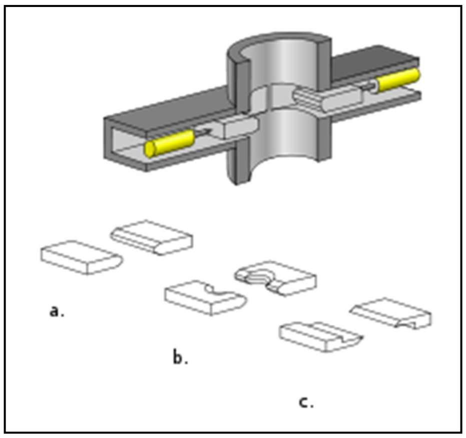
INNOVATIVE ANALYSIS

IMPROVED BLOWOUT PREVENTER

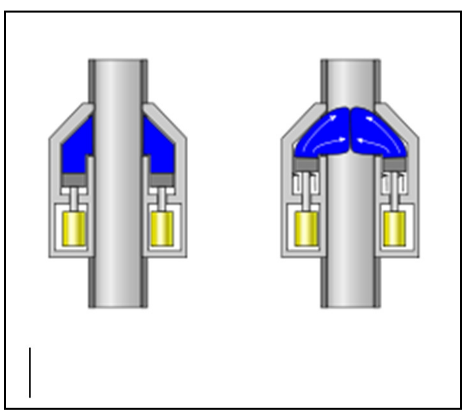
1. BRIEF DESCRIPTION OF THE SITUATION

The blowout preventer (BOP) is a valve assembly usually mounted on the sea floor at the mouth of an oil well to control pressure. Oil comes from under the ground and through the BOP before continuing on to a surface vessel tanker through a pipeline. A blowout can occur if there is a sudden change in pressure of the oil which is natural with oil wells. Blowouts can literally blow piping and tubing from the drill hole thereby resulting in a catastrophic and uncontrollable flow of oil usually leading to explosions and fires.

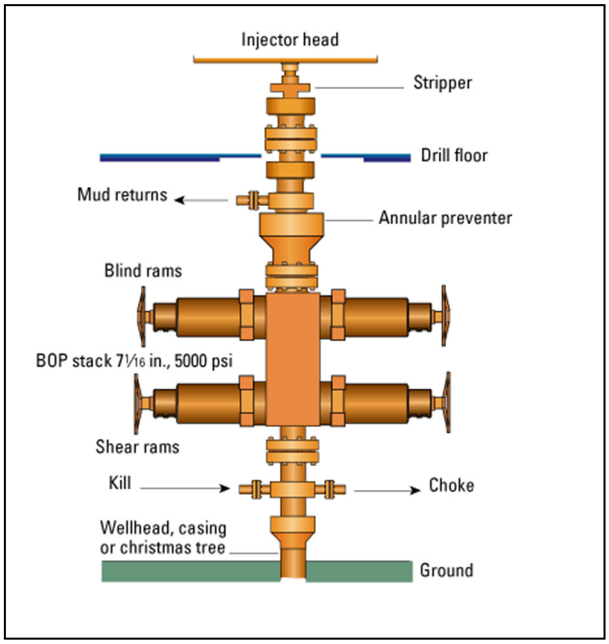
One type of BOP is the *ram* type shown below. Two opposing plungers (the rams) can be pushed into the pipe (oil would flow vertically in the diagram below) to stop the flow. A force of some kind is needed to force the rams together and hold them in place. Typically, this is hydraulic in nature (fluid under pressure).



An *annular* BOP uses a donut-like rubber seal to close off a pipe as shown in the figure below. The rubber seal is forced into position by hydraulic pistons.



It is common for oil companies to employ several BOPs and BOPs of different types together in w hat is called a "BOP stack." The figure below shows the design of the BOP used on the Deep Horizon.

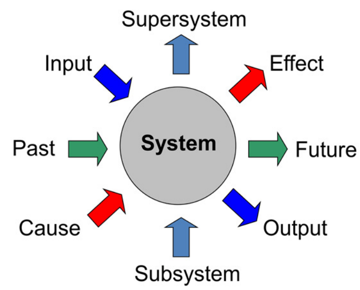


The stack consists of an annular ram, a blind ram, and a shear ram. The blind ram can close the well when an internal pipe (called the drill string) is not within the well. When the drill string is in the well, the shear ram can cut through the pipe and close the well.

