selected inputs FIGS. **22**A and **22**B in accordance with an embodiment of the present invention;

FIGS. **24**A and **24**B depict the drilling fluids BDN model of FIG. **16**A and various user selected inputs in accordance with an embodiment of the present invention;

FIG. **25** is a table of expected utilities output by the drilling fluids BDN model of FIG. **16**A based on the selected inputs FIGS. **24**A and **24**B of in accordance with an embodiment of the present invention;

FIG. **26** is a block diagram of a process for constructing a drilling fluids BDN model for a drilling fluids expert system in accordance with an embodiment of the present invention;

FIG. **27** is a block diagram of a computer in accordance with an embodiment of the present invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but to the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

As discussed in more detail below, provided in some embodiments are systems, methods, and computer-readable media for a drilling fluids expert system based on a Bayesian decision network. In some embodiments, the drilling fluids expert system includes a user interface and probability data based on expert opinions. The drilling fluids expert system includes a temperature selection, a formation selection, and a potential hole problems selection arranged in a Bayesian decision network. The Bayesian decision network may evaluate the temperature, the formation, and the potential hole problem probabilities and provide recommendations for drilling fluids. A user may select a temperature, a formation, and a potential hole problem and receive one or more recommended drilling fluids from the drilling fluids expert system.

FIG. **1** is a block diagram that illustrates a system **100** in accordance with an embodiment of the present invention. The system **100** includes a formation **102**, a well **104**, and a drilling system **106**. The system **100** also includes a drilling fluids expert system **108** for use with the drilling system **106**. As described further below, the drilling fluids expert system **108** may be implemented on a computer and may include a Bayesian decision network to evaluate inputs and output recommended drilling fluids for use with the drilling system **106**. As will be appreciated, the well **104** may be formed on the formation **102** to provide for extraction of various resources, such as hydrocarbons (e.g., oil and/or natural gas), from the formation **102**. In some embodiments, the well **104** is land-based (e.g., a surface system) or subsea (e.g., a subsea system). The formation **102** may include

The drilling system **106** may develop the well **104** by drilling a hole into the formation **102** using a drill bit, e.g., a roller cone bits, drag bits, etc. The drilling system **106** may generally include, for example, a wellhead, pipes, bodies, valves, seals and so on that enable drilling of the well **104**, provide for regulating pressure in the well **16**, and provide for the injection of chemicals into the well **104**. During operation, the drilling system **106** may include a drilling fluid used to clean cuttings from the hole, cool the drill bit, and lubricate the drill bit. As described below, such drilling fluids may include a liquid (sometimes referred to as "drilling mud"), a gas, or other fluids and may be formed from a wide variety of formulations. In some embodiments, the well **104**, drilling system **106** and other components may include sensors, such as temperature sensors, pressure sensors, and the like, to monitor the drilling process.

The drilling system **106**, well **104**, and formation **102** may provide a basis for various inputs **112** to the drilling expert system **108**. For example, as described below, temperature ranges, the formation **102**, and potential hole problems may be provided as inputs **112** to the drilling fluids expert system **08**. The drilling expert system **108** may access an expert data repository **114** that includes expert data, such as probability data used by the drilling fluids expert system **108**. The expert data may be derived from best practices, expert opinions, research papers, and the like. As described further below, based on the inputs **112**, the drilling fluid expert system **108** may output recommended drilling fluids **116** for use in the drilling system **106**. For example, the drilling fluids expert system **108** may provide the one or more optimal drilling fluid formulations for the combination of formation lithology, temperature, and potential hole problems associated with the drilling system **106**. Based on these recommendations, a drilling fluid may be selected and the selected drilling fluid **118** may be used in the drilling system **106**.

FIG. **2** depicts a computer **200** implementing a drilling fluids expert system **202** in accordance with an embodiment of the present invention. As shown in FIG. **2**, a user **204** may interact with the computer **200** and the drilling fluids expert system **202**. In some embodiments, as shown in FIG. **2**, the drilling fluids expert system **202** may be implemented in a single computer **200**. However, in other embodiments, the drilling fluids expert system **202** may be implemented on multiple computers in communication with each other over a network. Such embodiments may include, for example, a client/server arrangement of computer, a peer-to-peer arrangement of computers, or any other suitable arrangement

that enables execution of the drilling fluids expert system **202**. In some embodiments, the drilling fluids expert system **202** may implemented as a computer program stored on a memory of the computer **200** and executed by a process of the computer **200**.

In some embodiments, the drilling fluids expert system **202** may include a user interface **206** and an expert data repository **208**. The user interface **206** may be implemented using any suitable elements, such as windows, menus, buttons, web pages, and so on. As described in detail below, the drilling fluids expert system **202** may include a Bayesian decision network (BDN) model **210** that implemented Bayesian probability logic **212**. The BDN model **210** may evaluate selections of inputs and associated probabilities **214** and output a decision **216** from the BDN model. In the embodiments described herein, the inputs may include a formation, potential hole problems (that may be dependent on a specific formation), a temperature range, and drilling fluid formulations. The BDN model **210** may then calculate Bayesian probabilities for the consequences resulting from the selected inputs, and then output recommended drilling fluids. The output may include an expected utility value for each drilling fluid formulation to enable to user to evaluate and select the drilling fluid formulation having the optimal expected utility for the selected inputs.

As described below, a user **204** may use the user interface **206** to enter selections **210** of inputs for the BDN model **210**. The associated probabilities for the inputs may be obtained from the expert data repository **208**. Based on the inputs **210**, a user **204** may receive the outputs **212** from the BDN model **210**, such as recommended drilling fluid formulations and expected utility value. The output **212** may be provided for viewing in the user interface **206**. Further, as explained below, a user may return to the drilling fluids expert system **202** to add or change the inputs **214**. The BDN model **210** may recalculate the outputs **216** based on the added or changed inputs **214** and the Bayesian probability logic **212**. The recalculated outputs **216** may then provide additional or changed recommended drilling fluid formulations and expected utility values. Here again, the outputs **216** may be provided to the user in the user interface **206**.

FIG. **3** depicts a process **300** of the operation of a drilling fluids expert system in accordance with an embodiment of the present invention. Initially, a user interface for a drilling fluids expert system may be provided to a user (block **302**). From the user interface, various selections of inputs may be received. For example, a selection of a formation may be received (block **304**), a selection of a potential hole problem may be received (block **306**), and a selection of a temperature range (block **308**). Any one of or combination of these selections may be received. As described below, the BDN model enables a user to enter inputs at any node of the BDN model. Moreover, as also illustrated below in FIG. **16**A, the potential hole problems may be dependent on the selected formation.

Next, the received selections may be provided as inputs to uncertainty nodes of a drilling fluids BDN model of the drilling fluids expert system (block **310**), and the selected inputs may include associated probability states, as received from expert data **312**. Next, the data from the uncertainly nodes may be combined (i.e., propagated to) a consequence node based on the expert systems data (block **312**). The propagation and determination of consequences is based on the Bayesian logic described below in FIGS. **16**A-**16**G and implemented in the drilling fluids BDN model. Next, recommended drilling fluid formulations and expected utility values may be calculated by the BDN model (block **316**). Finally, the recommended drilling fluid formulations and expected utility values may be output in a user interface of the drilling fluids expert system (block **318**).

FIGS. **4**-**15** depict an example of a BDN model simulating the decision-making process of the selection of a swelling packer. The model described below in FIGS. **4**-**15** is illustrative of the application of a Bayesian decision network to the selection of a swelling packer for use in a drilling system. Based on the techniques illustrated in FIGS. **4**-**15** and described below, a drilling fluid BDN model, such as that described above in FIGS. **1**-**3**, may be implemented. Such a drilling fluids BDN model is illustrated in detail in FIGS. **16**A-**16**G. Thus, the techniques and implementation described in FIGS. **4**-**15** may be applied to the more detailed drilling fluids expert system illustrated in FIGS. **16**A-**16**G.

FIG. **4** depicts a BDN model **400** for the selection of a swelling packer in accordance with an embodiment of the present invention. The BDN model **400** depicted in FIG. **4** includes a swelling packer decision node **402**, a treating fluid uncertainty node **404**, a drilling fluid type uncertainty node **406**, a consequences node **408**, and a completion expert system value node **410**. As will be appreciated, the selection of a swelling packer may be relevant in the completion of a well to production status. In the illustrated BDN model **400**, the various connection lines **412** indicate direct dependencies between the different nodes. Accordingly, the consequences node may be influenced by the inputs to the uncertainty nodes **404** and **406** and the decision node **402**. Similarly, the treating fluid uncertainty node **404** may be influenced by the swelling packer decision node **402**.

