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(54) METHODS AND APPARATUS FOR HAZARD ABATEMENT USING NORMALIZED EFFECT ANALYSIS

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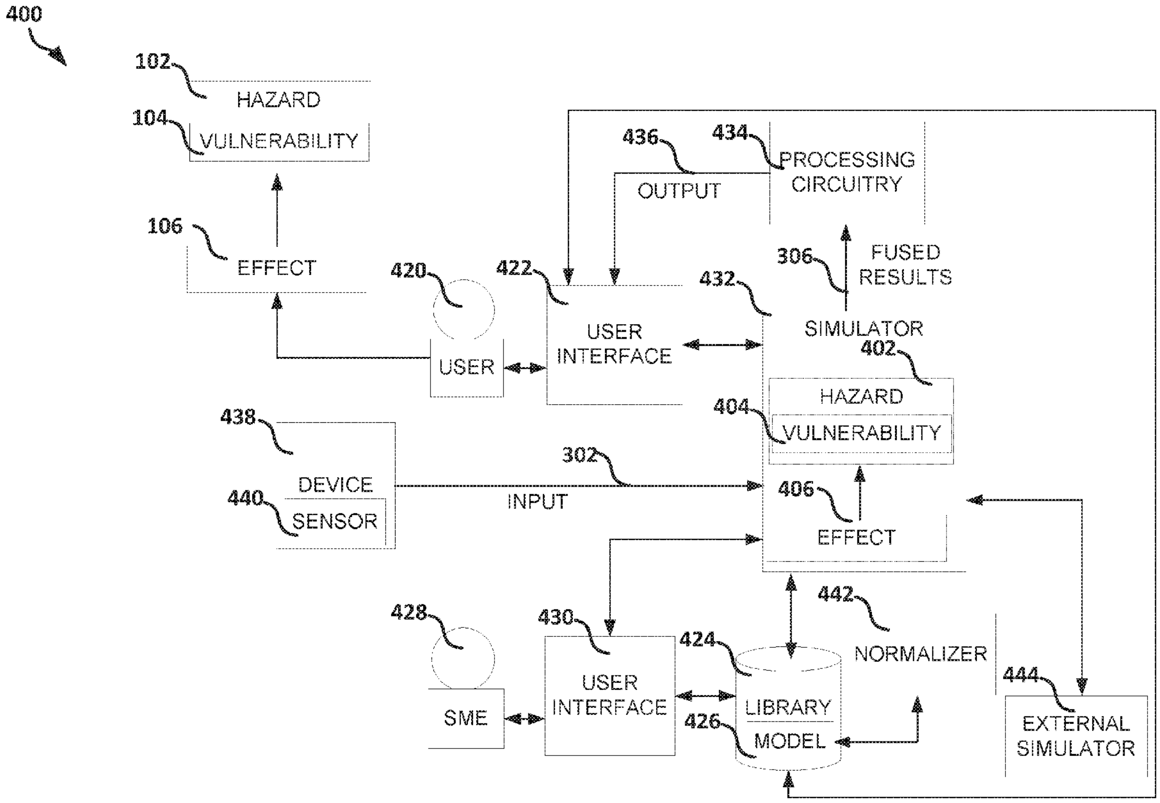
(52) **U.S. Cl.**

CPC ***G06F 17/5009*** (2013.01); ***G06F 17/11*** (2013.01); ***G06N 7/005*** (2013.01)

(57) **ABSTRACT**

Generally discussed herein are systems, devices, and methods for mitigating damage caused by a hazard. A method can include identifying at least two effects that, with some probability, at least partially mitigate the hazard, identifying one or more vulnerabilities of the hazard that are the target for an effect of the identified effects, for each hazard, vulnerability pair, identifying a respective hazard model that simulates a state of the hazard in response to the effect, identifying effect models that simulate the respective effects, normalizing each of the identified effect models to a common model and determining a confidence level for each parameter of each normalized model, and simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.



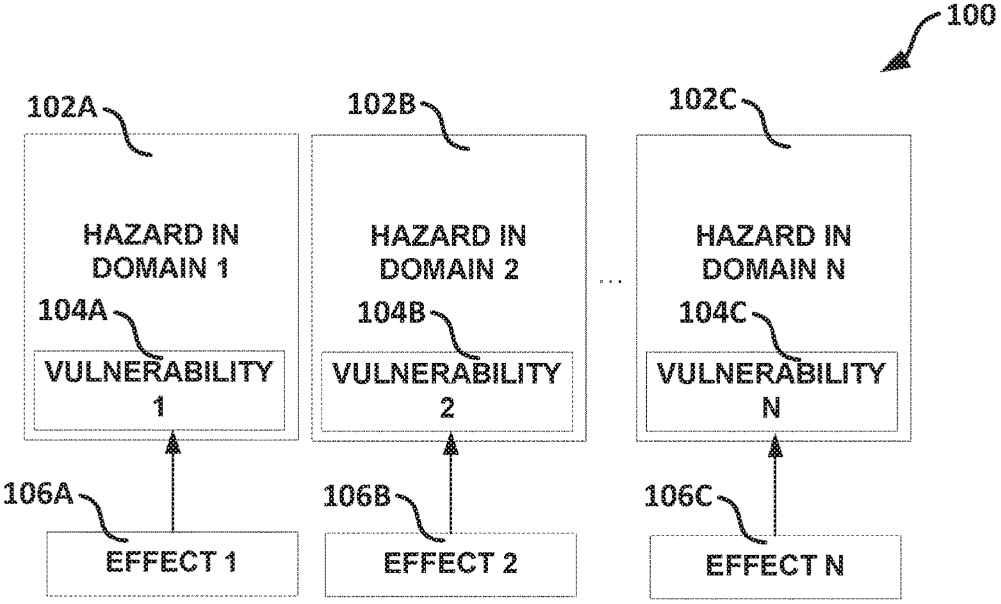

100
102A
102B
102C
HAZARD IN DOMAIN 1
HAZARD IN DOMAIN 2
...
HAZARD IN DOMAIN N
104A
104B
104C
VULNERABILITY 1
VULNERABILITY 2
VULNERABILITY N
106A
106B
106C
EFFECT 1
EFFECT 2
EFFECT N

FIG. 1

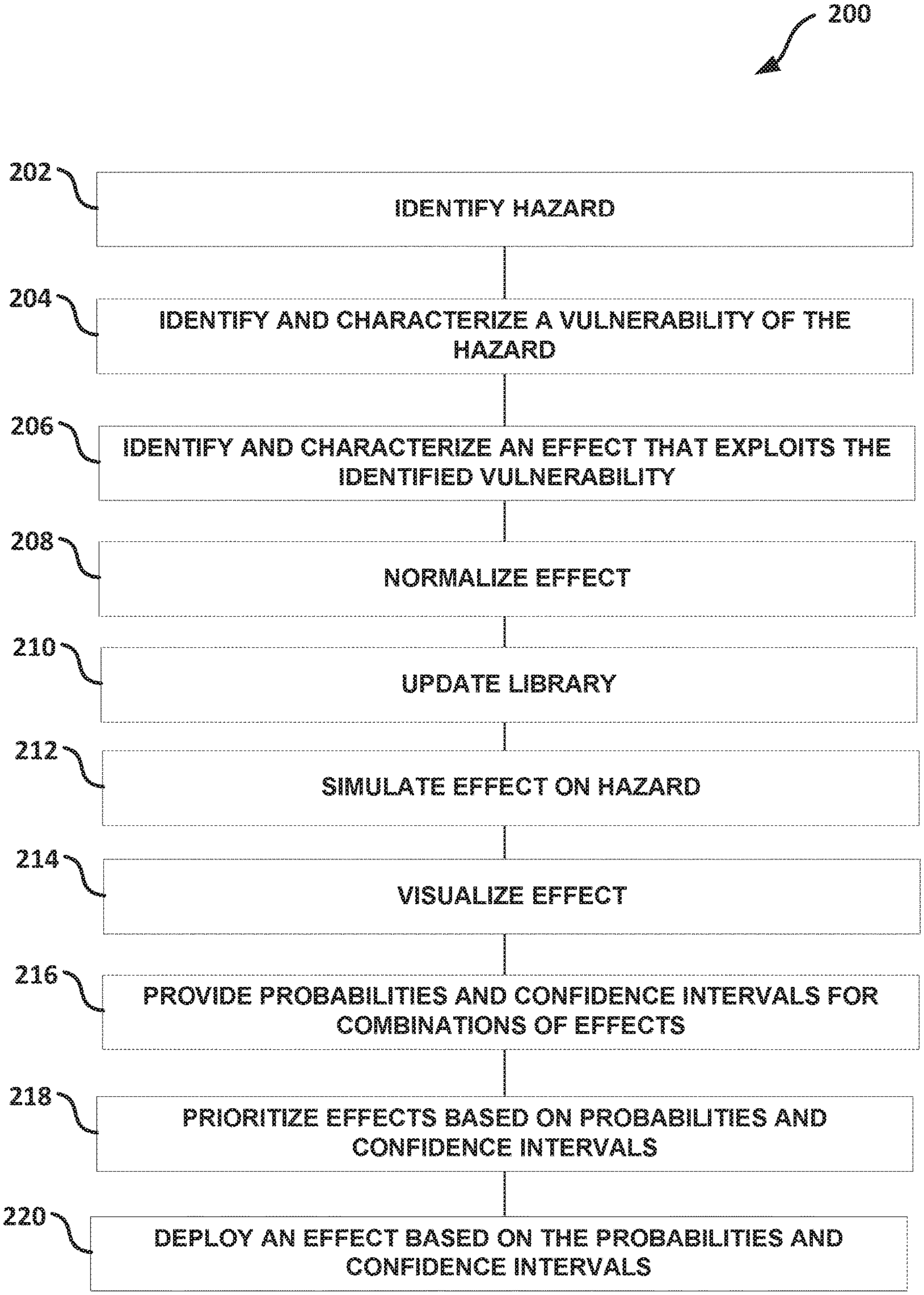

200
202
IDENTIFY HAZARD
204
IDENTIFY AND CHARACTERIZE A VULNERABILITY OF THE HAZARD
206
IDENTIFY AND CHARACTERIZE AN EFFECT THAT EXPLOITS THE IDENTIFIED VULNERABILITY
208
NORMALIZE EFFECT
210
UPDATE LIBRARY
212
SIMULATE EFFECT ON HAZARD
214
VISUALIZE EFFECT
216
PROVIDE PROBABILITIES AND CONFIDENCE INTERVALS FOR COMBINATIONS OF EFFECTS
218
PRIORITIZE EFFECTS BASED ON PROBABILITIES AND CONFIDENCE INTERVALS
220
DEPLOY AN EFFECT BASED ON THE PROBABILITIES AND CONFIDENCE INTERVALS

