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Formal Safety Assessment of Dynamically Positioned Vessels

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Formal Safety Assessment of Dynamic Positioned Vessels

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Background

The candidate has in his Project work studied so called simultaneous operations (SIMOPS) by which is understood vessels operating near to platforms or other floating units on an offshore field. There is a certain risk for collision due to operator error or systems failure. Typical scenarios are drive-off or drift-off. The International Marine Contractors Association (IMCA) is reporting these accidents or incidents in a systematic manner and format. The data represents a source of information for analysis of dominating accident mechanisms.

The Bayesian Belief Network (BBN) technique has emerged as a promising method for analysis and projection of accidents. The method offers greater flexibility for modelling of accidents compared to traditional methods like FTA and ETA. A number of software packages are available for the application of the method.

Objective

The overall aim of the Master Thesis assignment is to undertake a risk analysis of drive-off and drift-off accidents for Dynamically Positioned Vessels (DPV).

Tasks

The candidate shall cover following tasks:

1. Give an overview of the operational situation and requirements for a DPS in SIMOPS near an installation.
2. Give an outline of requirements set by the Classification society with respect to design and analysis of Dynamic Position (DP) systems.
3. Undertake a revised analysis of the causal factors leading to Drift-off and Drive-off. The analysis technique should be Bayesian Belief Network (BBN).
4. Based on the BBN model, analyse the main factors and mechanisms leading loss of position. Compare the accident pictures for Drift-off and Drive-off.
5. Undertake sensitivity studies to assess the most critical factors leading loss of position.

6. Discuss findings and propose plans for further work.

The project work should be reported in accordance with the guidelines given by the Department for MSc Thesis work.

Advisor is Em. Professor Svein Kristiansen.

Trondheim, September 2014.

Ingrid Bower Utne

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Abstract

The main objective of this paper is to make use of the Bayesian Belief Network (BBN) method for analysis of marine accidents in relation to Dynamic Positioning incidents (DP-incidents), and try to improve upon the model of earlier works.

BBN has become an accepted method in the last two decades for analyzing conditional probabilities and incidents, especially where extensive data may be lacking.

The report will explain the methodology used in sensitivity analysis of the causal factors, and analyze DP accident scenarios. Data is provided by IMCA Incidents reports from the years 2000 to 2007, previously analyzed and sorted by Global Maritime.

The computer software, GeNIe 2.0, was used to build a BBN to visualize the full system and sub-systems, along with dependencies among causal factors and calculate probabilities. A sensitivity analysis was also performed to see which causal factors had most influence on the different terminal events. This analysis showed that human errors had a high occurrence and impact on the terminal events.

Poor procedures was the causal factor that occurred most often (25 % of all incidents), and most often lead to a loss of position. Amongst the preliminary causes, poor procedures had the highest improvement potential in terms of every terminal event.

Operator error was another human error that proved to have a high improvement potential. It occurred in 16 % of the incidents as a main cause, and in 6 % as a preliminary cause, but the improvement potential was higher for this cause than all the latent human errors combined.

Amongst the components, DP-software had the highest improvement potential in terms of drive-off, major and minor loss of position, (LOP1 and LOP2), and second highest in terms of uncertain (drive-off or drift-off).

In terms of drift-off, environmental main causes such as wind and current proved to have the highest improvement potential, but in order to actually improve such causes, focus should be made on the human preliminary causes, along with thrusters and power generation.

Sammendrag

Hovedmålet med denne oppgaven er å forsøke og forbedre bruken av det Bayesianske Nettverket (BBN), som i tidligere arbeider er brukt for å analysere marine ulykker relatert til Dynamisk Posisjons (DP) hendelser.

BBN har de to siste tiårene blitt en akseptert metode for å analysere betingede sannsynligheter og hendelser, spesielt i tilfeller hvor det kan være omfattende mangler i datagrunnlaget. Dette dokumentet vil analysere DP ulykker og forklare metodene som er brukt i sensitivitetsanalyse av årsaksfaktorer. Data er hentet fra IMCA hendelser rapporter for årene 2000-2007, tidligere analysert og sortert av Global Maritime.

For å bygge en BBN modell som visualiserer alle systemer og undersystemer, samt avhengigheter mellom årsaksfaktorer og beregner sannsynligheter, ble dataprogrammet GeNIe 2.0 benyttet.

En sensitivitetsanalyse ble også utført for å se hvilke årsaksfaktorer som har hatt størst innflytelse på ulike terminale hendelser. Denne analysen viste at menneskelige feil hadde høy forekomst og stor innflytelse på de terminale hendelsene.

Dårlige rutiner var den årsaksfaktoren som inntraff oftest (25% av alle hendelser), og som hyppigst førte til tap av posisjon. Blant de rapporterte årsaker klassifisert som menneskelig feil var dårlige rutiner den årsaken som hadde høyest forbedrings potensiale med tanke på å redusere antall terminale hendelser.

Operatørfeil var en annen årsaksfaktor som hadde stort potensiale for forbedring. Operatørfeil var rapportert som hovedårsak i 16% av hendelsene, og i 6% av hendelsene som en innledende årsak. Men forbedringspotensialet for denne årsaken var høyere enn alle årsaker kategorisert som latente menneskelig feil til sammen.

DP programvaren hadde det høyeste forbedringspotensialet når det gjaldt drive-off, samt større og mindre tap av posisjon (LOP1 og LOP2), og nest høyest i form av Usikker (drive-off eller drift-off). Når det gjelder drift-off ulykker, viste det seg at miljø, som vind og strømninger, hadde det største forbedringspotensialet, men for å faktisk forbedre slike årsaker må fokuset rettes mot menneskelig faktorer, samt thrustere og kraftproduksjon.

Preface

This master thesis has been written during the fall 2014 at the Department of Marine Technology, Norwegian University of Science and Technology (NTNU). The overall objective of the thesis is to develop an improved BBN model for DP-incidents and evaluate results provided by it, in terms of improvement potential to the DP-system.

The objective of the thesis is formed by my supervisor, Svein Kristiansen. The work is a continuation of my project thesis from the spring 2014.

Working on this master thesis has been rewarding for both my professional and personal development. I have learned to work independently on a big task, but also to highly appreciate input from others when I have been struggling.

I would like to thank my supervisor Professor Svein Kristiansen at the Department of Marine Technology for all the guidance and valuable discussions throughout the last two semesters. I would also like to thank MSc.techn. Kristian Hauff for productive cooperation during the spring 2014, and for discussions during the work on this thesis.

Trondheim, January 25th 2015.

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1. Introduction

The motivation for this study is to utilize BBN as an analyzing tool in relation to DP-incidents. BBN is a method that makes use of expert knowledge in a more thorough way than the classical statistical method. It can be used to handle incomplete datasets by systemizing qualitative knowledge, meaning it is especially useful for systems and incidents where extensive data is lacking. This is the main reason why BBN has become widely accepted in different scientific fields in the past 25 years.

Data used in this study has been provided by the International Marine Contractors Association (IMCA), which has gathered incident reports from its 900 members (2013).

1.1 Background

The author has previously in his project assignment assessed the use of BBN as an analyzing tool in relation to the reference sub-system of the DP-system, and found it to be a viable method for conducting analysis. During this work, the author worked closely with MSc.techn. Kristian Hauff, who wrote his Master Thesis “Analysis of Loss of position incidents for dynamically operated vessels” – 2014, in which he made a BBN-model for the DP-system.

1.2 Objectives

This thesis will give an overview of the operational situation and requirements for a Dynamically Positioned Vessels (DPV) in Simultaneous Operations near an installation, list requirements set by the Classification society with respect to DP-systems, and give an overview of different loss of positioning (LOP) scenarios.

The main objective of this thesis is to build a revised and improved BBN-model for DP-incidents in relation to LOP, by investigating incident reports in order to understand the causal factors.

The model shall also include a more detailed look on the human element than previous models, with latent causes as well as active.

By evaluating the results extracted from the model, this thesis will present the improvement potential of different parts of the DP-system, evaluate these results, and discuss plans for further work.

2. Dynamic Positioning

This chapter explains how the DP system works and the uses of DP in a maritime environment, and how a typical DP system is set up.

2.1 Overview

The use of Dynamic Positioning in Marine Operations

Definition of DP:

"A means of holding a vessel in relatively fixed position with respect to the ocean floor, without using anchors accomplished by two or more propulsive devices controlled by inputs from sonic instruments on the sea bottom and on the vessel, by gyrocompass, by satellite navigation or by other means." - Holvik, J. (1998).

DP started its evolution in the early 60s, when offshore drilling moved to waters too deep for the conventional jack-up barges.

Drilling far beneath a vessel required a high degree of accuracy and maintainability of the vessel's position to avoid damage to the drill string. Such operations without assistance from a DP system are near impossible.

Today, DP systems are installed on various vessels, not only in the offshore industry. Typical vessels include:

- Platform Supply Vessels
- Diving Support and ROV Support Vessels
- Drill Ships
- Cable Lay and Repair Vessels
- Pipe Laying Ships
- Dredgers
- Crane Barge or Crane Vessel
- Rock Dumping Vessels
- Passenger Vessels
- Specialist – Semi-submersible Heavy-Lift Vessels
- Mobile Offshore Drilling Units
- Shuttle Tankers
- FPSO Ships
- Naval Vessels and Operations

(Singh. B, 2013).

2.1.1 Operational Modes

The DP system has many different uses, and can be tailored to meet specific needs for different kinds of operations. Common operational modes include:

- Manual mode: The operator controls the ship's position by use of a joystick and rotational controller.
- Auto positioning and heading mode: A predefined position and heading is automatically maintained.
- Auto area positioning mode: Not as strict as the former mode, this mode allows for deviation from the position inside a specified area. This usually saves fuel consumption.
- Auto track mode: The vessel automatically follows a specified track of waypoints.
- Autopilot mode: The vessel automatically follows a specified course.
- Follow target mode: The vessel automatically follows a changing position set-point; ex., another vessel.

(Holvik, 1998).

SIMOPS

Simultaneous marine operations (SIMOPS) refers to two or more potentially clashing operations occurring, for example, at the same time and same place. (IMCA, 2010). These simultaneous operations could lead to an undesired event or set of circumstances, e.g. safety, environment, schedule and economically drawbacks. These operations are very common in the offshore industry. A vessel operating within an installation's 500m zone is a typical example of a SIMOPS.

SIMOPS often involve multiple companies, large workforces, 24 hour schedules, routine and non-routine activities.

When a SIMOPS has been identified, a meeting between all involved parties will be arranged where work dossiers will be prepared, and responsibilities divided.

Appropriate tools should be used to identify all the risks:

- Hazard identification and risk assessment
- Clash analysis
- Interdependency analysis

The risks associated with SIMOPS can be eliminated, minimized or managed through proper planning, communication and supervision. (IMCA, 2010).

2.1.2 Mechanics

The primary degrees of freedom in motion that the DP system considers are the ship's sway, surge, and yaw. (Holvik, 1998). These are subjected to forces from wind, waves, currents, and the propulsion system. To compensate for these forces, the DP system uses data from at least one reference system—DGPS, microwave, hydro-acoustic, laser beam, or taut wire—to determine position and make necessary adjustments with the thrusters. Gyrocompasses give data on the heading. Wind sensors give data on wind forces and direction, while draught sensors gives data on currents. The motion reference units or vertical reference sensors give data on roll, pitch, and heave. The DP-computer then calculates the necessary actions for the thrusters.

The most reliable DP system today is model based. (Holvik, 1998). Instead of merely adjusting for what has already happened to the position, the system uses mathematical models to predict future movements and compensate for these ahead of time, to keep the vessel inside a specified position and heading limit. The system also minimizes fuel consumption and wear and tear.

The Kalman filtering technique is used to correct the mathematical model continuously in response to the data input from the subsystems, and keep it as accurate as possible.

The model controlled DP system can keep the ship in position for a short time after all reference systems are lost, for 5 to 15 minutes.

2.2 DP-System

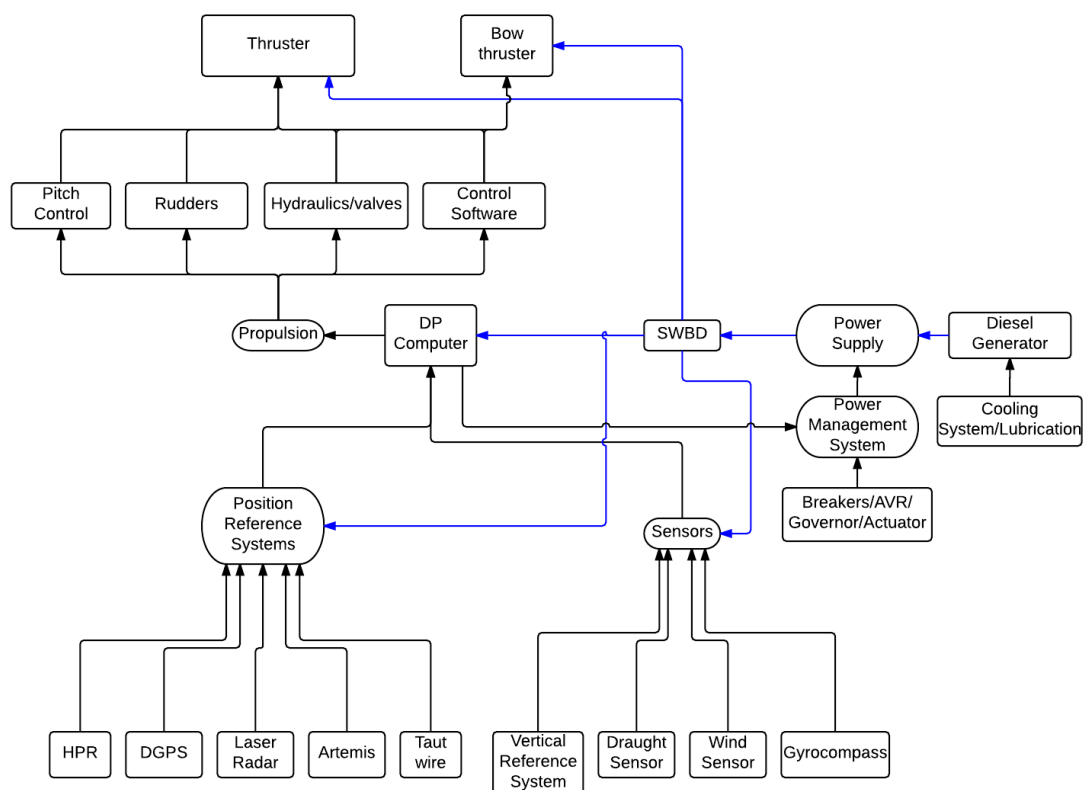


FIGURE 2-1 DP-SYSTEM STRUCTURE

The above system structure outlines how the DP-system is dependent on input from the position reference system and sensors, and power from the power supply, for the DP computer to give the correct commands to the propulsion system. The propulsion system is also dependent on the power supply and correct power management.

2.3 Sub-systems

The DP-system can be divided into 5 main sub-systems:

TABLE 2-1 DP SUB-SYSTEMS

Sub-systems:	
References	All sensors and instruments used to read position and environmental conditions.
DP Computer	The computer that utilize the information from the reference sensors and calculates position and upcoming movements, and issues commands to the thrusters.
Power Supply (Power Generation)	Diesel Generator, oil and cooling system, and also power management/speed control responsible for delivering power, and the correct amount, to the system.
Propulsion (Thruster)	Thrusters, rudders, hydraulics and control software responsible for the actual thrust force of the vessel.
Electrical	The electrical system consists of switchboard, UPS, AVR, circuits and wiring throughout the entire system.

2.4 Components

Table 2-2 lists all the main components throughout the entire DP-system. Not all vessels have all these components, and there are several different setups and variations, but all the components listed are used frequently, if not all the time.

TABLE 2-2 DP SYSTEM COMPONENTS

Sub-system:	Component:	
References	DGPS	Or DGNSS, is the receiver of positioning data (gps-signals) through satellites and a reference station on shore.
	Artemis	Distance measurements through radio signals.
	Acoustics	Hydro acoustics (HPR) makes use of transponders on the seabed, and a transducer below the vessels hull to measure distance

		based on the time the acoustic signal takes back and forth.
	DARPS	Specifically made for offshore loading operations, DARPS utilizes positioning reference signals between two vessels to calculate relative and absolute position.
	Taut Wire	A wire is lowered to the seabed, and the length of wire and the angle estimates the vessels position.
	Gyrocompass	Gives data on heading.
	Riser angles	An instrument that measures angles, tilt and elevation with respect to gravity fitted to the riser.
	Wind sensor	Register wind forces and direction.
	Draught sensor	Register current forces and direction.
DP Computer	Computer Software	The DP computer software is essential in analyzing all inputs and calculating position and upcoming movements/commands.
	Computer Hardware	The physical DP computer and components.
Power Supply	Diesel Generator	The main engine, a diesel engine with an electric generator that generates electrical energy. Runs on fuel oil or natural gas.
	Oil and cooling system	Can be seawater cooling in an open circuit, with heat transportation between a closed circuit oil system.
	PMS Software	The software that calculates needed power demand and if any generators are operating too close to their maximum load.
	PMS Hardware	The physical PMS components, computers.
	Governor	A device that regulates the speed of the engine
	Actuator	This is a type of transducer that transform electrical energy into motion.
Propulsion	Thruster	Can be an azimuth thruster where the propeller can rotate horizontally, or a conventional propeller/rudder system.
	Bow thruster	Thruster in the bow for increased precision.
	Hydraulics/valves	Hydraulics are used in many variations on a ship, but here it is referring to hydraulics in the automation and control system of the engine.

	Rudders	Rudders that work in cooperation with propellers to adjust pitch.
	Control	Software that adjust pitch and angles of rudders/propellers/azimuth.
Electrical	AVR	Automatic voltage regulator, designed to maintain a constant voltage level.
	UPS	Uninterruptible power supply provides immediate emergency power from its battery storage in case of main power failure.
	Switchboard	Directs and distributes electricity from the power source to the users.
	Inverter	Converts DC current to AC current.
	T/R	Transformer/rectifier converts AC current to DC current
	Converter	Changes the voltage of the electrical power source.
	Wiring	The electrical wiring that runs throughout the entire DP-system.

2.5 DP Classes

International Maritime Organization defines three classes for dynamically positioned ships:

- “Equipment Class 1 has no redundancy. Loss of position may occur in the event of a single fault.
- Equipment Class 2 has redundancy so that no single fault in an active system will cause the system to fail. Loss of position should not occur from a single fault of an active component or system such as generators, thruster, switchboards, remote controlled valves etc. But may occur after failure of a static component such as cables, pipes, manual valves etc.
- Equipment Class 3 which also has to withstand fire or flood in any one compartment without the system failing. Loss of position should not occur from any single failure including a completely burnt fire sub division or flooded watertight compartment.”

- *IMO (1994)*.

A more detailed requirements list can be found in Appendix C. DP Class Requirements.

Global Maritime did an analysis of the IMCA reports for the years 1994 – 2003, where they found that no DP Class I vessel were included. This is assumed true for the later reports as well, even though it's not always explicitly stated. So every incident examined in this thesis is assumed to be of DP Class 2 and 3.

Furthermore, Global Maritime concluded that *“the only reasonable benefit of DP Class III is that it separates engine rooms, and that this is of small benefit in terms of position loss. No evidence could be found to show that the back-up DP control system had been used in earnest to stop loss of position.”* (Global Maritime, 2006).

3. Loss of position

Loss of position (LOP) is when a vessel is unable to maintain its desired position. There are two main failure modes for a DP-operation, drive-off and drift-off. (Shi, Philips & Martinez, 2005) Both these scenarios can have severe financial and ecological consequences. (Chen & Moan, 2008) LOP without safe disconnection of the drill string could result in critical damage to the well barrier as well as to exposed subsea equipment. The ultimate consequence could be a well blowout and severe damage to subsea production systems like production templates resulting in risk to personnel, environmental damage and financial loss. (Bakken, 2001). Collision with nearby vessels is also a severe potential consequence.

3.1 Drive-Off

Drive-off is when the DP-system is given faulty position reference input and tries to correct this by use of its thrusters. Historical causes for this include failures in the position reference system, thrusters, wind sensors, DP computer (both hardware and software), and operator error.

3.2 Drift-Off

Drift-off is when the vessel has insufficient propulsion power to maintain position, mainly due to a blackout, partial blackout, or loss of thrusters, and drifts off because of external forces i.e. the environment.

Table 5-3 will list all the terminal events.

3.3 Causal Factors

The causal factors to the incidents are many, and from various sources. They can be failures with system components, human errors, environmental forces etc. The causal factors are categorized as preliminary causes and main causes. The preliminary causes are the ones that leads to the main causes, or let the main cause happen. The preliminary causes will always lead to a main cause before the terminal event, if not, it is in fact a main cause itself.

Failure with any system component listed in chapter 2.4 Components is a causal factor. Most often a main cause, but they could also be a preliminary cause in some incidents.

Further information and tables on causal factors will be presented in Chapter 5. Model.

3.4 Worst Case Failure

Any loss of positioning (LOP) has in the incident reports been classified as either LOP1 or LOP2. LOP2 are minor loss of positions, while LOP1 are major. Minor is understood to be of less than a few meters, while major are all incidents greater than minor.

“It is more likely that damage occurs in a drive-off situation than in a drift-off situation.”

(Hansen, 2011). A drive-off can potentially include full thrust, which means there will be a lot of energy if a collision occurs. For a drift-off to reach the same level of energy, the level of environmental forces are so high that operations are most likely not initiated, or suspended.

The worst case scenario is a major drive-off during SIMOPS.

Whether a major drift-off is more severe than a minor drive-off depends on the initial distance to other vessels, but usually major are more severe than minor.

3.5 Frequency

No DP Class I vessels are included in the IMCA reports, so the frequency for Drift-Off and Drive-Off should only reflect DP Class II and III. S. Kristiansen has made an estimation for the yearly frequencies for DP Class III based on former studies by Global Maritime, Scandpower and Safetec.

TABLE 3-0-1 FREQUENCIES, KRISTIENSEN 2014

Frequency	
Drift-off	0,078 /year
Drive-off	0,053 /year

As stated in chapter 2.5 DP Classes, the only reasonable benefit of DP Class III versus DP Class II is that it separates engine rooms, and that this is of small benefit in terms of position loss.

Therefore it is safe to assume that the frequencies for position loss for both DP Class II and III are similar, and the above frequencies applies to both.

4. Human Error

Human errors, as will become clear later in this report when investigating the results of the BBN model, is included in a considerable portion of the incidents during DP operations. (Almost two-thirds of the reported incidents feature a human error as either a preliminary cause, a main cause or both.) This is errors that either occur during operations, or has occurred earlier and happens to take effect at the time of the incident.

4.1 Classification (HFACS)

James T. Reason developed a model to show the relationship between human contributions to accidents in the different areas of a system. This model consists of three layers of protection from latent failures and one layer of protection from active failures.

The latent failures have their primary origin from the fallible decisions made by senior executives. They are translated into different forms as the effects of these decisions pass through the system during the production process. (Reason, 1990)

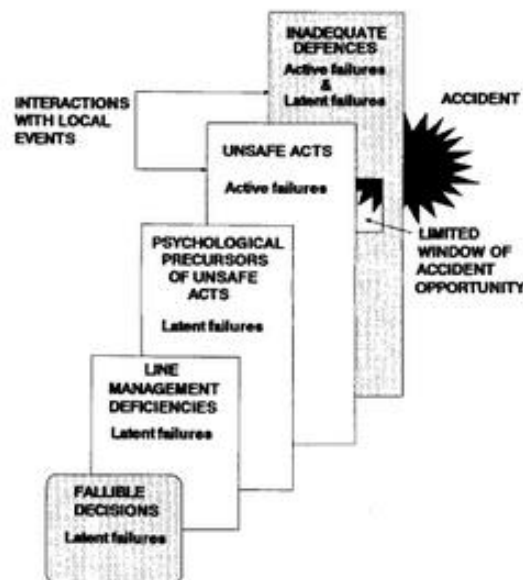


FIGURE 4-1 REASON'S MODEL FOR HUMAN CONTRIBUTIONS TO ACCIDENTS

This model is often represented as the Swiss Cheese model in which the layers of protection from accidents is illustrated as slices of Swiss cheese. The holes in the cheese represents failures in the defensive layers, and with enough holes in each layer, an accident will occur.

The Human factors analysis and classification system (HFACS) is a framework to systematically examine underlying human causal factors and improve accident investigations (Shappell &

Wiegmann, 2001), that puts Reason's theory to use in a practical manner, and investigates what the holes in the Swiss Cheese model actually represents.

Unsafe Acts

The bottom layer is Unsafe Acts. This is the active failures that happens usually right before the incident. These are further divided into skill-based, rule-based or knowledge-based errors.

Knowledge-based errors typically happens in situations where the operator has to use all of his focus and attention. It could be during a very complex situation, or if the operator is under learning.

While knowledge-based errors usually occurs in complex situation, sometime errors occur during trivial procedures. These errors are called skill-based errors, and could be unintended actions, slips or lapses etc. during tasks or situations where the operator doesn't need to pay much attention. The operator has the required skills to perform something and the tasks at hand should go on "autopilot", but he makes an error nevertheless.

Rule-based errors is when decisions or actions are done based on earlier experiences, which has worked previously and been deemed safe, even though they are faulty. This leads to errors even though the operator follows protocol, because the actual protocol is wrong or lacking. It is also a rule-based error if the operator misjudge the situation and applies the wrong protocol.

An unsafe act is often classified as either a skill-, rule-, or knowledge-based error, but it could be a mixture of all as well.

Psychological precursors of unsafe acts

The second layer from the accident consists of latent failures that may have been lying undetected for a considerable amount of time. This type of failure includes mental and physiological states and limitations with the operator, primarily due to the working conditions. These conditions may be self-inflicted by lacking crew resource management or personal preparations and readiness. Often though, they stem from latent failures from the above layer.

Line Management Deficiency

Also known as unsafe supervision, line management deficiency are the preconditions for the precursors of unsafe acts, and consists of failures on the supervisory chain of command such as inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations.

Fallible Decisions

The top layer are fallible decisions made by the upper-level management. These organizational influences directly affect the supervisory practices and in turn the actions of the operators, but these failures are the ones that are most often overlooked by safety professionals (Shappell & Wiegmann, 2001). The HFACS framework was designed with this in mind to better capture failures on this level within resource management, organizational climate and organizational process.

4.2 Human errors in the incident reports

The human errors found in the IMCA reports have been categorized into 7 groups:

TABLE 4-1 HUMAN ERRORS AND MAIN CATEGORY

Human error:	Failure category:
Operator error	Active
Poor procedures	Latent
Communication	Active, Latent
Insufficient T/C/QA	Latent
Poor design	Latent
Poor maintenance	Latent
Poor management	Latent

The human errors have been further sorted into two main groups, errors that happens during operations and underlying errors that has been present for a potentially long time. The difference between the two groups is closely related to the difference in active and latent errors, but not identical.

4.2.1 Human error during operations

Operator Error

Operator error is a direct human error where the operator does something wrong, or neglect to do something he should. It could be a skill-based error, knowledge-based error, or a rule-based error in which the operator misjudge the situation and applies the wrong procedure.

Poor Procedures

Poor procedures is an error in which the actual procedures or routines followed is faulty. This is a latent error in which the rules previously made are faulty. It can be argued that it could also be an

active rule-based error in which the operator applies the wrong rules for the given situation, but in the incidents reports, this would probably be labeled as an operator error.

Communication

Communication errors is when information is distorted during passing. This can be caused by bad reception on instruments, misunderstandings between individuals, lost communication etc., which can be latent errors within the system, or any of the unsafe acts errors. Communication errors can occur during SIMOPS between different vessels.

4.2.2 Underlying human error

Insufficient T/C/QA

Testing/commissioning and quality assurance is applied in the pre-production of products, systems and solutions to verify that the product meets the specification and requirements as intended. The quality control is also applied by sampling the products later on. Insufficient T/C/QA can therefore lead to a faulty product and create a latent error.

Poor Design

This error is related to the previous, but is caused by faulty decisions in either the design phase of components, or the setup of systems, rather than a lack of quality control. It could be a manufacturing fault in the production as well, and is latent error.

Poor Maintenance

Lack of, or inadequate, maintenance can cause components to fail, and in turn whole systems. Poor maintenance leads to a latent error.

Poor Management

Poor management is when the company decides to implement protocols that leads to errors, or if they don't implement enough protocols. It can also be inadequate resource management. This is a latent error in the top layer of the HFACS framework.

5. Model

Chapter 5. will present the theory behind Bayesian Belief Network, the computer software used and how the models are built.

5.1 Theory

“The Bayesian probability of an event X, represents the person’s degree of belief or confidence in that event’s occurrence based on prior and observed facts.” – David Heckerman, 2006.

Classical probability predicts the likelihood of any given event, regardless of the number of occurrences or observed behavior, by using established frequencies. Bayesian probability only predicts the next event and will update its likelihood after each event. (Heckerman, 2006). If a coin is tossed 100 times, the classical probability for heads on toss no. 101 is the same as it was for toss no. 1, but the Bayesian probability may have changed if the 100 observed tosses don’t correspond to the classical frequency. Our belief of the probability may have changed.