After defining the BDN model **400**, the probability states associated with each node may be defined. FIGS. **5**-**7** depict various tables illustrating the states, such as probability states, associated with each node of the BDN model **400**. The probability distributions may be defined based on expert data entered in the BDN model **400**. FIG. **5** depicts a table **500** illustrating the states associated with the swelling packer decision node **402**. As shown in table **500**, the swelling packer decision node **402** may have a first probability state **502** of "water swelling packer" and a second probability state **504** of "oil swelling packer." Next, FIG. **6** depicts a table **600** illustrating the probability states associated with the treating fluid uncertainty node **404**. The probability states associated with the treating fluid uncertainty node **404** are influenced by the dependency on the swelling packer decision node **402**. As shown in table **600**, the probability states for two treating fluids **602** ("Lactic acid") and **604** ("HCl acid") are shown. For example, for a lactic acid treating fluid **602**, the probability state for a water swelling packer **606** is 0.9 and the probability state for an oil swelling packer **608** is 0.5. Similarly, for an HCl acid treating fluid **604**, the probability state for the water swelling packer **606** is 0.1 and the probability state for the oil swelling packer **608** is 0.5.

FIG. **7** depicts a table **700** illustrating the probability states associated with the drilling fluid type uncertainty node **406**. As shown in the BDN model **400** depicted in FIG. **4**, the drilling fluid type uncertainty node **406** is influenced by the dependency on the treating fluid uncertainty node **404** and the swelling packer decision node **406**. In the table **700**, the probably states associated with two drilling fluid types **702** ("Formate drilling fluid") and **704** ("$CaCO_3$ drilling fluid") are depicted for combinations of a water swelling packer **706**, an oil swelling packer **708**, a lactic acid treating fluid **710**, and an HCl acid treating fluid **712**. For example, as shown in FIG. **7**, for the formate drilling fluid type **702**, the probability state for the water swelling packer **706** and lactic acid treating fluid **710** is 0.8 and the probability state for the water swelling packer **706** and HCl acid treating fluid **712** is 0.2. Similarly,

for the $CaCO_3$ drilling fluid type **704**, the probability state for the water swelling packer **706** and lactic acid treating fluid **710** is 0.2 and the probability state for the water swelling packer **706** and HCl acid treating fluid **712** is 0.8. In a similar manner, the table **700** of FIG. **7** depicts the probability states for the oil swelling packer **708** and the various combinations of lactic acid treating fluid **710** and the HCl acid treating fluid **712**, and the formate drilling fluid type **702** and the $CaCO_3$ drilling fluid type **704**.

FIG. **8** depicts a table **800** illustrating the probability states of the consequences node **408**. The consequences node **408** is influenced by its dependency on the swelling packer decision node **402**, treating fluid uncertainty node **404**, and the drilling fluid type uncertainty node **406**. As shown in table **800**, the probability states associated with two consequences **802** ("Recommended") and **804** ("Not recommended") are depicted for various combinations of a water swelling packer **806** or an oil swelling packer **808**, a formate drilling fluid type **810** or a $CaCO_3$ drilling fluid type **812**, and a lactic acid treating fluid **814** or an HCl acid treating fluid **816**. For example, for the Recommended consequence **802**, the probability state for the combination of water swelling packer **806**, the formate drilling fluid **810**, and lactic acid treating fluid **814** is 0 and the probability state for the combination of the water swelling packer **806**, the formate drilling fluid **810**, and HCl acid treating fluid **816** is 1. In another example, as shown in table **800**, for the Not recommended consequence **804**, the probability state for combination of the water swelling packer **806**, the formate drilling fluid **810**, and lactic acid treating fluid **814** is 1 and the probability state for the combination of the water swelling packer **806**, the formate drilling fluid **810**, and HCl acid treating fluid **816** is 0.

In the BDN model **400**, the consequences associated with the consequences utility node **408** may be assigned input utility values. FIG. **9** depicts a table **900** illustrating the input utility values assigned to the consequences from the consequences utility node **408**. As shown in table **900**, a value **902** may be assigned to each consequence of the consequence node **408**. For a consequence **904** of Recommended, an input utility value of 1 may be assigned. Similarly, for a consequence **906** of Not Recommended, an input utility value of 0 may be assigned. As described below, after the probability states for the consequences are determined in the BDN model **400**, the input utility values assigned to each consequence may be combined.

Using the model and probabilities described above, the functionality of the BDN model **400** will be described. After receiving inputs to the model **400**, the model **400** may simulate the uncertainty propagation based on the evidence, e.g., the probability states, at each node, using Bayesian probability determinations. A Bayesian probability may be determined according to Equation 1:

$$p(\text{hypothesis} \mid \text{evidence}) = \left(\frac{p(\text{evidence} \mid \text{hypothesis})p(\text{hypothesis})}{p(\text{evidence})}\right) \quad (1)$$

Where:

p(hypothesis|evidence) is the probability of a hypothesis conditioned upon evidence;

p(evidence|hypothesis) is the probability the evidence is plausible based on the hypothesis;

p(hypothesis) is the degree of certainty of the hypothesis; and

p(evidence) is the degree of certainty of the evidence.

Referring again to the BDN model **400** discussed above, the model **400** illustrates that a selection of drilling fluid affects the treating fluid and the swelling packer, as illustrated by the dependencies in the model **400**. First, the total probability for a drilling fluid type may be calculated based on the evidence from the uncertainty nodes by Equation 2:

$$\sum_{i=1}^{m} P(B \mid A_i)P(A_i) \quad (2)$$

Where:

P(B|A) is the probability based on B in view of A_i;

$P(A_i)$ is the probability of A_i; and

m is the total number of evidence items.

Using Equation 2, the total probability for a drilling fluid type and lactic acid treating fluid may be calculated according to Equation 3:

$$\sum_{i=1}^{m} p(formateddrillingfluid \mid lacticacid_i)P(lacticacid_i) \quad (3)$$

For example, using the probability data illustrated in FIGS. **6** and **7**, the total probability for a formate drilling fluid type may be calculated as the sum of 0.9 (probability for a lactic acid treating fluid and water swelling packer) multiplied by 0.8 (probability for a formate drilling fluid type, lactic acid treating fluid, and water swelling packer) and 0.1 (probability for a lactic acid treating fluid and water swelling packer) multiplied by 0.2 (probability for a lactic acid treating fluid and water swelling packer).

The results of the total probability calculations for drilling fluid types are illustrated in table **1000** depicted in FIG. **10**. Table **1000** depicts the total probabilities for various combinations of drilling fluids **1002** ("Formate drilling fluid) and **1004** ("CaCO3 drilling fluid") and a water swelling packer **1006** and an oil swelling packer **1008**. As explained above, the total probabilities at the drilling fluid uncertainty node are dependent on the evidence from the treating fluid uncertainty node and the swelling packer decision node. As shown in table **1000** of FIG. **10**, the total probability for a formate drilling fluid **1002** and the water swelling packer **1006** is 0.74, and the total probability for a formate drilling fluid **1002** and the oil swelling packer **1008** is 0.5. Similarly, total probabilities for the $CaCO_3$ drilling fluid type **1004** are also depicted in table **1000**.

Using the total probabilities determined above, the Bayesian probability determination of Equation 1 may be used to calculate the Bayesian probability of a treating fluid used with a specific drilling fluid type and a particular swelling packer. Accordingly, a Bayesian probability may be derived by combining the Bayesian probability of Equation 1 with the total probability calculation of Equation 2, resulting in Equation 4:

$$P(A_j \mid B) = \frac{p(B \mid A_j)P(A_j)}{\sum_{i=1}^{m} P(B \mid A_i)(P(A_i)} \quad (4)$$

Thus, based on Equation 4, the Bayesian probability determination for a lactic acid treating fluid and a formate drilling fluid type for a water swelling packer may be determined according to Equation 5, using the total probabilities depicted in the table **700** of FIG. **7** and the table **1000** of FIG. **10**:

$$P(lacticacid \mid \text{formate}) = \left(\frac{P(\text{formate} \mid lacticacid)P(lacticacid)}{P(\text{formate})}\right) \quad (5)$$
$$= \frac{0.8 \times 0.9}{0.74}$$
$$= 0.9729$$