FIG. 2

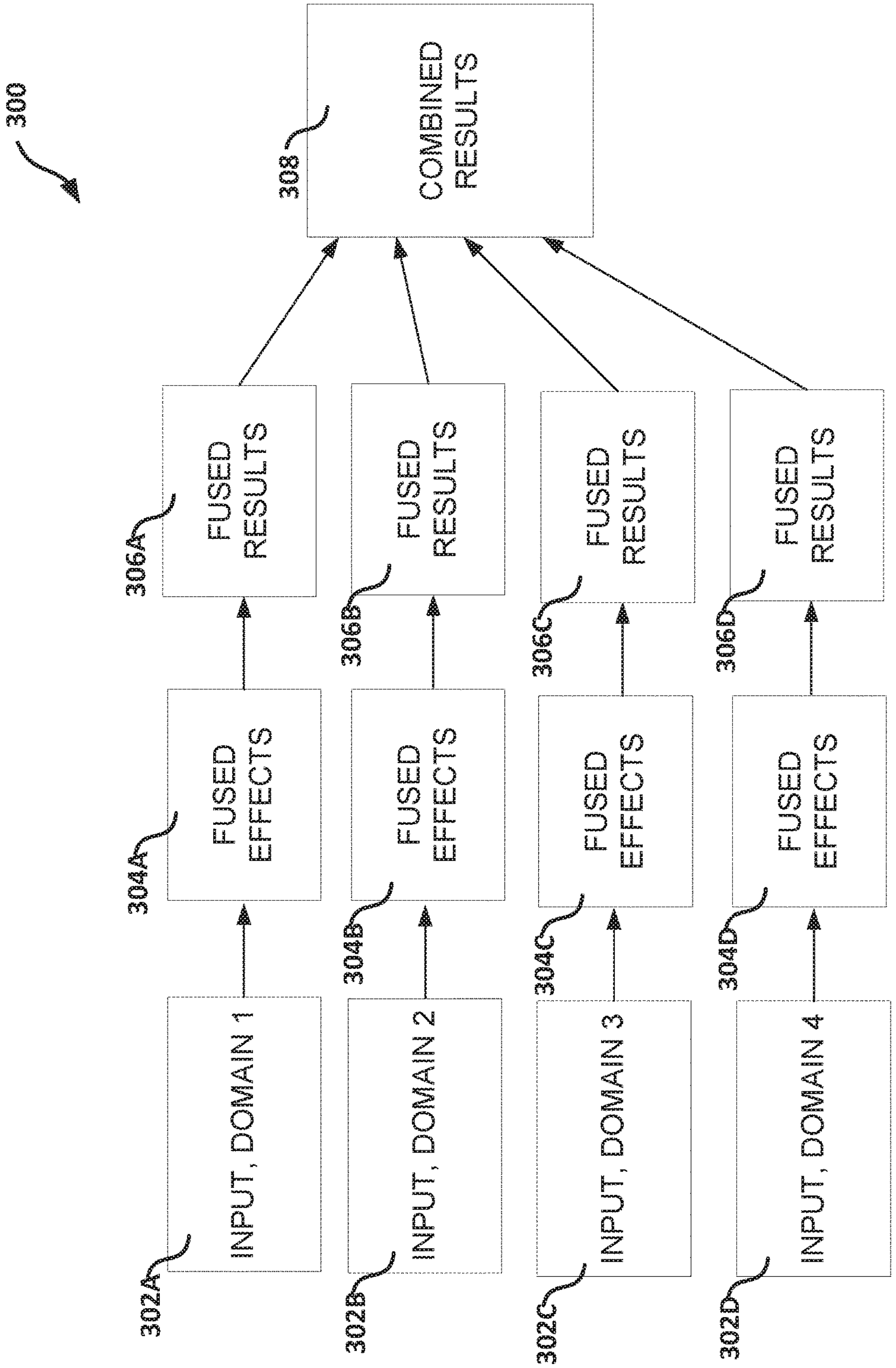

300
308
COMBINED RESULTS
306A
FUSED RESULTS
306B
FUSED RESULTS
306C
FUSED RESULTS
306D
FUSED RESULTS
304A
FUSED EFFECTS
304B
FUSED EFFECTS
304C
FUSED EFFECTS
304D
FUSED EFFECTS
302A
INPUT, DOMAIN 1
302B
INPUT, DOMAIN 2
302C
INPUT, DOMAIN 3
302D
INPUT, DOMAIN 4

FIG. 3

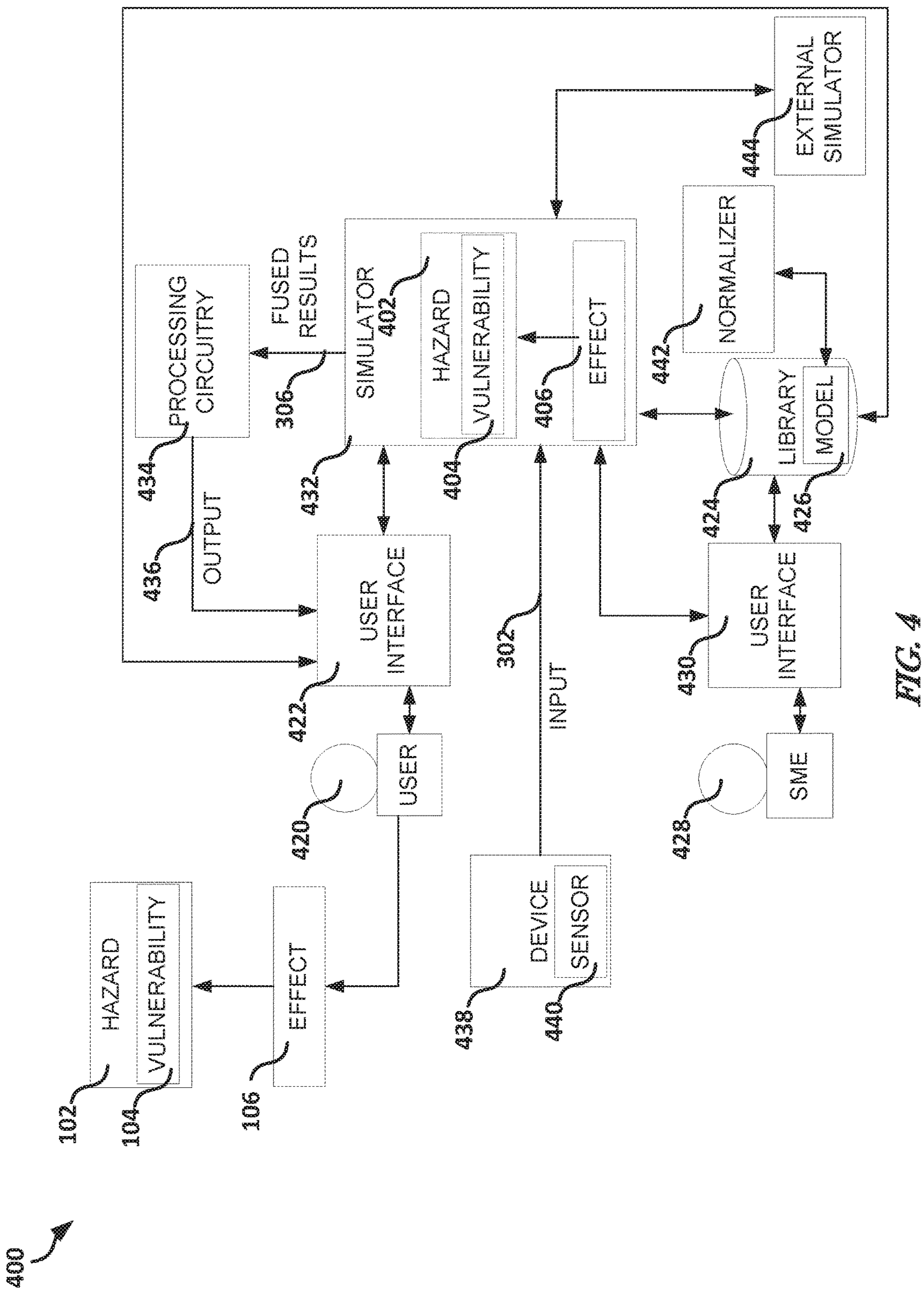

400
102
HAZARD
104
VULNERABILITY
106
EFFECT
420
USER
422
USER INTERFACE
438
DEVICE
440
SENSOR
INPUT
302
428
SME
430
USER INTERFACE
436
OUTPUT
434
PROCESSING CIRCUITRY
432
SIMULATOR
402
HAZARD
404
VULNERABILITY
406
EFFECT
306
FUSED RESULTS
424
LIBRARY
426
MODEL
442
NORMALIZER
444
EXTERNAL SIMULATOR