Bayes’ Theorem describes conditional probability, and can be expressed as:

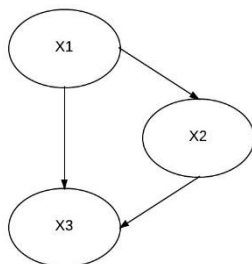
$$P(A|B, c) = \frac{P(B|A, c) \cdot P(A|c)}{P(B|c)}$$

- $P(A|c)$ is the prior probability of hypothesis A given background information c only.
- $P(A|B,c)$ is the posterior probability after having accounted for B and c .
- $P(B|A,c)/P(B|c)$ is a factor that represents the impact B has on A.

Conditional probability is used by both the classical probability and Bayesian probability, but with the Bayesian approach, the probability estimate for a hypothesis is updated as additional evidence is acquired.

Bayesian Belief Network

The Bayesian Belief Network (BBN) is a tool to visualize the relationship between variables in a system, both qualitative and quantitative with the corresponding conditional probabilities



between variables. The variables may be observable quantities, latent variables, unknown parameters or hypotheses. The variables are represented by nodes, and the dependencies between them by arcs. The network is a Directed Acyclic Graph. By following the directed path along an arc from node X1, you will never return to X1 as you would a cyclic graph. (This limitation

can be overcome by duplicating the same nodes and making a dynamic Bayesian network, but this is not addressed further in this paper.)

The nodes are classified as parents and children. In the figure, node X1 leads to both node X2 and X3; therefore, node X1 is the parent node to X2 and X3, and they in turn are the children of X1. Since node X2 also leads to X3, X2 is also a parent of X3.

When analyzing a complex system consisting of many variables, the number of parameters may exceed a manageable amount. (Vanek). For example, 10 variables with values “true” and “not-true” gives 2^{10} parameters in table. Simplifying by limiting the number of parent nodes to a child makes it more manageable. For example, a maximum of 3 parent nodes gives, at most, 10×2^3 parameters.

5.2 Data

The BBN model was made by collecting data from IMCA reports for the years 2000 to 2007. These reports are the most detailed as they have previously been analyzed by Chris Jenman, Global Maritime, and categorized with main causes and preliminary or secondary causes. The original reports were not very detailed, so Global Maritime did their own follow-up of the incidents, which resulted in reports usable for making a BBN.

For what type of vessel each incidents occurs are not reported, so the reports can only be used to make models for DP-vessels, not more specific, such as Platform supply vessel, PSV. Nor do they mention in what operational mode the vessel was in.

The reports does not inform under what type of operation the vessel was in during the incident, so this cannot be modeled either.

5.3 GeNIe

GeNIe is a free-to-use development environment for building decision-theoretic models, developed at the Decision Systems Laboratory, University of Pittsburgh. It's the main program used by the author to learn and evaluate a BBN of DP-incidents.

GeNIe can create a network based solely on the input data sheet, or it can use the data sheet to learn the parameters of a predefined network. With limited datasets, the latter method, with the use of expert knowledge, proved most fitting. The method of letting GeNIe create the network for you was more prone to bugs such as dependency arcs that were clearly wrong.

Before drawing the BBN in GeNIe, it is crucial to have expert knowledge of the system. This is acquired by understanding the system and collecting data, as well as analyzing the relations between factors. A matrix showing how often a factor occurred alongside another is an effective way of doing this.

	LOP1	LOP2	Timeloss	DGPS diff	DGPS
LOP1	100 %	0 %	0 %	23 %	32 %
LOP2	0 %	100 %	0 %	12 %	48 %
Timeloss	0 %	0 %	100 %	6 %	38 %
DGPS diff	42 %	42 %	17 %	100 %	0 %
DGPS	18 %	51 %	31 %	0 %	100 %

FIGURE 5-1 CUT FROM DEPENDENCIES MATRIX

The above matrix can be read as of all the DGPS incidents, 31 % of them leads to a “Time loss” incident. Of all the “Time loss” incidents, only 6 % comes from a “DGPS” incident. Such a matrix gives an overview of some of the most important dependencies in the system.

When sufficient knowledge about the system is acquired, you can make an initial BBN in GeNIe.

5.4 Full Model

The BBN model has the same sub-systems introduced in chapter 2.3 Sub systems, but with an added 2 sub-systems, giving it a total of 7. This is to implement Environment and Operator error as their own systems. They aren’t a part of the physical DP-system, but they are a part of the causal factors that leads to an incident.

TABLE 5-1 SUB-SYSTEMS OCCURENCE

Sub-systems:	Occurrence:
References	96
DP Computer	81
Operator error	78
Power generation (power supply)	71
Thruster (propulsion)	66
Environment	53
Electrical	31
Total no. of incidents:	476

Every incident has been placed in one of the above sub-systems. Each sub-system has their own sets of main causes. For instance, some of the main causes of Environment are External force, Waves or Tide change. These main causes are unique to Environment.

The preliminary causes on the other hand are not always unique to one sub-system. The majority of the human preliminary causes occurs in all of the sub-systems, while there are some component errors that acts as preliminary causes and are unique to one sub-systems. Both these

types of preliminary causes are categorized as preliminary causes 1. (Table 5-2).

Also, a sub-system can act as a preliminary cause in another sub-system. For instance, the Environment sub-system occurs 53 times (See Table 5-1). But in addition to these incidents, a preliminary cause labeled Environment occurs 7 times in the other sub-systems (Table 5-2).

These preliminary causes are categorized as preliminary causes 2.

TABLE 5-2 PRELIMINARY CAUSES OCCURRENCE

Preliminary Causes Type 1:	Occurrence:
Poor procedures	121
T/C/QA	65
Poor Design	50
Poor Maintenance	20
Software	8
Communication	3
Poor Management	2
Fan-beam	2
Preliminary Causes Type 2:	
Operator Error	27
Environment	7
DP Computer	6
Power Generation	6
References	6
Thruster	2

The total number of incidents involving an environmental cause is 60, but only 53 of them are in the Environment sub-system. The rest appear in other sub-systems as a preliminary cause.

The end nodes are called terminal events:

TABLE 5-3 TERMINAL EVENTS

Terminal Events:	Occurrence:
Drift-off	155
Drive-off	72
Uncertain	86
Time loss	157
LOP1	145
LOP2	172

Every incident will lead to either drift-off, drive-off, “uncertain” or time loss, where “uncertain” is an LOP incident, but it is not known if it is a drift-off or drive-off. It should therefore be viewed as more critical than drift-off. All terminal events is a LOP incident, except for time loss. All LOP incidents are further categorized as LOP1 or LOP2 depending on severity.

Partial blackout is a node in a few of the sub-systems models (see chapter 5.5 Sub-models), but not discussed further as the main cause’s relation to the final terminal event is most interesting, and the incidents reports are not detailed enough to read if a partial blackout occurred or not.

Two different full models were made. Figure 5-2 features all the main causes, while in Figure 5-3 the main causes has been merged into one with their respective sub-class node.

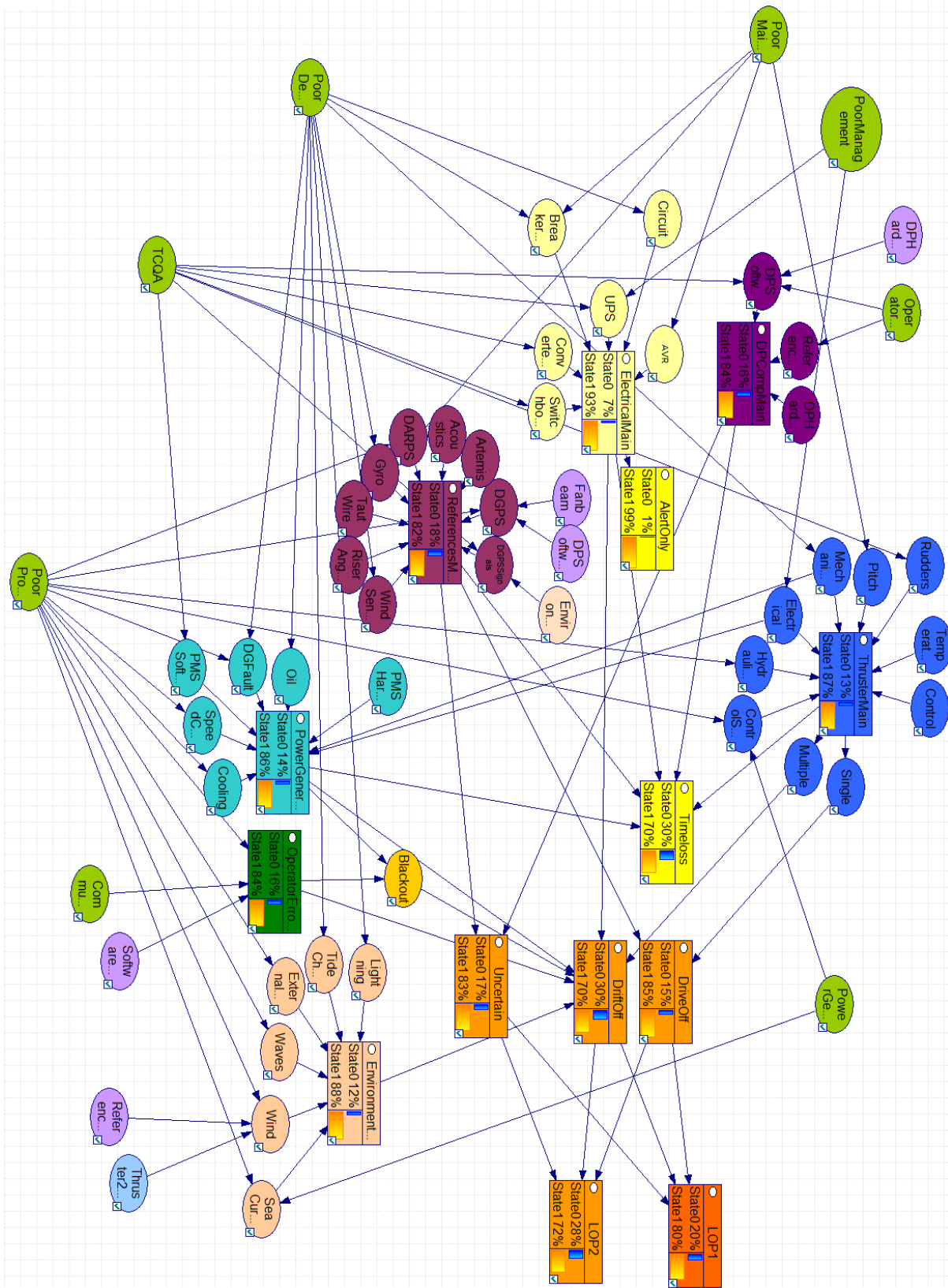


FIGURE 5-2 FULL BBN MODEL, COMPLETE

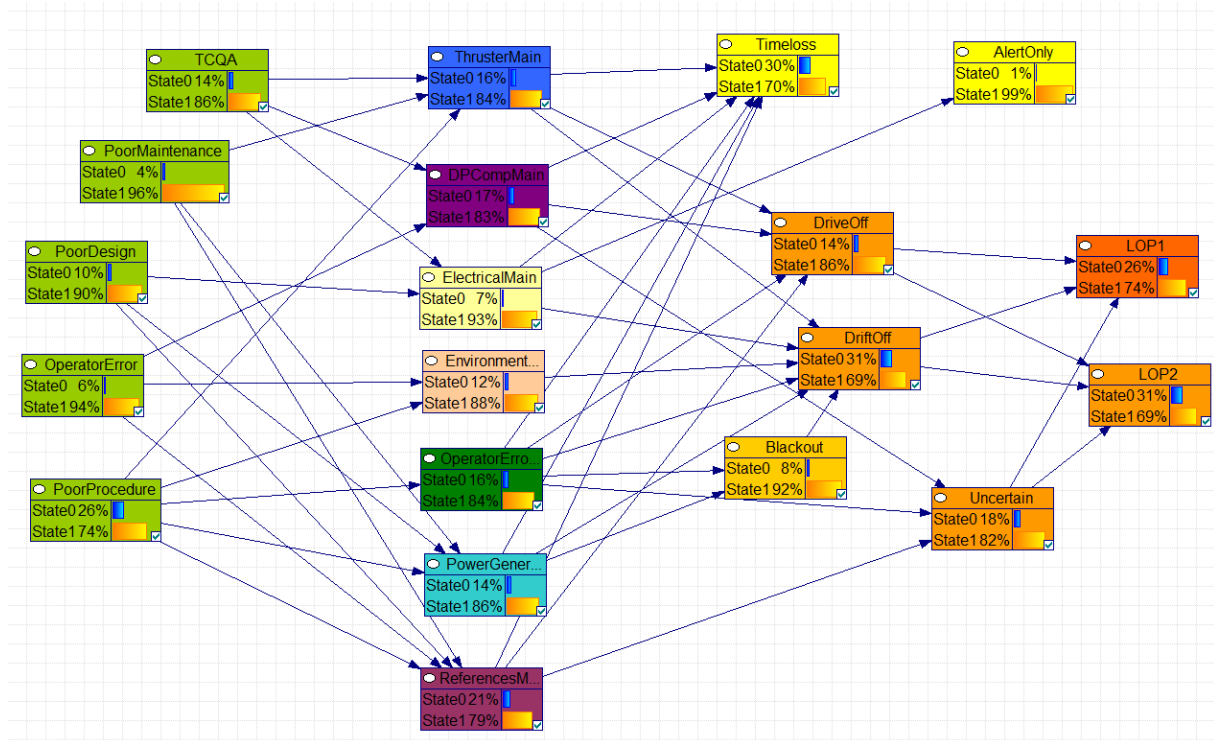


FIGURE 5-3 FULL BBN MODEL, SIMPLIFIED

Figure 5-3 is the model used in this thesis to generate data. The preliminary nodes have been reduced to feature only the most occurring human factors; Poor procedures, Poor maintenance, Poor design, Operator error and T/C/QA, while the rest of the preliminary causes and main causes have been merged with their respective sub-system nodes.

This makes for a clearer model with respect to human factors, since they are by far the most occurring preliminary factors. Another reason is that each of the main cause nodes, ex: UPS under the sub-class Electrical, has very little impact when adjusted and viewed in the full system.

5.5 Sub-models

An individual model has been made for each of the 7 sub-systems.

The sub models have many of the same preliminary causes as the full model, but with a few unique. All the main causes are unique to each sub-model. The References sub-model will be used to illustrate.

References

The preliminary causes added in this model is DP-software, Fan beam and Environment, the latter appearing once in two other sub-models, whereas the two first are unique to this model.

TABLE 5-4 REFERENCES, PRELIMINARY CAUSES

Preliminary Causes:	Occurrence:	Type:
Poor Procedures	26	1
T/C/QA	10	1
Poor Design	9	1
DP software	6	1
Poor Maintenance	5	1
Operator Error	5	2
Environment	4	2
Fan beam	2	1
Total no. of incidents:	96	

The main causes are all unique to this sub-model:

TABLE 5-5 REFERENCES, MAIN CAUSES

Main Causes:	Occurrence:
DGPS	39
DGPS Signals	12
Gyro	13
Artemis	9
DARPS	9
Taut Wire	8
Acoustics	5
Riser Angle	2
Wind Sensor	2
Total no. of incidents:	96

In the full model, all these main causes are combined into one sub-model node, References. As seen in Table 5-5, DGPS and signals in connection to the DGPS make up 53 % of the total incidents in References.

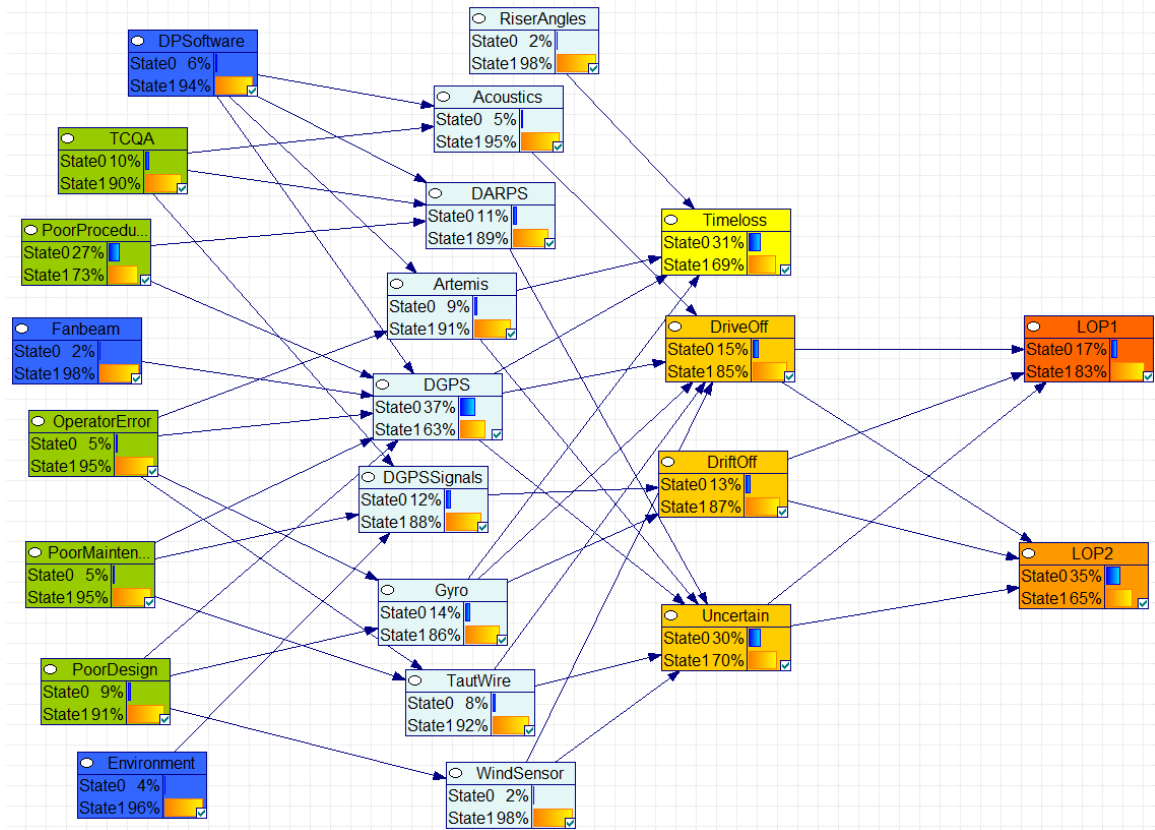


FIGURE 5-4 REFERENCES BBN SUB-MODEL

The rest of the sub-models can be viewed in Appendix A. BBN Models.

5.6 Evaluation of model

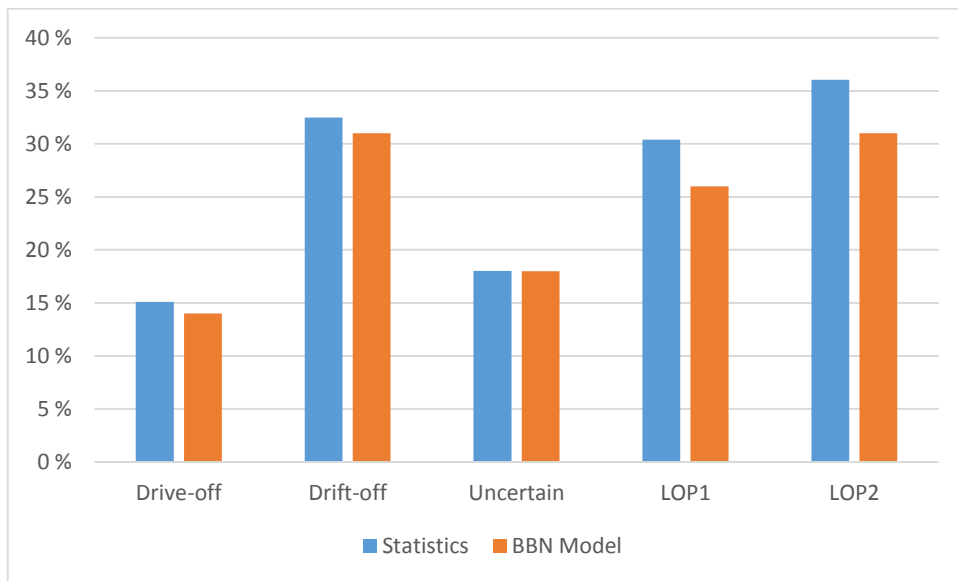


FIGURE 5-5 STATISTICS AND BBN MODEL COMPARISON

Figure 5-5 shows the percentage of the incidents that lead to the different terminal events, versus the percentage that the BBN model estimates, for the full model. The similarities is an indication that the BBN is built correctly. This conclusion is only valid when the nodes are set to the type general, i.e. they change based only on the conditional probability of the parents. Noisy-Max is a type of node commonly used when the number of parents become very high, that creates an additional “parent” to account for missing information. If you draw arcs to a Noisy-Max node that are factual wrong, this parent will become more dominant to compensate for this and keep the nodes percentage close to the statistical answer.

All nodes in the model have been set to general, as none of the nodes has a high number of parents.

For LOP1 and LOP2, the difference to the statistical data increases slightly. This difference is due to the fact that they are further from the rest of the nodes. The longer your BBN chain is, the more complicated the relations become.

6. Analysis

This chapter will explain the methods used to extract valuable information from the different BBN models. When looking at the sub-models, References will be used as an example throughout this chapter.

6.1 Former method

The author previously devised a method in cooperation with MSc.techn. K. Hauff to evaluate which causal factors contributes most to the terminal events. The idea was to see how much the probability of the terminal event, X3, increased when a causal factor, X1, was changed to 100 % certainty, and adjust this increase with the original frequency of the causal factor. (Hauff, 2014).

$$\begin{aligned} & \textit{Influence of X1 on X3} \\ & = \frac{(P(X3|X1) - P(X3))}{P(X3)} \cdot P(X1) \end{aligned}$$

TABLE 6-1 FACTORS IN THE INFLUENCE FORMULA

$P(X3 X1)$	Probability of X3, when X1 is set to 100%.
$P(X3)$	Initial probability of X3.
$P(X1)$	Initial probability of X1.

Although this method was found to give fair results, other methods has been used in this thesis that takes the opposite approach, “what happens if we remove the causal factors?”. What is the improvement potential?

6.1 Methods

To explain the sensitivity analysis performed by GeNIe, a simple example with two parent nodes Comet and Fire, and one child node (the terminal event), Damage to ship, will be used.

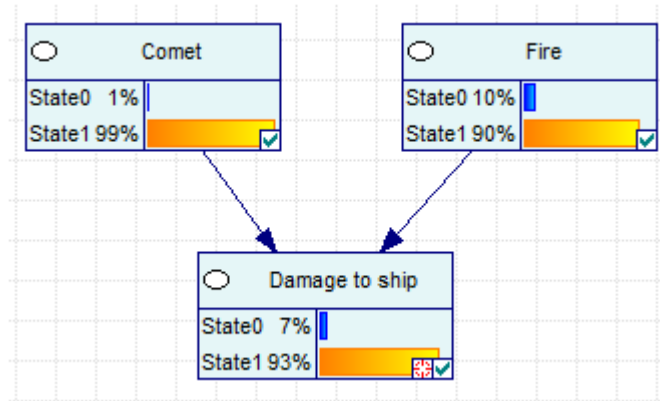


FIGURE 6-1 BBN EXAMPLE 1

The probability of a comet striking down upon the ship is very small. In this example it is set at 1 % so it can be visualized. The chance of fire emerging somewhere on the ship is set at 10 times that for simplification. The conditional probabilities of damage to our ship is $P(\text{“Damage to ship”} | \text{“comet”}) = 100 \%$, and $P(\text{“Damage to ship”} | \text{“Fire”}) = 50 \%$.

The visual tools in GeNIe is only concerned with these conditional probabilities. Since $P(\text{“Damage to ship”} | \text{“comet”}) > P(\text{“Damage to ship”} | \text{“Fire”})$, it will choose “Comet” as the most influential node.

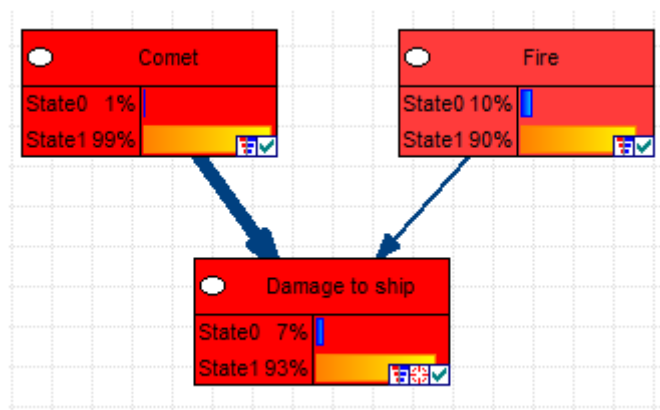


FIGURE 6-2 BBN EXAMPLE 2

As seen in this figure, the Fire node has a lighter shade of red than Comet, and also a lesser width of the arc which resembles strength of influence. So by this visualization Fire is considered less important than Comet.

When setting both parent nodes’ State0 to 100 % in turn (State0 represents that the incident occurs), we get similar results:

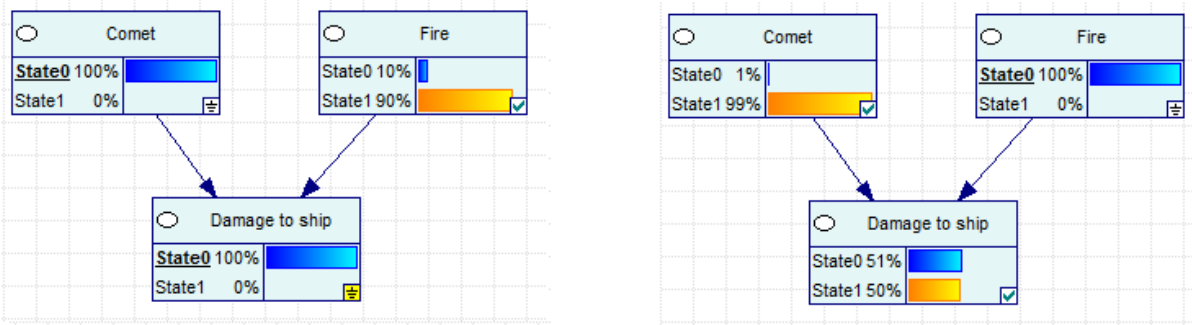


FIGURE 6-3 BBN EXAMPLE 3

We see that Damage to ship increases twice as much in the “Comet happens”-scenario, as it does in the “Fire happens”-scenario, due to the certainty of damage in the “Comet happens”-scenario.

But when we are to consider which parts of a system we should invest resources in to improve, the above results aren’t detailed enough. We already know that if a comet strikes our ship, damage is guaranteed. If we do the opposite, changing the scenarios to “Comet doesn’t happen” and “Fire doesn’t happen”, the results becomes different:

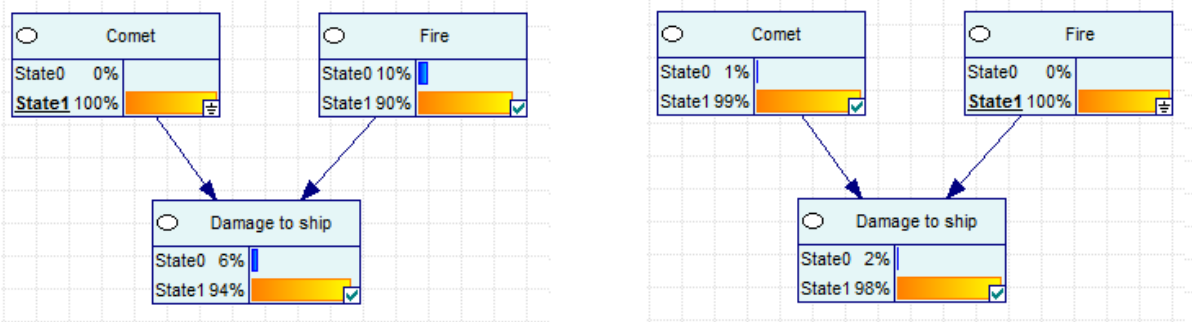


FIGURE 6-4 BBN EXAMPLE 4

When removing comet as a possibility, the probability of damage to our ship decreases by only 1 % from the original 7 % to 6 %, because there is still the possibility of fire. Removing the fire on the other hand decreases the probability of damage to 2 %, because fire is the most common cause of Damage to ship, even though not all fires result in damage.

Sensitivity Tornado

Sensitivity Tornado is a function in GeNIe where you can change the parameters and see the effect on the target. In the following chart GeNIe is estimating the outcome for “Damage to ship”=State1, the probability that damage doesn’t happen, by adjusting the parameters in the range from 0 to 1.