As depicted above in FIG. **7**, the probability associated with a formate drilling fluid type conditioned on lactic acid treating fluid is 0.8 and the probability of lactic acid for a water swelling packer is 0.9. Additionally, as calculated above in FIG. **10**, the total probability associated with a formate drilling fluid and a water swelling packer is 0.74. Using these probabilities, the Bayesian probability for a lactic acid treating fluid and a formate drilling fluid type may be calculated as shown in Equation 5. Similarly, Equation 6 depicts the Bayesian probability determination for an HCl treating fluid and a formate drilling fluid type, as shown below:

$$P(HClacid \mid \text{formate}) = \left(\frac{P(\text{formate} \mid HClacid)P(HClacid)}{P(\text{formate})}\right) \quad (6)$$
$$= \frac{0.2 \times 0.1}{0.74}$$
$$= 0.0270$$

As noted above, the values for the probabilities depicted in Equation 6 may be obtained from the probability states depicted in tables **600** and **700** of FIGS. **6** and **7** and the total probability calculations depicted in table **1000** of FIG. **10**. In a similar manner, Equations 7 and 8 depict the Bayesian probability determinations for a $CaCO_3$ drilling fluid type:

$$P(lacticacid \mid \text{CaCo}_3) = \left(\frac{P(CaCo_3 \mid lacticacid)P(lacticacid)}{P(\text{CaCo}_3)}\right) \quad (7)$$
$$= \frac{0.2 \times 0.9}{0.26}$$
$$= 0.6923$$

$$P(HClacid \mid \text{CaCo}_3) = \left(\frac{P(CaCo_3 \mid HClacid)P(HClacid)}{P(\text{CaCo}_3)}\right) \quad (8)$$
$$= \frac{0.8 \times 0.1}{0.26}$$
$$= 0.3076$$

The Bayesian probability determinations may also be performed for an oil swelling packer for the various combinations of treating fluid and drilling fluid types. Using the probability states depicted in tables **600** and **700** of FIGS. **6** and **7** and the total probability calculations depicted in table **1000** of FIG. **10**, these Bayesian probability determinations are shown below in Equations 9-12:

$$P(lacticacid \mid \text{formate}) = \left(\frac{P(\text{formate} \mid lacticacid)P(lacticacid)}{P(\text{formate})}\right) \quad (9)$$
$$= \frac{0.8 \times 0.5}{0.5}$$
$$= 0.8$$

-continued

$$P(HClacid \mid formate) = \left(\frac{P(formate \mid HClacid)P(HClacid)}{P(\text{formate})}\right) - \quad (10)$$
$$= \frac{0.2 \times 0.5}{0.5}$$
$$= 0.02$$

$$P(lacticacid \mid \text{CaCo}_3) = \left(\frac{P(CaCo_3 \mid lacticacid)P(lacticacid)}{P(\text{CaCo}_3)}\right) \quad (11)$$
$$= \frac{0.8 \times 0.5}{0.5}$$
$$= 0.8$$

$$P(HClacid \mid \text{CaCo}_3) = \left(\frac{P(CaCo_3 \mid HClacid)P(HClacid)}{P(\text{CaCo}_3)}\right) \quad (12)$$
$$= \frac{0.2 \times 0.5}{0.5}$$
$$= 0.2$$

The results of the calculations shown above in Equations 5-12 are depicted in table **1100** in FIG. **11**. Table **1100** depicts the Bayesian probability determinations for treating fluids **1102** ("Lactic acid") and **1104** ("HCl acid") and swelling packers **1106** ("water swelling packer") and **1108** ("oil swelling packer"). The Bayesian probability determinations are shown for both a formate drilling fluid type **1110** and $CaCO_3$ drilling fluid type **1112**.

After determining the Bayesian probabilities described above, the BDN model **400** may be used to select a swelling packer based on the inputs provided to the uncertainty nodes of the model **400**. For example, the BDN model **400** may be used with two different interpretations of the output to provide the optimal swelling packer for the inputs provided to the model **400**. In one interpretation, the model **400** may receive a user selection of an input for one uncertainty node, and an optimal swelling packer may be determined based on the possible inputs to the other uncertainty node. Thus, as shown table **1100** and FIG. **11**, the drilling types **1110** and **1112** may be "Selected by user." By specifying a type of drilling fluid, the respective Bayesian probability determinations may be read from the table **1100**.

FIG. **12** depicts a table **1200** illustrating the consequences for a user selection of a $CaCO_3$ drilling fluid type based on the Bayesian probability determinations depicted in FIG. **11**. For example, if a $CaCO_3$ drilling fluid type is used to drill a well, the consequences of using a water swelling packer **1202** or an oil swelling packer **1204** are depicted in table **1200**. The consequences illustrated in table **1200** may include a "Recommended" consequence **1206** and a "Not Recommended" consequence **1208**. Accordingly, for a user selection of a $CaCO_3$ drilling fluid type, the Bayesian probabilities read from table **1100** for a water swelling packer are 0.6923 for a lactic acid and 0.3076 for an HCl acid treating fluid. Similarly, values for a user selection of a $CaCO_3$ drilling fluid type and an oil swelling packer are 0.8 and 0.2. As shown in FIG. **12**, the Bayesian probability determinations greater than 50% (0.5) may be provided as Recommended consequences **1206** and the Bayesian probability determinations less than 50% (0.5) may be included as Non Recommended consequences **1208**.

As mentioned above, table **900** of FIG. **9** depicts input utility values associated with Recommended and Not Recommended consequences. As shown in this table, a Recommended consequence has an input utility value of 1 and a Not Recommended consequence has an input utility value of 0. By combining the input utility values and the Bayesian prob-

abilities depicted in FIG. **12**, the expected utility may be calculated according to Equation 13:

$$Expectedutiilty = \sum_{i=1}^{n} consequenceresult \times inpututilityvalue \quad (13)$$

Where:

Expectedutility is the expected utility value;

Consequence result is the Bayesian probability value associated with a consequence;

Inpututilityvalue is the input utility value associated with a consequence; and

n is the total number of consequences.

Accordingly, based on the input utility values depicted in FIG. **9** and the Bayesian probabilities depicted in FIG. **12**, the expected utility value may be calculated using Equation 13. For example, for a user selection of a $CaCO_3$ drilling fluid type, the Bayesian probability associated with the Recommended consequence is 0.6923 (table **1100** in FIG. **11**) and the input utility value associated with the Recommended consequence is 1 (table **900** in FIG. **9**). Similarly, for a user selection of a $CaCO_3$ drilling fluid type, the Bayesian probability associated with the Recommended consequence is 0.3076 (table **1100** in FIG. **11**) and the input utility value associated with the Recommended consequence is 0 (table **900** in FIG. **9**). The calculation of the expected utility for a water swelling packer and a user selection of a $CaCO_3$ drilling fluid type is illustrated below in Equation 14:

$$Expectedutiilty = \sum_{i=1}^{n} consequenceresult \times inpututilityvalue = 0.6923 \times 1 + 0.3076 \times 0 = 0.6923 \quad (14)$$

The calculation the expected utility of the expected utility for an oil swelling packer and a user selection of a $CaCO_3$ drilling fluid type is illustrated below in Equation 15:

$$Expectedutiilty = \sum_{i=1}^{n} consequenceresult \times inpututilityvalue = 0.8 \times 1 + 0.2 \times 0 = 0.8 \quad (15)$$

The results of the calculations performed in Equations 14 and 15 are summarized in FIG. **13**. FIG. **13** depicts a table **1300** showing the expected utility **1302** calculated above. As shown in this figure, the expected utility **1302** for a water swelling packer **1304** is 0.6293 (Equation 14), and the expected utility **1302** for an oil swelling packer **1306** is 0.8 (Equation 15). Thus, after inputting a drilling fluid type in the drilling fluid uncertainty node **406** in the BDN model **400**, the BDN model **400** may output these expected utility values for the swelling packers associated with the swelling packer decision node **402**. Based on these expected utility values, a user may select an optimal swelling packer for use with the selected drilling fluid type. For example, a user may select the swelling packer with the higher expected utility value, i.e., the oil swelling packer. That is, as shown in table **1300** of FIG. **13**, the expected utility value of 0.8 associated with the oil swelling packer is greater than the expected utility value of 0.6923 associated with the water swelling packer.