FIG. 4

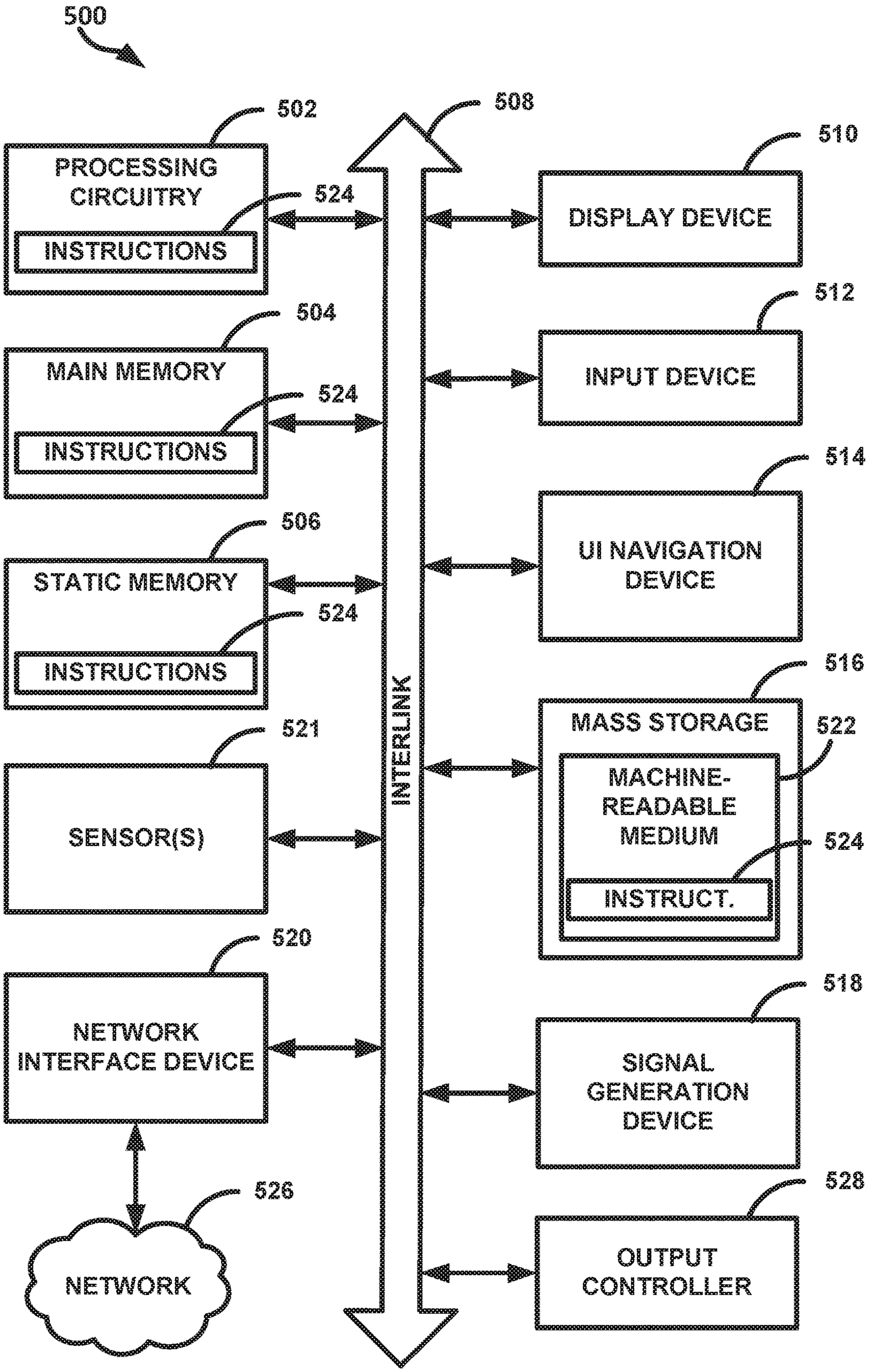

500
502
PROCESSING CIRCUITRY
524
INSTRUCTIONS
504
MAIN MEMORY
524
INSTRUCTIONS
506
STATIC MEMORY
524
INSTRUCTIONS
521
SENSOR(S)
520
NETWORK INTERFACE DEVICE
526
NETWORK
508
INTERLINK
510
DISPLAY DEVICE
512
INPUT DEVICE
514
UI NAVIGATION DEVICE
516
MASS STORAGE
522
MACHINE-READABLE MEDIUM
524
INSTRUCT.
518
SIGNAL GENERATION DEVICE
528
OUTPUT CONTROLLER

FIG. 5

METHODS AND APPARATUS FOR HAZARD ABATEMENT USING NORMALIZED EFFECT ANALYSIS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 62/607,048, filed on Dec. 18, 2017, and titled "PRIORITIZATION OF CYBER EFFECTS IN MULTI-DOMAIN ENVIRONMENTS", which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] Generally discussed herein are systems, devices, techniques, and machine-readable media for determining a response to a hazard. In some embodiments, multiple effects, from one or more domains, are normalized and combined to determine a net effect on the hazard. In some embodiments, effects from distinct domains can be combined to determine the net effect. A likelihood can be determined that indicates how likely it is that the effect(s), with determined confidence, will at least partially mitigate the hazard.

TECHNICAL BACKGROUND

[0003] Hazard abatement approaches vary widely. For example, the Department of Defense (DoD) respond to a hazard in a manner very differently from the Federal Emergency Management Agency (FEMA). This is at least partially because, the hazards that the DoD and FEMA handle are very different. It is also because, no uniform method existed for analysis of effects applied against hazards. Previous approaches examine only a portion of a single domain. These approaches provide end-users with only partial results from which to make critical decisions. This problem is particularly difficult in the presence of cyber hazards where timely response is critical for system survival.

[0004] This problem has been approached for non-cyber hazards (e.g., kinetic weapons that explode) by prioritizing responses manually, following procedures that make use of information that resides in various standards and manuals (e.g., Joint Munitions Effectiveness Manuals (JMEMs)). These standards and manuals provide a means to manually compare kinetics effects with respect to their relative success at defeating or degrading kinetic hazards. However, these mechanisms lack uniformity with respect to the unique effect equations and their respective parameters. Therefore, they lack the ability to integrate and fuse together the results of the equations to provide one consistent result for multi-domain environments where multiple effects may be applied against one or more hazards over the temporal period of the hazard kill chain. Additionally, there exists no automated capability to derive the fused and integrated analysis within that multi-domain environment.

[0005] A Common Vulnerability Scoring System (CVSS) from the Compute Security Resource Center of the National Institute of Standards and Technology (NIST) provides an open framework for communicating characteristics and impacts of information technology (IT) vulnerabilities. The quantitative model of the CVSS ensures repeatable accurate measurement while enabling users to see the underlying vulnerability characteristics that were used to generate the scores. However, the basis for the results is subject matter experts answers to a series of questions. This leads to highly variable results not suitable for critical decision-making.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0007] FIG. **1** illustrates, by way of example, a diagram of a hazard and hazard abatement scenario.

[0008] FIG. **2** illustrates, by way of example, a diagram of an embodiment of a method for hazard abatement.

[0009] FIG. **3** illustrates, by way of example, a data flow diagram of a system for hazard abatement.

[0010] FIG. **4** illustrates, by way of example, a diagram of a system for hazard abatement.

[0011] FIG. **5** illustrates, by way of example, a block diagram of an embodiment of a machine in the example form of a computer system within which instructions, for causing the machine to perform any one or more of the methodologies discussed herein, may be executed.

DESCRIPTION OF EMBODIMENTS

[0012] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0013] Embodiments can provide a structured methodology with which to analyze and prioritize effects, such as, within multi-domain environments. Innovative aspects can include: 1. New capability to integrate and fuse analysis for multiple, diverse effects, such as in a multi-domain environment. 2. Novel capability to normalize analytics equations) in accordance with industry and/or government standards. 3. New methods for deriving and applying mathematical functions for effects and hazard representations. 4. New methods for prioritizing effects based on success against targets derived from analysis results.

[0014] As discussed in the background, no structured and repeatable method exists for analysis of effects, or effects in different domains. The effects can be applied against one or more hazards over diverse media within multi-domain environments (e.g., wired & wireless networks on land, sea, and space for manufacturing, transportation, command and control (C2), and mission flight).

[0015] FIG. **1** illustrates, by way of example, a diagram of an embodiment of a hazard and hazard abatement scenario **100**. The scenario **100** as illustrated includes a hazard in a first domain **102**A, second domain **102**B, and a third domain **102**C. The hazard includes or may be associated with one or more vulnerabilities **104**A, **104**B, and **104**C in each domain **102**A-**102**C, respectively. The vulnerability **104**A can be the same or different from the vulnerability **104**B-**104**C. An effect **106**A, **106**B, **106**C can exploit the vulnerability **104**A-**104**C, respectively, such as to help mitigate the hazard in the domain **102**A-**102**C.

[0016] The hazard can include one or more physical hazards to a person, place, or thing. The hazard can include a manned, unmanned, or natural physical hazard. A manned physical hazard can include, for example, a weapon, a vehicle, or the like. An unmanned physical hazard can include, for example, a drone, robot, turret, or the like. A natural hazard can include a hurricane, tornado, mudslide, earthquake, drought, flooding, or the like. As another example, a hazard may comprise a disease, an injury and/or a health disorder.