In the Deep Horizon event, the BOP failed to close the well for reasons that are still unknown. One reason is that a failsafe battery was not charged. The battery should have powered an automatic closing of the shear ram when the BOP lost contact with the surface vessel. Another reason may be that debris had entered the pipeline from below preventing the rams from closing properly. A bubble of methane gas rose through the well (expanding as it rose) and caused a catastrophic explosion and fire in the surface vessel. All contact (data and control) was lost to the BOP so the crew was unable to command the BOP's activation. Under these conditions, the BOP should have reacted automatically and self-activated. Later, even manual activation of the BOP did not cause it to close.

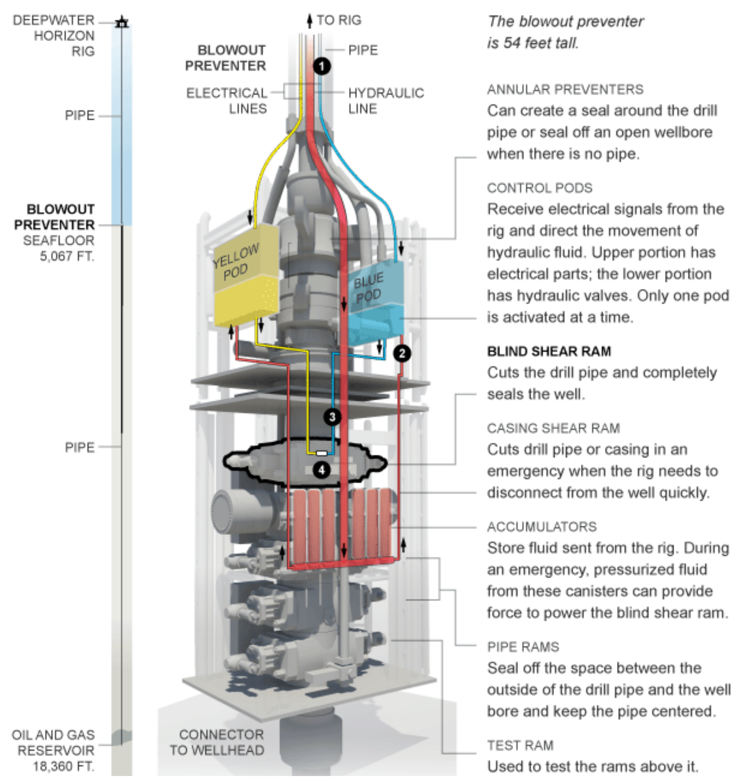
The challenge is to design a better system of well closure. Consider re-designing the BOP, the BOP stack, or the ram devices themselves. However, completely new approaches will be considered too.

2. DETAILED DESCRIPTION OF THE SITUATION



2.1 SUPERSYTEM/SUBSYSTEM ANALYSIS

1. Rig
2. Pipe
    a. Electrical lines
    b. Hydraulic line
3. Blowout Preventer
    a. Yellow Electrical Pod
    b. Blue Electrical Pod
    c. Stripper
    d. Drill Floor
    e. Mud return
    f. Annular Preventers
    g. Control pods
    h. Rams
        i. Blind Shear ram
            1. Shuttle Valve
            2. Piston
            3. Wedge Lock
            4. Ram
            5. Rubber Seal
        ii. Casing Shear Ram
        iii. Pipe Rams
        iv. Test Ram
    i. Accumulators
    j. Kill/Choke
    k. Control Method
        i. Electrical Control Signal
        ii. Acoustical Control Signal
        iii. ROV Intervention
        iv. Deadman Switch
4. Pipe
5. Oil and Gas Reservoir



2.2 INPUT/OUTPUT ANALYSIS CAUSE/EFFECT ANALYSIS

INPUT	EFFECT	OUTPUT
ELECTRICITY	POWERS THE VALVES	SHUTS THE VALVE
PRESSURE SENSOR	CLOSES HYDRALIC VALVE WHEN BLOWOUT OCCURS	TRIGGERS VALVE CLOSING
DRILLING THROUGH SEA FLOOR	OIL RESERVE TAPPED	OIL IS ACCESSIBLE FROM OIL RIG
PIPE IS INSERTERED	PRESSURE MAKES OIL RISE TO SURFACE	COLLECT OIL IN TANK AT SURFACE
ELECTRICAL CONTOL CENTER	SIGNAL TO SHUTTING MECHANISMS	VALVE CLOSES
ACOUSTICAL CONTROL SIGNAL	SENDS SOUND WAVES THROUGH WATER TO ACTIVATE TRANSDUCER	VALVE CLOSES
REMOTELY OPERATED VEHICLE	MANUALLY APPLYS PRESSURE TO TRIGGER OR CLOSE VALVE	VALVE CLOSES
HYDRAULIC PRESSURE	POWERS SHEARS	VALVE CLOSES
SHUTTLE VALVE	CONTROLS HYDRAULIC PRESSURE BEING INTRODUCED	OPENS TO ALLOW HYDRAULIC PRESSURE TO SHEARS
ANNULAR RAMS ACTIVATED	RUBBER SEAL IS FORCED INTO PIPE	SEALS OIL PIPE
BLIND SHEAR RAMS	CUTS THE PIPE AND CRIMPS THE PIPE AROUND THE DRILL STRING	SEALS OIL PIPE AND CUTS DRILL STRING
CASING SHEAR RAM	CUTS THE PIPE BUT NOT DRILL STRING	SEALS OIL PIPE
ACCUMLATORS	HYDRAULIC PRESSURE IS STORED FROM SURFACE	POWERS SHEARS