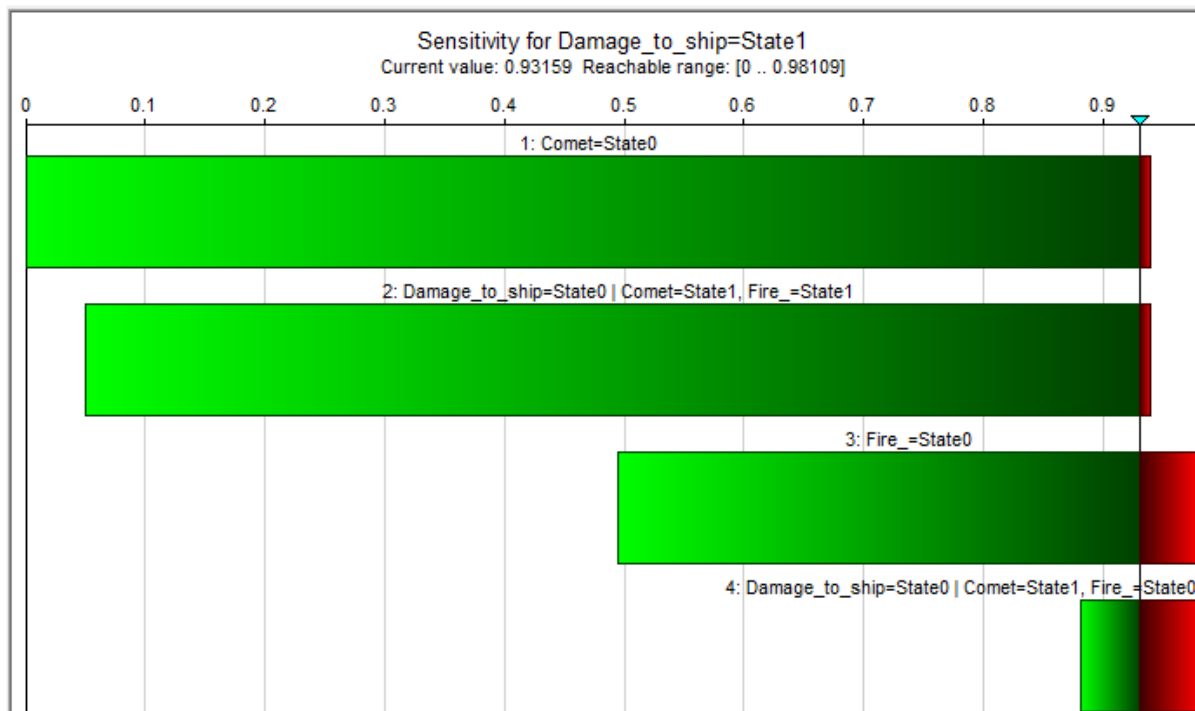


FIGURE 6-5 SENSITIVITY TORNADO EXAMPLE 1

As seen by the first bar, Comet can affect the probability of damage not happening to 0 % (green bar). This is the same as damage happening to 100 %. But it can only increase the probability of damage not happening by a small percent (red bar.) Fire, on the other hand, can increase the probability of damage not happening by much more (3rd red bar).

Improving a system parameter enough to guarantee its total reliability is not realistic. Instead we can see what happens if it is improved by a fraction.

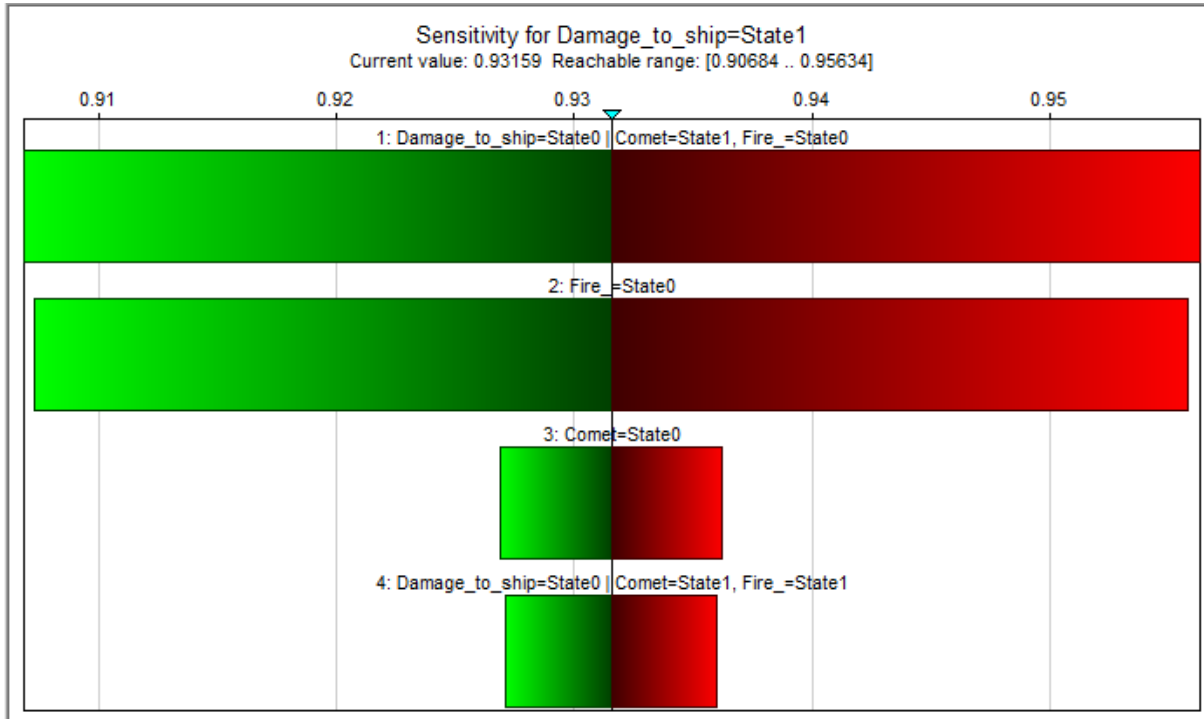


FIGURE 6-6 SENSITIVITY TORNADO EXAMPLE 2

Here the parameters are allowed to be adjusted by 50 %, either way, meaning increasing or decreasing state0 of Fire and Comet by 50 % in turn. So in the case of Comet, adjusting state0 between 0,5 % and 1,5 %.

This gives data that better resembles reality. Adjustments of 10 % can also give results worth analyzing, and is perhaps closer to what can be expected when improving a system.

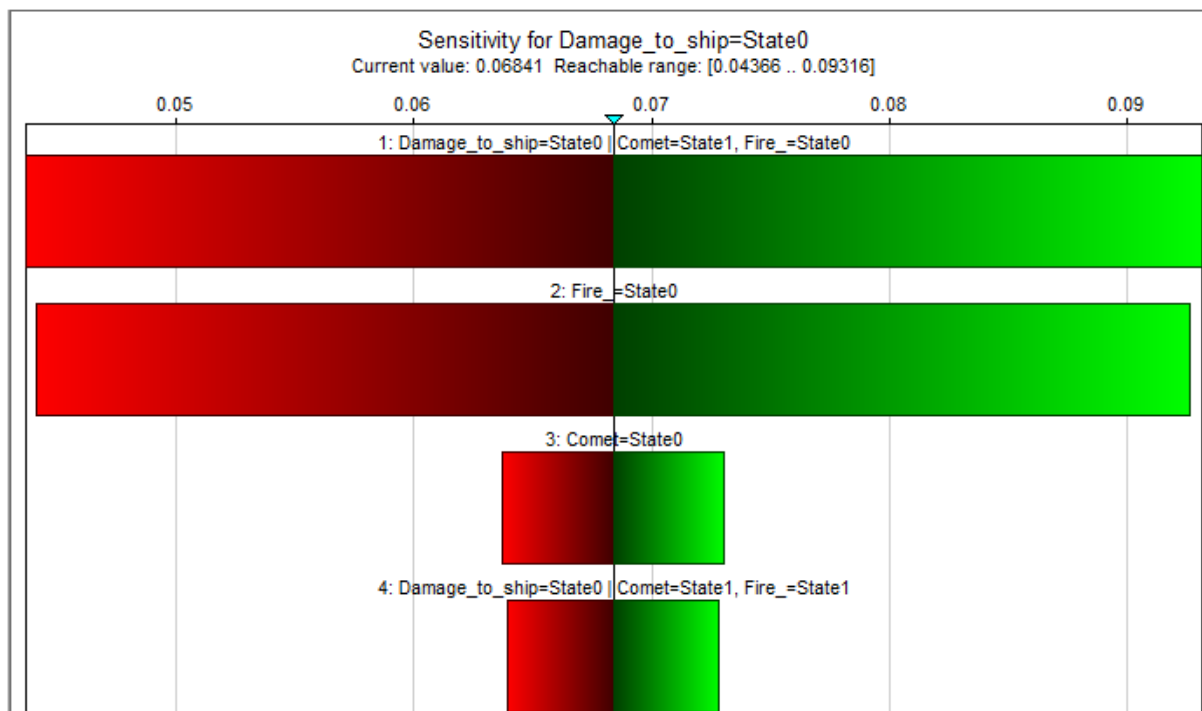


FIGURE 6-7 SENSITIVITY TORNADO EXAMPLE 3

This chart gives the exact same result as the previous, but it shows the difference in State0 instead of State1. The red bare on Fire shows the possible decrease in State0 of Damage to ship, by adjusting Fire by 50 %.

The full range adjustments of the parameters from 0 to 1 can remove almost all of the total population of events, as seen when setting Comet to 100 %, but smaller fraction changes does not.

For this thesis two methods will be used for the sensitivity analysis. The first will be a 20 % fraction adjustments for the preliminary causes, and their impact on the increase of the reliability mode/decrease of the failure mode of the target, i.e. the red bar in the two previous charts. The second method will be to remove each contributing factor completely, i.e. set State0=0%, in turn, and see the impact on the terminal events.

6.3 20% reduction adjustment

The first method used was the use of the sensitivity tornado to adjust the preliminary causes by 20 %.

6.3.1 Full Model

To visually see how small adjustments in the preliminary factors impact the terminal events, GeNIe's integrated sensitivity analysis was used. In the following figure, drift-off is the target node. The degree of red coloring of the other nodes indicate their probability of leading to the target node, given that they happen. Ex: $P(\text{"Drift Off"} | \text{"Blackout"}) \gg P(\text{"Drift Off"} | \text{"Poor Design"})$, therefore blackout has a darker coloring.

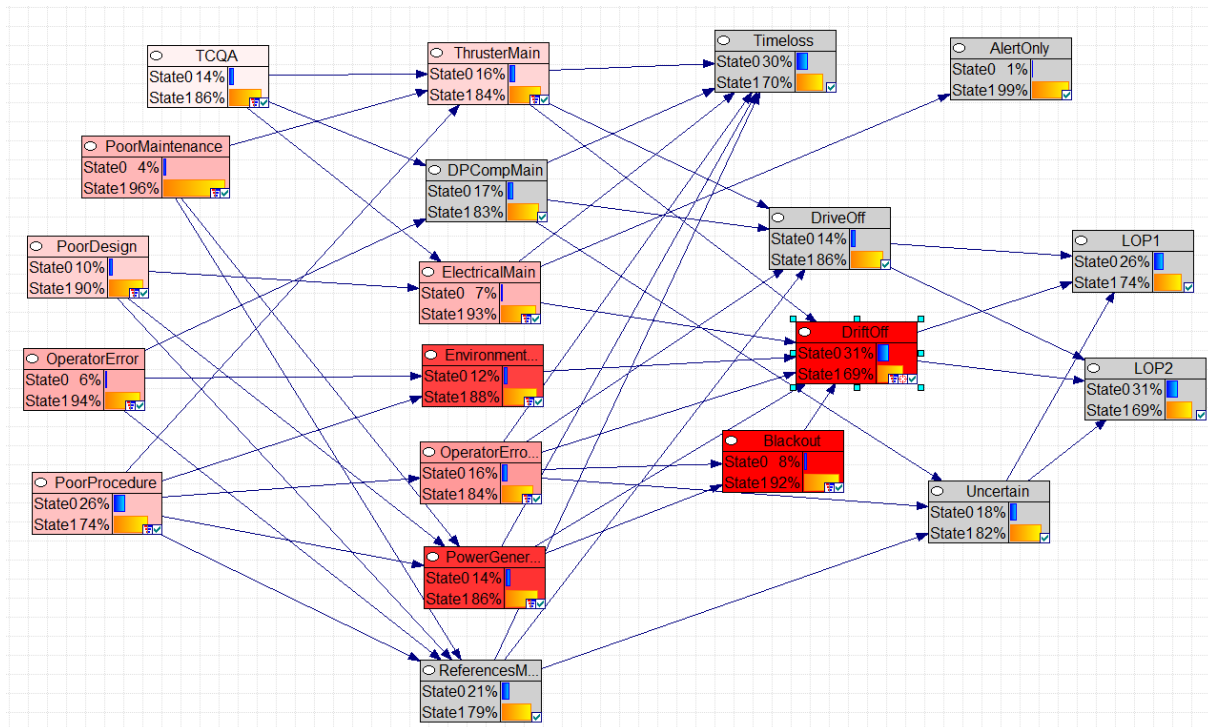


FIGURE 6-8 GENIE SENSITIVITY ANALYSIS FOR "DRIFT-OFF"

To see which parameters would make a higher improvement on the system if adjusted, the impact of each node was displayed in a sensitivity tornado chart.

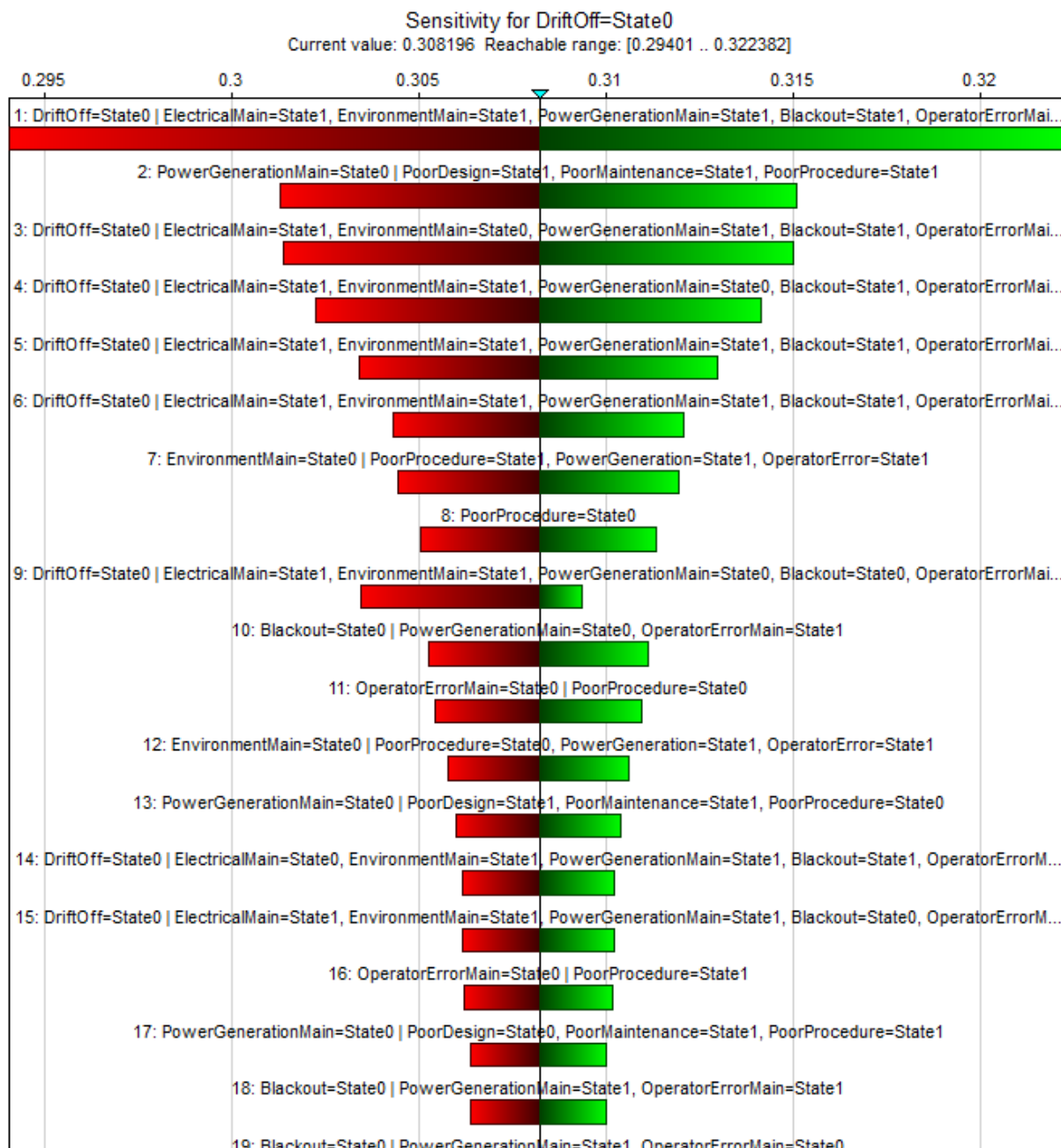


FIGURE 6-9 SENSITIVITY TORNADO FOR "DRIFT-OFF"

This chart shows the impact on drift-off by adjusting factors by 20 %, in both directions. Many of the results show the impact from several factors at once, but this thesis has limited itself to only look at one cause at a time. The preliminary causes are adjusted one at a time, as seen above for poor procedures. The original probability of drift-off was 0,308. Adjusting poor procedures by 20 % in the direction of improvement, in this case State0 from 0,25 to 0,20, decreases State0 for drift-off to 0,305. This improvement on drift-off is as expected, small. This is because all the other factors are still operating as before. But comparing this improvement to the improvement

given by the other adjusted preliminary causes shows which is more dominating and should be given most attention.

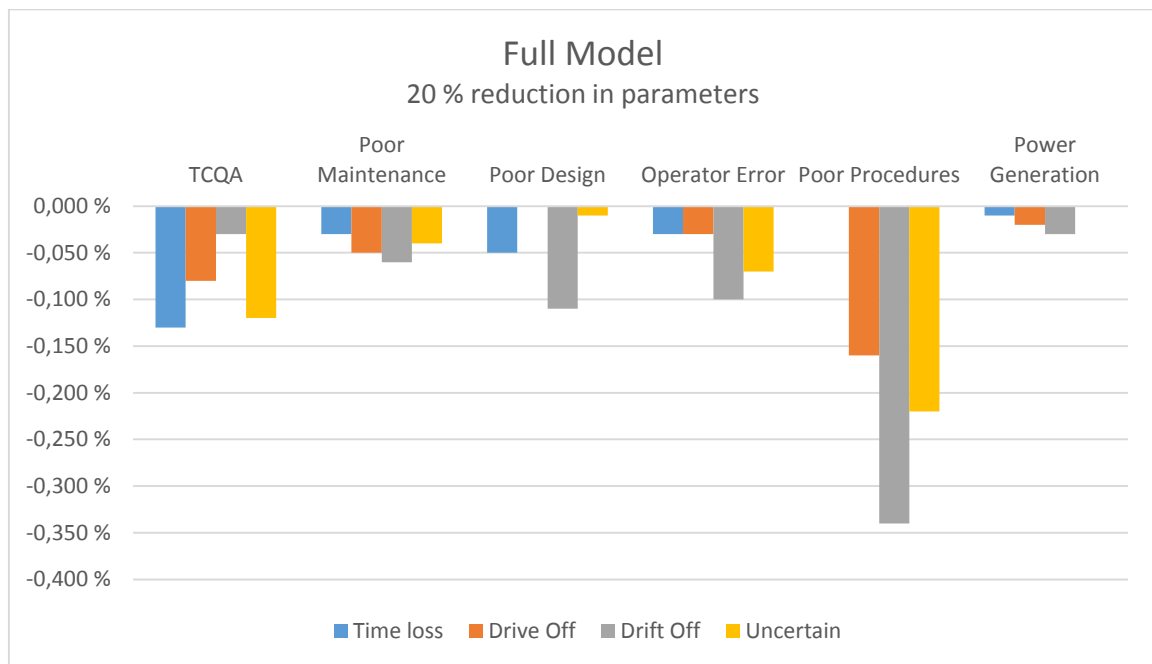


FIGURE 6-10 20% REDUCTION PRELIMINARY CAUSES, FULL MODEL 1

The Y-axis in this chart displays the difference in the target nodes after adjustment of 20 %. As previously stated, poor procedures decreases state0 for drift-off by 0,34 %.

Poor procedures also has higher impact on the terminal events drive-off and “uncertain” than any of the other preliminary causes.

TC/Q/A has the highest impact on time loss.

6.3.2 Sub-models

The same procedures as for the full model has been done for every sub-system. The human error preliminary causes are mainly the same, and some other preliminary causes unique to each sub-system are added.

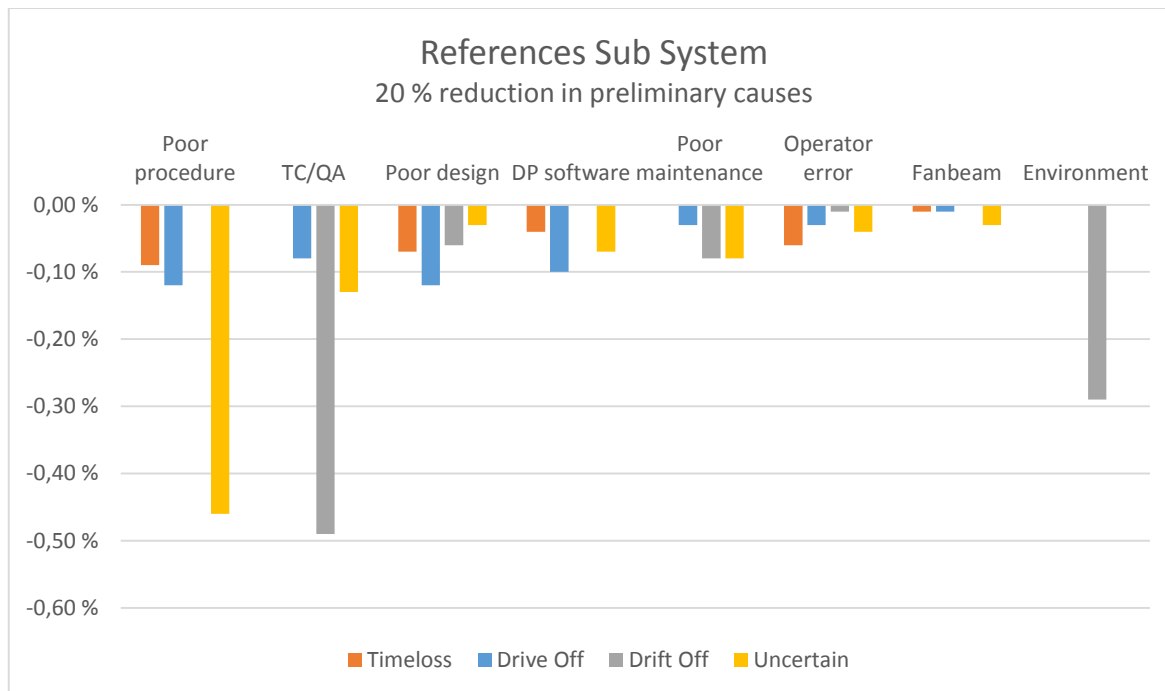


FIGURE 6-11 20 % REDUCTION IN PRELIMINARY CAUSES, REFERENCES 1

As for the full model, the impacts are small, but trends emerge as to which are the most dominant contributors. In this case, also poor procedures and TC/Q/A.

6.4 Full reduction adjustment

When the sensitivity tornado evaluates main causes that have parent nodes, it adjust the parents in both directions by up to 20 % in order to adjust the target. Therefore the target node will not be adjusted by 20 %, but as close as it can get. This leads to differences in adjustments when viewing different main causes, and the above method is not as useful.

Another way to see which factors has the highest impact on the terminal events, is to adjust each factors state0 to 0%, or state1 to 100%, in turn. This removes the possibility of that factor happening, and we can see what would be the result on the system if it was completely removed. One reason that this method is a viable one, even though a full reduction is near impossible, is that any improvement made to a system will probably be a fraction. If you invest to improve a system component, you will see a reduction in these events corresponding to a fraction, not a given number of incidents. If one component is responsible for 100 incidents, and another 20 incidents, a reasonable improvement after investment could be 20 %. This is a reduction of 20 incidents for component 1 and 4 incidents for component 2.

So when viewing the reduction on the terminal events made by a full reduction in one component versus another, one can say that such improvements are highly unlikely to be

achieved, but they both scale with the same fraction, so the one with the highest improvement potential will still be highest after any scaling.

6.4.1 Full Model

In the following chart, this has been done to the preliminary causes, and the main causes.

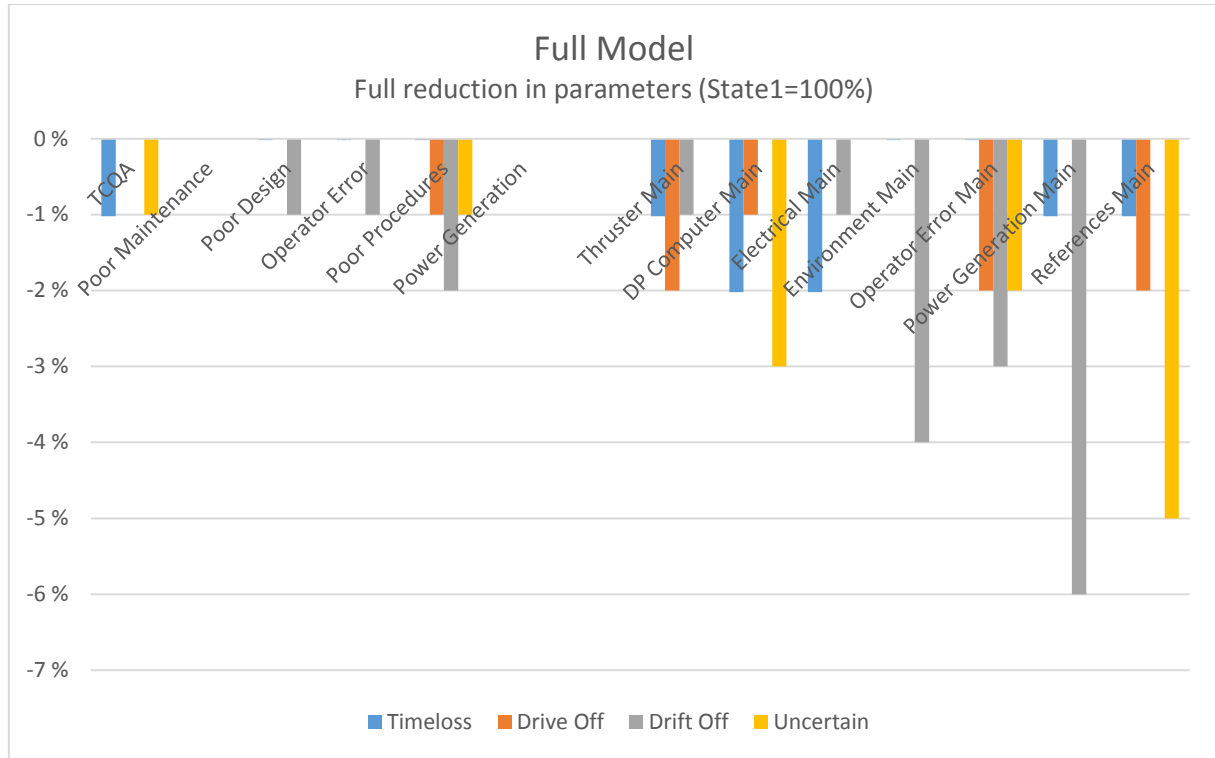


FIGURE 6-12 FULL REDUCTION IN CAUSES, FULL MODEL 1

Only reductions of the terminal events of at least 1 % has been listed. Poor procedures is again the preliminary cause with the highest impact. This is a result of both the given probability that it will lead to the terminal events, and the original frequency.

Amongst the sub-systems nodes, operator error and references has the highest added impact of all three LOP terminal events, -7 % for both. Power generation has the highest impact on drift-off, -6 %, and references has the highest impact on “uncertain”, -5 %. Thruster, operator error and references all have a -2 % impact on drive-off.

6.4.2 Sub-Models

The full reduction method has also been done for every sub-model, mainly to see the effects of the different components, because they are too many to include in, and make to little impact on the full model.

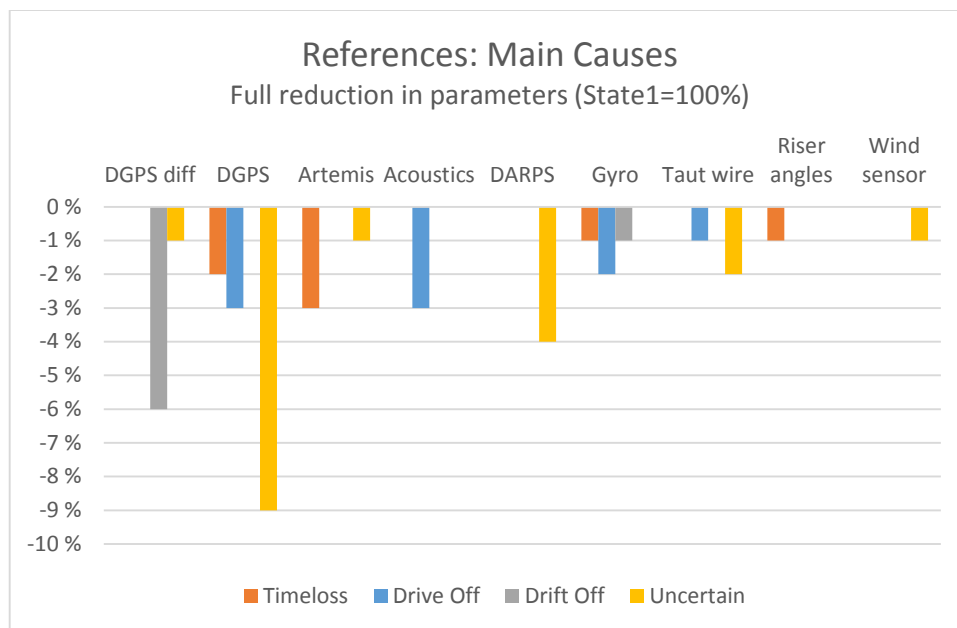


FIGURE 6-13 FULL REDUCTION IN MAIN CAUSES, REFERENCES

What's seen from these results, is that eliminating DGPS and DGPS signals would reduce the LOP terminal events by approximately 19 %. This is of course 19 % of the references events, and would not correspond to 19 % of the terminal events for the full model.