[0017] The vulnerability **104**A-**104**C may comprise a weakness in the hazard that can be exploited, such as to help mitigate or prevent some of the damage caused by the hazard. For example, the vulnerability **104**A-**104**C may include an eye of a hurricane, a jamming frequency, a speed of a tornado, a strength of an earthquake, a road on which a missile is to be carried, a transport vehicle carrying a missile, a battery life of a powered device, a human of a human-operated hazard, or the like.

[0018] The effect **106**A-**106**C exploits the vulnerability **104**A-**104**C to help mitigate the hazard. The effect **106**A-**106**C can include structural reinforcement (e.g., boards, beams, sandbags, or the like), preemptive delivery of goods, a preemptive or counterattack (e.g., destruction of a vehicle, weapon, robot, drone, facility, person, frequency jamming, or the like), or the like.

[0019] The domain **102**A-**102**C includes the environment in which the hazard is operating. The domain **102**A-**102**C can include land, water, air, or wired or wireless channels for manufacturing, medium, network, transportation, combat, control, flight, operation, or the like.

[0020] The vulnerability **104**A-**104**C can be same or different for a same hazard in different domains **102**A-**102**C. For example, a hurricane over water can have different strengths and weaknesses than the same hurricane over land. An effect **106**A-**106**C can have a different probability of success in mitigating the hazard in a different domain **102**A-**102**C.

[0021] As previously discussed, prior approaches examine only a portion of a single domain. These approaches provide end-users with only partial results from which to make critical decisions. Various features of the embodiments described herein can analyze a hazard and corresponding vulnerability **104**A-**104**C and effect **106**A-**106**C (1) in multiple domains, or (2) with multiple effects **106**A-**106**C. The techniques described herein can help determine a response to the hazard that can be effective in mitigating damage inflicted by the hazard. The described embodiments can provide confidence intervals that indicate to a user a likelihood that the effect **106**A-**106**C will successfully mitigate a portion of the hazard. The embodiments can provide a framework in which diverse, distinct hazards, effects, and vulnerabilities can be analyzed simultaneously.

[0022] FIG. **2** illustrates, by way of example, a diagram of an embodiment of a method **200** for hazard-effect analysis. The method **200** as illustrated includes identifying a hazard, at operation **202**; identifying and characterizing a vulnerability of the hazard, at operation **204**; identifying and characterizing an effect that exploits the identified vulnerability, at operation **206**; normalizing the identified effect, at operation **208**; updating a library of effects, at operation **210**; simulating the effect on the hazard, at operation **212**; and visualizing the effect on the hazard, at operation **214**. Further operations **216**, **218** and **220** of the method **200** are also illustrated in FIG. **2**. Some of the operations of the method **200** are optional and may or may not be performed as desired depending on the embodiment.

[0023] The operation **202** can include identifying a goal of mitigating the hazard, sometimes called a concept of operation (CONOP) or concept of employment (CONEMP). The operation **202** can include identifying a number and type of hazard. The goal can be chosen so that it is applicable under operation of an effect.

[0024] The operation **204** can include producing or identifying a mathematical model of the vulnerability associated with the hazard. The operation **204** can include determining that the vulnerability is consistent with the goal.

[0025] The operation **206** can include producing or identifying a mathematical model of the effect. The mathematical model is sometimes called a probability of defeat (pDefeat) equation. The mathematical model can indicate a probability, given environmental circumstances, a likelihood that the effect at least partially mitigates the hazard by exploiting the vulnerability. In some embodiments, the effect can be paired with one or more vulnerabilities, such that operation **204** is performed in selecting the effect at operation **204**. The operation **206** can include identifying or producing one or more parameters, constraints, or the like of the mathematical model.

[0026] The operation **208** can include normalizing the effect model to a common probability model. The common probability model can be defined so that an effect, normalized to the common probability model (CPM), can be re-used for multiple hazards, vulnerabilities, or combining with other effects. In some embodiments, the common probability model can include a stochastic math model (SMM). Normalizing the mathematical model of the effect can include normalizing the parameters thereof so that they are consistent within the framework of the model. The operation **208** can include determining or identifying a confidence level or variability in a given parameter.

[0027] An example of a mathematical model for the probability of success (Psuccess) of an effect (such as an interceptor) on a hazard (such as a missile) is provided:

$$P_{success}=P_{ES}*P_{CS}*P_{REL}*P_{CTS}*P_{FOV}*P_{DIV} \quad \text{Equation 1}$$

[0028] In Equation 1, P_{ES} indicates a likelihood of combat system support services operating correctly. This can include the probability of detection and tracking, probability of hazard engagement, probability of target designation, or a probability of engagement reliability. P_{CS} indicates a reliability of a communication support system operating. P_{REL} indicates a reliability of an interceptor missile. This can include a probability of missile reliability or a probability that a transport vehicle is disabled using the missile. P_{CTS} indicates a probability of a correct target selection. This can depend on targeting logic and on-board target selection logic. P_{FOV} indicates a probability of field of view containment. P_{DIV} indicates a probability of divert containment. A combination of P_{DIV} and P_{FOV} is sometimes called a probability of containment. Each of the probabilities are parameters of the mathematical model.

[0029] The operation **208** can include adjusting the probability models such that the data inputs, the metrics comprising the equation parameters, and the resulting outputs are on the defined common scale and common format. These adjustments are referred to as normalizing the effect. For example, if P_{ES1} for effect **1** includes parameters defined in terms of meters, and if P_{ES2} for effect **2** includes parameters defined in terms of feet, then normalizing these probability models would require the conversion of the distance parameters in one model to conform to the common distance scale and format used by the other (i.e., convert feet in P_{ES1} to meters).

[0030] The operation **210** can include storing the normalized effect model in a library of normalized effect models. The normalized effect models can be normalized to a same target (e.g., a common probability model) so that they can be combined and an outcome using multiple effects can be accurately simulated. For example, consider effects for mitigating harm from a missile. The effects can include cyber effects (e.g., jamming, hacking, or the like), or kinetic effects (e.g., an interceptor missile, a target replacement (forcing missile explosion by intercepting the missile with a substitute target), or the like). Each of the effects can be dependent on one or more systems operating properly. For example, a probability of interceptor success can be dependent on a tracking system operating properly, a detection system operating properly, and an engagement system operating properly. The probability of success of the effect can also be dependent on the missile being operational, being removed from a storage location, being loaded onto a carrier, being transported by the carrier to the launch site, being loaded into the launcher, launched, tracking to a target, detecting a target, and engaging a target. Each of these stages of the missile can have different models that can be combined to form an overall model of the missile deployment (the hazard deployment). An effect can be useful in one or more of any of the stages of the missile deployment.

[0031] FIG. **3** illustrates, by way of example, a diagram of an embodiment of a method **300** for combining and simulating combinations of effects (sometimes called fusing). The method **300** includes receiving inputs **302**A, **302**B, **302**C, and **302**D. The inputs **302**A-**302**D can be from different domains (e.g., environments). For example, a first domain can include air, a second domain can include water, a third domain can include land, and a fourth domain can include space.

[0032] The input **302**A from an air domain can include data from an unmanned aerial vehicle, a manned aerial vehicle, or the like. The aerial vehicle can include one or more sensors that gather data regarding a condition in the air. Such sensors can include one or more of an optic sensor, a temperature sensor, a pressure sensor, electromagnetic sensor, liquid sensor, wind sensor, image sensor/camera, or the like.

[0033] The input **302**B from a water domain can be from a boat, submarine, other manned or unmanned water vessel, or a monitoring station on water that can capture data. The water vessel (or another such platform as mentioned above) can include one or more sensors that gather data regarding a condition in or on the water. Such a sensor can include a turbidity sensor, a flow sensor, a temperature sensor, an optical sensor, a salinity sensor, or the like.

[0034] The input **302**C from a land domain can be from a land vehicle or otherwise on the land. A sensor on the land can include a same or different sensor as those in the air domain or the water domain.

[0035] The input **302**D from a space domain can be from a satellite or other object in space. The sensor in space can include a same or different sensor as those in the land, air, or water.

[0036] As previously discussed, effects can be from different domains. Effects in different domains can have different inputs that govern the operation of the effects. The effects from each domain can be fused **304**A, **304**B, **3040**, and **304**D. The inputs **302**A-**302**D can inform the operation of the fused effects **304**A-**304**D to produce simulation results **306**A, **306**B, **306**C, and **306**D. The results from each of the domains can then be fused, because the effects have been normalized to each other, to produce combined results **308**.

[0037] The fused results **306**A-**306**D and combined results **308** can include a probability, a confidence interval, and an indication of a target of the effect(s). The probability can indicate a likelihood that the effect(s) from the fused effects **304**A-**304**D will exploit a vulnerability and mitigate at least a portion of harm caused by the hazard. The confidence interval can indicate how much variability there is in the probability of the results **308**. The target can indicate the hazard (if there are multiple hazards) or a vulnerability of the hazard to be exploited by the effects.

[0038] The confidence interval can be determined by making changes to the input **302**A-**302**D and recording the results. These simulations with changes in inputs are sometimes called Monte Carlo simulations. In Monte Carlo simulations, random samples of the inputs **302**A-**302**D are chosen for operation of the simulation. The results from the random input values are used to generate the probability and the confidence interval. The average or a weighted average of the results from the Monte Carlo simulation can be used to determine a resultant probability. A variance, standard deviation, or some other measure of variability can be used as the confidence interval. The combined results **308** can be determined in a same or a different manner as the fused results **306**A-**306**D except based on the fused results **306**A-**306**D rather than the result of the effects **304**A-**304**D.