In other interpretations, a user may input values for all of the uncertainty nodes of the BDN model **400** to determine the optimal selection of a swelling packer. In such instances, the consequences may be determined directly from the consequences node **408** of the BDN model **400**, as depicted above in table **800** of FIG. **8**. For example, a user may select inputs for the treating fluid uncertainty node **404** and the drilling fluid type uncertainty node **406** of the BDN model **400**. Accordingly, FIG. **14** depicts a table **1400** showing the consequences for different swelling packers based on a user selection of a formate drilling fluid type and a lactic acid treating fluid. As shown in FIG. **14**, the consequences may include a "Recommended" consequence **1402** and a "Not Recommended" consequence **1404** for both a water swelling packer **1406** and an oil swelling packer **1408**. For a user selection of a formate drilling fluid type and a lactic acid treating fluid, table **800** of FIG. **8** shows a Recommended consequence value of 0 Not Recommended consequence value of 1 for a water swelling packer. Accordingly, the table **1400** shows that the water swelling packer **1406** has a Recommended consequence value of 0 and a Not Recommended consequence value of 1. Similarly, for a user selection of a formate drilling fluid type and a lactic acid treating fluid, table **800** of FIG. **8** shows a Recommended consequence value of 1 and a Not Recommended consequence value of 0 for an oil swelling packer. Thus, the table **1400** shows that the oil swelling packer **1408** has a Recommended consequence value of 1 and a Not Recommended consequence value of 0.

Based on the consequences described above, the expected utility for the different swelling packers may be determined using Equation 13 described above. For example, based on table **1400** of FIG. **14**, the calculation of the expected utility for a water swelling packer is illustrated below in Equation 16:

$$Expectedutiilty = \sum_{i=1}^{n} consequenceresult \times inpututilityvalue = 0 \times 1 + 1 \times 0 = 0 \quad (16)$$

Similarly, the calculation of the expected utility for an oil swelling packer, using the values for consequences shown in table **1400** of FIG. **14**, is illustrated below in Equation 17:

$$Expectedutiilty = \sum_{i=1}^{n} consequenceresult \times inpututilityvalue = 1 \times 1 + 0 \times 0 = 0 \quad (17)$$

FIG. **15** depicts a table **1500** illustrated the results of the calculations performed above in Equations 16 and 17. An expected utility **1502** for a water swelling packer **1504** and an oil swelling packer **1506** is illustrated in table **1500**. Based on a user selection of a formate drilling fluid type and a lactic acid treating fluid, an expected utility value for the water swelling packer **1504** is 0 and the expected utility value for the oil swelling packer **1506** is 1. Based on these values, a user may select a swelling packer for use based on the BDN model **400**. For example, a user may select the swelling packer with the higher expected utility value in table **1500**, i.e., an oil swelling packer. Here again, a user may select an optimal swelling packer for use with the inputs, i.e., a selected treating fluid and drilling fluid type, provided to the BDN model **400**. For example, a user may select the swelling packer with the

higher expected utility value, i.e., the oil swelling packer. That is, as shown in table **1500** of FIG. **15**, the expected utility value of 1 associated with the oil swelling packer is greater than the expected utility value of 0 associated with the water swelling packer.

In view of the techniques described above, a BDN model may be applied to more complicated determinations. Such models may serve as a training tool or a guide to aid engineers, scientists, or other users in selecting and executing operations of the drilling system **106**. In such embodiments, a BDN model may be used to create drilling fluids expert system used for selecting a drilling fluid for use in the drilling system **106**, as described above in FIGS. **1-3**. Accordingly, FIG. **16**A depicts an example of a drilling fluids BDN model **1600** for determining an optimal drilling fluid formulation based on selected inputs in accordance with an embodiment of the present invention. The BDN model **1600** depicted in FIG. **16**A includes a recommended fluids decision node **1602**, a temperature range uncertainty node **1604**, a formation uncertainty node **1606**, a potential hole problems uncertainty node **1608**, a consequences node **1610**, and a drilling fluids expert system utility node **1612**. The connection lines **1613** indicate the relationships between the nodes of the BDN model **1600**. As shown in the BDN model **1600**, the potential hole problems uncertainty node **1608** is influenced by the inputs to the formation uncertainty node **1606**. The potential hole problems uncertainty node **1608** may be referred to as a child node of the formation uncertainty node **1606**. In the BDN model **1600**, the consequences node **1610** may be affected by the selections of a temperature range via the temperature range uncertainty node **1604**, a formation via the formation uncertainty node **1606**, and a potential hole problem via the potential hole problem uncertainty node **1608**. As described further below, the BDN model **1600** for drilling fluids may be developed from literature review and drilling fluids expert's opinions.

In some embodiments, the BDN model **1600** may be implemented in a user interface, such as the user interface **206** of the drilling fluids expert system **202**, that displays a representation of the model **1600** in FIG. **16**A. Thus, while the BDN model **1600** illustrates the logical relationship of the nodes of the model **1600**, it may also provide a visual depiction of the model **1600** for use in a user interface. In such embodiments, for example, each node of the model **1600** may include a button **1614** that enables a user to select a value for the node or see the determinations performed by a node. For example, as described below, a user may select (e.g., click) the button **1614**B to select a temperature range input for the model **1600**, select the button **1614**C to select (e.g., click) a formation input for the model **1600**, and so on.

FIGS. **16**B-**16**D depict the inputs for each node of the BDN model **1600** in accordance with an embodiment of the present invention. FIG. **16**B depicts inputs **1616** for the temperature range uncertainty node **1604**. The inputs **1616** may be temperature ranges and may include N number of inputs from "temp_range__1" to "temp_range_N." For example, in some embodiments, the inputs **1616** may include: "Less_than__120 F"; "120_to__220 F"; "220_to__330 F"; and "330_to__400 F." As will be appreciated, in some embodiments the inputs **1616** may include associated probabilities, such as probabilities p__1 through p_N. The temperature ranges used may be provided in any suitable units, such as Fahrenheit, Celsius, or Kelvin. The inputs **1616** may be provided in a dialog window, a dropdown list, or other element of a user interface. The inputs **1616** for the temperature range uncertainty node **1404** may be based on actual or projected operating temperatures for a drilling system, i.e., the temperature ranges at which a drilling fluid will be used. For example, a user may monitor the drilling system **106** illustrated in FIG. **1** and determine the operating temperature ranges. Alternatively, the temperature ranges may be determined from computer estimations, such as simulations of existing or virtual drilling systems.

FIG. **16**C depicts inputs **1618** for the potential hole problems uncertainty node **1608** in accordance with an embodiment of the present invention. As shown in FIG. **16**C, the inputs **1618** may include potential hole problems and may have N number of inputs from "hole_problem__1" to "hole_problem_N." In some embodiments, for example, the inputs **1618** may include: "Tight_hole_and_lost_circulation"; "Loss_of_circulation_and_hard_fractured_unstable_formation"; "Loss_of_circulation_and_water_flows"; "Tight_hole_problems"; "H2S_and_water_flow"; "Water_flow"; "Lost_circulation"; "Lost_circulation_and_water_flow_and_tight_hole"; "Water_hydrocarbon_and_H2S_flows"; "Lost_circulation_and_H2S"; "Abnormal_pressure" "H2S", "Tight_hole_and_flow_and_abnormal_pressure", "Possible_ sticking_and_possible_flow"; "Possible_sloughing_and_slow_drilling_and_difficult_ directional_control_ due_hard_abrasive_sands"; "Possible_flow_and_H2S_and_possible_differential_sticking"; "Possible_flow_and_hard_drilling_and_coring_and_possible_loss_of_circulation"; and "Potential formation damage." As will be appreciated, in some embodiments the inputs **1618** may include associated probabilities, such as probabilities p__1 through p_N. In other embodiments, alternative or additional potential hole problems may be included as inputs **1618** in the drilling fluids BDN model **1600**. The selectable potential hole problems **1618** may be provided in a dialog window, a dropdown list, or other element of a user interface. The inputs **1618** for the potential hole problems uncertainty node **1608** may be based on potential hole problems for the various formations included in the formation uncertainty node **1606**.

FIG. **16**D depicts inputs **1620** for the formation uncertainty node **1606** in accordance with an embodiment of the present invention. The inputs **1618** may include different formation lithologies, such as oil fields, and may include N number of inputs from "formation **1**" to "formation_N." As will be appreciated, in some embodiments the inputs **1620** may include associated probabilities, such as probabilities p__1 through p_N. The inputs **1620** may be names of specific formations, such as the names of specific oil fields, or the names of general formation lithologies. The inputs **1620** may be provided in a dialog window, a dropdown list, or other element of a user interface.

Finally, inputs may be provided via the drilling fluids decision node **1602**. FIG. **16**E depicts inputs **1621** for the drilling fluids decision node **1602** in accordance with an embodiment of the present invention. As shown in FIG. **16**E, the inputs may include various drilling fluid formulations and may have N number of inputs from "formulation__1" to "formulation_N."