DEADMAN SWITCH	IF CONTROL, ELECTRICAL AND HYDRAULIC LINES HAVE BEEN CUT IT ACTIVATES	TRIGGERS THE BOP TO SEAL THE WELL

2.4 PAST/FUTURE ANALYSIS

Blow off preventers are the primary safety control mechanisms well drilling. These devices were created to manage extreme variable pressures as well as uncontrolled flow. BOPs were first used in offshore well drilling in the 1960s. Some of the functions of the BOP include confining well fluid to the wellbore, providing means to add fluid to the wellbore, allowing controlled volumes of fluid to be withdrawn from the wellbore, regulating and monitoring wellbore pressure, providing a kill switch mechanism, and also a mechanism to permanently close the wellbore. BOPs come equipped with devices that either control the flow of fluids coming out of the well or close it off completely. Since the early 1920s, land wells have used BOPs with mechanisms called “rams” which are capable of closing the well through mechanical operation and manually turning valves on and off. Hydraulic ram BOPs were first introduced in the 1940s and they could operate with much higher pressured wells.

As more BOPs and drilling techniques were developed, more technological advancements began to be implemented in to the machines. These technological advances allowed drillers to reach wells at much greater depths as well as pressures. These technologies also allowed for better reliability, reduced maintenance, facilitated replacement of components, reduced hydraulic fluid consumptions, and improved connectors and seals. There are also new advances in deep underwater BOPs that offer better ROV (remote operated vehicle) intervention. These new technologies allow for companies to drill not only in near shore waters but also in the ultra deep waters such as those in the Gulf of Mexico.

In today’s deepwater drilling, BOPs are usually controlled by many more methods than in the past. Some of the controlling mechanisms included electrical control signals, acoustical control systems, ROV interventions, and Dead man / Auto Shear Switches. There have also been advances made in economically viable solutions incorporating new technologies and methods.

Future BOPs are being developed to handle and mitigate the issues of a wild well. A wild well is a well that is flowing uncontrollably and producing undesired effects. For example, during the Deepwater Horizon oil well disaster, that well became a wild well that was flowing uncontrollably. New developments and government restrictions have encouraged, if not forced, companies to develop safer and more emergency-ready BOPs. These new designs may or may not incorporate better systems for things like sensors (pressure, material, loads, fluid), shear rams, hardware/software, automatic control devices, material barriers, monitoring devices, ROV support, safety, reliability, sustainability, and hydraulic operations in general. The future of BOPs is headed in an environmental and humanistic protection route with governmental regulations that must be met before operation.

3. RESOURCES, CONSTRAINTS, AND LIMITATIONS

3.1 AVAILABLE RESOURCES

Pressures	**Sea water**	**Salt**	**Corrosion**	**Gravity**	**Hydraulic fluids**
Shears	**Pipe rams**	**Electrical lines**		**Fail safe devices**	
Drill string	**T- Valves**	**Cabling**	**Piping**	**Electricity**	**Securing bolts**
Sea floor	**Drill bit**	**Metal**	**Oil**	**Gas**	**Control pods**

Temperatures (above, middle, and below water level)

3.2 ALLOWABLE CHANGES TO THE SYSTEM

Per government regulations the BOP is being requested to be redesigned incorporating redundant blind shears rams and redesigning BOP's themselves. To overhaul entire system from beginning to end and to introduce counter measures to prevent wild well. Anker Oil Rig to sea floor.