[0039] The operation **214** can include providing a visualization of a geographic area, a computer network, a battlefield, one or more items or components (e.g., buildings, vehicles, roadways, waterways, or other assets), or the like that could be affected by the hazard. The visualization can be of the fused effects **304**A-**304**D operation on the hazard. The operation **216** can include providing the combined results **308**.

[0040] What follows is three example applications of embodiments. The Examples include missile defense, hurricane relief, and biological disaster response.

[0041] Example 1 is a detailed example for missile defense.

[0042] For operation **202**, initial information can be available, but the details can be developed and refined throughout the process. The process can be iterative, and steps may require rework as new knowledge comes up with new use cases.

[0043] For operations **202**, **204**, and **206** one or more hazards, associated effects, and CONOPS or CONEMP can be identified or generated that describe the intended use of the effect against an initial list of hazards. For operation **206**, it can be determined if the effect might be used against multiple hazards or multiple types of hazards. At operation **206**, it can be determined if the effect might be used in conjunction with other effects, such as to increase efficacy.

[0044] Operation **202** can include documenting or developing a CONOP or concept of deployment, as applicable, to describe how the effect might be used against the hazard.

Operation **202** can include documenting any known operational constraints and assumptions. Operations **202**, **204**, and **206** can include considering the use of one or more effects from different platforms and at different phases of the hazard kill chain. The operation **202** can include identifying any applicable deployment locations and schedules, and any applicable launch/target locations and schedules.

[0045] The operation **202** can include identifying at least some hazard information. The hazard information can include a hazard name and unique identifier, sites or site locations associated with the hazard (e.g., manufacturing sites, deployment sites, launch sites, or the like), hazard scenarios (full Hazard life cycle or subset), such as with process times and time lines, and hazard trajectories (e.g. to/from locations), as applicable.

[0046] The operation **204** can include identifying and characterizing the hazard vulnerability(s). The operation **204** can include identifying the corresponding hazard vulnerabilities against which the effect can be applied. For each vulnerability, the associated CONOPS and/or CONEMP for deploying the new effect can be identified at operation **204** or **206**.

[0047] As previously discussed, an effect may be used against more than one hazard, and a given hazard may have multiple vulnerabilities. The operations **202**, **204**, and **206** can identify not only at the initially selected hazard, but also at additional hazards against which the effect may be applied. In operations **202** and **204** each unique hazard, vulnerability pair can be separately identified.

[0048] At operation **204**, vulnerabilities associated with different stages of hazard deployment and activation scenarios can be identified. For example, a hazard that must be transported may have additional vulnerabilities that are associated with the transport system. At operation **204**, a separate entry can be added to an effects library for each pairing of the effect to a unique hazard, vulnerability pair.

[0049] The operation **206** can include identifying subject matter experts (SME) for the effect and any other applicable associated effects. A purpose of the effects library can include providing a user with a selection of effects that can be either used, individually or combined, against an identified hazard, vulnerability pair. Note that each effect model equation (e.g., pDefeat equation) can be based on the pairing of a specific effect with a specific hazard, vulnerability pair. Other applicable hazards can be identified at the same time.

[0050] The operation **206** information associated with the effect can be identified. The information can include an effect name, a unique identifier, applicable sites, site locations associated with the effect (e.g., manufacturing sites, deployment sites, launch sites, or the like), effect scenarios with process times and time lines, effect trajectories (e.g., to/from locations), as applicable, effect constraints and limitations, or hazard states (e.g., one or more of the required state of the hazard and the state of the hazard upon successful application of the effect). Some effects work on the hazard indirectly (e.g., a Denial of Service (DoS) effect on a transport vehicle can applied to the transport vehicle and it affects the delivery of hazard(s) in its cargo).

[0051] The operation **206** can include identifying or generating a model for each effect and hazard, vulnerability pairing. A top-level model is defined in application Ser. No. 15/445,095 to P. Hershey, et al., titled "Method and Technique for Simulation and Integration of Multi-Domain Nonkinetic/Kinetic Systems (MATSIMS)", filed 28 Feb. 2017. The top-level model can be the same for all effect and hazard, vulnerability pairings. The top-level parameters can usually be broken down into lower-level formulas with lower-level parameters. Each of those lower-level parameters has the potential for being broken down even further. The specific composition of those equations is dependent on the factors that influence the model for that specific effect against that specific hazard, vulnerability. Some of those factors include type of effect (e.g., kinetic, Electronic Warfare (EW), cyber, or the like), timing of effect (e.g., before or after launch, or specific phase of the hazard kill chain), architecture on which the equations and parameters are based, dependencies on other systems, or any additional assumptions.

[0052] Several models already exist for different effect/vulnerability pairings. Reuse of existing equations can help take advantage of the existing common probability model and software, keep model terms and vocabulary consistent, and take advantage of prior SME experience in deriving and defining models. If an existing model does not exist for an effect/vulnerability pairing, an equation can be generated. Use of SME when identifying/generating the model can help identify subtle differences in perspective or terminology that can influence the definition of the equation. The operation **206** can include identifying the model for the use of a single effect against a vulnerability or generating or identifying a corresponding model for the use of multiple instances of an effect against the vulnerability, if applicable.

[0053] The operation **206** can include expanding the definition of each parameter in the model to identify the source of the parameter and the use. For one or more parameters, one or more of the following can be identified at operation **206**: parameter name, unique identifier, definition, source(s) of the default parameter values, a probability distribution, with associated parameter values, that represents the value, or range of values, for the parameter, source(s) of mission-specific parameter value changes, to include user (e.g., mission operator or analyst), static (cannot be changed), and dynamic (e.g., based on intelligence or other incoming information). The parameter values may, or may not, be different for each different effect and hazard vulnerability pairing.

[0054] The operation **206** can include identifying any constraints that are related to the use of the effect against each vulnerability. Note that constraints can influence the model. Examples of constraints are time, and/or phase of the kill chain during which the effect can be used, number of times an effect can be used/re-used, command and control or other required procedures, and associated latencies.

[0055] The operation **206** can include SME review. The SME review can include reviewing and finalizing the draft model by one or more SMEs. Note that the implementation of the effect and the experience gained by utilizing the effect can result in an updated model that takes into account lessons learned.

[0056] The operation **208** can include generating a reusable effect model that can combined with other effect models. The operation **208** can simplify software to operate the models, take advantage of re-use, and enhance understanding and trust of the simulations performed at operation **212**. The operation **208** can include verifying that the parameters of the effect conform to the existing Common Probability Model (CPM). The operation **208** can include normalizing the parameter values so that they are consistent within the models. The operation **208** can include analyzing each parameter to determine the needed level of fidelity (e.g., deviation or variance). The operation **208** can include assessing a confidence level and variability of the parameter. The operation **208** can include consulting SMEs to upgrade the model to define and support additional capabilities.

[0057] The operation **208** can include updating a Stochastic Math Model (SMM), as needed, to enhance the CPM to cover the effect, hazard, or vulnerability. After the SMM has been updated, the CPM enhancements can be available for use with other effects and hazards.

[0058] A stochastic model is a tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs over time. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques.

[0059] The operation **210** can include storing the normalized effect model in a database of hazards, vulnerabilities, and effects. The operation **210** can include updating the libraries and configuration files in the database to integrate the effect (or combination of effects) into the models in the database.

[0060] The operation **210** can include updating the normalized models to include any new parameters associated with the new effect so that the effects models can be combined. The operation **210** can include adding any new scenario logic to a simulator that may be required to perform the operation **212**. The operation **210** can include updating the parameters in a scenario definition input file to reflect the new parameter values associated with the effect. Example parameters are effect name, effect identifier, effect type, and associated probability model. The operation **210** can include updating the scenario generation logic to enable the creation of scenarios that demonstrate any new simulation threads driven by the Concept of Operations (CONOPS) and Concept of Employment (CONEMP) for the effect.

[0061] Updating the effects library can include adding an entry for each new effect/vulnerability pairing. Note that the introduction of an effect against one hazard type may result in an opportunity to use that same effect against other hazards. The probability of defeat (the result of the model simulation) may, or may not, differ for each effect/hazard vulnerability pairing. One or more of the following parameters, as a minimum, can be entered for each entry in the effects library: effect name or unique identifier, hazard name or unique identifier, vulnerability against which the effect is targeted, effect type (e.g., kinetic, EW, cyber, or the like), phase(s) of employment during which the effect can be used against the vulnerability, or the like.

[0062] Additional information related to the deployment of an effect can support operational decisions to use, or not to use, the effect. An example of additional information is the results of a failure mode effects analysis (FMEA), which characterizes the effect and associated vulnerability in greater detail.

[0063] The parameters of a model can come from multiple sources. The parameters of the model can have varying degrees of volatility. Volatility indicates how frequently the parameter values change. The probability distributions, to be input to the model for the effect, can be updated in the library. These different parameter distributions may be stored in different locations within the system. For example, static parameters, which rarely, if ever, change, are usually stored in the library, user-selectable parameters can be configured as part of a user interface, with defaults stored in the library, dynamic parameters, such as locations based on intelligence Surveillance and Reconnaissance (ISR), can be ingested dynamically as they are received as input.

[0064] The operation **214** can include providing a map visualization of scenarios and scenario results, and a graphical user interface (GUI) for the input of simulation commands. The map and GUI can be tailored to a given scenario via the use of configuration files. The operation **214** can include integrating the input and/or output of any effect simulators with the map visualization or other GUI. The operation **214** can include updating the effects library configuration file to display any new user configurable parameters.