Poor procedures on the other hand would only reduce the terminal events in references by 4 %. But a full reduction of poor procedures would also lower the terminal events in the full model through all the other sub-systems, so it's not clear which factor should be considered more critical without further analysis.

7. Results

This chapter will present the results extracted from the BBN models, using the analysis methods described in chapter 6.

The full BBN model is the best option to use to evaluate which preliminary causes warrant most attention, and also which sub-models. After the most dominant sub-models are decided, further investigations can be done into the BBN sub-models to evaluate which main causes/components should be improved.

7.1 Preliminary Causes

When evaluating the preliminary causes, the full BBN model is the best option to use as it accounts for the full effect of a reduction. As shown in Figure 7-1 and Figure 7-2, poor procedures has the highest improvement potential when reduced by 20 %. This will lead to a decrease of LOP1 and LOP2 by 0,25 % and 0,27 % respectively.

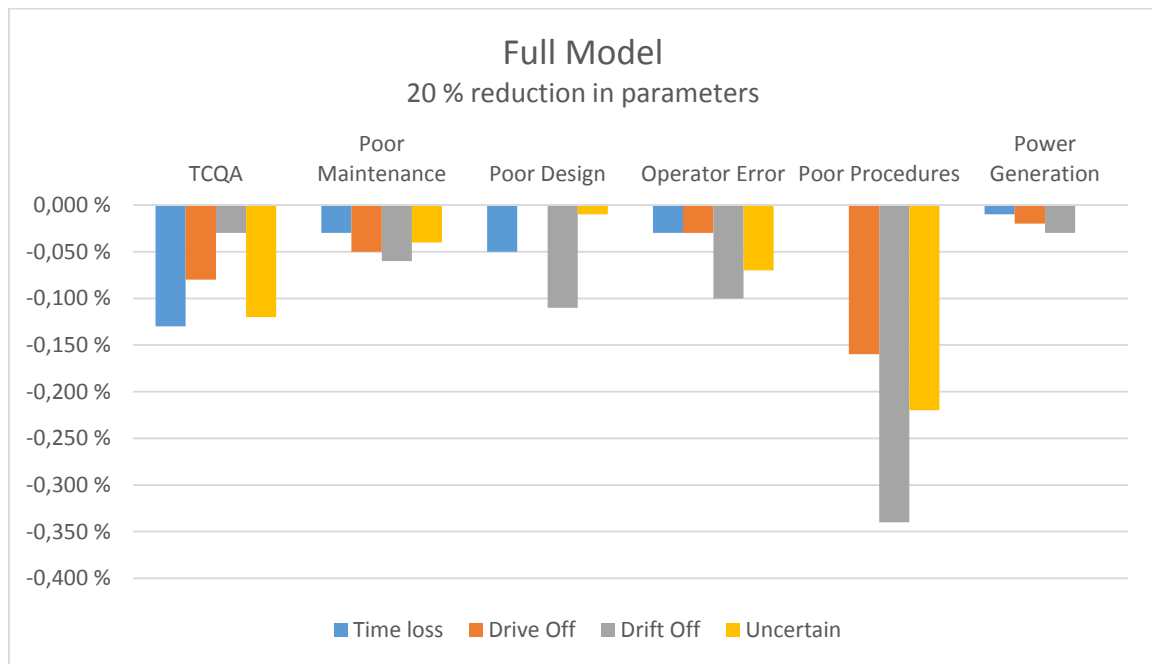


FIGURE 7-1 20% REDUCTION IN PRELIMINARY CAUSES, FULL MODEL 1

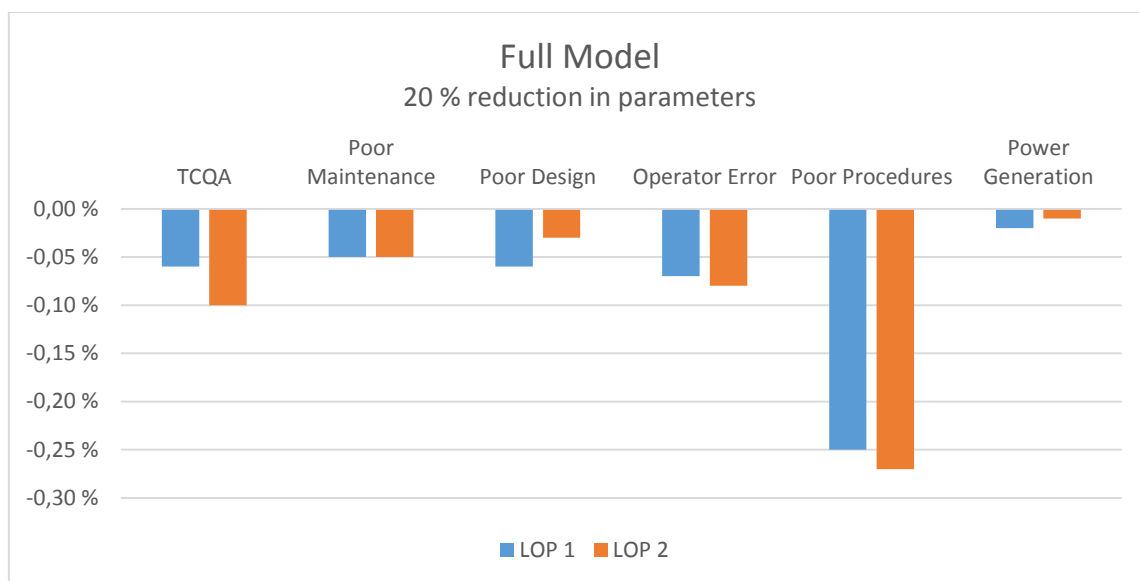


FIGURE 7-2 20 % REDUCTION IN PRELIMINARY CAUSES, FULL MODEL 2

Figure 7-2 displays the impact on LOP1 and LOP2. As expected, it shows similar trends as in Figure 7-1, due to the fact that drive-off, drift-off and “uncertain” all leads to either LOP1 or LOP2.

TABLE 7-1 PRELIMINARY CAUSES RANKED BY IMPROVEMENT POTENTIAL

Preliminary cause	Drive-off	Drift-off	Uncertain	LOP1	LOP2
Poor procedures	1	1	1	1	1
T/C/QA	2	5	2	3	2
Poor maintenance	3	4	4	5	4
Operator error	4	3	3	2	3
Poor Design	-	2	5	4	5

Table 7-1 lists the five preliminary causes ranked after their improvement potential for the different terminal events. The numbers are placements, ex: T/C/QA has the second highest improvement potential for drive-off, giving it a number 2 in that column. The coloring displays if there are big differences. For LOP1, all except poor procedures has the same coloring, because the improvement potential are very close to each other. The coloring is to be viewed for each column separately. Orange in LOP1 isn't necessarily close to orange in LOP2.

Even though they are arranged by their placement for drive-off, all factors should be taken into account when deciding on which cause to invest in improvements.

Poor procedures is shown to be the preliminary cause with the highest improvement potential in all categories, and T/C/QA comes next in all categories except drift-off.

7.2 Main Causes

To establish which main causes should be considered improved, a look at which sub-systems has the most impact on the terminal events must be done.

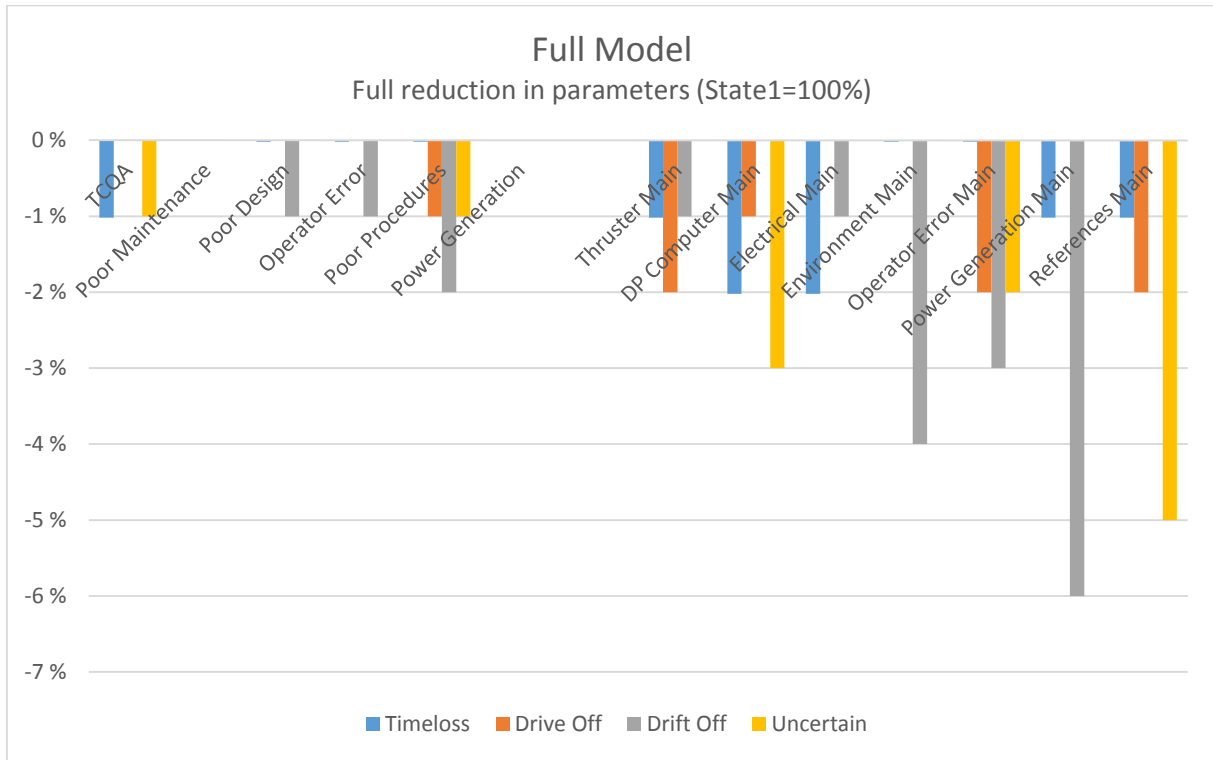


FIGURE 7-3 FULL REDUCTION IN CAUSES, FULL MODEL 1

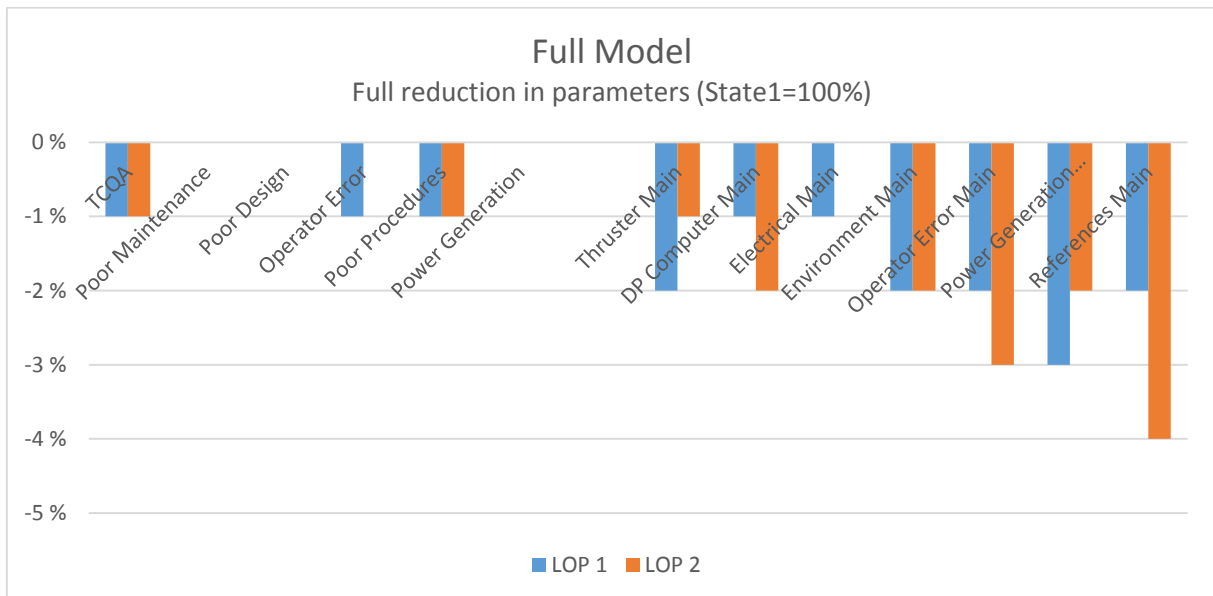


FIGURE 7-4 FULL REDUCTION IN CAUSES, FULL MODEL 2

For LOP 1 and LOP 2, references has the highest added impact. A full reduction of references leads to an added 6 % reduction of LOP 1 and LOP 2. But power generation has a higher impact

on LOP1 than references, -3% vs. -2%, which is the most severe terminal event. Operator error is the third most important sub-system, but the main cause in this sub-system are all the same, so further investigations into this system is not necessary at this point. More on the human errors can be found in chapter 7.3 Human Error.

Thruster and environment also has an impact of -2% on LOP1, so they should also be considered.

Drive-off is also considered more severe than a drift-off, and with this in mind, references and thruster are the most critical systems, but also DP-computer since it has a high occurrence of “uncertain”, which could be drive-off incidents.

As mentioned in chapter 6.4.2 Sub-Models, when investigating how the main causes of a sub-system impacts the terminal events, the results are limited to the sub-system. A reduction of drive-off with 3 % for a sub-system isn't the same reduction for the full system. The following table has listed the most critical main causes' impact on the terminal events, weighted against how big a fraction the terminal event in the sub-system is compared to the total. Ex: The number of drive-off incident in references are 18. The total number of drive-off incidents are 72. This 25 % fraction is multiplied with the impacts done by the main causes on the terminal events in the sub-system. A full reduction of DGPS leads to a reduction of drive-off in references of 3 %. For the full system, this can be viewed as a reduction of 0,75 %. This gives an indication for the main causes that are unique to one sub-system, but should not viewed as factual numbers, see chapter 7.6 Accuracy.

TABLE 7-2 MOST CRITICAL MAIN CAUSES

Sub-system	Main cause	Drive-off	Drift-off	Uncertain	LOP1	LOP2
References	DGPS Signals	-	-0,50 %	-0,36 %	-0,46 %	-0,24 %
	DGPS	-0,75 %	-	-3,24 %	-0,30 %	-1,22 %
	Acoustics	-0,75 %	-	-	-0,15 %	-0,24 %
	DARPS	-	-	-1,44 %	-0,15 %	-0,49 %
Power Generation	Speed Control	-	-0,87 %	-	-0,19 %	-0,12 %
	Diesel Generator	-	-0,58 %	-	-0,19 %	-0,12 %
	Oil	-	-0,29 %	-	-0,19 %	0,00 %
	Cooling	-	-0,58 %	-	-0,19 %	-0,12 %
Environment	Wind	-0,49 %	-1,35 %	-	-0,72 %	-0,85 %
	Current	-0,07 %	-1,16 %	-	-0,58 %	-0,24 %
	Tide change	-0,14 %	-0,39 %	-0,07 %	-0,14 %	-0,12 %
Thruster	Control	-1,50 %	-	-0,21 %	-0,47 %	-0,38 %
	Hydraulics/valves	-0,25 %	-0,33 %	-	-0,23 %	-0,13 %
	Electrical	-	-0,44 %	-0,14 %	-0,23 %	-0,38 %
	Pitch	-0,75 %	-	-	-0,23 %	-0,13 %
DP-Computer	DP Software	-3,33 %	-0,31 %	-1,95 %	-1,49 %	-1,81 %

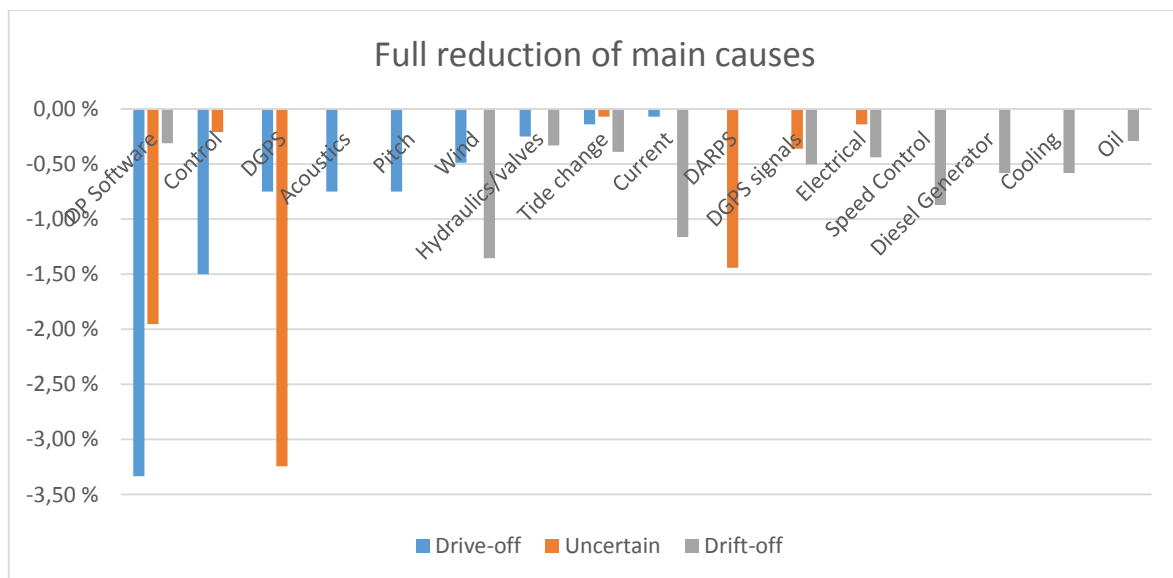


FIGURE 7-5 CRITICAL MAIN CAUSES 1

The main causes listed in Figure 7-5 are arranged after the highest improvement potential for drive-off, from left to right. DP Software (DP-computer) has the highest improvement potential for drive-off, -3,33 %. Control (thruster) has the second highest potential for drive-off, -1,5 %, and a shared third highest for DGPS (references), acoustics (references), and pitch (thruster) with -0,75 %.

DP Software (DP-computer) has the second highest improvement potential for uncertain, -1,95 %, where the highest is DGPS (references) with -3,24 %. DARPS (references) comes third with -1,44 %.

Drift-off differs in that the causes with highest improvement potential are mostly environmental or power generation causes. Wind (environment) has the highest with -1,35 %, followed by current (environment) with -1,16 %, and speed control (power generation) with -0,87 %. Diesel generator (power generation) and cooling (power generation) share fourth with -0,58 %.

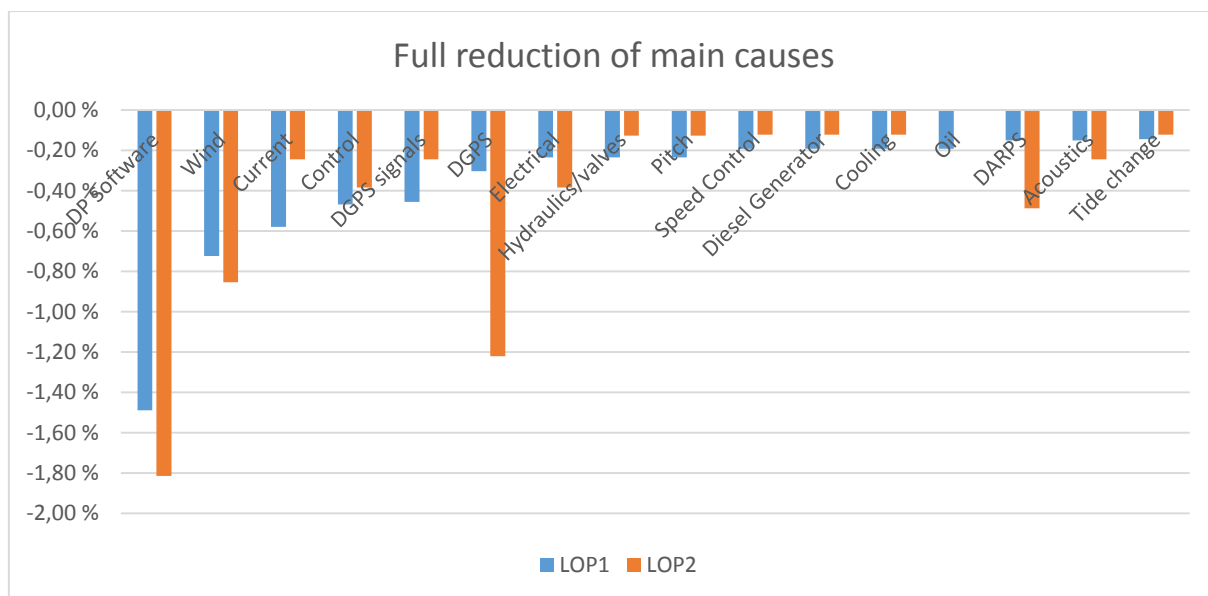


FIGURE 7-6 CRITICAL MAIN CAUSES 2

Figure 7-6 lists the main causes ordered by the highest improvement potential to LOP1, from left to right. DP Software (DP-computer) has the highest, with -1,49 %. Wind (environment) comes second with -0,72 %, followed by current (environment) with -0,58 %. Control (thruster) has a potential of -0,47 %, DGPS signals (references) -0,46 %, and DGPS (references) -0,30 %. The rest has close to -0,20 %.

Even though wind (environment) and current (environment) have a high improvement potential for LOP1, they are drift-off incidents, not drive-off. A LOP1 drift-off incident is less severe than a LOP1 drive-off. Control (thruster) on the other hand consists of mostly drive-off incidents and could therefore be considered more critical than the environmental causes.

DP Software (DP-computer) also has the highest potential in terms of LOP2, with -1,81 %, followed by DGPS (references) with -1,22 %. Third is wind (environment) with -0,85 %, then DARPS (references), control (thruster) and electrical (thruster) with -0,49 %, -0,38 % and -0,38 %, respectively.

TABLE 7-3 MAIN CAUSES RANKED BY IMPROVEMENT POTENTIAL

Sub-system	Main cause	Drive-off	Drift-off	Uncertain	LOP1	LOP2
DP-Computer	DP-Software	1	10	2	1	1
Thruster	Control	2	-	5	4	5
References	DGPS	3	-	1	6	2
Environment	Wind	6	1	-	2	3
Environment	Current	9	2	-	3	7

Table 7-3 displays the five most influential causes in the same manner as Table 7-1. DP-software is the component with the highest improvement potential, by a good margin. It ranks first for drive-off, LOP1, LOP2 and second for uncertain. The two environmental causes, wind and current, has the highest potential in terms of drift-off, and also a high potential in terms of LOP1.

Control (thruster) comes second in terms of drive-off, and DGPS (references) third, but also first for “uncertain”.

Improving environmental causes is done by either implementing stricter guidelines for operational conditions, or by increasing resilience against the environment by improving the preliminary causes.

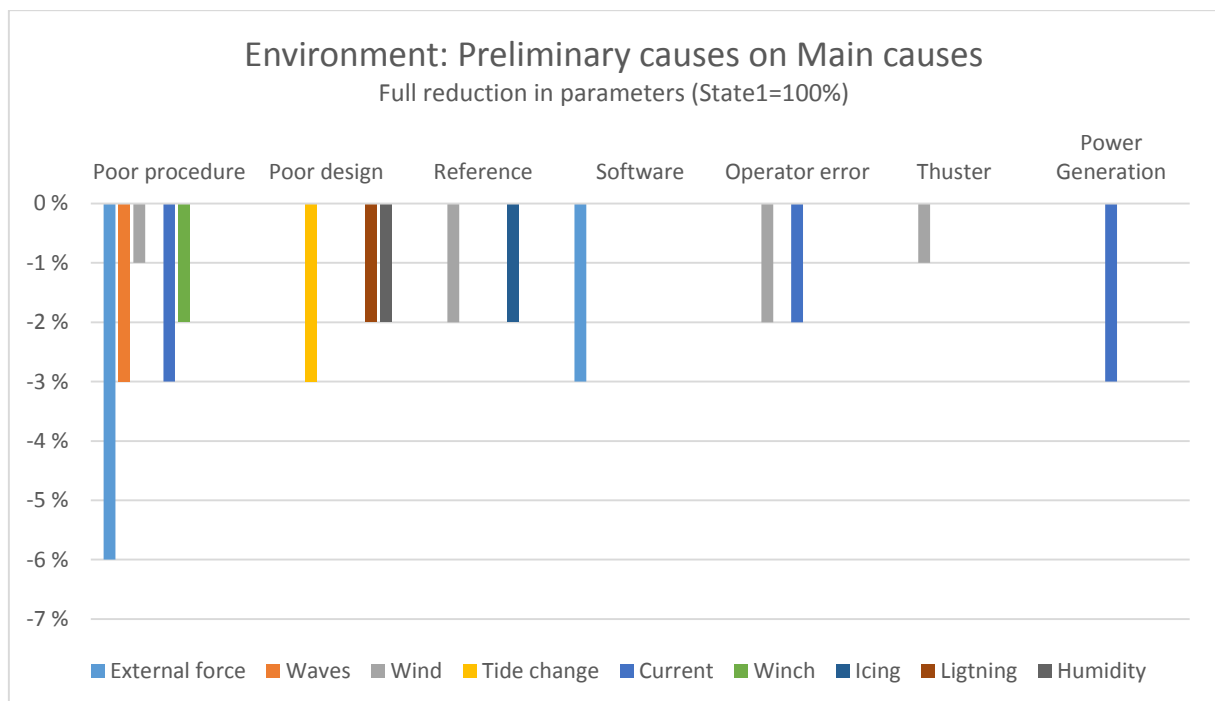


FIGURE 7-7 PRELIMINARY CAUSES' EFFECT ON MAIN CAUSES, ENVIRONMENT

Figure 7-7 shows that in order to reduce the number of incidents caused by current, improvements should be made on poor procedures, operator error, references or power

generation.

In terms of wind the results are similar. Poor procedures, operator error, references or thruster should be improved.

7.3 Human Error

As seen in Figure 7-3 and Figure 7-4, the sub-system operator error has a high potential for improvement. It differs from the other sub-systems in that it is the only main cause in its own sub-system. Therefore the sub-model consists of only preliminary causes and terminal events. (See Appendix A BBN Models). It has a shared first place for drive-off, third place for drift-off and “uncertain”, a shared second place for LOP1, and ranks second for LOP2. (Amongst the sub-systems, not main causes.) This makes the improvement potential very high. An improvement made on the main cause DGPS improves the References sub-system, which in turn improves the full system. But an improvement made on the main cause operator error is a direct improvement on the full system, and therefore has a higher impact than any component improvement.

16 % of the total incidents have operator error as the main cause, whereas roughly 60 % of the total incidents have a human error as a preliminary cause. 13 % of these preliminary causes are in relation to the main cause operator error, so the total percentage of all incidents that has a human error as either a preliminary cause, main cause or both are 63 %, almost two-thirds. (Note: Time loss accounts for 33 % of the incidents, and for these incidents preliminary causes are rarely listed in the reports, so the actual percentage of human errors as a preliminary cause is probably higher.)

Of all the incidents, 54 % has a latent human error as a preliminary cause, while 6 % are active.

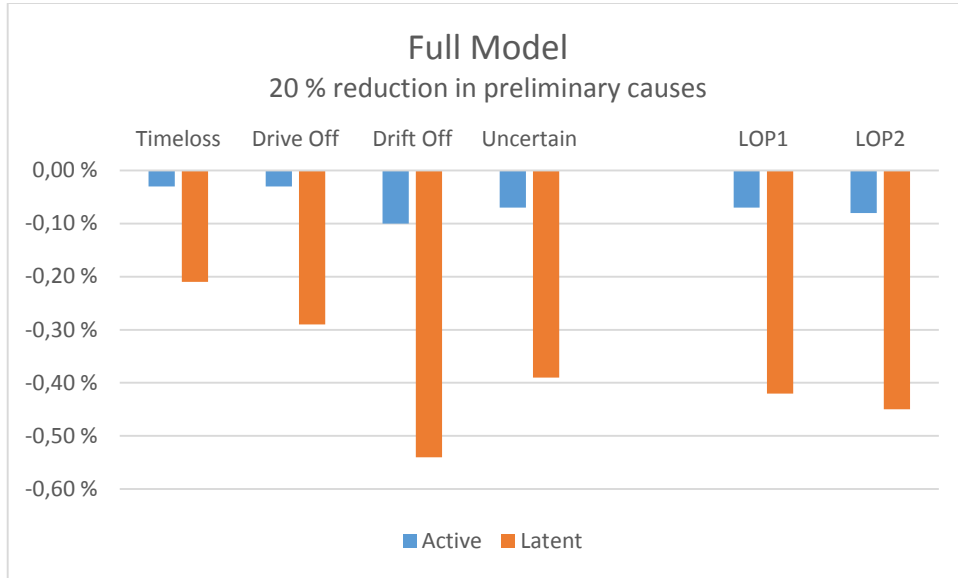


FIGURE 7-8 ACTIVE VS. LATENT PRELIMINARY ERRORS

Figure 7-8 displays the effect of a 20 % reduction in the latent human errors added together, versus the effect of the same reduction in the active human errors, operator error. The latent errors have the highest potential for improvement. This is related to the higher occurrence of that type of failure.