3.3 CONSTRAINTS AND LIMITATIONS

Recommendations	Key Components (with implementation plan)
Blowout Preventer (BOP) Equipment and Emergency Systems	Order re-certification of subsea BOP stacks (immediately) Order BOP equipment compatibility verification (immediately) Establish formal equipment certification requirements (rulemaking)
New Safety Equipment Requirements and Operating Procedures	Develop new BOP and remote operated vehicle (ROV) testing requirements (immediately) Develop new inspection procedures and reporting requirements (immediately) Develop secondary control system requirements (emergency rulemaking) Establish new blind shear ram redundancy requirements (emergency rulemaking) Develop new ROV operating capabilities (rulemaking)
Well-Control Guidelines and Fluid	

Displacement Procedures

Establish new fluid displacement procedures (immediately)

Establish new deepwater well-control procedure requirements (emergency rulemaking)

Well Design and Construction – Casing and Cementing

Establish new casing and cementing design requirements – two independent tested barriers (immediately)

Establish new casing installation procedures (immediately)

Develop formal personnel training requirements for casing and cementing operations (rulemaking)

Develop additional requirements for casing installation (rulemaking)

Enforce tighter primary cementing practices (rulemaking)

Develop additional requirements for evaluation of cement integrity (immediately)

Study Wild-Well intervention techniques and capabilities (immediately)

Increased Enforcement of Existing Safety Regulations and Procedures

Order compliance verification for existing regulations and April 30, 2010, National Safety Alert (immediately)

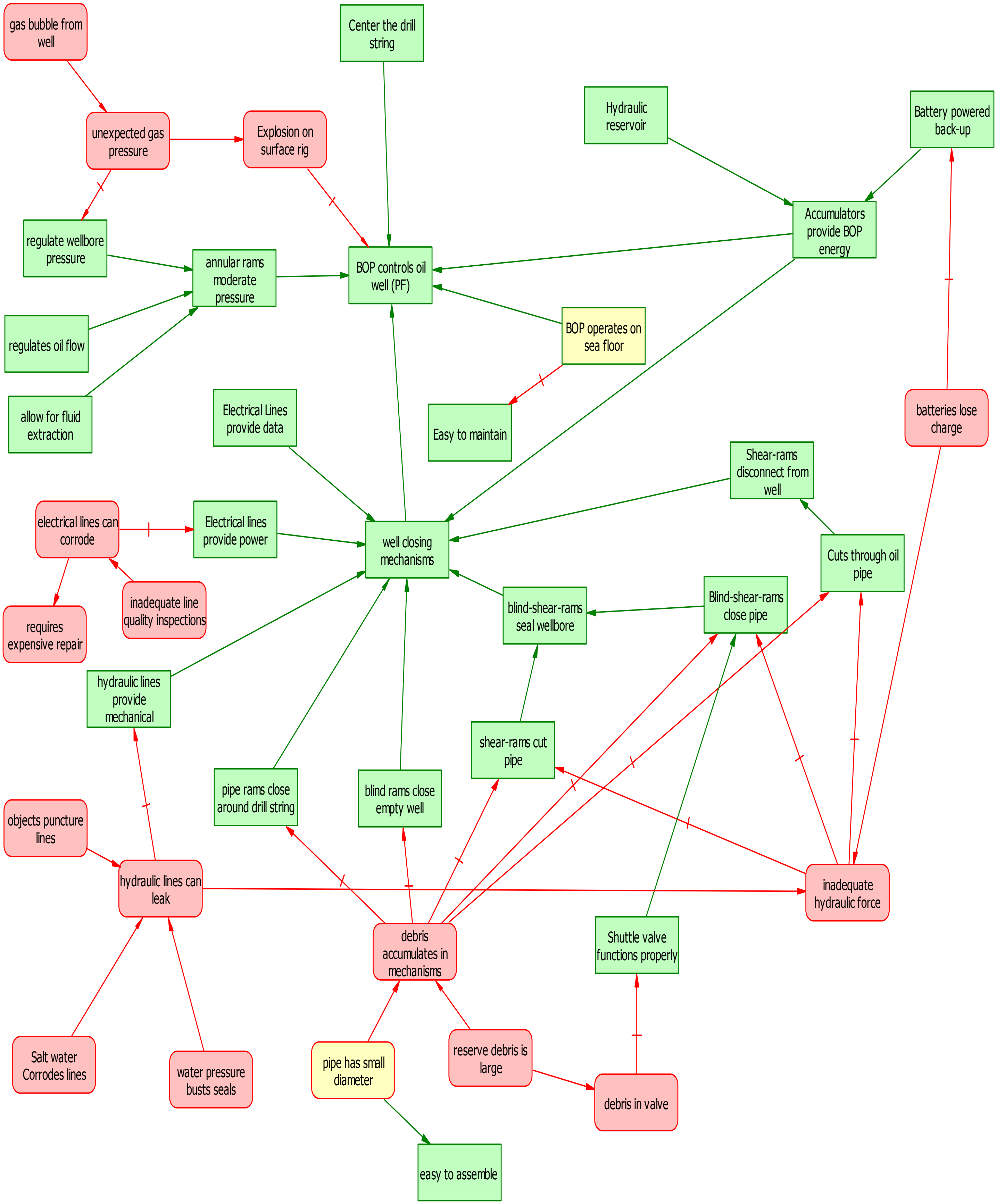
Adopt safety case requirements for floating drilling operations on the Outer Continental Shelf (emergency rulemaking)