[0065] As previously discussed, the operation **216** can be produced using a Monte Carlo simulation at operation **212**. The operation **216** can include combining results from multiple simulations (e.g., Monte Carlo simulations).

[0066] At some point in the method, the method **200** can include verifying or updating the model or simulation of the model. The model(s) were reviewed (e.g., by the SMEs) at operation **206**, but more can be known about the simulation or model at some time during the method **200**. For example, by running the simulation(s), additional details regarding the effect can be gained by simulating the model and monitoring operation. Additional information or errors in the models can be determined from analysis of the results (e.g., by the SME). The model(s) can be updated accordingly.

[0067] Verification of the models can include test cases to verify that one or more of the default input values produce a result value that meets the expected value, input parameter values that test boundary conditions produce model values that meet the expected values, and the use of the effect in combination with another effect produces a model value that meets the expected value, or the like.

[0068] The verification of the models can help establish and maintain user trust in both the method and/or implemented algorithm and its results. Saving and archiving documentation that captures the results of the verification activities can help preserve user trust. The documentation can include, as a minimum, detailed model equations, with associated definitions, descriptions, or other related documentation, or as "executed" verification test procedure and test report.

[0069] The operation **218** can include comparing, for different combinations of effects or single effects, the probabilities and confidence intervals provided at operation **216**. The operation **218** can include producing, for each vulnerability, a list of effects or combinations of effects. The list can include the effects by probability in descending order. The priority of the effect or combination of effects can be based on the number of vulnerabilities that the effect exploits, the probability of the effect mitigating the hazard, the size of the confidence interval (a larger confidence interval being associated with a lower confidence in the provided probability), the importance of exploiting the vulnerability (e.g., the CONOPS or CONEMP), a combination thereof, or the like. The operation **220** can include deploying the effect or combination of effects determined to be associated with the highest priority.

Example 2: Disaster Recovery—Hurricane Response

[0070] For operation **202**, a radar or other weather system can be used to identify a hurricane. The operation **204** can include identifying an eye of the hurricane. The operation **206** can include identifying and characterizing a cloud seeding technique that exploits the calm weather experienced in the eye. A CONEMP can be based on a probabilistic weather model that considers the strength, expected damage, and whether infrastructure will remain available during the hurricane.

[0071] For operation **202**, the hazard and affected system can have multiple phases. First, the infrastructure can be available, then the infrastructure can be reached by workers, the power can be on, goods can reach the infrastructure, the port can be open, ships can get in, loaded ships can get back out, or the like.

[0072] For operation **206**, the co-locations of all these stages in the supply chain can be important for this effect. The characterization of the effect (e.g., the model) can include weather models, past data on hurricane strength, damage likeliness, or the like. At operation **208**, the model can be expressed in standard format, where each phase and step can have an underlying probability model (or models) which can result in a binomial yes/no answer determining the outcome of the step.

[0073] At operation **210**, the probability model(s), can be stored in the libraries, and the configuration files updated with the configuration for the new analysis. At operation **212**, data from external simulators, such as weather models, can be integrated into the simulation.

Example 3: Biological—Illness Recovery

[0074] For a generic system, the operations **202**, **204**, and **206** can include determining the actor (hazard), what is being acted on (the vulnerability), and how it will be affected (the effect). For example, in a hospital, the actor can be an unknown virus. The affected system can be the human body. The concept of employment can be based on a probabilistic treatment model to include the symptoms, the present and expected health condition of the patient, the available medicine(s) treat the virus, and the predicted recovery time of the patient.

[0075] The hazard can be carried out in multiple phases. First, that the patient's body can be exposed to the virus. Next, the patient can begin to exhibit symptoms, such as runny nose, sneezing, or stiffness. Then, the patient can develop a fever, indicating a definite infection. The patient can go to a doctor for diagnosis (identification of the hazard). Based on the diagnosis, the doctor can prescribe possible drugs (e.g., the effects) to counter the hazard (the virus in this example). The CONEMP can be that the patient returns from a trip where they were exposed to a virus in the confines of the plane. Symptoms started the next day and became severe by evening, at which time they went to the emergency room (ER) for treatment. The ER doctor can then use the method **200** to diagnose and treat the illness.

[0076] The vulnerability in this example can include the virus's susceptibility to antibodies or other virus-resistant mechanism. The example effects in this case are drugs, food, sleep, isolation, cleanliness, a combination thereof, or the like; but could apply to any other illness hazard. For this biology example, the model can define how well various types of medicines have worked against similar viruses. Parameters of the model can include a state of patient's heath at time of infection, patient's immunizations, historical success statistics for each type of medicine considered, or the like.

[0077] At operation **208**, the probability model can be expressed in a common format, where each phase and step can have an underlying probability model (or models) which would result in a binomial yes/no answer determining the outcome of the step. In other words, for each medicine or other treatment (sometimes called an effect), all parameters can be expressed in the same terms so that an exact comparison and evaluation can be accomplished.

[0078] The normalized probability models, for all medicines considered to counter the illness, may be placed in the library at operation **210**. Related configuration files can be updated at operation **210**. If the models and configuration files are already stored in the library repository, then no action need be taken at operation **210** in this example. Otherwise, the new or updated model can be encoded into the library, and the configuration files can be updated with the configuration for the new analysis.

[0079] Operation **212** can include using data from external simulators, such as medical treatment models. The operation **214** can include tailoring the visualization to fit the scenario.

[0080] FIG. **4** illustrates, by way of example, a diagram of an embodiment of a system **400** for effect analysis, prioritization, deployment, or a combination thereof. The system **400** as illustrated includes the hazard **102**, vulnerability **104**, effect **106**, input **302**, simulated hazard **402**, simulated vulnerability **404**, simulated effect **406**, user **420**, user interface **422**, model library **424**, model **426**, SME **428**, user interface **430**, simulator **432**, processing circuitry **434**, device **438**, sensor **440**, and a normalizer **442**. Some of the illustrated elements of system **400** may be optional and desirable in some embodiments while not necessarily in others. Thus, not all the illustrated elements are necessarily required and/or used in all embodiments. For example, in an automated implementation, user **420** and/or SME **428** may not be involved.

[0081] The user **420** can interact with the user interface **422**, such as to change a model **426**, generate the model **426**, execute the model **426**, review the model **426**, or the like. The user **420** is anyone or anything that can interact with the model **426**, such as to make the simulator **432** to execute the model **426** and generate the results **306**.

[0082] The user interface **422** is implemented by a display that provides a computer-based input or output mechanism. Through the user interface **422**, the user can view results of simulations, interact with a visualization of the simulation, alter a model, execute a model, or the like.

[0083] The library **424** stores the normalized models **426** and other information corresponding to executing a simulation of one or more models **426**. The library **424** can be accessible by either of the user interfaces **422**, **430** or the simulator **432**.

[0084] The SME **428** is an expert regarding a particular effect **106**, **406** and its influence on the hazard **102**, **402**. The SME **428** can understand, mathematically or physically, how the effect mitigates the damage of the hazard **402** by exploiting the vulnerability **404**. The SMF **428** can perform similar operations as the user **420** through the user interface **430**.

[0085] The user interface **430** is implemented by a display that provides a computer-based input or output mechanism. Through the user interface **430**, the SME **428** can view results of simulations, interact with a visualization of the simulation, alter a model, execute a model, or the like. The user **420** or the SME **428** can perform the operations **202**, **204**, or **206** through the user interface **422**, **430**. In some embodiments, the user **420** may be the expert (SME **428**) and the system **400** may comprise a single user interface **422/430**.

[0086] The simulator **432** can execute the model **426** and tabulate results of the execution. The simulator **432** can perform a Monte Carlo simulation of the model **426**, such as to determine a confidence interval associated with a probability of the effect **106**, **406** mitigating damage caused by the hazard **102**, **402**. The simulator **432** can receive input from the device **438** (e.g., a sensor **440** of the device **438**), a predefined input from the sensor **440** that can be stored in the library **424** as a configuration file, an external simulator **444** that simulates the sensor **440** or other component that is part of the simulation, such as the hazard **402**, the vulnerability **404**, or the effect **406**, a configuration file in the library **424** that details a value for a parameter of the model **426**, the user interface **422**, **430** through which a user can specify the model **426**, external components from which to receive input, parameters of the model **426**, a number of simulations to perform, combinations of effects, or the like. The sensor **440** can include an optic sensor, a temperature sensor, a pressure sensor, electromagnetic sensor, liquid sensor, wind sensor, or the like, a turbidity sensor, a flow sensor, a salinity sensor, or the like.

[0087] The simulator **432** can be implemented using electrical or electronic components, such as those similar to or same as the processing circuitry **434**. The simulator **432** can execute the model **426** to generate one or more of the simulated hazard **402**, simulated vulnerability **404**, or the simulated effect **406**. One or more of the simulated hazard **402** and the simulated vulnerability **404** can be provided by output from the external simulator **444**.

[0088] The simulator **432** can generate the fused results **306**. The processing circuitry **434** can operate on the fused results **306** to generate the output **436**. The output **436** can include the combined results **308**, a prioritized list of effects, or the like. The processing circuitry **434** can include electrical or electronic components configured to perform operations on the results **306**. The electrical or electronic components can include one or more resistors, transistors, capacitors, inductors, diodes, power supplies, processors (e.g., a central processing unit (CPU), an application specific integrated circuit (ASIC), field programmable gate array (FPGA), graphics processing unit (GPU), or the like), converters (e.g., analog to digital converters (ADCs) or digital to analog converters (DACs)), diodes, regulators, oscillators, logic gates (e.g., AND, OR, XOR, negate, buffer, or the like), switches, multiplexers, or the like. The simulator **432** can perform the operation **212**. The processing circuitry **434** can perform one or more of the operations **216**, **218**.