If the main cause portion of operator error is included, not only the preliminary causes, there are 22 % incidents with an active human error. Then the improvement potential changes quite drastically. Figure 7-9 displays a full reduction in parameters.

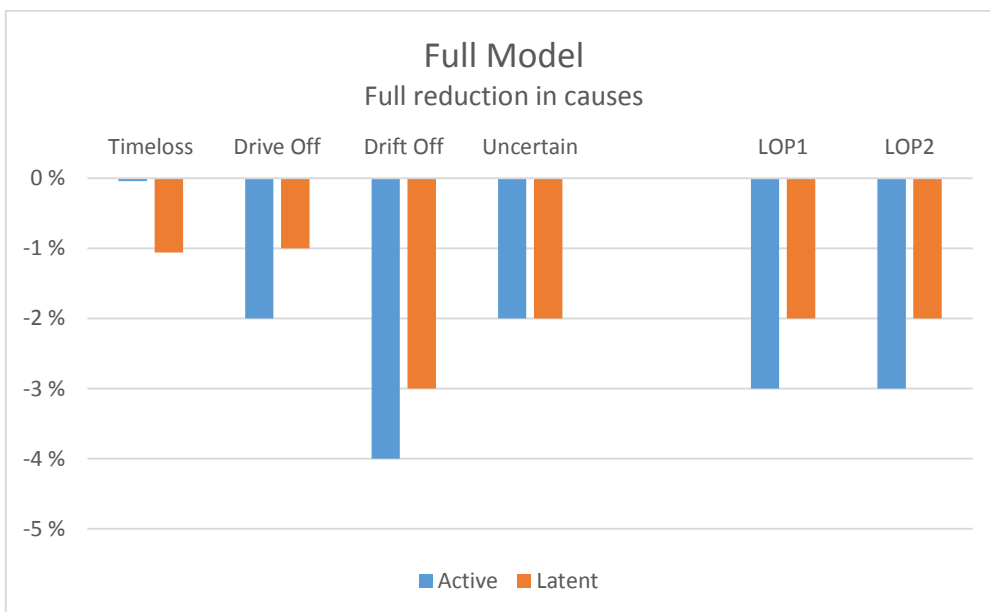


FIGURE 7-9 ACTIVE VS. LATENT CAUSES

Even though active errors account for only 22 % of the incidents, and latent errors for 54 %, this charts shows that the active errors has the highest improvement potential. This is because active errors consists of main causes, not only preliminary, and main causes are closer to the terminal events on the BBN chain, which means it has a higher conditional probability to lead to them. It should be noted that identifying latent human errors is more difficult than active ones, and easier to neglect when making incident reports.

7.4 Time loss

Time loss is the least severe terminal event. It is an incident with no loss of position or other consequence. It will therefore not be discussed in much detail. Of the preliminary causes, only T/C/QA stands out with a -1 % improvement potential in full reduction.

Among the sub-system, DP-Computer and electrical are the ones with highest potential, -2 %. This is one of only two areas where electrical have any potential, along with drift-off of -1%.

7.5 Comparisons

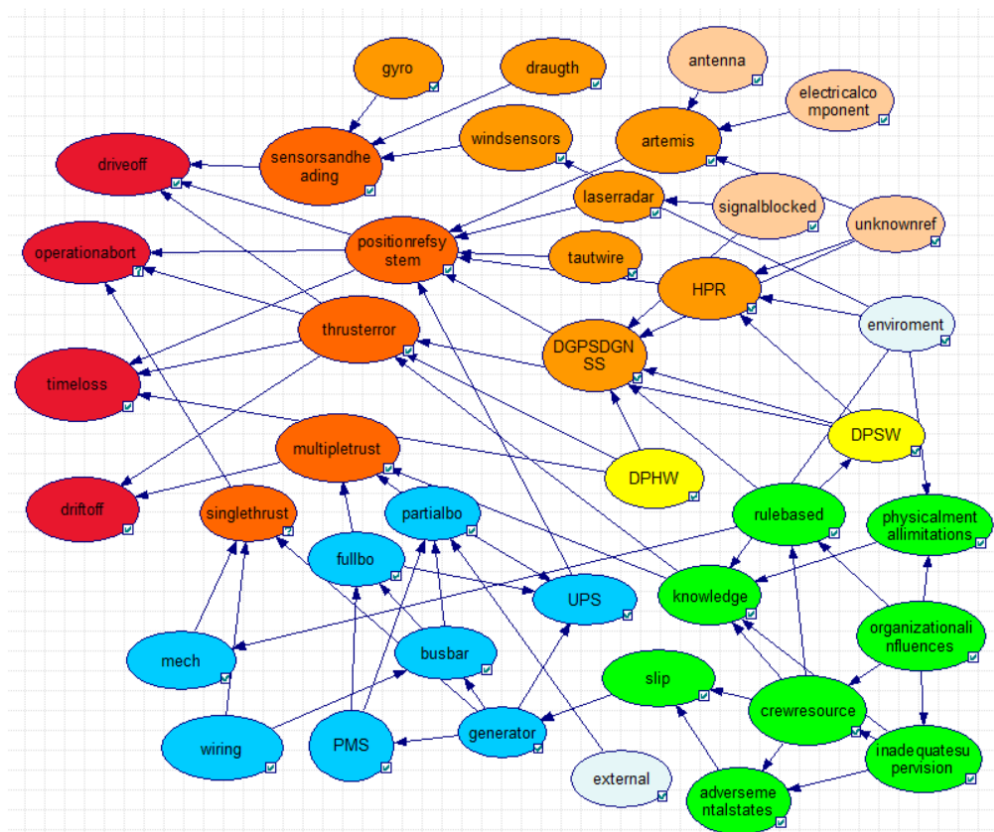


FIGURE 7-10 FULL BBN MODEL, HAUFF 2014

To compare the results with earlier work (Hauff, 2014), numbers can't be used because of the different methods used. Hauff estimated a cause's influence on the terminal event by increasing

the frequency of the cause, as opposed to this thesis' method of decreasing it. But the trends in which causes is most influential versus which has the highest improvement potential can be compared on qualitative level.

Hauff gives similar results for drive-off. In his results, thruster is listed as the most influential cause, followed by references and sensors. In this thesis, thruster and references are shown to have the highest improvement potential on drive-off, along with operator error.

For drift-off, Hauff lists thrusters and blackouts as the most influential causes. As stated in chapter 5.4 Full Model, blackouts in this thesis is only treated as additional (albeit lacking) information in terms of terminal events in some sub-systems, not as causes themselves. Power generation, operator error and the environment sub-systems are found to have the highest potential improvement. Hauff has classified power generation as a cause under the thruster sub-system, so those results can be viewed as similar.

Differences in the results can be explained by different analysis method, but the main contributor to the difference is the structure of the models. Hauff has fewer sub-classes, so each sub-class becomes more dominant. This explains why thruster faults are more dominant in his results than in this thesis.

Advantages

There are four main advantages to the new models made in this thesis:

1. They include the terminal events LOP1 and LOP2 to show if the incidents are major or minor LOP.
2. It has the possibility to investigate sub-systems in more detail through the sub-models.
3. The human element is included to a higher degree. Only 21 % of Hauff's investigated incidents were listed with a human error, as opposed to 63 % of the incidents used in this thesis. This is due to the inclusion of latent human errors, not just active.
4. More than double the number of incident reports has been included, and they have previously been investigated by experts (Global Maritime, 2006) in depth, and labeled with preliminary and main causes.

7.6 Accuracy

None of the numbers collected from the models should be viewed as completely accurate percentages. They are estimations that relies heavily upon how the model is built. The difference in results if an arc is drawn to a node or not can be considerable, and these decisions are done by the model creator, and relies heavily upon his or hers knowledge of the system.

The method described in chapter 7.2 Main Causes for how to adjust results from the sub-models to compare with the full method is also an estimation. When a BBN model A consists of a set of X nodes, and BBN model B consists of the same set X, but also a set Y, the results from model A aren't directly scalable with model B, because set Y might be so dominant that X becomes negligible. However, if Y is very dominant, it indicates that X has a low frequency, so the scaling would also be low.

Also, arcs can be drawn somewhat differently in the two models, because an arc in model A may become very insignificant in model B. This is also by decision of the expert.

For the full reduction method, the numbers extracted are measured in integer percentages, not decimals. This means two main causes can in fact be almost a whole percentage point apart ex: 1,50 % and 2,49 %, but still be listed as the same.

7.7 Frequency improvement

To see how the incident frequency changes if improvements are made, a full reduction of the main cause operator error has been used as an example in Table 7-4.

TABLE 7-4 FULL REDUCTION OF OPERATOR ERROR

Frequency	Original	Full reduction
Drift-off	0,078 /year	0,076 /year
Drive-off	0,053 /year	0,052 /year

Even though a full reduction of operator errors is an unrealistically high improvement, the effects such an improvement would have on the incident frequency is very low. Approximately -3 % for drift-off and -2 % for drive-off.

A more realistic improvement to the system would be smaller improvements made on several components and human factors. An added effect of these is outside the scope of this thesis, but considering the results presented, it is safe to assume that this would also be a small fraction improvement on the full system, and thus on the incident frequency.

A thorough cost analysis of the improvement implementation would need to be done in order to evaluate if it's economically justifiable to further improve the system. (See chapter 8.1 Further Work).

8. Conclusions

The results from the analysis shows that human errors have a high occurrence and impact on the terminal events. Poor procedures is the causal factor that occurs most often (25 % of all incidents), and amongst the preliminary causes, most often leads to a loss of position. Poor procedures has the highest improvement potential in terms of every terminal event, by a good margin. With a 20 % reduction, it has approximately four times the improvement potential for both LOP1 and LOP2 than the other three latent human errors.

Operator error is another human error that has an even higher improvement potential. This is because it also occurs as a main cause in 16 % of the incidents, as opposed to only 6 % as a preliminary cause. The improvement potential for this active human error is higher than all the latent human errors combined, except for the terminal event Time loss.

For the other main causes, DP-software is the component that has the highest improvement potential in terms of drive-off, LOP1 and LOP2, and second highest in terms of uncertain. In terms of drift-off, environmental main causes such as wind and current has the highest improvement potential. This is not an unexpected result as environmental forces needs to be present in order for the vessel to drift. But in order to reduce the consequence or occurrence of environmental forces, other causes would need the actual improvements, as you can't improve the weather. Again, it is shown that the human errors operator error and poor procedures has the highest improvement potential on wind and current incidents, in addition to thruster and power generation.

8.1 Further Work

The BBN model can always be revised and improved. A higher degree of expert knowledge of the system, and input from several experts, allows for more accurate models.

More specific data will allow for more specific models in terms of vessel type and/or operational mode. This can be achieved by a more detailed and organized reporting on incidents. This method is also known to be an effective measure in which to increase reliability for any system, as more detailed incident reports are fed to management and supervisors, who in turn makes use of the information when training personnel. (Gordon, 1996).

Another useful next step in this work would be to identify how the different parts of the system can be improved, the actual improvement measures, and how much of an improvement such measurements would constitute. Then use the BBN-model to estimate how much of an improvement this will translate to in terms of the full system. This combined with a detailed cost

analysis of the measurements makes it possible to evaluate which measurements has the highest improvement/cost ratio.

9. References

- Bakken, B. (2001) *Risk Associated with Drive-off/Drift-off when drilling on DP*
Scandpower A/S
- Chen, H. & Moan, T. (2008) *Safety of DP Drilling Operations in the South China Sea*
- Gjerde, T., Chen, H. & Haatuft, M. (2014) *Blowout risk caused by position loss during DP drilling operations*
- Gordon, R. (1996) *The contribution of human factors to accidents in the offshore oil industry.*
Aberdeen University, Psychology Department, Kings College, Aberdeen
- Hansen, E. (2011) *DP Dependability – Dynamic Positioning Conference October 11-12, 2011*
Rolls-Royce Marine, Offshore Automation & Control
- Hauff, K. (2014) *Analysis of Loss of position incidents for dynamically operated vessels*
NTNU Trondheim
- Heckerman, D. (2006) *Learning with Bayesian Networks*
- Holvik, J. (1998) *Basics of Dynamic Positioning*
Kongsberg Simrad Inc.
- Kristiansen, S. (2014) *West Venture DP Failure Analysis. Technical note ST-5323-2*
Safetec ABS Group, Trondheim
- Reason, J. (1990) *The Contribution of latent human failures to the breakdown of complex systems*
Department of Psychology, University of Manchester, Manchester
- Shappell, S. & Wiegmann, D. (2001) *Applying Reason: the human factors analysis and classification system (HFACS)*
University of Illinois at Urbana-Champaign, USA
- Shi, X.B., Philips, D. & Martinez, D. (2005) *Case Study of DP Vessels Performing SIMOPS*
American Global Maritime 2005
- Singh, B., (2013) *14 Types of Ships with Dynamic Positioning System*
- Vanek, L. *Introduction into Bayesian networks*
Global Maritime, (2006) *Analysis of Station Keeping Incident Data 1994-2003*

IMCA (2000-2007) *IMCA incident reports*

IMCA (2010) *Guidance on Simultaneous Operations (IMCA M 203)*

IMO (1994) *Publication 645: Guidelines for Vessels with Dynamic Positioning Systems*