Adopt final rule to require operators to adopt a robust safety and environmental management system for offshore drilling operations (rulemaking)

Study additional safety training

4. PROBLEM FORMULATION

Case studies from classes led by Dr. Ron Fulbright, University of South Carolina Upstate.



5. IDEAS

1. Duplicate Critical Elements
    a. To increase reliability, consider implementing a redundant design for the annular rams and well closing mechanisms.
    b. To increase reliability, consider implementing a redundant design for the blind shear rams.
    c. Allow for multiple shuttle valves to increase reliability in BOP.
2. Add isolating substance
    a. Try to isolate the electoral lines from corroding by introducing an isolating material.
3. Make an object demountable
    a. Try to make the batters in such a way that it can be disassembled. If possible, assemble batteries (partially or completely) out of existing BOP, to allow easier replacement of batteries.
    b. Make the BOP completely detachable from the oil rig on the surface in the event of a gas bubble or explosion.
    c. Make the shears removable and replaceable for service/age.
    d. Make accumulators on the BOP removable so that they can be serviced/replaced.
4. Transform objects shape
    a. Make the BOP into a cone shape that would contain the oil in the event of an explosion or breakage of the BOP on the sea floor.
    b. Make the shear rams in to a shape that works from the inside out rather than the outside in.
    c. Incorporate a “Plumber’s trap” into the piping as a failsafe.
    d. A large ball bearing that is within the pipe in a attached socket, that is released into the pipe and pushed into place by the oil pressure stopping the oil from going up the pipe. This would be used as a contingent to the BOP failing, to prevent a wild well situation. You would have a excess area added to the pipe to house this giant ball bearing.
    e. Drill shear used instead of a shear ram which are a traditional wedge shape.
5. Segment (modularize)
    a. Make the pieces of drill pipe segmented in such a way that in the event of a gas bubble explosion, make those pieces disconnect from the oil rig to save lives.
6. Add a strengthening element
    a. Make the shear rams much stronger with much more hydraulic force.
    b. In the Deep Water Horizon incident, investigators said the drill pipe became un-centered and the shear rams were trying to cut through a joint in the pipe pieces. This joint prevented the shear ram from cutting the pipe and stopping the flow of oil. In order to stop this from happening, the shear rams should be strong and powerful enough to cut through the pipe at any section in it.

7. Facilitate detection in advance
    a. Add sensors to the drilling rig, the BOP Stack, and also to the pipe itself to warn workers that a gas bubble is coming up the pipe.
    b. Add mechanical and acoustical devices that will sound in the event of gas bubble detection.
8. Change on conditions
    a. If leaks or blow outs are sensed, create mandatory fail safe devices activate without user intervention.
    b. Consider liquid nitrogen as a freezing substance inside of the drill pipe, underneath the sea floor, that bursts, and freezes the oil, blocking the pipe.
9. Destroy an Object
    a. Try to overcome debris accumulating by having a ram designed to destroy debris or using chemical means.
10. Improve the mechanical strength of unreliable elements
    a. Consider increasing the mechanical strength of the blind shear rams to cut through pipe and debris.
    b. Consider increasing the mechanical strength of the hydraulic pumps to provide more strength to pipes.
11. Apply multiple actions
    a. If electrical lines corrode, try using repetitive line inspections to examine lines for quality and strength.
12. Adding an object for a period of time.
    a. Have a coagulant substance that injects into the BOP to clog/seal it, in the event of emergency. This could be something similar to cement that could be drilled through when trying to re-open the pipe.
13. Combustion
    a. Consider having explosives running in a tunnel parallel to the oil well about a mile below the surface and below the BOP, to explode and push rock/debris into the well and close it.
14. Improve Adaptability
    a. Consider improving the ROV, may instead of a seaborne vessel, have a ROV that traverses down the pipe very quickly to gain access to the BOP, to initiate manual preventative measures.
    b. Improve ROV docking station at BOP, that has multiple initiation stations to trigger different shears/sealing mechanisms.
15. Isolate a tool
    a. Have the shears housed in containers on the BOP, that are introduced to the pipe, but are not actually in the pipe and exposed to debris that travels in it.