[0089] The normalizer **442** can adjust a model or parameter to be consistent with a standard model. The normalizer **442** can perform the operation **208**. The normalizer **442** can determine a statistical confidence interval for a given parameter, group of parameters, model, or the like. An original confidence interval can be determined based on a priori historical device/sensor input. The normalizer **442** can be implemented using electrical or electronic components, such as those similar to or same as the processing circuitry **434**. In some embodiments, the effect(s) may be deployed to mitigate the hazard, (e.g., based on the simulated combined effect and a combined confidence level).

Modules, Components and Logic

[0090] Certain embodiments are described herein as including logic or a number of components, modules, or mechanisms. Modules may constitute either software modules (e.g., code embodied (1) on a non-transitory machine-readable medium or (2) in a transmission signal) or hardware-implemented modules. A hardware-implemented module is tangible unit capable of performing certain operations and may be configured or arranged in a certain manner. In example embodiments, one or more computer systems (e.g., a standalone, client or server computer system) or one or more processors may be configured by software (e.g., an application or application portion) as a hardware-implemented module that operates to perform certain operations as described herein.

[0091] In various embodiments, a hardware-implemented module may be implemented mechanically or electronically. For example, a hardware-implemented module may comprise dedicated circuitry or logic that is permanently configured (e.g., as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC)) to perform certain operations. A hardware-implemented module may also comprise programmable logic or circuitry (e.g., as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. It will be appreciated that the decision to implement a hardware-implemented module mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) be driven by cost and time considerations.

[0092] Accordingly, the term "hardware-implemented module" is understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired) or temporarily or transitorily configured (e.g., programmed) to operate in a certain manner and/or to perform certain operations described herein. Considering embodiments in which hardware-implemented modules are temporarily configured (e.g., programmed), each of the hardware-implemented modules need not be configured or instantiated at any one instance in time. For example, where the hardware-implemented modules comprise a general-purpose processor configured using software, the general-purpose processor may be configured as respective different hardware-implemented modules at different times. Software may accordingly configure a processor, for example, to constitute a particular hardware-implemented module at one instance of time and to constitute a different hardware-implemented module at a different instance of time.

[0093] Hardware-implemented modules may provide information to, and receive information from, other hardware-implemented modules. Accordingly, the described hardware-implemented modules may be regarded as being communicatively coupled. Where multiple of such hardware-implemented modules exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) that connect the hardware-implemented modules. In embodiments in which multiple hardware-implemented modules are configured or instantiated at different times, communications between such hardware-implemented modules may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple hardware-implemented modules have access. For example, one hardware-implemented module may perform an operation, and store the output of that operation in a memory device to which it is communicatively coupled. A further hardware-implemented module may then, at a later time, access the memory device to retrieve and process the stored output. Hardware-implemented modules may also initiate communications with input or output devices, and may operate on a resource (e.g., a collection of information).

[0094] The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions. The modules referred to herein may, in some example embodiments, comprise processor-implemented modules.

[0095] Similarly, the methods described herein may be at least partially processor-implemented. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented modules. The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but also deployed across a number of machines. In some example embodiments, the processor or processors may be located in a single location (e.g., within a home environment, an office environment or as a server farm), while in other embodiments the processors may be distributed across a number of locations.

[0096] The one or more processors may also operate to support performance of the relevant operations in a "cloud computing" environment or as a "software as a service" (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., Application Program Interfaces (APIs).)

Electronic Apparatus and System

[0097] Example embodiments may be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. Example embodiments may be implemented using a computer program product, e.g., a computer program tangibly embodied in an information carrier, e.g., in a machine-readable medium for execution by, or to control the operation of, data processing apparatus, e.g., a programmable processor, a computer, or multiple computers.

[0098] A computer program may be written in any form of programming language, including compiled or interpreted languages, and it may be deployed in any form, including as a stand-alone program or as a module, subroutine, or other unit suitable for use in a computing environment. A computer program may be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

[0099] In example embodiments, operations may be performed by one or more programmable processors executing a computer program to perform functions by operating on input data and generating output. Method operations may also be performed by, and apparatus of example embodiments may be implemented as, special purpose logic circuitry, FPGA or ASIC.

[0100] The computing system may include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In embodiments deploying a programmable computing system, it will be appreciated that that both hardware and software architectures require consideration. Specifically, it will be appreciated that the choice of whether to implement certain functionality in permanently configured hardware (e.g., an ASIC), in temporarily configured hardware (e.g., a combination of software and a programmable processor), or a combination of permanently and temporarily configured hardware may be a design choice. Below are set out hardware (e.g., machine) and software architectures that may be deployed, in various example embodiments.

Example Machine Architecture and Machine-Readable Medium (e.g., Storage Device)

[0101] FIG. **5** illustrates, by way of example, a block diagram of an embodiment of a machine in the example form of a computer system **500** within which instructions, for causing the machine to perform any one or more of the methodologies discussed herein, may be executed. In one or more embodiments, the effect **106**, device **438**, user interface **422**, **430**, simulator **432**, library **424**, external simulator **444**, or processing circuitry **434**, or other device or component discussed herein can include one or more items of the system **500**. In one or more embodiments, the effect **106**, device **438**, user interface **422**, **430**, simulator **432**, library **424**, external simulator **444**, or processing circuitry **434**, or other device discussed herein can be implemented using one or more items of the system **500**.

[0102] In alternative embodiments, the machine operates as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client machine in server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. The machine may be a personal computer (PC), a tablet PC, a set-top box (STB), a Personal Digital Assistant (PDA), a cellular telephone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein.

[0103] The example computer system **500** includes a processor **502** (e.g., a CPU, GPU, or both), a main memory **504** and a static memory **506**, which communicate with each other via a bus **508**. The computer system **500** may further include a video display unit **510** (e.g., a liquid crystal display (LCD), light emitting diode (LED), or a cathode ray tube (CRT)). The computer system **500** also includes an alphanumeric input device **512** (e.g., a keyboard), a user interface (UI) navigation device **514** (e.g., a mouse), a disk drive unit **516**, a signal generation device **518** (e.g., a speaker), a network interface device **520**, and sensor(s) **521**.

Machine-Readable Medium

[0104] The disk drive unit **516** includes a machine-readable medium **522** on which is stored one or more sets of instructions **524** and data structures (e.g., software) embodying or utilized by any one or more of the methodologies or functions described herein. The instructions **524** may also reside, completely or at least partially, within the main memory **504** and/or within the processor **502** during execution thereof by the computer system **500**, the main memory **504** and the processor **502** also constituting machine-readable media.

[0105] While the machine-readable medium **522** is shown in an example embodiment to be a single medium, the term "machine-readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more instructions or data structures. The term "machine-readable medium" shall also be taken to include any tangible medium that is capable of storing, encoding or carrying instructions for execution by the machine and that cause the machine to perform any one or more of the methodologies of the present invention, or that is capable of storing, encoding or carrying data structures utilized by or associated with such instructions. The term "machine-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, and optical and magnetic media. Specific examples of machine-readable media include non-volatile memory, including by way of example semiconductor memory devices, e.g., Erasable Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM), and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

Transmission Medium

[0106] The instructions **524** may further be transmitted or received over a communications network **526** using a transmission medium. The instructions **524** may be transmitted using the network interface device **520** and any one of a number of well-known transfer protocols (e.g., hypertext transfer protocol (HTTP), such as HTTP secure (HTTPS)). Examples of communication networks include a local area network ("LAN"), a wide area network ("WAN"), the Internet, mobile telephone networks, Plain Old Telephone (POTS) networks, and wireless data networks (e.g., WiFi and WiMax networks). The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine, and includes digital or analog communications signals or other intangible media to facilitate communication of such software.

Additional Notes and Examples

[0107] Example 1 can include a method for responding to a hazard, the method comprising identifying at least two effects that, with some probability, at least partially mitigate the hazard, identifying one or more vulnerabilities of the hazard that are the target for an effect of the identified effects, for each hazard, vulnerability pair, identifying a respective hazard model that simulates a state of the hazard in response to the effect, identifying effect models that simulate the respective effects, normalizing each of the identified effect models to a common model and determining a confidence level for each parameter of each normalized model, and simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

[0108] In Example 2, Example 1 can further include or use deploying the effects to at least partially mitigate the hazard based on the simulated combined effect and the combined confidence level.

[0109] In Example 3, at least one of Examples 1-2 can further include, wherein the hazard is a physical hazard to a geographical area or person.

[0110] In Example 4, at least one of Examples 1-3 can further include, wherein simulating combinations of effects includes simulating at each respective step of the hazard, whether the respective step will succeed or fail and an associated confidence level of success or failure in light of the combination of effects.

[0111] In Example 5, Example 4 can further include, wherein each of the normalized models provides a binomial result.

[0112] In Example 6, at least one of Examples 4-5 can further include, wherein simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level include simulating combinations of effects on different steps of the hazard.

[0113] In Example 7, Example 6 can further include, wherein the confidence level is determined using Monte Carlo simulations and tabulating results of the simulations.

[0114] In Example 8, at least one of Examples 1-7 can further include, wherein characterizing the effect includes identifying an effect name, a location of the effect, process times and time lines of the effect, constraints and limitations of the effect, and a state of the hazard after the effect is successfully deployed against hazard.