GeNIe 2.0 (1998) <http://genie.sis.pitt.edu>

Decision Systems Laboratory, University of Pittsburgh

Appendices

A. BBN Models

Full Models

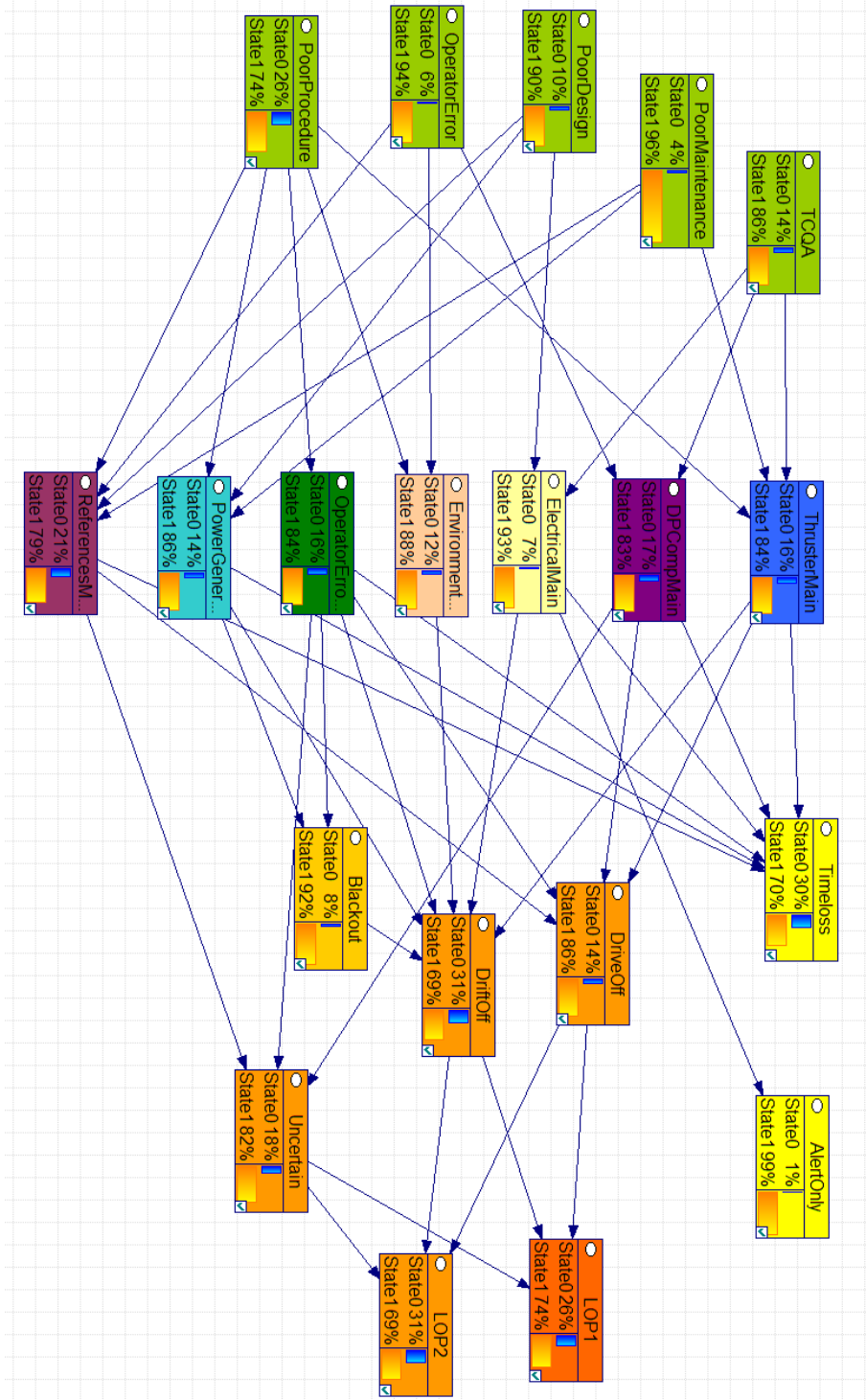


FIGURE A.0-1 FULL MODEL, SIMPLIFIED

Sub-Models

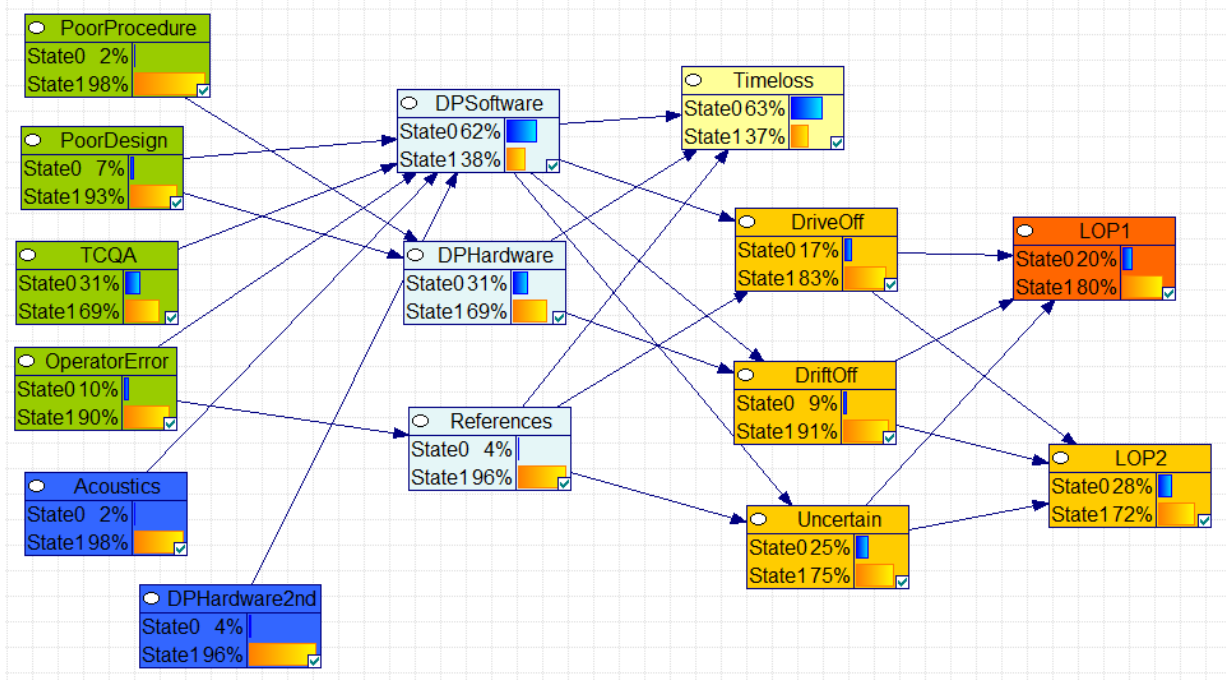


FIGURE A.0-3 DP COMPUTER

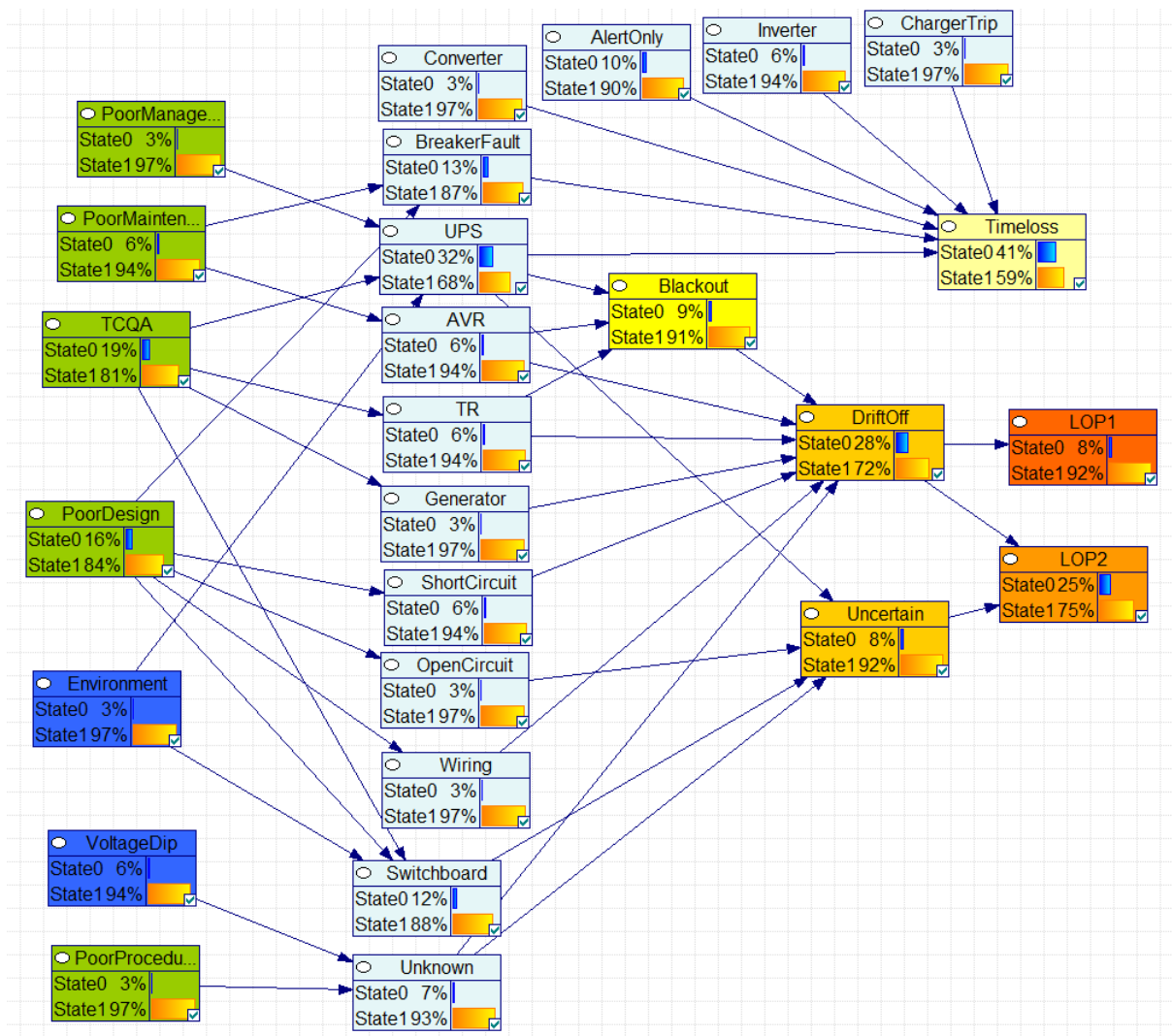


FIGURE A.0-4 ELECTRICAL

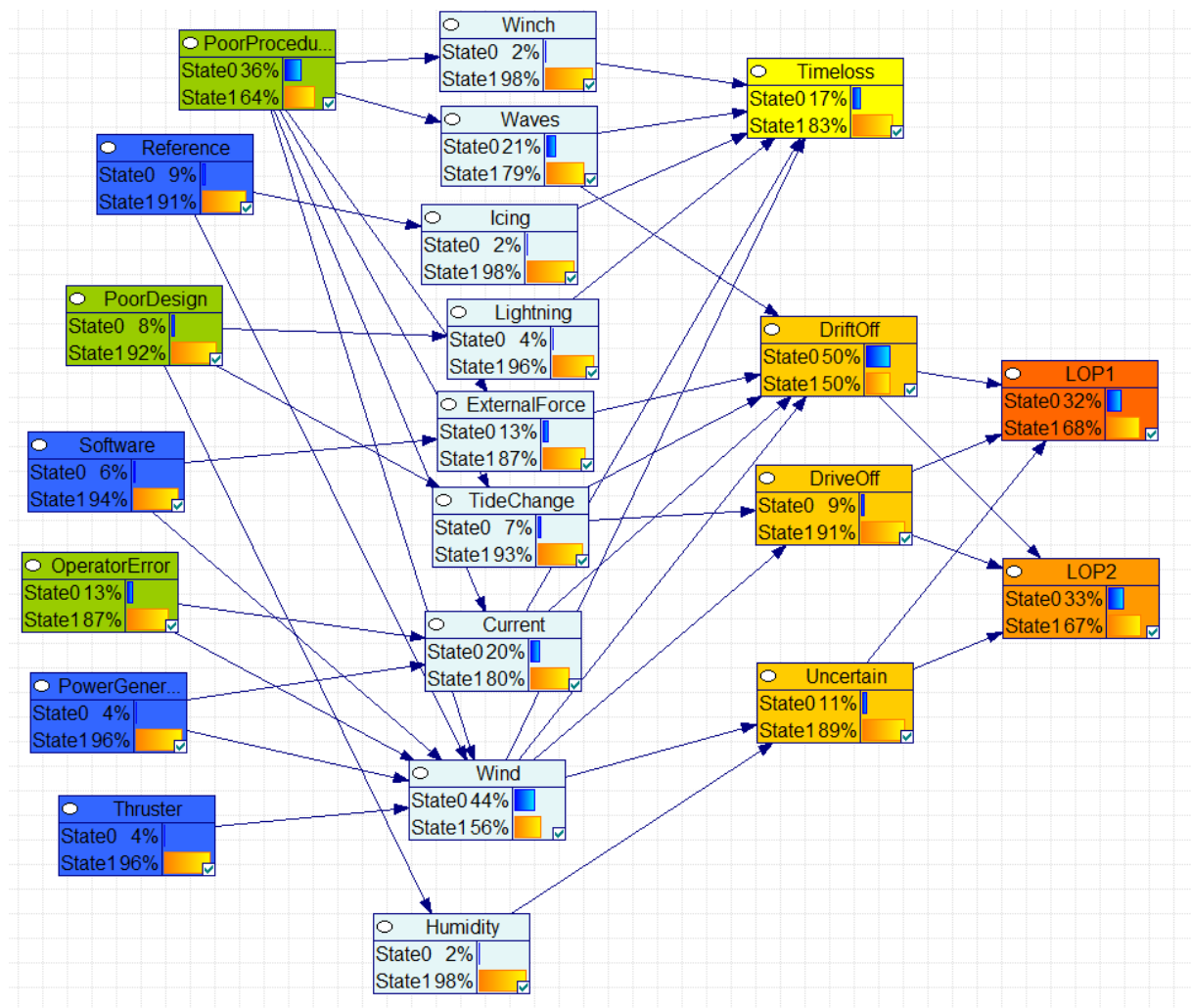


FIGURE A.0-5 ENVIRONMENT

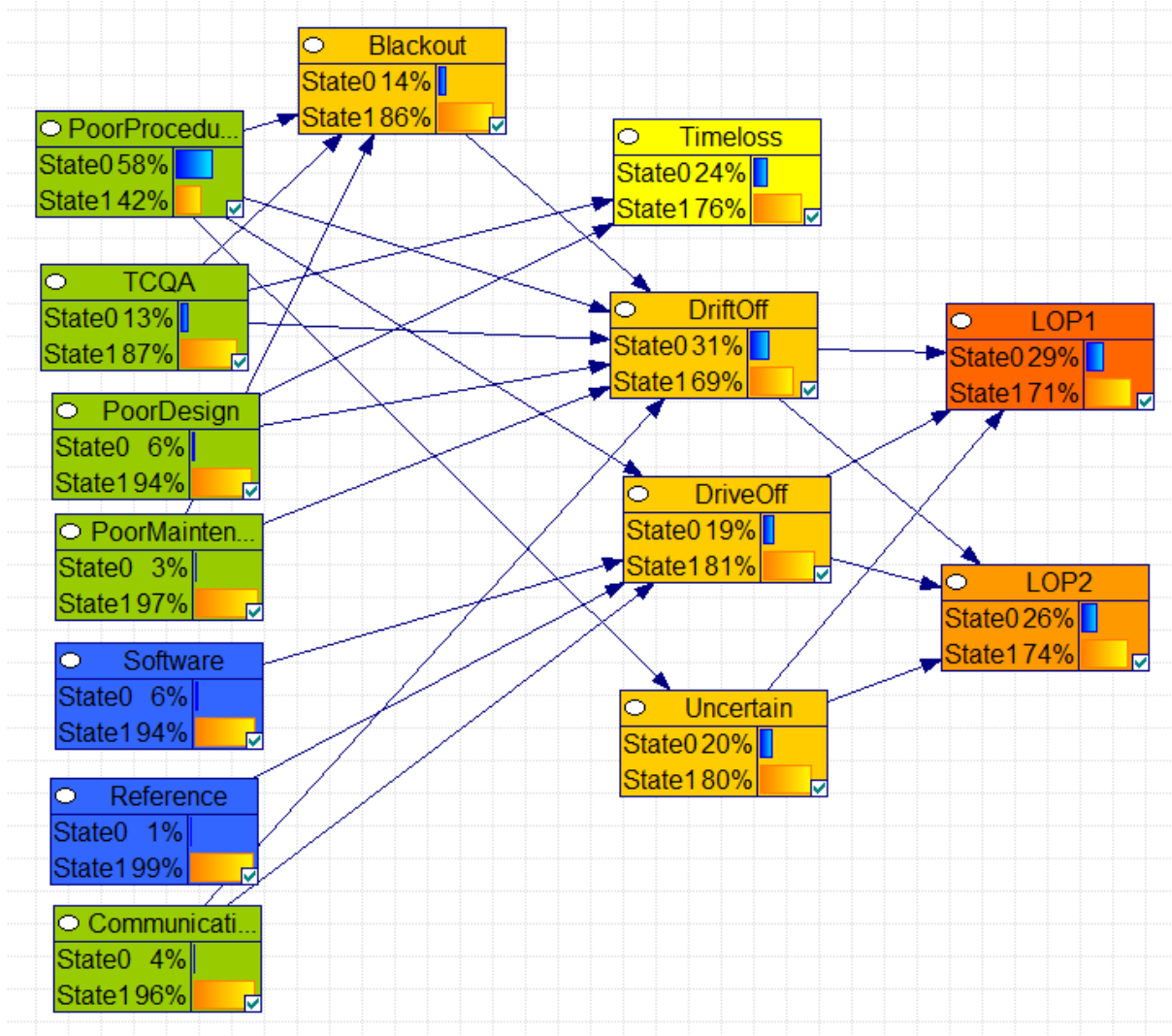


FIGURE A.0-6 OPERATOR ERROR

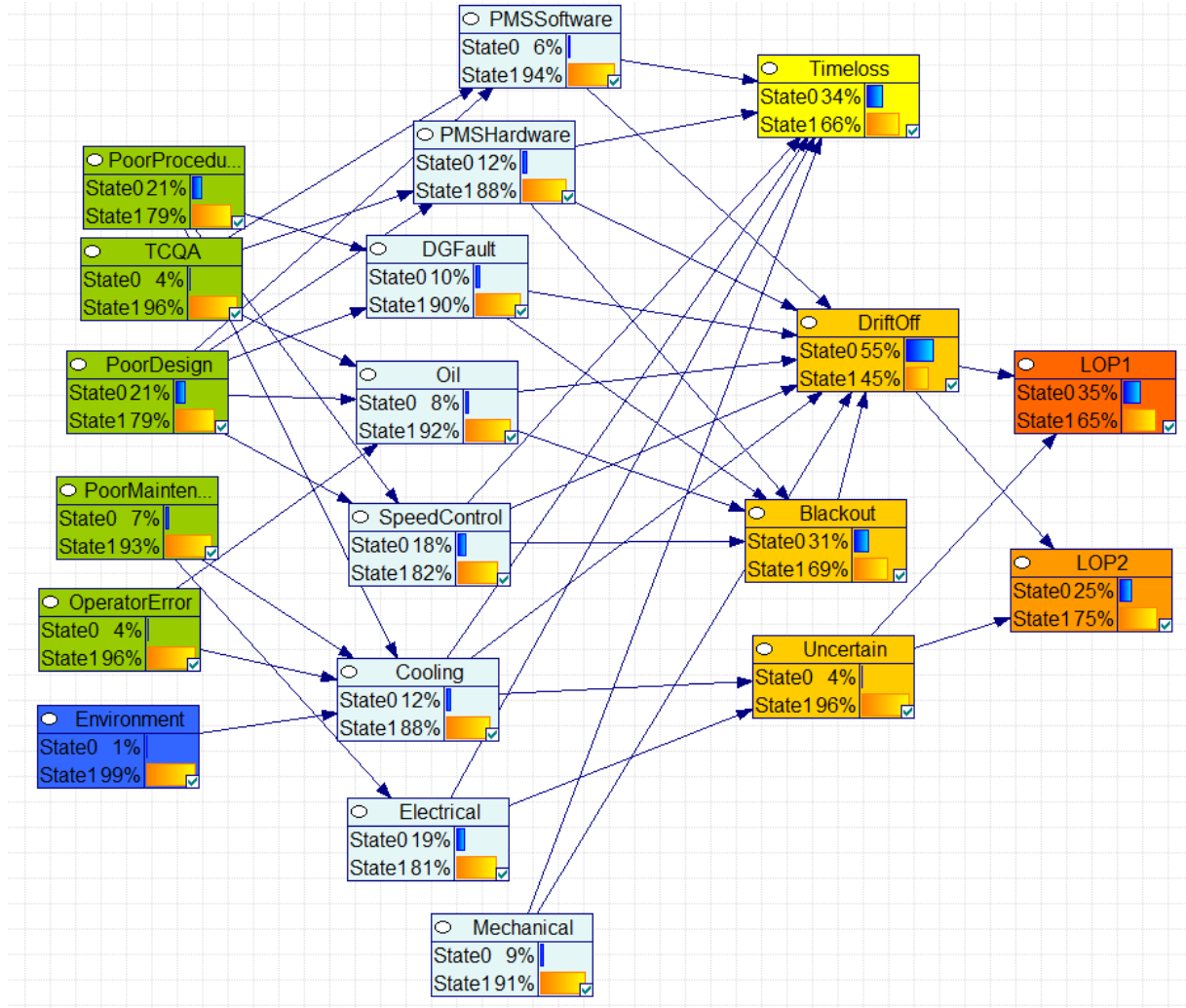


FIGURE A.0-7 POWER GENERATION

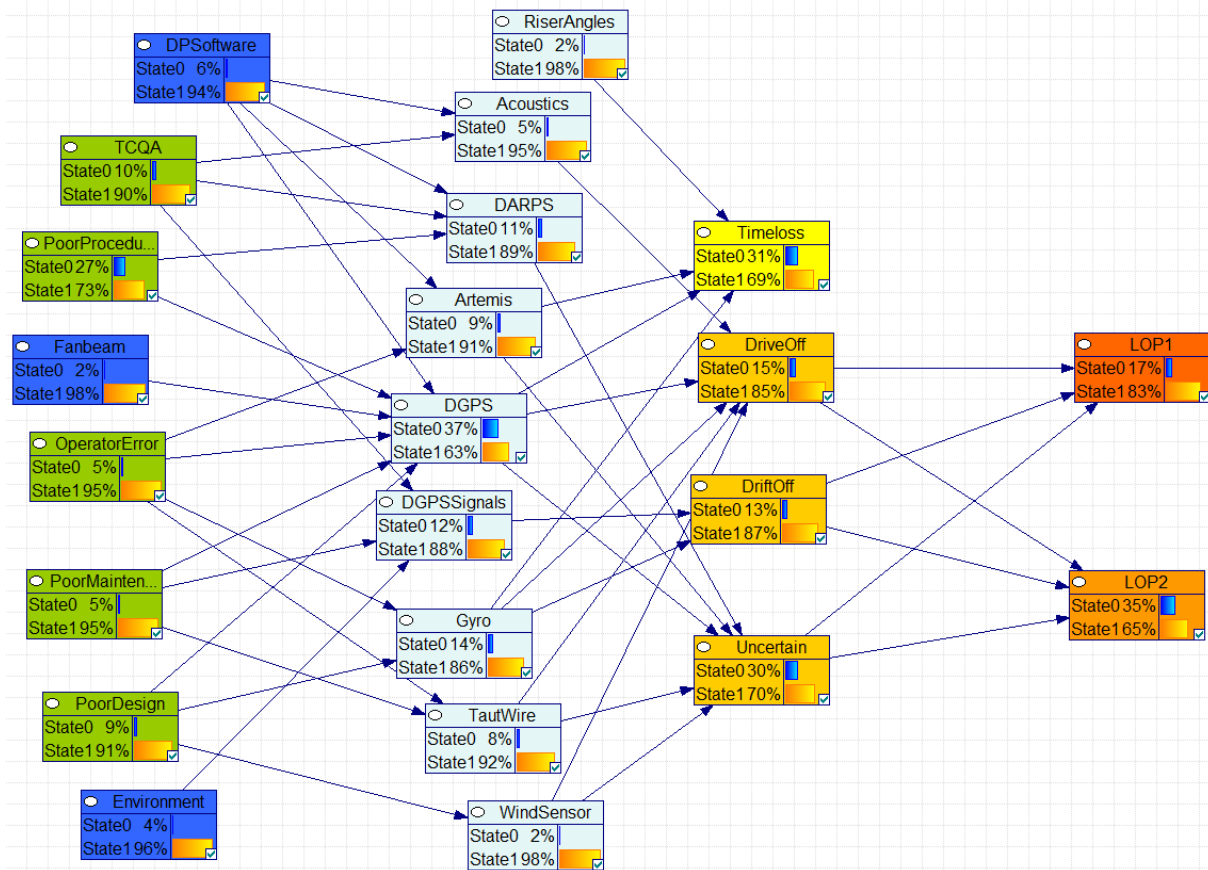


FIGURE A.0-8 REFERENCES

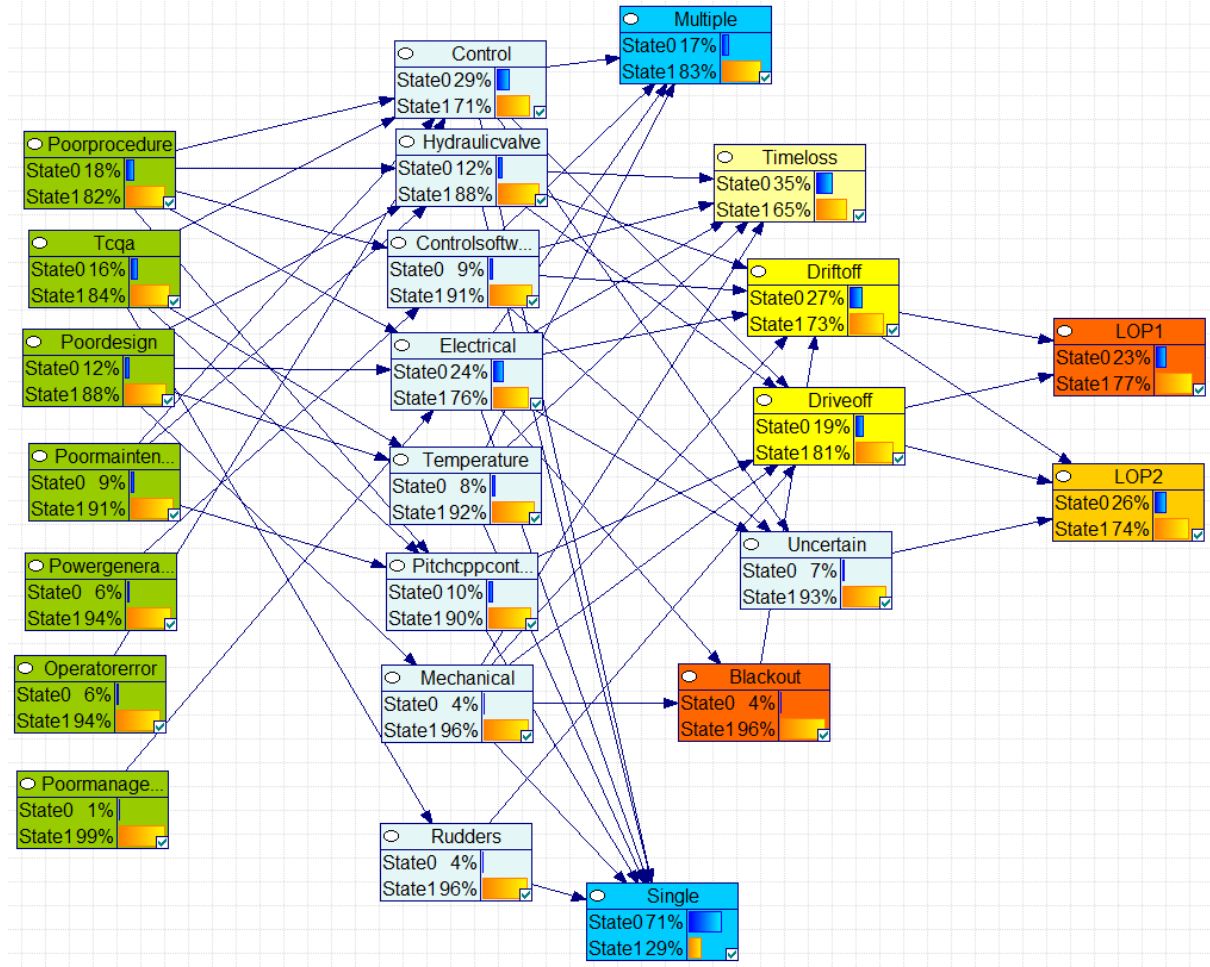


FIGURE A.0-9 THRUSTER

B. Result Charts

Full Model

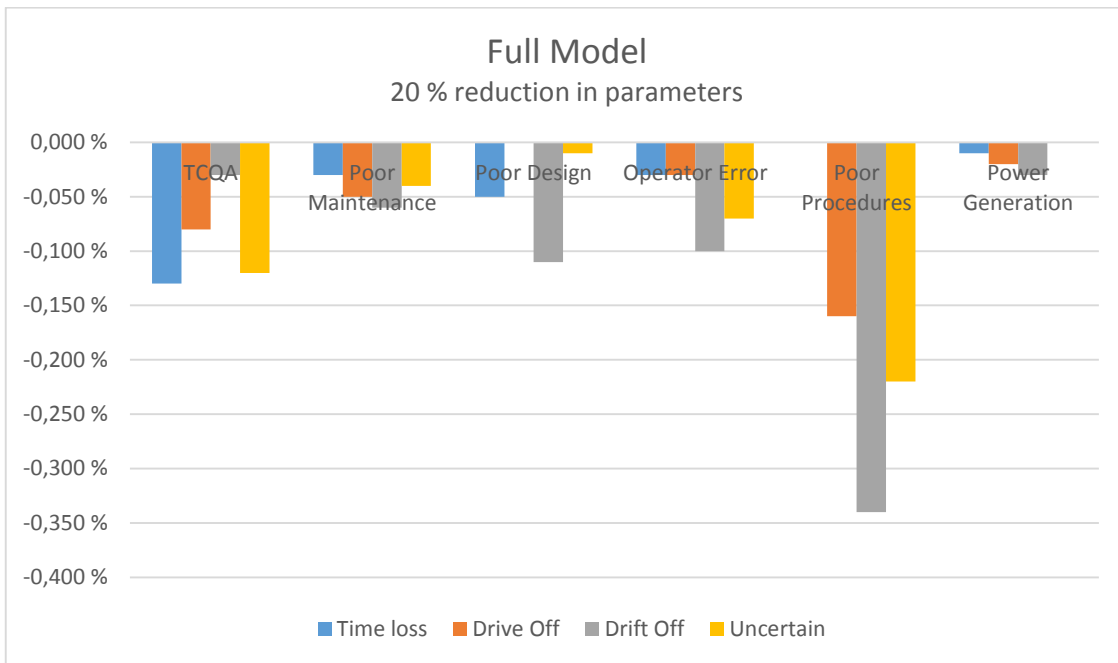
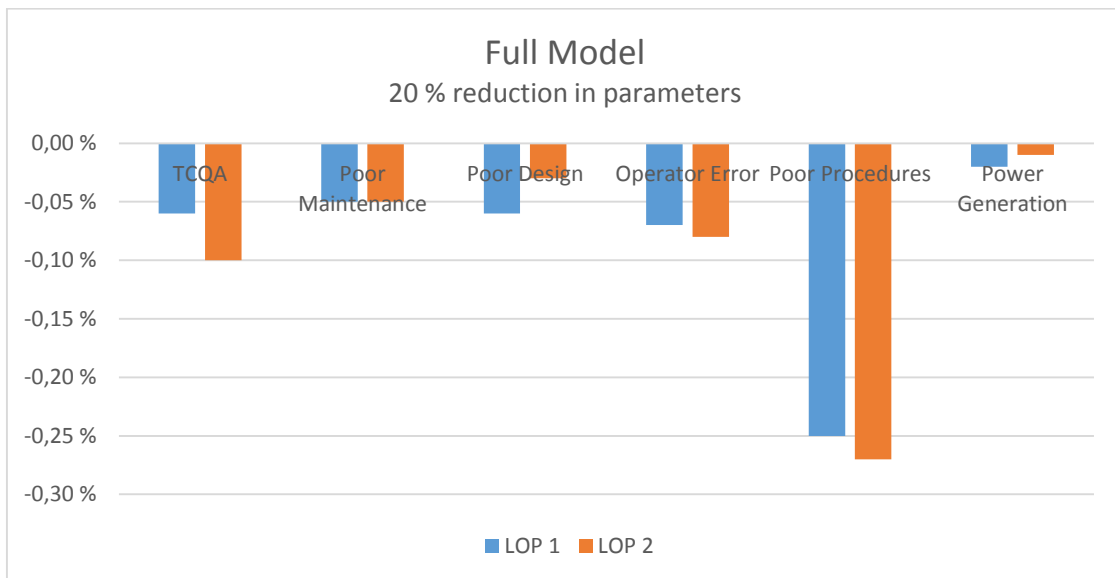
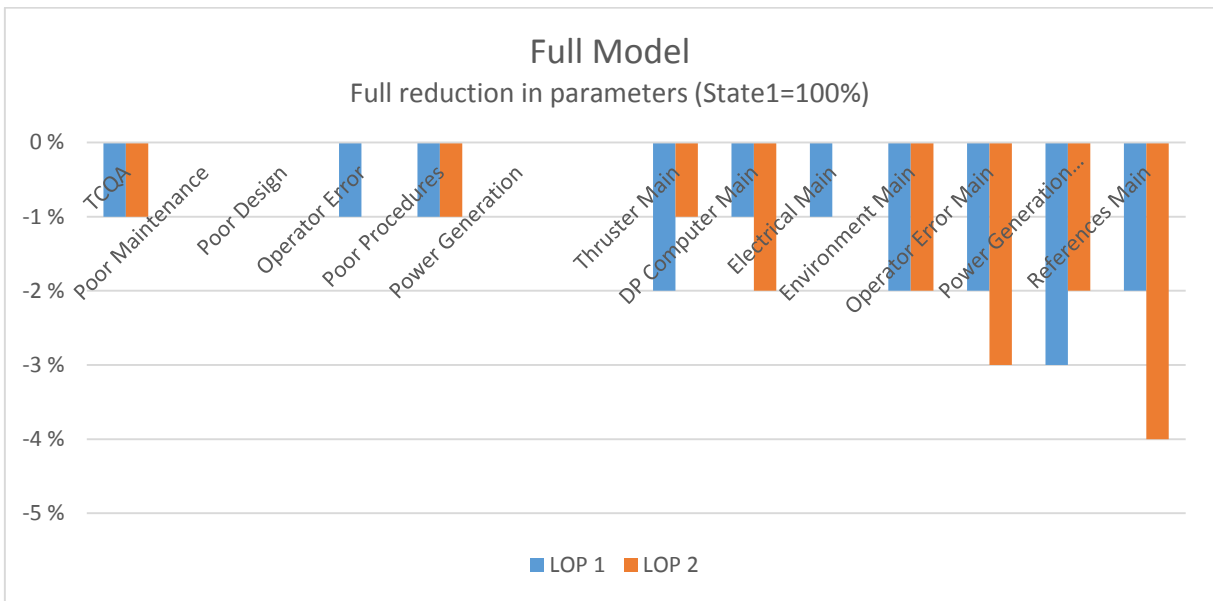
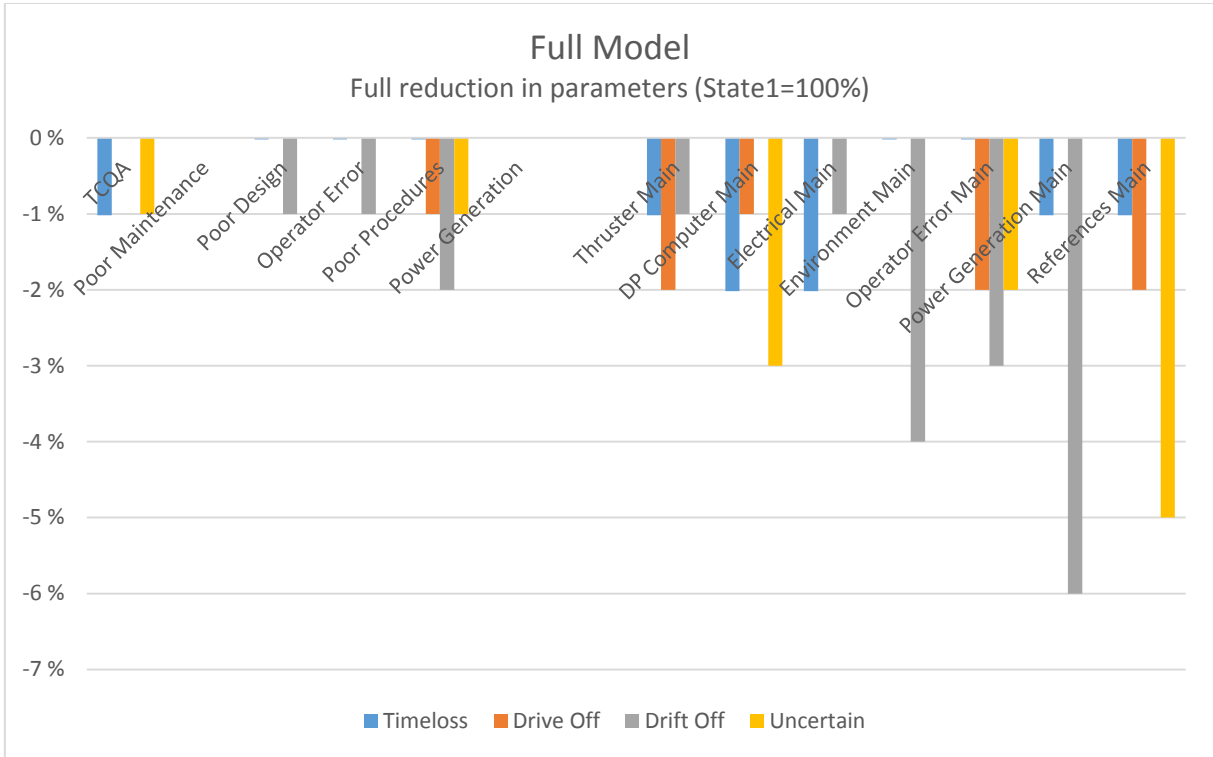


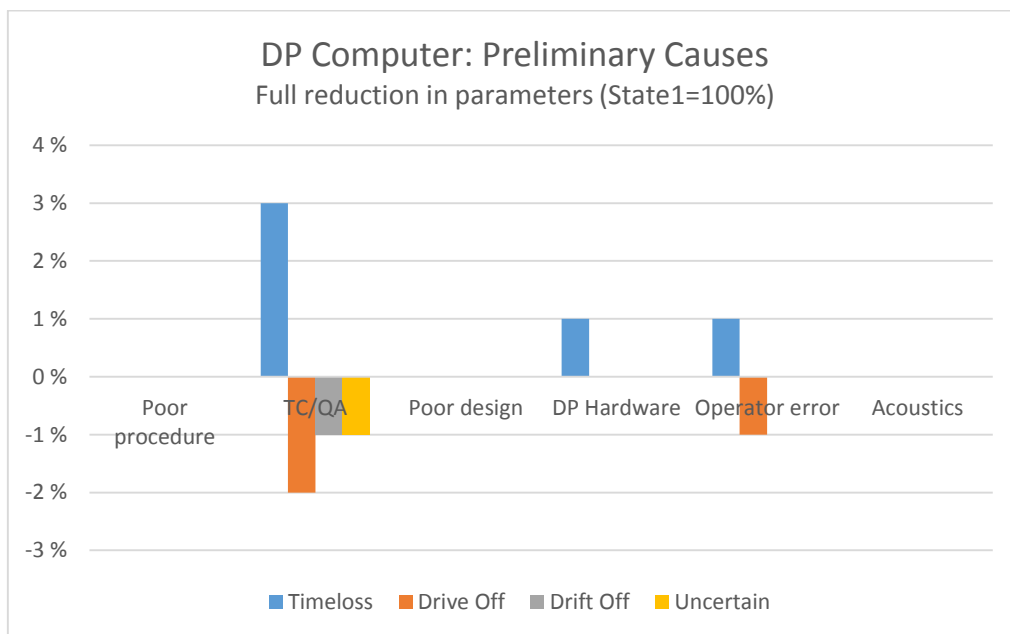
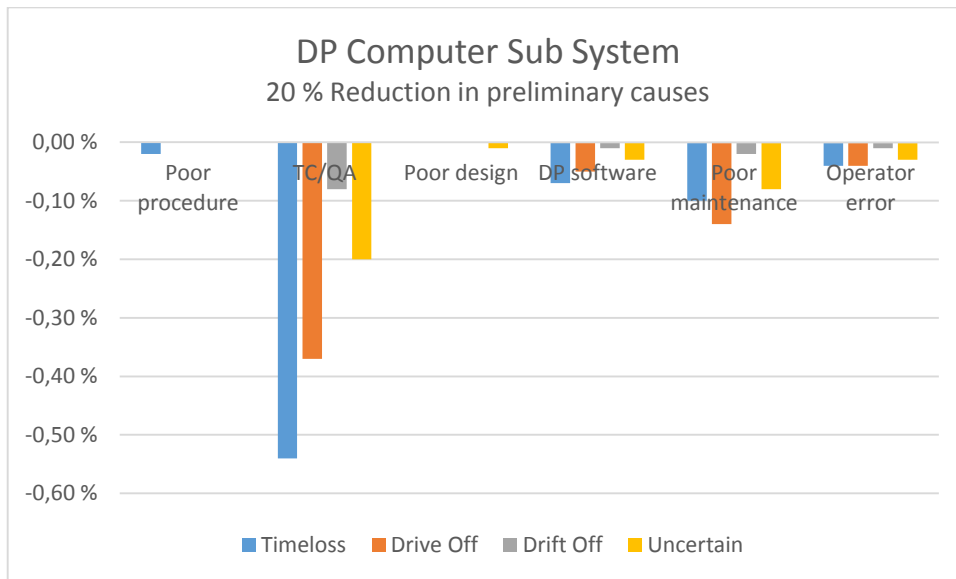
FIGURE 0-10 FULL MODEL 1