A user may interact with the drilling fluids BDN model **1600** as part of a drilling fluids expert system, such as the drilling fluids expert system **202**, to enter inputs at uncertainty nodes and receive outputs from the consequence node, such as recommended drilling fluid formulations. Each uncertainty node may include inputs having an associated probability distribution of probabilities. Additionally, a user may select a particular input for an uncertainty node such that a probability state of 1 is assigned to the selected input. Accordingly, the selected input may be the only input to the selected uncertainty node. FIGS. **16**D-**25** describe various inputs and

the outputs of the BDN model **1600**. A user may enter inputs at any node of the BDN model **1600**. The BDN model **1600** may implement the BDN probability determinations described above in FIGS. **4-15** to determine Bayesian probabilities and expected utilities at the consequences node **1610**.

FIGS. **16**F and **16**G depict the entering of inputs at the uncertainty nodes **1608** and **1604**. Accordingly, FIG. **16**F depicts a user selected input **1624** for the potential hole problems uncertainty node **1608** in accordance with an embodiment of the present invention. A user may select (e.g., click) the button **1614**C to display potential hole problems for the potential hole problems uncertainty node **608**. A user may then select (e.g., click) the input **1624** for the node **1608**. For example, as shown in FIG. **16**F, a user may select the potential hole problem "Potential_formation_damage" from as the input **1624**. The input **1624** may be displayed to indicate the selected input to the potential hole problems uncertainty node **1608**.

Next, a user may select inputs for other uncertainty nodes of the drilling fluids BDN model **1600**. FIG. **16**G depicts a user selected input **1626** for the temperature range uncertainty node **1604** in accordance with an embodiment of the present invention. A user may select the button **1614**B to display temperature ranges for the temperature range uncertainty node **1604**. The selected input **1624** ("220_to_330 F") may then be displayed in response to the user selection to indicate the selected input for the temperature range uncertainty node **1604**.

After selecting inputs for the nodes of the drilling fluids BDN model **1600**, the selections may be propagated to the consequences node **1610** by performing the Bayesian probability determinations described above in Equation 1, 2, and 4. By using the probabilities assigned to each of the inputs, the drilling fluids BDN model **1600** may then provide recommendations based on the inputs from the nodes **1602**, **1604**, **1606**, and **1608**. As noted above, in some embodiments, the uncertainty nodes of the drilling fluids BDN model **1600** may have inputs with associated probabilities. A user may select an input for one or more uncertainty nodes and view the recommendations based on the propagation of the selected input. By using the probabilities states for each node, the drilling fluids BDN model **1600** may then provide the expected utility of various drilling fluid formulations as described above in Equation 13. As shown above, the expected utility may then enable a determination of Recommended and Not recommended drilling fluid formulations. For example, a user may select (e.g., click) the consequences node **1610** to receive the recommendations of the user selected inputs. FIG. **17** depicts output from the drilling fluids BDN model **1600** based on the selections described above in FIGS. **16**E and **16**F in accordance with an embodiment of the present invention. As shown in FIG. **17**, in some embodiments the output may be presented as tables **1700** and **1702** displaying an expected utility **1704** for multiple recommended drilling fluids formulations **1706** (e.g., "Formulation_1" to "Formulation_10").

The tables **1700** and **1702** may display an expected utility value determined according to the techniques described above and calculated by Equations 13. For example, the selected inputs and probability states of the uncertainty nodes of the drilling fluids BDN model **1600** may be used to determine the consequences via the consequences uncertainty node **1610**. Based on the results, recommended drilling fluid formulations may be determined and expected utility values may be calculated. As shown in FIG. **17**, for example, based on the selected inputs entered into the BDN model **1600**, the drilling fluids "Formulation_3", "Formulation_5," and "Formulation_10" may have an expected utility value of 1. In contrast, the other drilling fluids included in tables **1700** and **1702**, such as "Formulation_1," "Formulation_2," "Formulation_4" and so on, may have an expected utility value of 0. Accordingly, a user may choose to use drilling fluids "Formulation_3", "Formulation_5," or "Formulation_10" in a drilling system characterized by the selected inputs.

If a user selects different inputs to some or all of the uncertainty nodes of the BDN model **1600**, a different output may be produced by the BDN model **1600**. FIGS. **18** and **19** depict another determination of the drilling fluids BDN model **1600** based on different user selected inputs entered into the potential hole problems uncertainty node **1608** and the temperature range uncertainty node **1604**. As shown in FIG. **18**A, a user may select a different input for the potential hole problems uncertainty node **1608**, such as by selecting (e.g., clicking) the button **1614**C. The selected input **1800** ("Loss_of_circulation_and_water_flows") may be displayed to indicate the input to the selected hole problem uncertainty node **1608**. Similarly, in FIG. **18**B, a user may select a temperature ranges as an input **1802**, such as by selecting (e.g., clicking) the button **1614**B of the temperature range uncertainty node **1604**. The input **1802** ("120 to 220 F") may be displayed to indicate the input to the temperature range uncertainty node **1604**.

As explained above, after entering inputs to the uncertainty nodes **1604** and **1608** of the model **1600**, a user may select (e.g., click) the drilling fluids expert node **1612** to view the output determined by the drilling fluids BDN model **1600**. FIG. **19** depicts the output from the drilling fluids BDN model **1600** based on the selected inputs described above in FIGS. **18**A and **18**B and in accordance with an embodiment of the present invention. As shown in FIG. **19**, in some embodiments the output from the drilling fluids BDN model **1600** may be presented as tables **1900** and **1902** that display an expected utility **1904** for multiple recommended drilling fluid formulations **1906** (e.g., "Formulation_1" to "Formulation_10").

Here again, the drilling fluids BDN model **1600** may calculate the expected utility values according determination illustrated in Equation 13 and described above. The recommended drilling fluids may be then determined and displayed in the tables **1900** and **1902**. As shown in FIG. **19**, for example, based on the selected inputs depicted in FIGS. **18**A and **18**B, the drilling fluids "Formulation_1", "Formulation_2," and "Formulation_8" may have an expected utility value of 1. In contrast, the other drilling fluids included in tables **1900** and **1902**, such as "Formulation_3," "Formulation_4," "Formulation_5" and so on, may have an expected utility value of 0. Accordingly, a user may choose to use drilling fluids "Formulation_1", "Formulation_2," or "Formulation_8" in a drilling system characterized by the additional inputs described above in FIGS. **18**A and **18**B.

As noted above, inputs to the drilling fluids BDN model **1600** may be entered at any node of the BDN model **1600**. Accordingly, if a user of the drilling fluids expert system only knows a temperature range and a formation, a user may use the drilling fluids BDN model **1600** by entering an input to the temperature range uncertainty node **1604** and the formation uncertainty node **1606**, as shown below in FIGS. **20**A and **20**B. For example, as shown in FIG. **20**A, a user may select a temperature range for the uncertainty node **1604** by selecting (e.g., clicking) the button **1614**B of the temperature range uncertainty node **1604**. The selected input **2000** ("200_to_330 F") may be displayed to indicate the input to the uncertainty node **1604**.

Additionally, as shown in FIG. **20**B, a user may select (e.g., click) on the button **1614**C to select an input **2002** for the formation uncertainty node **1606**. If the user knows the formation used with the drilling system, the user may select an input for the formation uncertainty node **1606**. The selected input **2002** ("Formation_1") may be displayed to the user to indicate the input to the formation uncertainty node **1606**.

After a user has selected a formation, a user may view potential hole problems by selecting (e.g., clicking) the potential hole problems uncertainty node **1608**. As illustrated in the model **1600** by the connection lines **1614**, the potential hole problem inputs associated with the potential hole problems uncertainty node **1608** are affected by the input to the formation uncertainty node **1606**. FIG. **20**C depicts inputs **2004** to the potential hole problems uncertainty node **1608** based on the selected input to the formation uncertainty node **1606** shown in FIG. **20**B and in accordance with an embodiment of the present invention. As described above in FIG. **20**B, a user may select "Formation **1**" as a selectable input to the formation uncertainty node **1606**. Based on this selection, the inputs **2004** may be displayed after selecting (e.g., clicking) the button **1614**C of the potential hole problems uncertainty node **1608**. As shown in FIG. **20**C, the inputs **2004** depict probability states associated with each potential hole problem based on the selected input to the formation uncertainty node **1606**. The potential hole problem probabilities **2004** may include, for example, a probability of 0 for "Tight_hole_and_lost circulation," a probability of 0 for "Loss_of_circulation_and_hard_fractured_unstable_formation," a probability of 0 for "Loss_of_circulation_and_water_flows=0," a probability of 0.15 for "Tight_hole_problems," a probability of 0.15 for "H2S_and_water_flow," and so on.