[0115] In Example 9, Example 8 can further include, wherein characterizing the effect includes identifying a model for each step of setting up and deploying the effect and simulating the combinations of effects includes simulating each step of setting up and deploying the effects.

[0116] In Example 10, Example 9 can further include characterizing the hazard including identifying a hazard name, a location of the hazard, steps of the hazard, and a target of the hazard.

[0117] In Example 11, Example 10 can further include, wherein characterizing the hazard includes identifying a model for each step of setting up and deploying the hazard and simulating the combinations of effects includes simulating each step of setting up and deploying the hazard with the effects incident on the hazard.

[0118] In Example 12, at least one of Examples 1-11 can further include, wherein the identified effects include a cyber effect.

[0119] Example 13 includes at least one non-transitory machine-readable medium including instructions that, when executed by a machine, configure the machine to perform operations comprising, identifying at least two effects that, with some probability, at least partially mitigate the hazard, identifying one or more vulnerabilities of the hazard that are the target for an effect of the identified effects, for each hazard, vulnerability pair, identifying a respective hazard model that simulates a state of the hazard in response to the effect, identifying effect models that simulate the respective effects, normalizing each of the identified effect models to a common model and determining a confidence level for each parameter of each normalized model, and simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

[0120] In Example 14, Example 13 can further include, wherein the hazard is a physical hazard to a geographical area or person.

[0121] In Example 15, at least one of Examples 13-14 can further include, wherein simulating combinations of effects includes simulating at each respective step of the hazard, whether the respective step will succeed or fail and an associated confidence level of success or failure in light of the combination of effects.

[0122] In Example 16, Example 15 can further include, wherein each of the normalized models provides a binomial result.

[0123] In Example 17, at least one of Examples 15-16 can further include, wherein simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level include simulating combinations of effects on different steps of the hazard.

[0124] In Example 18, Example 17 can further include, wherein the confidence level is determined using Monte Carlo simulations and tabulating results of the simulations.

[0125] In Example 19, at least one of Examples 13-18 can further include, wherein characterizing the effect includes identifying an effect name, a location of the effect, process times and time lines of the effect, constraints and limitations of the effect, and a state of the hazard after the effect is successfully deployed against hazard.

[0126] In Example 20, Example 19 can further include, wherein characterizing the effect includes identifying a model for each step of setting up and deploying the effect and simulating the combinations of effects includes simulating each step of setting up and deploying the effects.

[0127] In Example 21, Example 20 can further include characterizing the hazard including identifying a hazard name, a location of the hazard, steps of the hazard, and a target of the hazard.

[0128] In Example 22, Example 21 can further include, wherein characterizing the hazard includes identifying a model for each step of setting up and deploying the hazard and simulating the combinations of effects includes simulating each step of setting up and deploying the hazard with the effects incident on the hazard.

[0129] In Example 23, at least one of Examples 13-22 can further include, wherein the identified effects include a cyber effect.

[0130] Example 24 includes a system for hazard mitigation, the system comprising: a model library including normalized effects models and configuration files stored thereon, the normalized effects models indicating how a corresponding effect or combination of effects exploits one or more vulnerabilities of a hazard to mitigate damage caused by the hazard, a user interface through which a user identifies one or more vulnerabilities of the hazard that are the target for an effect of the effects, for each hazard, vulnerability pair, identifies a respective hazard model that simulates a state of the hazard in response to the effect, and identifies effect models that simulate the respective effects, normalizer circuitry to normalize each of the identified effects models to a common model and determine a confidence level for each parameter of each normalized model, and simulator circuitry to receive a normalized effects model corresponding to at least two effects that, with some probability, at least partially mitigate the hazard, and simulate combinations of effects by combining normalized effect models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

[0131] In Example 25, Example 24 can further include, wherein the hazard is a physical hazard to a geographical area or person.

[0132] In Example 26, at least one of Examples 24-25 can further include, wherein simulating combinations of effects includes simulating at each respective step of the hazard, whether the respective step will succeed or fail and an associated confidence level of success or failure in light of the combination of effects.

[0133] In Example 27, Example 26 can further include, wherein each of the normalized models provides a binomial result.

[0134] In Example 28, at least one of Examples 26-27 can further include, wherein simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level include simulating combinations of effects on different steps of the hazard.

[0135] In Example 29, Example 28 can further include, wherein the confidence level is determined using Monte Carlo simulations and tabulating results of the simulations.

[0136] In Example 30, at least one of Examples 24-29 can further include, wherein characterizing the effect includes identifying an effect name, a location of the effect, process times and time lines of the effect, constraints and limitations of the effect, and a state of the hazard after the effect is successfully deployed against hazard.

[0137] In Example 31, Example 30 can further include, wherein characterizing the effect includes identifying a model for each step of setting up and deploying the effect and simulating the combinations of effects includes simulating each step of setting up and deploying the effects.

[0138] In Example 32, at least one of Examples 24-31 can further include characterizing the hazard including identifying a hazard name, a location of the hazard, steps of the hazard, and a target of the hazard.

[0139] In Example 33, Example 32 can further include, wherein characterizing the hazard includes identifying a model for each step of setting up and deploying the hazard and simulating the combinations of effects includes simulating each step of setting up and deploying the hazard with the effects incident on the hazard.

[0140] In Example 34, at least one of Examples 24-33 can further include, wherein the identified effects include a cyber effect.

[0141] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the invention. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof, show by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

What is claimed is:

1. A method for responding to a hazard, the method comprising:

identifying at least two effects that, with some probability, at least partially mitigate the hazard;

identifying one or more vulnerabilities of the hazard that are the target for an effect of the identified effects;

for each hazard, vulnerability pair, identifying a respective hazard model that simulates a state of the hazard in response to the effect;

identifying effect models that simulate the respective effects;

normalizing each of the identified effect models to a common model and determining a confidence level for each parameter of each normalized model; and

simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

2. The method of claim **1**, further comprising deploying the effects to at least partially mitigate the hazard based on the simulated combined effect and the combined confidence level.

3. The method of claim **1**, wherein the hazard is a physical hazard to a geographical area or person.

4. The method of claim **1**, wherein simulating combinations of effects includes simulating at each respective step of the hazard, whether the respective step will succeed or fail and an associated confidence level of success or failure in light of the combination of effects.

5. The method of claim **4**, wherein each of the normalized models provides a binomial result.

6. The method of claim **4**, wherein simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level include simulating combinations of effects on different steps of the hazard.

7. The method of claim **6**, wherein the confidence level is determined using Monte Carlo simulations and tabulating results of the simulations.

8. The method of claim **1**, wherein characterizing the effect includes identifying an effect name, a location of the effect, process times and time lines of the effect, constraints and limitations of the effect, and a state of the hazard after the effect is successfully deployed against hazard.

9. The method of claim **8**, wherein characterizing the effect includes identifying a model for each step of setting up and deploying the effect and simulating the combinations of effects includes simulating each step of setting up and deploying the effects.

10. The method of claim **9**, further comprising characterizing the hazard including identifying a hazard name, a location of the hazard, steps of the hazard, and a target of the hazard.

11. The method of claim **10**, wherein characterizing the hazard includes identifying a model for each step of setting up and deploying the hazard and simulating the combinations of effects includes simulating each step of setting up and deploying the hazard with the effects incident on the hazard.

12. The method of claim **1**, wherein the identified effects include a cyber effect.

13. A non-transitory machine-readable medium including instructions that, when executed by a machine, configure the machine to perform operations comprising:

identifying at least two effects that, with some probability, at least partially mitigate the hazard;

identifying one or more vulnerabilities of the hazard that are the target for an effect of the identified effects;

for each hazard, vulnerability pair, identifying a respective hazard model that simulates a state of the hazard in response to the effect;

identifying effect models that simulate the respective effects;

normalizing each of the identified effect models to a common model and determining a confidence level for each parameter of each normalized model; and

simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

14. The non-transitory machine-readable medium of claim **13**, wherein the hazard is a physical hazard to a geographical area or person.

15. The non-transitory machine-readable medium of claim **13**, wherein simulating combinations of effects includes simulating at each respective step of the hazard, whether the respective step will succeed or fail and an associated confidence level of success or failure in light of the combination of effects.

16. The non-transitory machine-readable medium of claim **15**, wherein each of the normalized models provides a binomial result.

17. The non-transitory machine-readable medium of claim **15**, wherein simulating combinations of effects by combining normalized models and recording their combined effect on the hazard and a corresponding combined confidence level include simulating combinations of effects on different steps of the hazard.

18. The non-transitory machine-readable medium of claim **17**, wherein the confidence level is determined using Monte Carlo simulations and tabulating results of the simulations.

19. A system for hazard mitigation, the system comprising;

a model library including normalized effects models and configuration files stored thereon, the normalized effects models indicating how a corresponding effect or combination of effects exploits one or more vulnerabilities of a hazard to mitigate damage caused by the hazard;

a user interface through which a user identifies one or more vulnerabilities of the hazard that are the target for an effect of the effects, for each hazard, vulnerability pair, identifies a respective hazard model that simulates a state of the hazard in response to the effect, and identifies effect models that simulate the respective effects;

normalizer circuitry to normalize each of the identified effects models to a common model and determine a confidence level for each parameter of each normalized model; and

simulator circuitry to receive a normalized effects model corresponding to at least two effects that, with some probability, at least partially mitigate the hazard, and simulate combinations of effects by combining normalized effect models and recording their combined effect on the hazard and a corresponding combined confidence level for the normalized models.

20. The system of claim **19**, wherein the identified effects include a cyber effect.

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