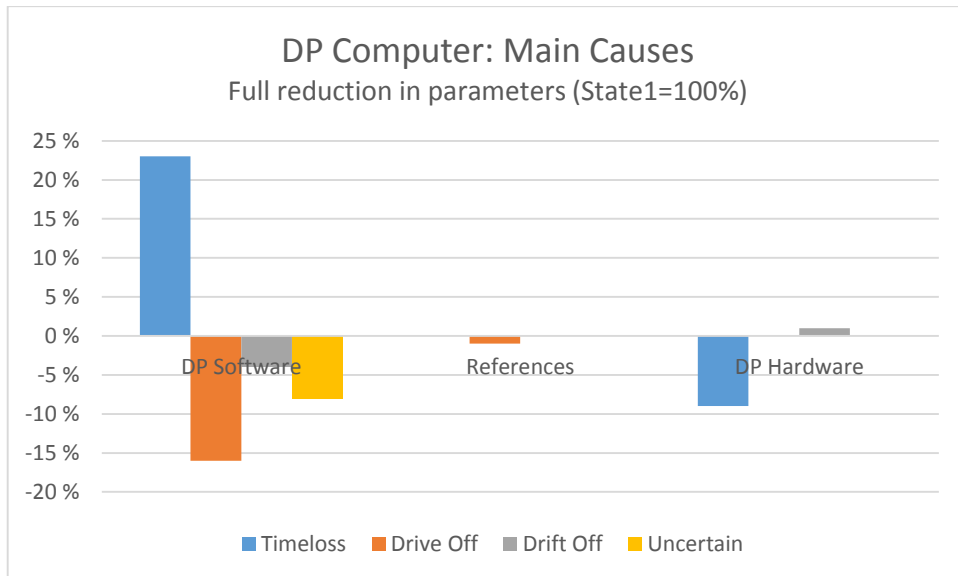
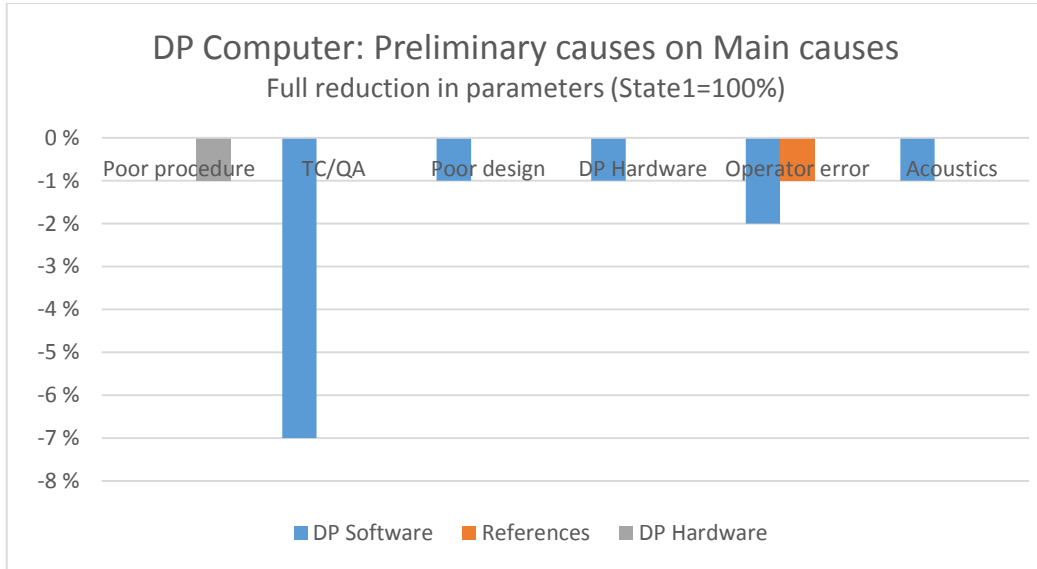


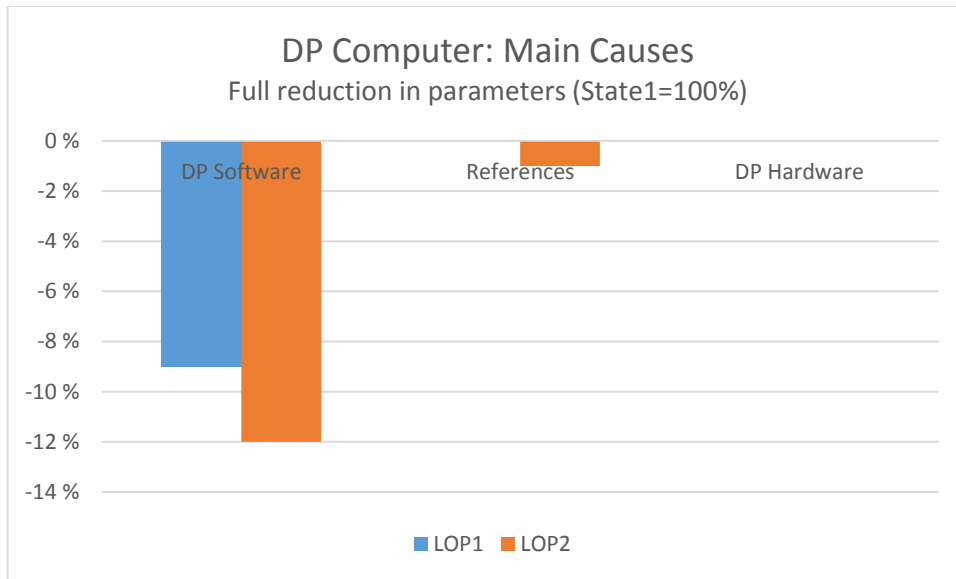


Sub Models

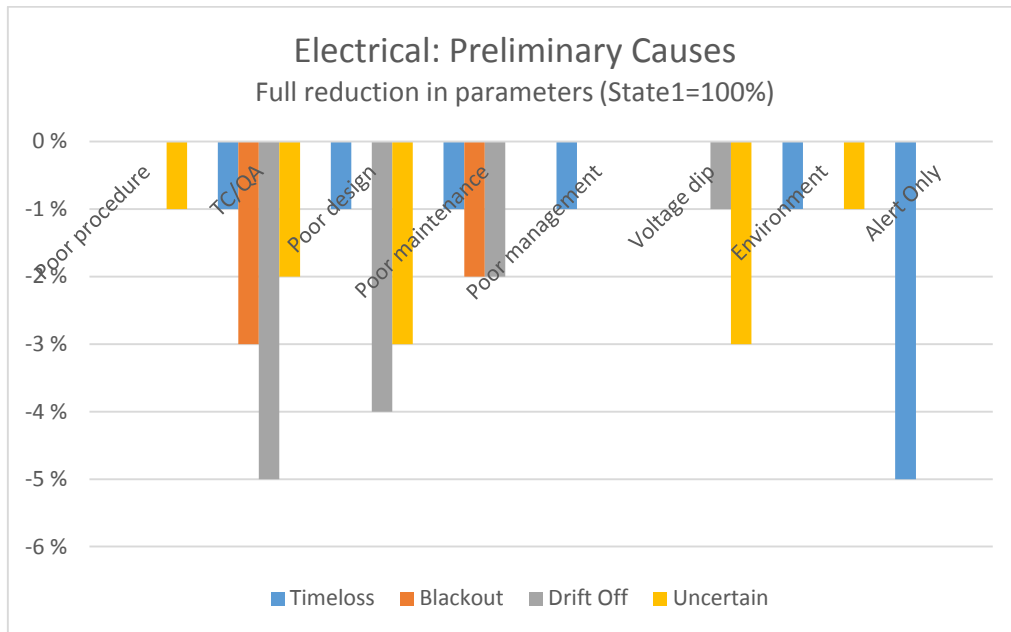
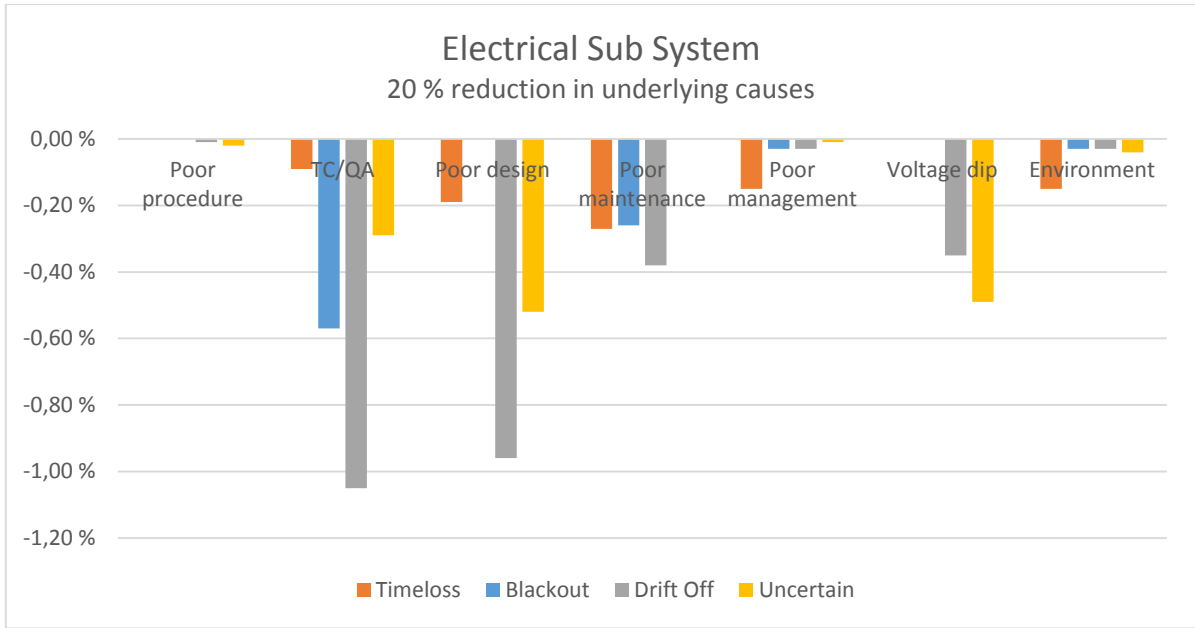
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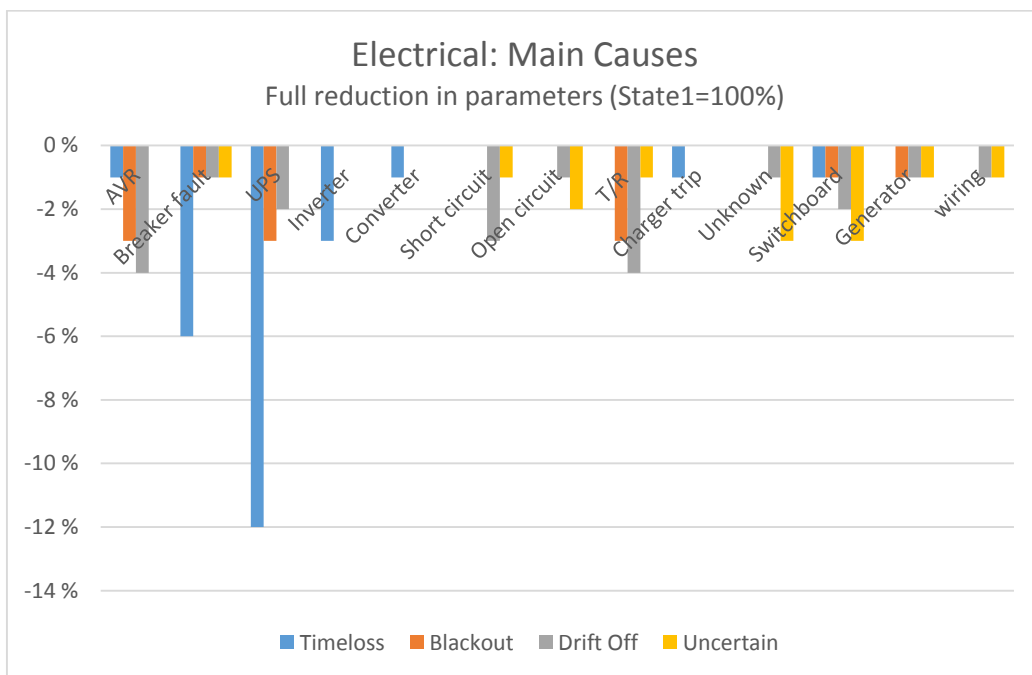
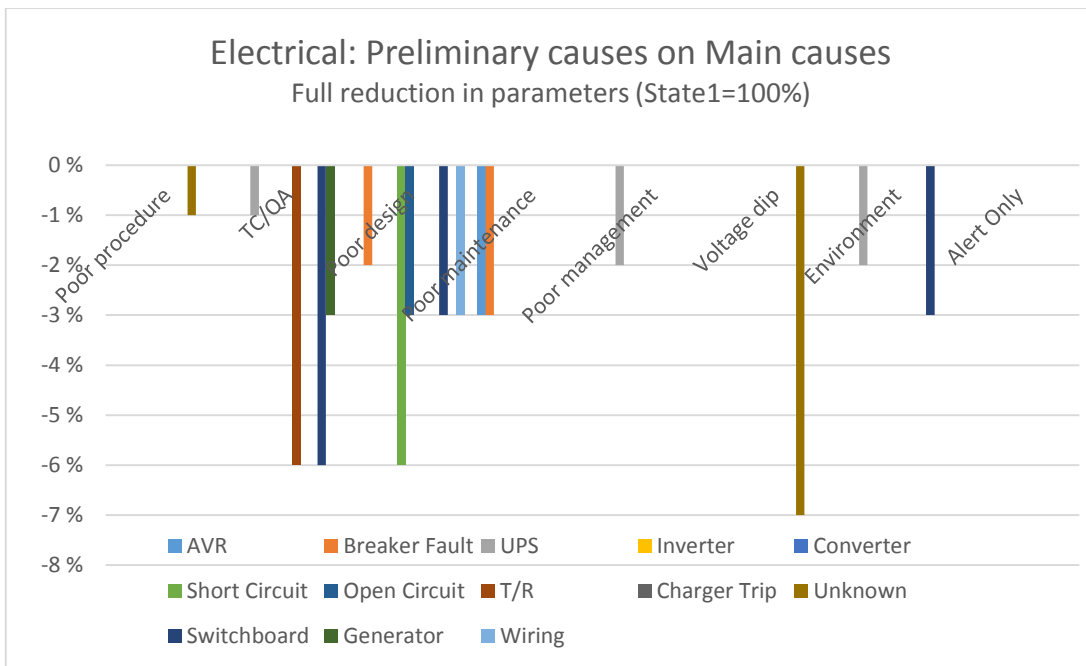




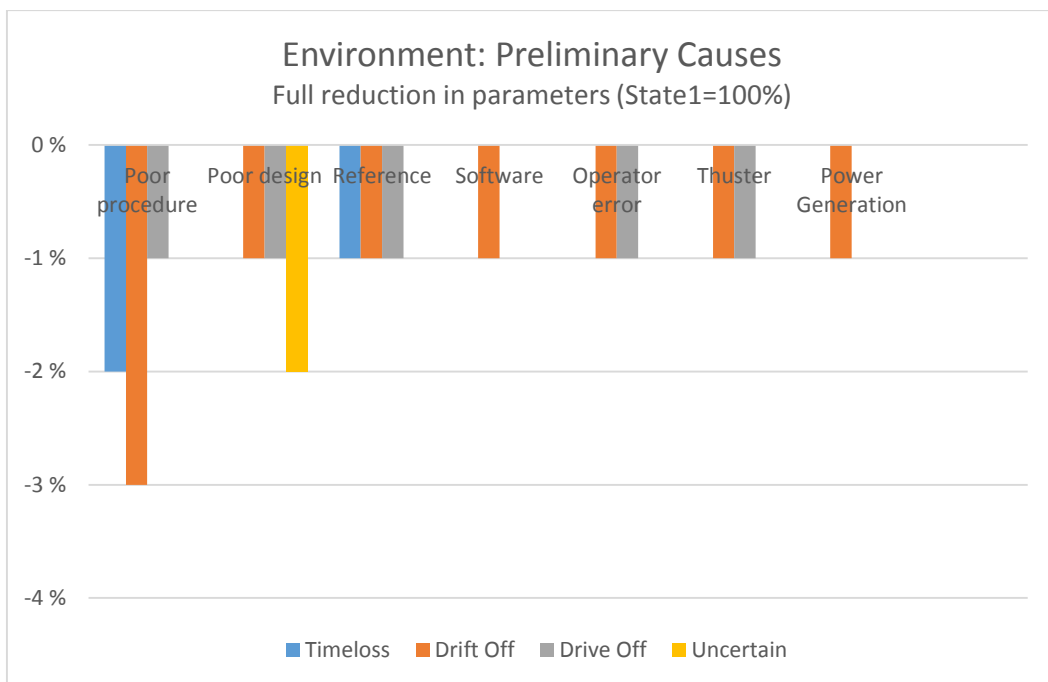
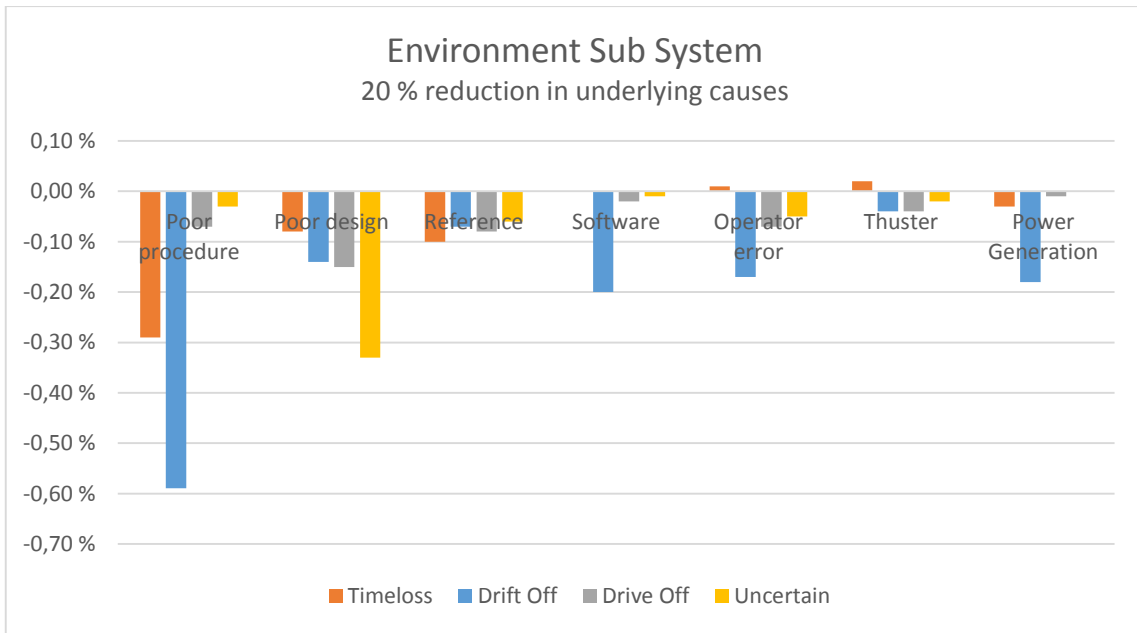


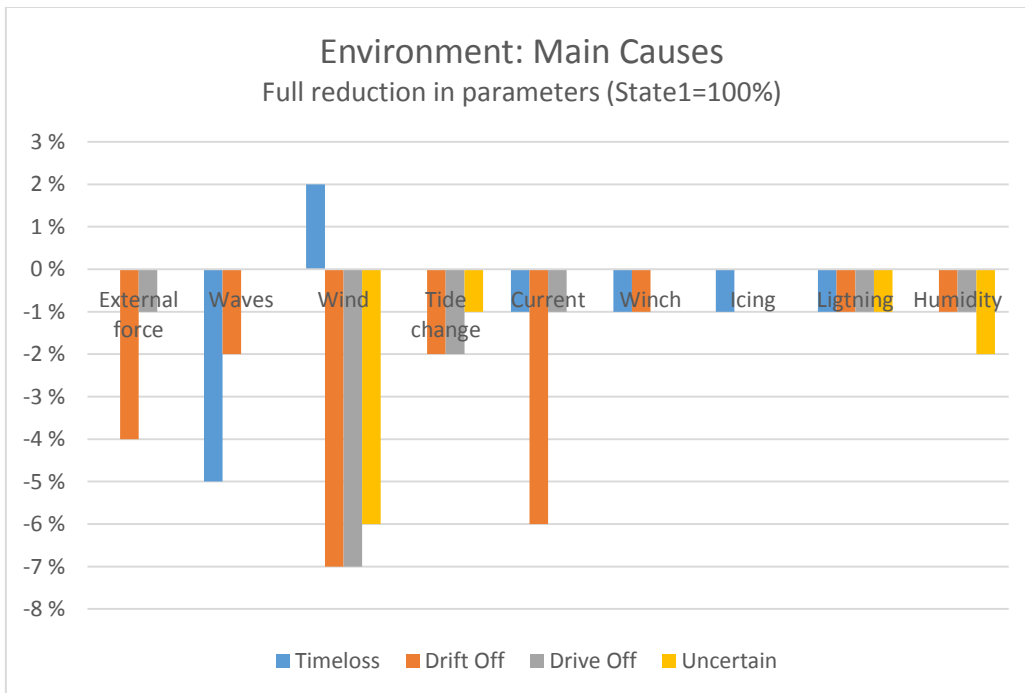
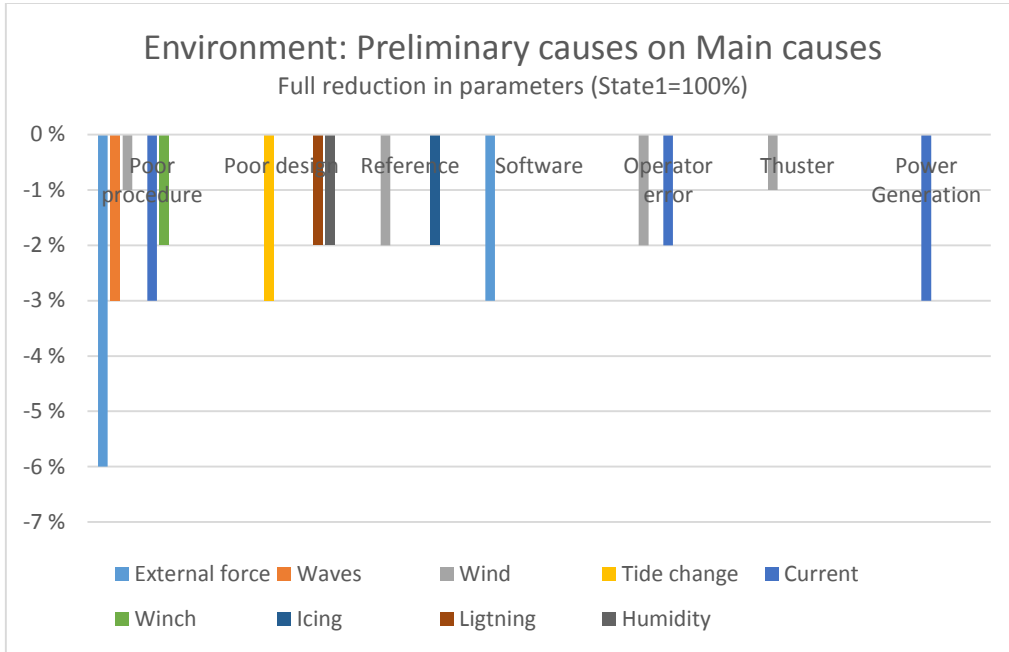
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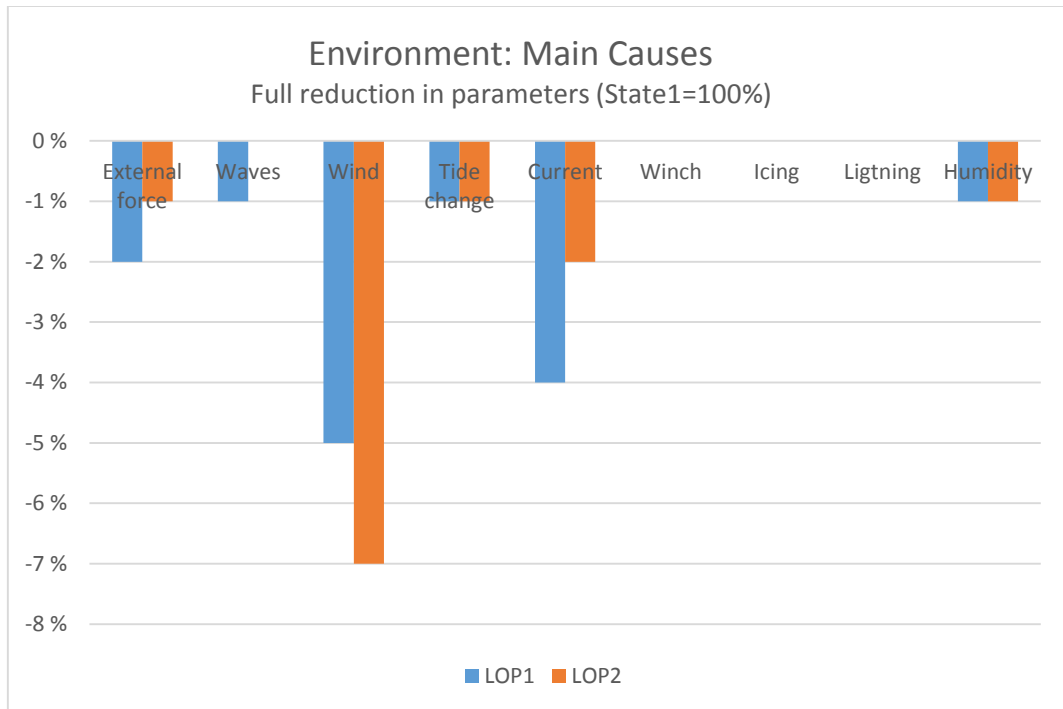




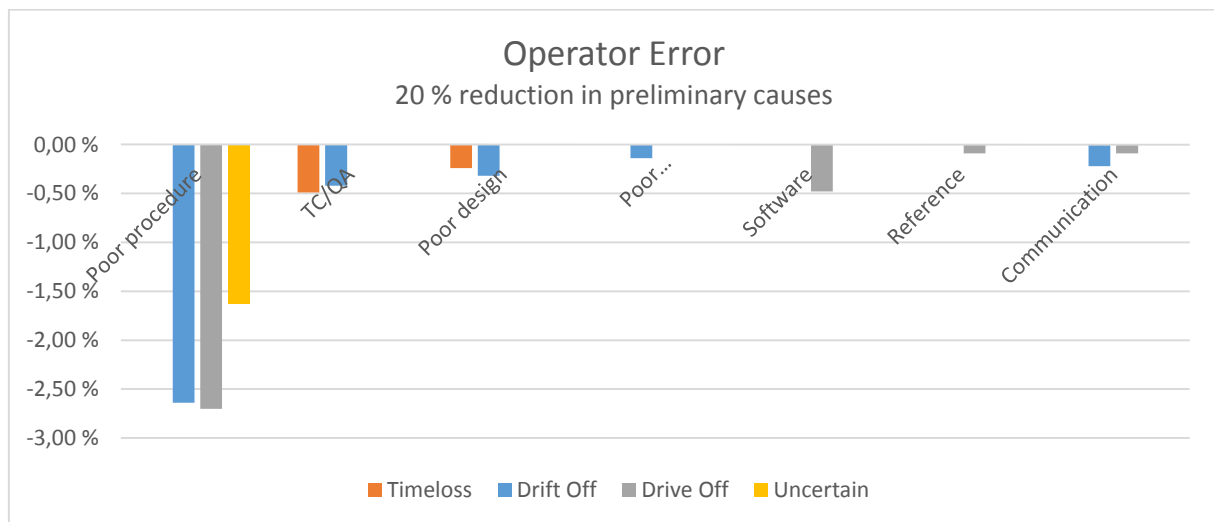
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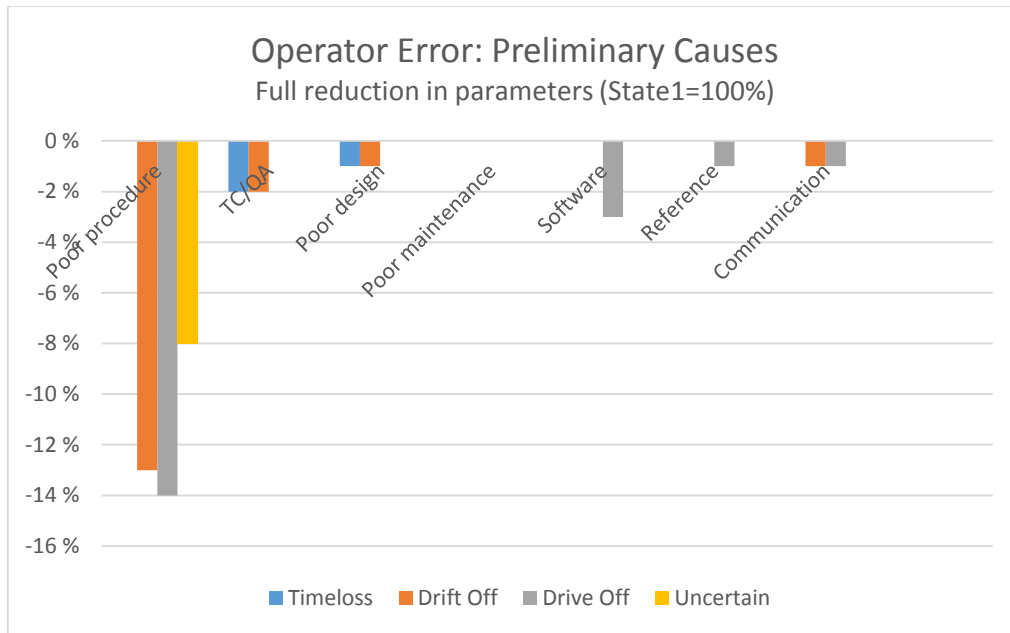