As explained above, the drilling fluids BDN model **1600** may propagate the selected inputs at each node to determine the consequences via the consequences uncertainty node **1610**, according to the techniques described above and illustrated in Equations 1, 2, and 4. In the embodiment described above in FIGS. **20**A-**20**C, a user may select inputs to the temperature uncertainty node **1604** and the formation uncertainty node **1606**. FIG. **21** depicts the output of the drilling fluids BDN model **1600** based on the inputs depicted in FIGS. **20**A-**20**C in accordance with an embodiment of the present invention. The tables **2100** and **2102** may display the expected utility **2104** for drilling fluids **2106** (e.g., "Formulation_1" to "Formulation_10"). For example, as shown in FIG. **21**, the drilling fluid "Formulation_2" has an expected utility value of 0.45, the drilling fluid "Formulation_4" has an expected utility value of 0.15, the drilling fluid "Formulation_5" has an expected utility value of 0.15, and the drilling fluid "Formulation_8" has an expected utility value of 0.85. The other formulations depicted in tables **2100** and **2102** have an expected utility value of 0. Accordingly, in this embodiment, a user may decide to select the recommended drilling fluid formulation having the highest expected utility value, i.e., Formulation_8.

FIGS. **22**-**23** depict additional user selections of a formation input and a temperature range input in accordance with an embodiment of the present invention. As shown in the drilling fluids BDN model **1600** depicted in FIG. **22**A, a user may input a temperature range, such as by selecting (e.g., clicking) the button **1614**B. The selected input **220** ("120_to_220 F") may be displayed and entered as the input to the temperature range uncertainty node **1604**. Next, as shown in FIG. **22**B, a user may select a formation for the formation uncertainty node **1606**, such as by selecting (e.g., clicking) the button **1614**C. The selected input **2202** ("Formation **2**") is displayed and provided as input to the formation uncertainty node **1606**.

Here again, after a user has selected a formation, the user may view the probabilities associated with the potential hole problems uncertainty node **1608** by selecting (e.g., clicking) the button **1614**D of the potential hole problems uncertainty node **1608**. FIG. **22**C depicts inputs **2204** to the potential hole problems uncertainty node **1608** based on the user selections described above in FIGS. **21**A and **21**B. As described above, the probabilities for the inputs to the potential hole problems uncertainty node **1608** are dependent on the input to the formation uncertainty node **1606**. As shown in FIG. **22**C, the inputs **2204** include probabilities associated with each potential hole problem as determined by the drilling fluids BDN model **1600** based on the selected inputs. The inputs **2204** may include, for example, a probability of 1 for "Tight_hole_and_lost_circulation" and a probability of 0 for the other potential hole problems.

Accordingly, the drilling fluids BDN model **1600** may use the selected described above to determine the consequences via the consequences uncertainty node **1610**, according to the techniques described above in Equations 1, 2, and 4. Based on these inputs to the model **1610**, and the determined probabilities for the potential hole problems uncertainty node **1608**, recommended drilling fluids may be determined and expected utility values may be calculated according to the techniques described above. FIG. **23** depicts the results of these determinations in a manner similar to that described above and in accordance with an embodiment of the present invention. As shown in FIG. **23**, tables **2300** and **2302** may display the expected utility **2104** for drilling fluids **2106** (e.g., "Formulation_1" to "Formation_10). For example, as shown in FIG. **23**, the drilling fluid "Formulation_1" has an expected utility value of 1, the drilling fluid "Formulation_3" has an expected utility value of 1, the drilling fluid "Formulation_5" has an expected utility value of 1, and the drilling fluids "Formulation_6" and "Formulation_7" also have an expected utility value of 1. The other formulations depicted in tables **2300** and **2302** have an expected utility value of 0. Accordingly, in this embodiment, a user may decide to select one of the drilling fluids formulations having expected utility values of 1, i.e., Formulation_1, Formulation_3, or the like.

After entering the inputs described above in FIGS. **22**A-**22**C and receiving the output depicted in FIG. **23**, a user may select different inputs for the model **1600** to receive different determinations of recommended drilling fluids and expected utility values. For example, as shown in FIG. **24**A, a user may enter a temperature range ("330_to_400 F") as an input **2400** to the temperature range uncertainty node **1604**. Further, as shown in FIG. **24**B, a user may enter a potential hole problems as an input **2402** to the potential hole problems uncertainty node **1608** by selecting (e.g., clicking) the button **1614**C. As shown in FIG. **24**B, for example, "potential_formation_damage" is selected as the input **2402**.

Based on the modified inputs to the temperature range uncertainty node **1604** and the potential hole problems uncertainty node **1608**, the drilling fluids BDN model **1600** may propagate the inputs to determine the consequences via the consequences uncertainty node **1610**, according to the techniques described above and illustrated in Equations 1, 2, and 4. As described above, recommended drilling fluid formulations may be determined and expected utility values for the formulations may be calculated according to the techniques described in Equation 13. FIG. **25** depicts the output of the BDN model **1600** based on the inputs depicted in FIGS. **24**A and **24**B in tables **2500** and **2502** and in accordance with an

embodiment of the present invention. As shown in FIG. **25**, tables **2500** and **2502** may display the expected utility **2504** for drilling fluids **2506** (e.g., "Formulation_1" to "Formulation_2"). As will be appreciated, in contrast to the tables **2300** and **2302** depicted in FIG. **23**, the modified inputs entered into the drilling fluids BDN model **1600** may result in different expected utilities **2504** for the recommended drilling fluids **2506**. For example, in contrast to FIG. **23** and as shown in FIG. **25**, the drilling fluid "Formulation_2" has an expected utility value of 1, the drilling fluid "Formulation_4" has an expected utility value of 1 and the drilling fluid "Formulation_8" has an expected utility value, whereas the other formulations depicted in tables **2500** and **2502** have expected utility values of 0.

The drilling fluids BDN model **1600** described herein may be constructed based on the various factors described above, such as formations (i.e., formation lithologies), temperature ranges, potential hole problems, and drilling fluid formulations. FIG. **26** depicts a process **2600** illustrating the construction of a drilling fluids BDN model, such as the drilling fluids BDN model **1600**, in accordance with an embodiment of the present invention. Initially, for example, formations for use with a drilling fluids BDN model may be determined (block **2602**). The formations may be determined based on the formations associated with a drilling system that may potentially use a drilling fluid formulation entered into the drilling fluids BDN model. Such formations may include, for example, names of oil fields or other specific formations, general formation lithologies, or other suitable identification of a formation. The determined formations may be entered into an uncertainty node in the drilling fluids BDN model (block **2604**).

Additionally, temperature ranges for use with the drilling fluids BDN model may be determined (block **2606**). The temperature ranges may be based on the operating ranges for the drilling fluids entered into the drilling fluids BDN model. For example, the temperature ranges may include ranges in any suitable units, such as Fahrenheit, Celsius, or Kelvin. Next, the determined temperature ranges may be entered into an uncertainty node in the drilling fluids BDN model (block **2608**).

Further as shown in FIG. **26**, potential hole problems may also be determined (block **2610**). The potential hole problems may be determined from expert data. For example, expert data may be obtained (block **2612**) from various sources, such as consultations with experts, scientific literature, expert reports, and the like. As described above, in the drilling fluids BDN model described herein, the potential hole problems and associated probability states may be influenced by the selected formations used in the model. Thus, the various probability states for these formations may be determined from the expert data obtained in the process **2600**. As described above, in some embodiments the expert data may be used to generate probability data stored in a database. Next, the determined temperature ranges may be entered into an uncertainty node of the BDN model (block **2612**).

Additionally, drilling fluid formulations for use in a drilling fluids BDN model may be determined (block **2608**). The drilling fluid formulations may include the desired formulations options that may potentially be used with the formations entered into the model. Such drilling fluids may include liquids, gases, or other fluids and may be formed from a wide variety of formulations. These formulations may include water, foams, polymers, salts, lubricant, carbonate compounds, clays, thickeners, any other suitable chemical compounds or any combination thereof. The determined drilling fluids may then be entered into the decision node of the drilling fluids BDN model (block **2618**). After all of the evidence has been entered into the nodes of the drilling fluids BDN model, the drilling fluid BDN model may be completed (block **2620**). In some embodiments, after completing the drilling fluids BDN model, the completed model may be tested (block **2622**). For example, inputs to the drilling fluids BDN model may be selected and the outputs, i.e., recommended drilling fluids and expected utility values, may be tested against manual determinations based on the expert data forming the basis for the drilling fluids BDN model. Finally, if the model is complete and tested, the drilling fluid expert system incorporating the drilling fluids BDN model may be provided for use (block **2624**).

Advantageously, in the case of new and changed practices, expert opinions, etc., the drilling fluids BDN model may be updated by changing the probability states for the appropriate nodes. For example, the practices, expert opinions, and the like may be reviewed to determine if there are changes (decision block **2626**). If there are new or changed practices, expert opinions, and the like (line **2628**), then additional expert data may be obtained (block **2612**) and used to determine potential hole problems (block **2610**), drilling fluid formulations (block **2616**), and so on. Any new and changed determinations may be entered into the appropriate nodes and an updated drilling fluids BDN model may be completed (block **2620**).

FIG. **27** depicts a computer **2700** in accordance with an embodiment of the present invention. Various portions or sections of systems and methods described herein include or are executed on one or more computers similar to computer **2700** and programmed as special-purpose machines executing some or all steps of methods described above as executable computer code. Further, processes and modules described herein may be executed by one or more processing systems similar to that of computer **2700**. For example, the completion expert system **108** described may be implemented on one or more computers similar to computer **2700** and programmed to execute the Bayesian decision network model described above.

As will be understood by those skilled in the art, the computer **2700** may include various internal and external components that contribute to the function of the device and which may allow the computer **2700** to function in accordance with the techniques discussed herein. As will be appreciated, various components of computer **2700** may be provided as internal or integral components of the computer **2700** or may be provided as external or connectable components. It should further be noted that FIG. **27** depicts merely one example of a particular implementation and is intended to illustrate the types of components and functionalities that may be present in computer **2700**. As shown in FIG. **27**, the computer **2700** may include one or more processors (e.g., processors **2702***a*-**2702***n*) coupled to a memory **2704**, a display **2706**, I/O ports **2708** and a network interface **2710**, via an interface **2714**.

Computer **2700** may include any combination of devices or software that may perform or otherwise provide for the performance of the techniques described herein. For example, the computer **2700** may be representative of the client computer **200** or a server implementing some or all portions of the completion expert system **108** or other components of the systems described above. Accordingly, the computer **2700** may include or be a combination of a cloud-computing system, a data center, a server rack or other server enclosure, a server, a virtual server, a desktop computer, a laptop computer, a tablet computer, a mobile telephone, a personal digital assistant (PDA), a media player, a game console, a vehicle-mounted computer, or the like. The computer **2700** may be a

unified device providing any one of or a combination of the functionality of a media player, a cellular phone, a personal data organizer, a game console, and so forth. Computer **2700** may also be connected to other devices that are not illustrated, or may operate as a stand-alone system. In addition, the functionality provided by the illustrated components may in some embodiments be combined in fewer components or distributed in additional components. Similarly, in some embodiments, the functionality of some of the illustrated components may not be provided or other additional functionality may be available.

In addition, the computer **2700** may allow a user to connect to and communicate through a network **2716** (e.g., the Internet, a local area network, a wide area network, etc.) and to acquire data from a satellite-based positioning system (e.g., GPS). For example, the computer **2700** may allow a user to communicate using the World Wide Web (WWW), e-mail, text messaging, instant messaging, or using other forms of electronic communication, and may allow a user to obtain the location of the device from the satellite-based positioning system, such as the location on an interactive map.

In one embodiment, the display **2706** may include a liquid crystal display (LCD) or an organic light emitting diode (OLED) display, although other display technologies may be used in other embodiments. The display **2706** may display a user interface (e.g., a graphical user interface), such a user interface for a Bayesian decision network. In accordance with some embodiments, the display **2706** may include or be provided in conjunction with touch sensitive elements through which a user may interact with the user interface. Such a touch-sensitive display may be referred to as a "touch screen" and may also be known as or called a touch-sensitive display system.

The processor **2702** may provide the processing capability required to execute the operating system, programs, user interface, and any functions of the computer **2700**. The processor **2702** may receive instructions and data from a memory (e.g., system memory **2704**). The processor **2702** may include one or more processors, such as "general-purpose" microprocessors, and special purpose microprocessors, such as ASICs. For example, the processor **2702** may include one or more reduced instruction set (RISC) processors, such as those implementing the Advanced RISC Machine (ARM) instruction set. Additionally, the processor **2702** may include single-core processors and multicore processors and may include graphics processors, video processors, and related chip sets. Accordingly, computer **2700** may be a uni-processor system including one processor (e.g., processor **2702***a*), or a multi-processor system including any number of suitable processors (e.g., **2702***a*-**2702***n*). Multiple processors may be employed to provide for parallel or sequential execution of one or more sections of the techniques described herein. Processes, such as logic flows, described herein may be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating corresponding output.

As will be understood by those skilled in the art, the memory **2704** (which may include one or more tangible non-transitory computer readable storage medium) may include volatile memory, such as random access memory (RAM), and non-volatile memory, such as ROM, flash memory, a hard drive, any other suitable optical, magnetic, or solid-state storage medium, or a combination thereof. The memory **2704** may be accessible by the processor **2702** and other components of the computer **2700**. The memory **2704** may store a variety of information and may be used for a variety of purposes. The memory **2704** may store executable computer code, such as the firmware for the computer **2700**, an operating system for the computer **2700**, and any other programs or other executable code necessary for the computer **2700** to function. The executable computer code may include program instructions **2718** executable by a processor (e.g., one or more of processors **2702***a*-**2702***n*) to implement one or more embodiments of the present invention. Instructions **2718** may include modules of computer program instructions for implementing one or more techniques described. Program instructions **2718** may define a computer program (which in certain forms is known as a program, software, software application, script, or code). A computer program may be written in a programming language, including compiled or interpreted languages, or declarative or procedural languages. A computer program may include a unit suitable for use in a computing environment, including as a stand-alone program, a module, a component, a subroutine. A computer program may or may not correspond to a file in a file system. A program may be stored in a section of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or sections of code). A computer program may be deployed to be executed on one or more computer processors located locally at one site or distributed across multiple remote sites and interconnected by a communication network. In addition, the memory **2704** may be used for buffering or caching during operation of the computer **2700**. The memory **2704** may also store data files such as media (e.g., music and video files), software (e.g., for implementing functions on computer **2700**), preference information (e.g., media playback preferences), wireless connection information (e.g., information that may enable media device to establish a wireless connection), telephone information (e.g., telephone numbers), and any other suitable data.

As mentioned above, the memory **2704** may include volatile memory, such as random access memory (RAM). The memory **2704** may also include non-volatile memory, such as ROM, flash memory, a hard drive, any other suitable optical, magnetic, or solid-state storage medium, or a combination thereof. The interface **2714** may include multiple interfaces and may couple various components of the computer **2700** to the processor **2702** and memory **2704**. In some embodiments, the interface **2714**, the processor **2702**, memory **2704**, and one or more other components of the computer **2700** may be implemented on a single chip, such as a system-on-a-chip (SOC). In other embodiments, these components, their functionalities, or both may be implemented on separate chips. The interface **2714** may be configured to coordinate I/O traffic between processors **2702***a*-**2702***n*, system memory **2704**, network interface **1270**, I/O devices **1412**, other peripheral devices, or a combination thereof. The interface **2714** may perform protocol, timing or other data transformations to convert data signals from one component (e.g., system memory **2704**) into a format suitable for use by another component (e.g., processors **2702***a*-**2702***n*). The interface **2714** may include support for devices attached through various types of peripheral buses, such as a variant of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard.

The computer **2700** may also include an input and output port **2708** to allow connection of additional devices, such as I/O devices **2712**. Embodiments of the present invention may include any number of input and output ports **2708**, including headphone and headset jacks, universal serial bus (USB) ports, Firewire or IEEE-1394 ports, and AC and DC power connectors. Further, the computer **2700** may use the input and

output ports to connect to and send or receive data with any other device, such as other portable computers, personal computers, printers, etc.

The computer **2700** depicted in FIG. **27** also includes a network interface **2710**, such as a wired network interface card (NIC), wireless (e.g., radio frequency) receivers, etc. For example, the network interface **2710** may receive and send electromagnetic signals and communicate with communications networks and other communications devices via the electromagnetic signals. The network interface **2710** may include known circuitry for performing these functions, including an antenna system, an RF transceiver, one or more amplifiers, a tuner, one or more oscillators, a digital signal processor, a CODEC chipset, a subscriber identity module (SIM) card, memory, and so forth. The network interface **1270** may communicate with networks (e.g., network **2716**), such as the Internet, an intranet, a cellular telephone network, a wireless local area network (LAN), a metropolitan area network (MAN), or other devices by wireless communication. The communication may use any suitable communications standard, protocol and technology, including Ethernet, Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), a 3G network (e.g., based upon the IMT-2000 standard), high-speed downlink packet access (HSDPA), wideband code division multiple access (W-CDMA), code division multiple access (CDMA), time division multiple access (TDMA), a 4G network (e.g., IMT Advanced, Long-Term Evolution Advanced (LTE Advanced), etc.), Bluetooth, Wireless Fidelity (Wi-Fi) (e.g., IEEE 802.11a, IEEE 802.11b, IEEE 802.11g or IEEE 802.11n), voice over Internet Protocol (VoIP), Wi-MAX, a protocol for email (e.g., Internet message access protocol (IMAP), or any other suitable communication protocol.