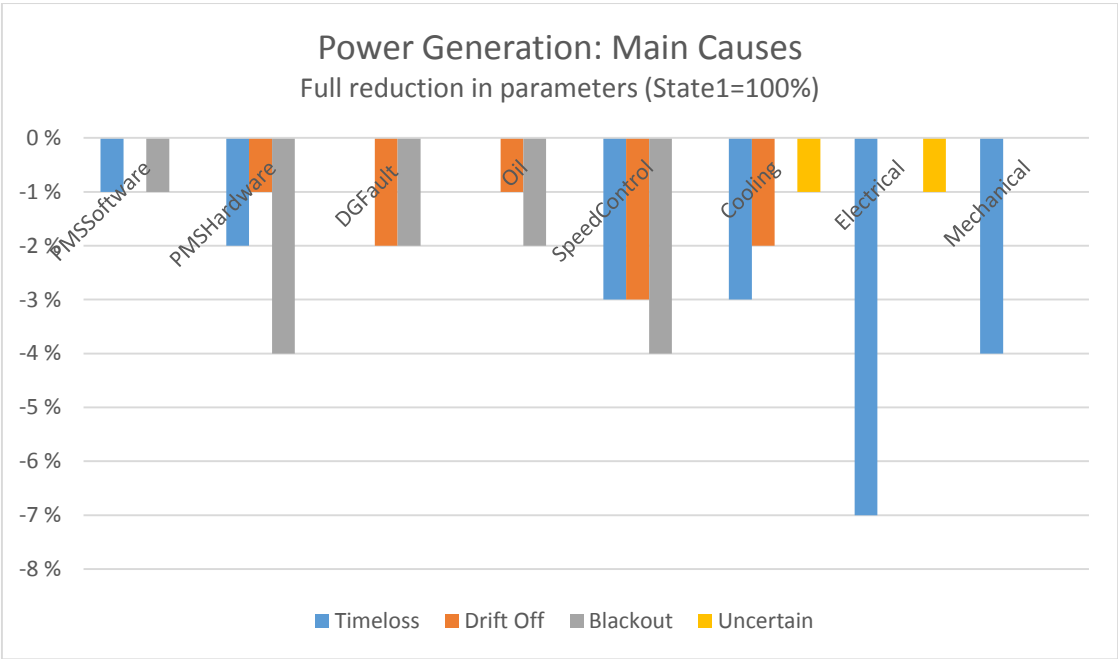
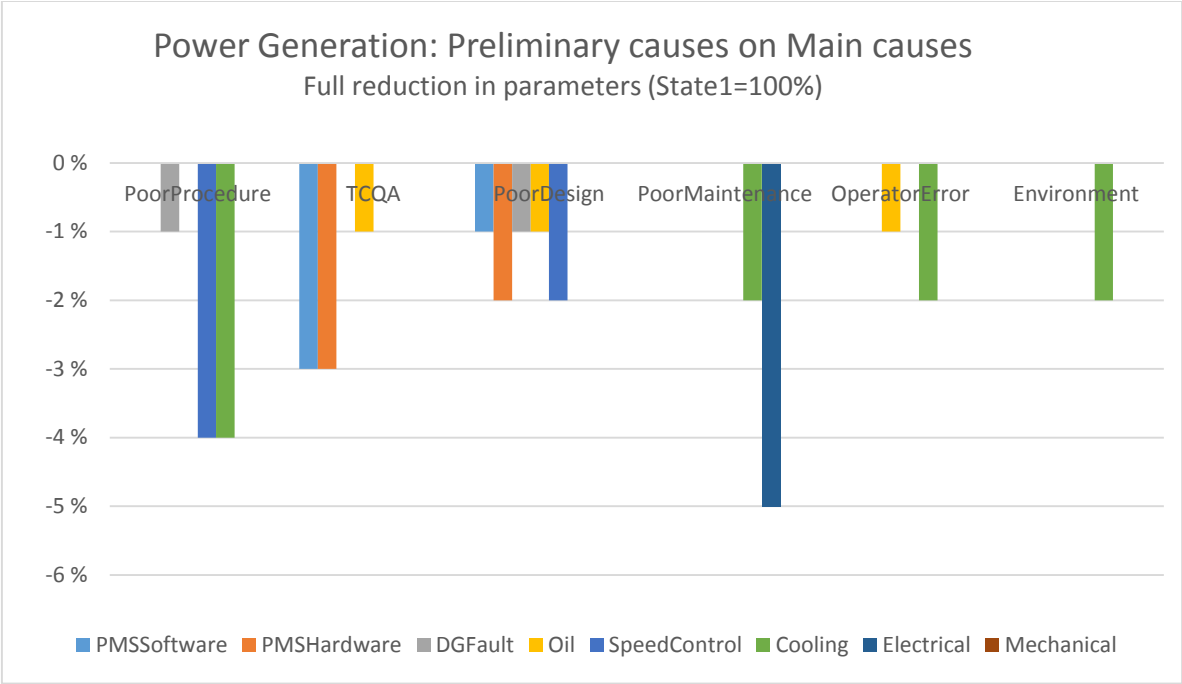


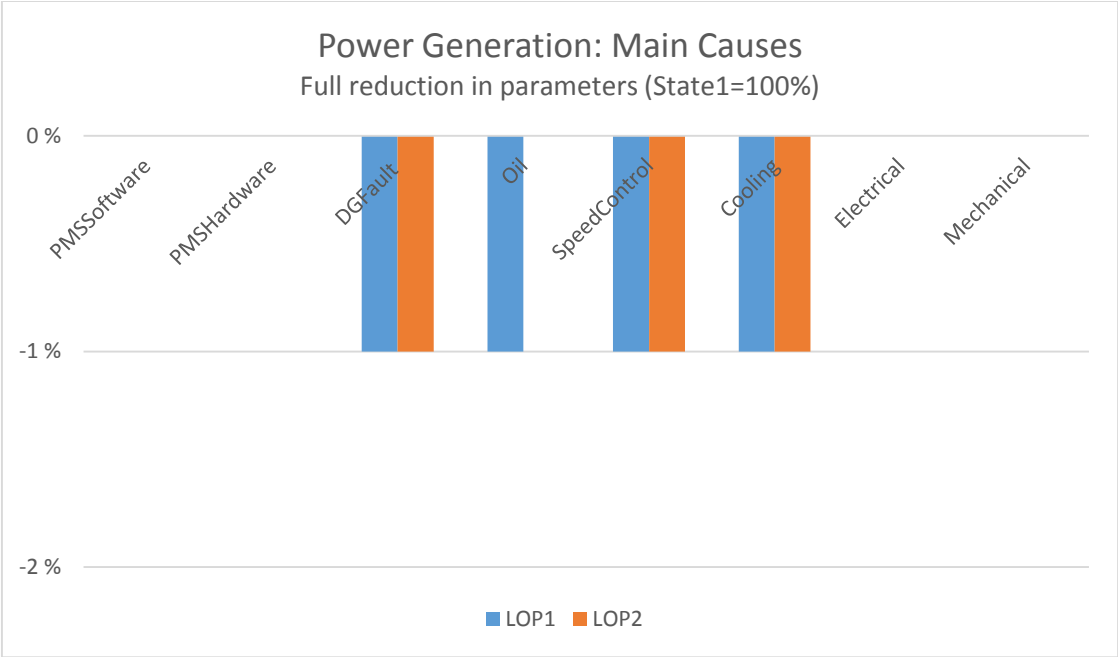


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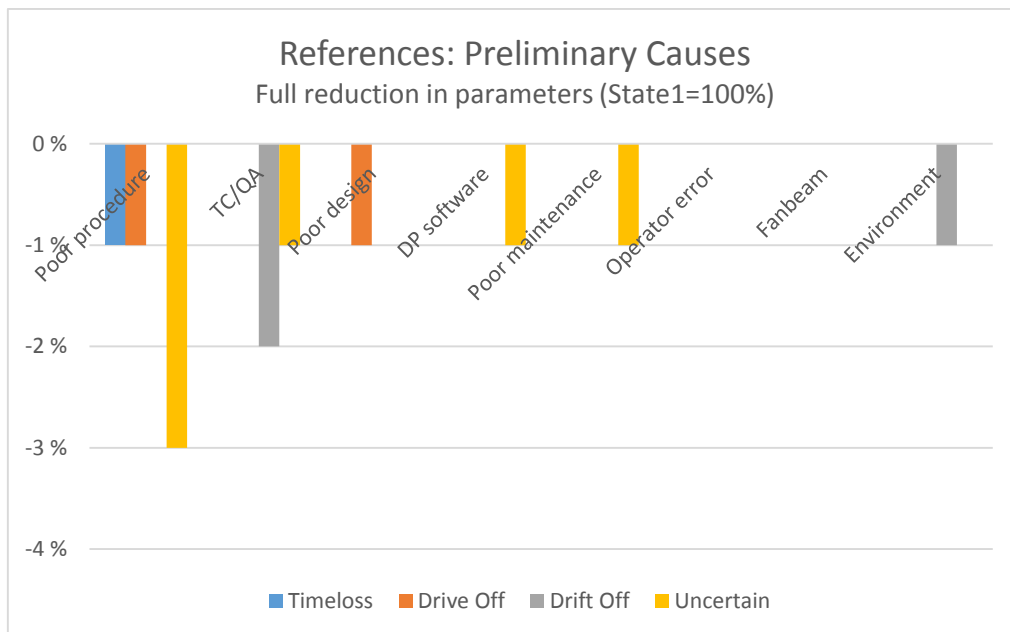
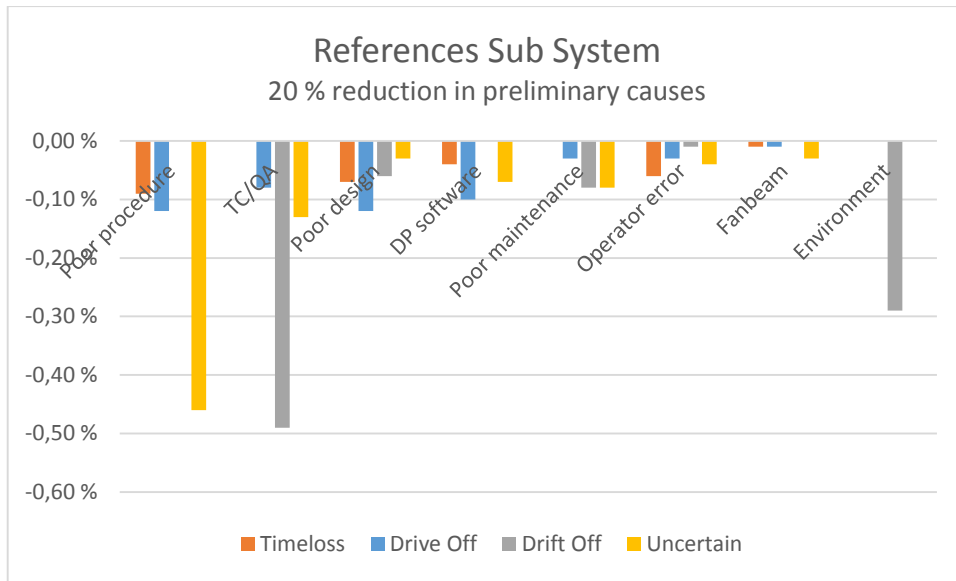


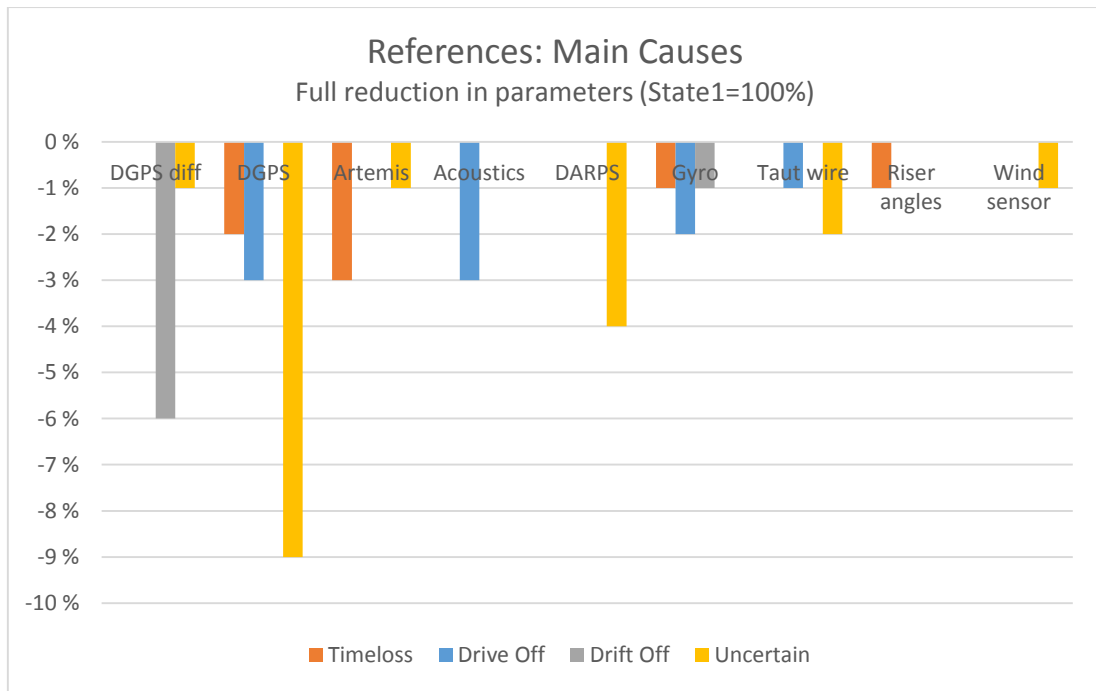
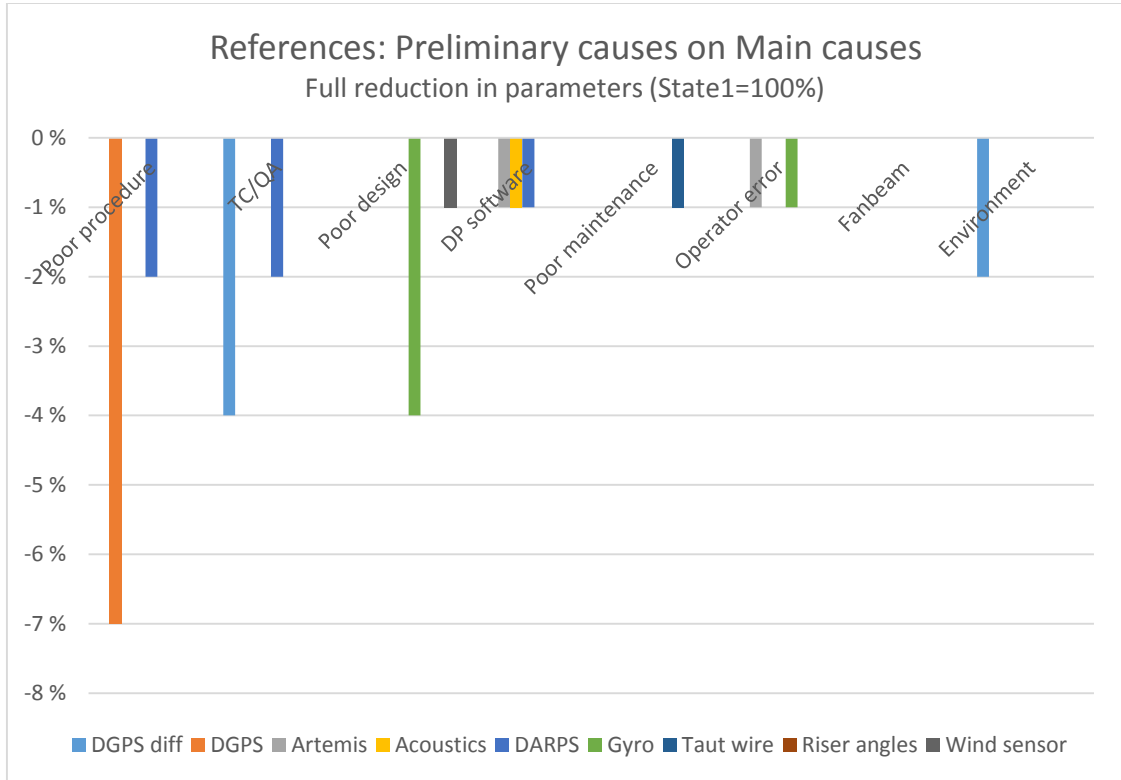


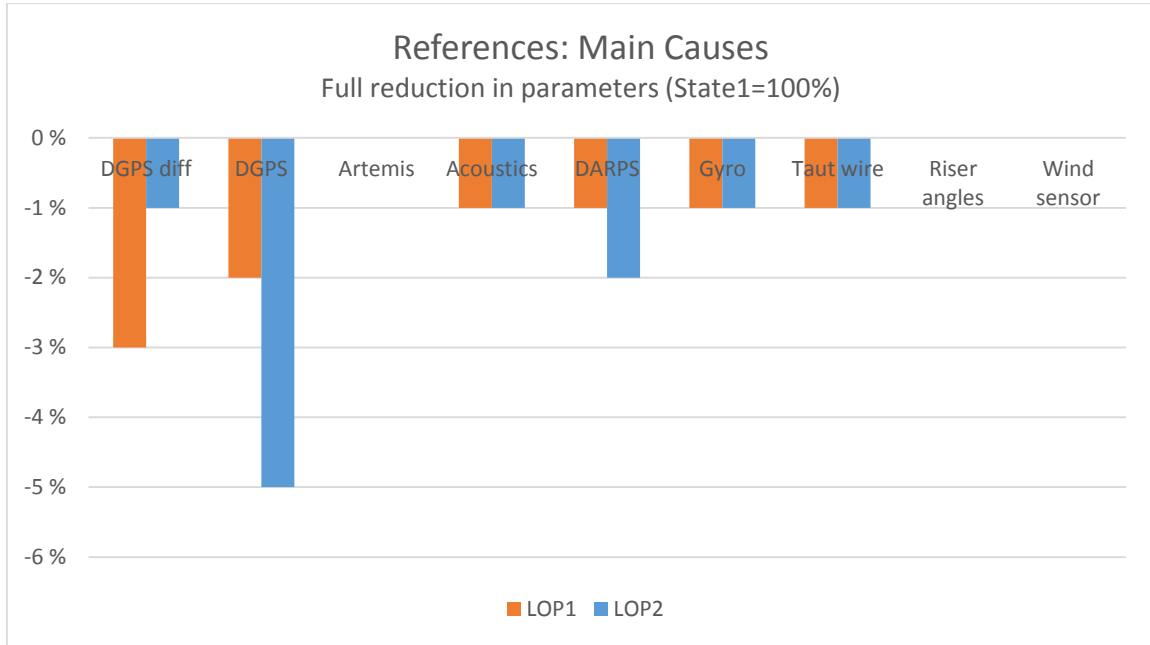




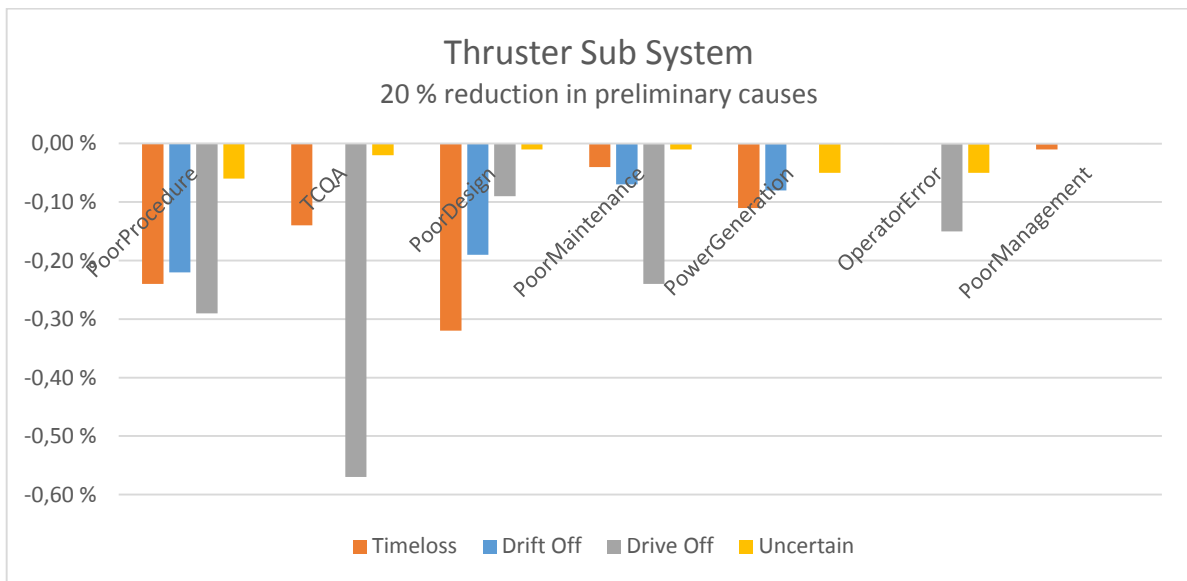
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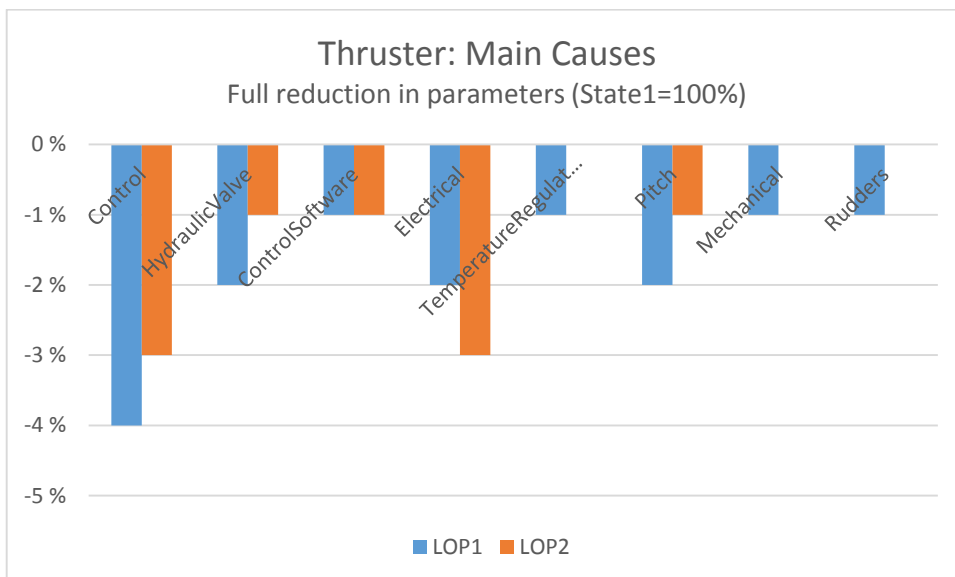
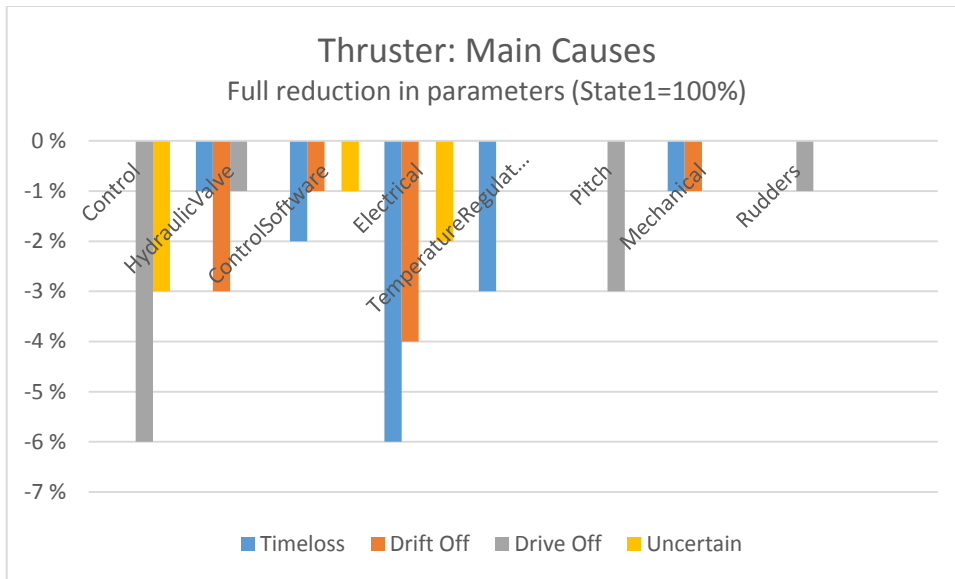






Thruster:





C. DP Class Requirements

TABLE 0-1 DP CLASS REQUIREMENTS, IMO 645 1994

Sub-systems:	Requirements	Additional requirements for DP 3
References	<p>-Position reference systems should be selected with due consideration to operational requirements, both with regard to restrictions caused by the manner of deployment and expected performance in working situation.</p> <p>-For equipment classes 2 and 3, at least three position reference systems should be installed and simultaneously available to the DP-control system during operation.</p> <p>-When two or more position reference systems are required, they should not all be of the same type, but based on different principles and suitable for the operating conditions.</p> <p>-The position reference systems should produce data with adequate accuracy for the intended DP-operation.</p> <p>-The performance of position reference systems should be monitored and warnings provided when the signals from the position reference systems are either incorrect or substantially degraded.</p>	<p>-At least one of the position reference systems should be connected directly to the back-up control system and separated by A.60 class division from the other position reference systems</p>
Sensors	<p>-Vessel sensors should at least measure vessel heading, vessel motions, and wind speed and direction.</p> <p>-When an equipment class 2 or 3 DP-control system is fully dependent on correct signals from vessel sensors, then these signals should be based on three systems serving the same purpose (i.e. this will result in at least three gyro compasses being installed).</p> <p>-Sensors for the same purpose, connected to redundant systems should be arranged independently so that failure of one will not affect the others.</p>	<p>-One of each type of sensors should be connected directly to the back-up control system and separated by A.60 class division from the other sensors.</p>

DP Computer	<p>-The DP-control system should consist of at least two independent computer systems. Common facilities such as self-checking routines, data transfer arrangements, and plant interfaces should not be capable of causing the failure of both/all systems.</p> <p>-The DP-control system should include a software function, normally known as 'consequence analysis', which continuously verifies that the vessel will remain in position even if the worst case failure occurs. This analysis should verify that the thrusters remaining in operation after the worst case failure can generate the same resultant thruster force and moment as required before the failure. The consequence analysis should provide an alarm if the occurrence of a worst case failure would lead to a loss of position due to insufficient thrust for the prevailing environmental conditions. For operations which will take a long time to safely terminate, the consequence analysis should include a function which simulates the thrust and power remaining after the worst case failure, based on manual input of weather trend.</p> <p>-Redundant computer systems should be arranged with automatic transfer of control after a detected failure in one of the computer systems. The automatic transfer of control from one computer system to another should be smooth, and within the acceptable limitations of the operation.</p> <p>-An uninterruptable power supply (UPS) should be provided for each DP-computer system to ensure that any power failure will not affect more than one computer. UPS battery capacity should provide a minimum of 30 minutes operation following a mains supply failure.</p>	<p>-For equipment class 3, the DP-control system should consist of at least two independent computer systems with self-checking and alignment facilities. Common facilities such as self-checking routines, data transfer arrangements and plant interfaces should not be capable of causing failure at both/all systems. In addition, one back-up DP-control system should be arranged, see 3.4.2.6. An alarm should be initiated if any computer fails or is not ready to take control.</p> <p>-The back-up DP-control system should be in a room separated by A.60 class division from the main DP-control station. During DP-operation this, back-up control system should be continuously updated by input from the sensors, position reference system, thruster feedback, etc., and be ready to take over control. The switch-over of control to the back-up system should be manual, situated on the back-up computer and should not be affected by failure of the main DP-control system.</p>
DP Control system	<p>-In general the DP-control system should be arranged in a DP-control station where the operator has a good view of the vessel's exterior limits and the surrounding area.</p>	

-The DP-control station should display information from the power system, thruster system, and DP-control system to ensure that these systems are functioning correctly.

Information necessary to operate the DP-system safely should be visible at all times. Other information should be available upon operator request.

-Display systems and the DP-control station in particular, should be based on sound ergonomic principles. The DP-control system should provide for easy selection of control mode, i.e. manual, joystick, or computer control of thrusters, and the active mode should be clearly displayed.

-For equipment classes 2 and 3, operator controls should be designed so that no single inadvertent act on the operators' panel can lead to a critical condition.

-Alarms and warnings for failures in systems interfaced to and/or controlled by the DP-control system are to be audible and visual. A permanent record of their occurrence and of status changes should be provided together with any necessary explanations.

-The DP-control system should prevent failures being transferred from one system to another. The redundant components should be so arranged that a failure of one component should be isolated, and the other component activated.

-It should be possible to control the thrusters manually, by individual joysticks and by a common joystick, in the event of failure of the DP-control system.

-The software should be produced in accordance with an appropriate international quality standard recognized by the Administration.

Power
Supply
(Power
Generation)

-The power system should have adequate response time to power demand changes.

-The power system should consist of at least two independent systems, located in different spaces. Separation should also be watertight if located below the operational

		waterline.
		-The power available for position keeping should be sufficient to maintain the vessel in position after worst case failure.
Propulsion (Thruster)	-The thruster system should provide adequate thrust in longitudinal and lateral directions, and provide yawing moment for heading control.	-The thruster system should be connected to the power system in such a way that previous statement can be complied with even after failure of one of the constituent power systems and the thrusters connected to that system.
Electrical (and piping)	-For equipment class 2, piping systems for fuel, lubrication, hydraulic oil, cooling water and cables should be located with due regard to fire hazards and mechanical damage.	<p>-Cables for redundant equipment or systems should not be routed together through the same compartments. Where this is unavoidable such cables could run together in cable ducts of A-60 class, the termination of the ducts included, which are effectively protected from all fire hazards, except that represented by the cables themselves. Cable connection boxes are not allowed in such ducts.</p> <p>-Redundant piping system (i.e. piping for fuel, cooling water, lubrication oil, hydraulic oil, etc.) should not be routed together through the same compartments. Where this is unavoidable, such pipes could run together in ducts of A-60 class, the termination of the ducts included, which are effectively protected from all fire hazards, except that represented by the pipes themselves.</p>