Various embodiments may further include receiving, sending or storing instructions and/or data implemented in accordance with the foregoing description upon a computer-accessible medium. Generally speaking, a computer-accessible/readable storage medium may include a non-transitory storage media such as magnetic or optical media, (e.g., disk or DVD/CD-ROM), volatile or non-volatile media such as RAM (e.g. SDRAM, DDR, RDRAM, SRAM, etc.), ROM, etc., as well as transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as network and/or a wireless link.

Further modifications and alternative embodiments of various aspects of the invention will be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as examples of embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed or omitted, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims. Headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description.

As used throughout this application, the word "may" is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). The words "include", "including", and "includes" mean including, but not limited to. As used throughout this application, the singular forms "a", "an" and "the" include plural referents unless the content clearly indicates otherwise. Thus, for example, reference to "an element" includes a combination of two or more elements. Unless specifically stated otherwise, as apparent from the discussion, it is appreciated that throughout this specification discussions utilizing terms such as "processing", "computing", "calculating", "determining" or the like refer to actions or processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic processing/computing device. In the context of this specification, a special purpose computer or a similar special purpose electronic processing/computing device is capable of manipulating or transforming signals, typically represented as physical electronic or magnetic quantities within memories, registers, or other information storage devices, transmission devices, or display devices of the special purpose computer or similar special purpose electronic processing/computing device.

What is claimed is:

1. A system, comprising

one or more processors;

a non-transitory tangible computer-readable memory, the memory comprising:

a drilling fluids expert system executable by the one or more processors and configured to provide one or more drilling fluids recommendations based on one or more inputs, the drilling fluids expert system comprising a drilling fluids Bayesian decision network (BDN) model, the drilling fluids BDN model comprising

a temperature ranges uncertainty node configured to receive one or more temperature ranges from the one or more inputs, each of the one or more temperature ranges associated with a respective one or more temperature range probabilities;

a formations uncertainty node configured to receive one or more formations from the one or more inputs, each of the one or more formations associated with a respective one or more formation probabilities;

a potential hole problems uncertainty node dependent on the formations uncertainty node and configured to receive one or more potential hole problems from the one or more inputs and the one or more formation probabilities, each of the one or more potential hole problems associated with a respective one or more potential hole problem probabilities;

a drilling fluids decision node configured to receive one or more drilling fluids from the one or more inputs; and

a consequences node dependent on the temperature ranges uncertainty node, the potential hole problems uncertainty node, and the drilling fluids decision node and configured to output the one or more drilling fluids recommendations based on one or more Bayesian probabilities calculated from the one or more temperature ranges and the one more temperature range probabilities, the one or more potential hole problems and the one or more potential hole problem probabilities, and the one or more drilling fluids.

2. The system of claim **1**, comprising a user interface configured to display the drilling fluids BDN model and receive user selections of the one or more input.

3. The system of claim **1**, wherein the one or more temperature ranges, the one or more formations, and the one or

more potential hole problems are each associated with a respective plurality of probabilities.

4. The system of claim **1**, wherein the respective plurality of probabilities is obtained from an expert date data repository storing expert data.

5. The system of claim **1**, wherein the one or more drilling fluids recommendations comprise one or more drilling fluid formulations.

6. The system of claim **1**, wherein the one or more drilling fluids recommendations comprises one or more expected utilities for the one or more drilling fluid formations.

7. The system of claim **1**, wherein the one or more expected utilities are provided in a table displayed to the user in the user interface, the table comprising the one or more drilling fluid formulations and the expected utility value for each of the one or more drilling fluid formulations.

8. The system of claim **1**, wherein the one or more formations comprise at least one of: formation names, formation lithologies, formation types, or any combination thereof.

9. A computer-implemented method for a drilling fluids expert system having a drilling fluids Bayesian decision network (BDN) model, the method comprising:

receiving, at one or more processors, one or more inputs;

providing, by one or more processors, the one or more inputs to one or more nodes of the drilling fluids BDN model, the one or more nodes comprising:

a temperature ranges uncertainty node configured to receive one or more temperature ranges from the one or more inputs, each of the one or more temperature ranges associated with a respective one or more temperature range probabilities;

a formations uncertainty node configured to receive one or more formations from the one or more inputs each of the one or more formations associated with a respective one or more formation probabilities;

a potential hole problems uncertainty node dependent on the formations uncertainty node and configured to receive one or more potential hole problems from the one or more inputs and the one or more formation probabilities, each of the one or more potential hole problems associated with a respective one or more potential hole problem probabilities;

a drilling fluids decision node; and

a consequences node dependent on the temperature ranges uncertainty node, the potential hole problems uncertainty node, and the drilling fluids decision node;

determining, at one or more processors, one or more drilling fluids recommendations at the consequences node of the drilling fluids BDN model, the determination comprising a calculation of one or more Bayesian probabilities based on the one or more inputs; and

providing, by one or more processors, the one or more drilling fluids recommendations to a user.

10. The computer-implemented method of claim **9**, wherein providing the one or more drilling fluid recommendations to a user comprises displaying, by one or more processors, the one or more drilling fluid recommendations in a user interface element of a user interface configured to display the drilling fluids BDN model.

11. The computer-implemented method of claim **9**, wherein receiving one or inputs comprises receiving, at one or more processors, a user selection for the temperature ranges uncertainty node, a user selection for the formations uncertainty node, a user selection for the potential hole problems uncertainty node, or a combination thereof.

12. The computer-implemented method of claim **9**, wherein the one or more drilling fluids recommendations comprise one or more drilling fluid formulations.

13. The computer-implemented method of claim **9**, wherein the one or more drilling fluids recommendations comprises one or more expected utilities for the one or more drilling fluid formations.

14. The computer-implemented method of claim **9**, wherein providing the one or more drilling fluids recommendations to a user comprises providing, by one or more processors, a table displayed to the user in the user interface, the table comprising the one or more drilling fluid formulations and the expected utility value for each of the one or more drilling fluid formulations.

15. The computer-implemented method of claim **9**, wherein the one or more formations comprise at least one of: formation names, formation lithologies, formation types, or any combination thereof.

16. The computer-implemented method of claim **9**, wherein the one or more inputs provided to the temperature ranges uncertainty node, the formations uncertainty node, and the potential hole problems uncertainty node, are associated with a respective plurality of probabilities.

17. The computer-implemented method of claim **16**, comprising associating, by one or more processors, the respective plurality of probabilities based on a user selection of the one or more inputs.

18. A computer-implemented method of determining a drilling fluid formulation for a drilling system, the method comprising:

receiving, at one or more processors, an input from a user, the input comprising a temperature range, a formation, a potential hole problem, or any combination thereof;

providing, by one or more processors, the input to a drilling fluids Bayesian decision network (BDN) model configured to receive one or more drilling fluid formulations;

determining, by one or more processors, an expected utility value for the one or more drilling fluid formulations based on the input, the determination comprising a calculation of one or more Bayesian probabilities for the one or more drilling fluid formulations based on the input; and

providing, by one or more processors, an output from the drilling fluids BDN model, the output comprising one or more recommended drilling fluid formulations selected from the one or more drilling fluid formulations.

19. The computer-implemented method of claim **18**, comprising displaying, by one or more processors, a plurality of temperature ranges, a plurality of formations, a plurality of potential hole problems or a combination there of in a user interface element displayed to the user.

20. The computer-implemented method of claim **19**, wherein providing, by one or more processors, the output from the drilling fluids BDN model comprises providing a table displayed to the user in the user interface, the table comprising the one or more drilling fluid formulations and the expected utility value for each of the one or more drilling fluid formulations.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,202,169 B2
APPLICATION NO. : 13/827408
DATED : December 1, 2015
INVENTOR(S) : Absullah Saleh Hussain Al-Yami et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In The Claims

In Column 25, Line 4, Claim 4, the third to last word "date" should be removed.

Signed and Sealed this
Twenty-third Day of February, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office