Development of Fault Tree Diagram for the Production Line of a Soft Drink Bottling Company in Benin City, Nigeria

Godfrey O. Ariavie and Godwin E. Sadjere

***Abstract* - We developed and analyzed a Fault Tree Diagram for the production section/line of a soft drink bottling company in Benin City, Nigeria. A number of faults were identified in this study. One of these faults (basic event) had the following characteristic: "Bottle not full with content and has particle inside". Responses were obtained from employees as to the cause of this failure. The probability of occurrence of this event was computed, after comparing with the Kirsten model. On the whole, 20 logic gates (G1 – G20), 14 interconnecting basic events (primary failures: X1 – X14), 9 undeveloped events, (secondary failures: Z1 – Z9), and nine initiating events (H1 – H9), were used to construct the fault tree. The resultant Fault tree was drawn and validated with ten First-order cut-sets. It was a valid path of occurrence of the top events. The probability of occurrence obtained using Boolean algebra and the bottom up algorithm yielded 0.38.**

***Index Terms*— Fault Tree, Production Section/Line, Basic Event, Undesired Event, Failure, Probability of Occurrence, Fault Tree Analysis**

I. INTRODUCTION

FAULT Tree Analysis (FTA), is a graphical "model" of the pathways within a system that can lead to a foreseeable, undesirable loss event[6], [14]. FTA identifies models and evaluates the unique interrelationship of events that could lead to failures, undesired events or states, and unintentional events or states. Developed in 1961 at Bell Telephone Laboratories for missiles launch control reliability during the Polaris project, Fault Tree A and has been extensively used in reliability studies nuclear and aerospace industry [6],[8],[9] and[15]. Fault tree analysis is best suited for high risk complex or multi-element systems where large perceived threats are envisaged with numerous potential contributors to a mishap. FTA starts from a single fault at the top of a flow chart and expands out and downward to identify the many contributing causes to that single top fault whose method proceeds from one event to many events [14], [15]. Fault tree analysis identifies a top fault even interlinked with lower levels of sub faults event by means of either "and" gates or "or" gates (Boolean Logic). The "and" gate in a fault tree demands all sub fault events are necessary for an upper-level event to occur while an "or" gate requires that the input sub faults in and of itself is sufficient to generate the upper-level event. Fig.1 shows standard Fault Tree Logic symbols and their utilization.

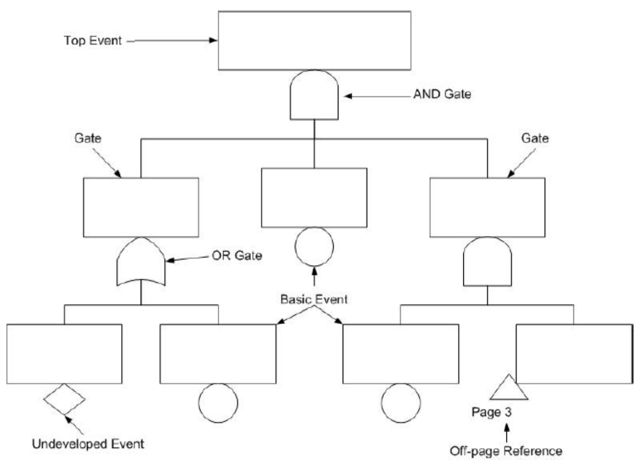

Fig.1. Standard Fault Tree Symbols [15]

II. METHODOLOGY OF FAULT TREE CONSTRUCTION

The construction of a fault tree diagram is an art rather than a science [11], [15],; however we would employ the following basic steps in constructing and performing the fault tree analysis of the production section/line of a soft drink bottling company. To evaluate the fault tree, the Kristen model probability table (Table I) was adapted and used to conduct both qualitative and quantitative analysis of the process.

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TABLE I
CLASSES FOR PROBABILITY OF OCCURRENCE [10]

S/N	QUALITATIVE EVALUATION	QUANTITATIVE EVALUATION
1	Certain	Every time (1.0)
2	Very High (very frequent or very often)	1 in ten (10^{-1})
3	High (frequent or often)	1 in a hundred (10^{-2})
4	Moderate (rarely)	1 in a thousand (10^{-3})
5	Low (very rare)	1 in ten thousand (10^{-4})
6	Very Low (not common)	1 in a hundred thousand (10^{-5})
7	Extremely Low	1 in a million (10^{-6})
8	Practically zero	1 in ten million (10^{-7})

In order to collect data, questionnaires, specially designed for the system (production line of the soft drink bottling company) were administered to the personnel working in production section. The responses of these workers were collated and analyzed.

A. Understanding the Building Blocks

The understanding of how the system functions helps in the tree building process. It consists of basic events, gate events, and transfer events [1],[2],[3] and [4]. We assumed a fault to be an abnormal undesirable state of a system or a system element. It may be induced either by the presence of an improper command, or absence of a proper one, or loss by a system of functional integrity to perform as intended [6].

B. Applying the principal concepts of fault tree construction [9].

Three principal concepts applied in the construction of a fault tree construction are I-N-S concept, SS-SC concept and P-S-C concept. The I-N-S Concept questions "What is Immediate (I), Necessary (N), and Sufficient (S) to cause the event?" and identifies the most immediate causes of the event; the causes that are absolutely necessary; and only includes the causes that are absolutely necessary and sufficient. In the SS-SC Concept, failures that are "state of the system" (SS) and "state of component" (SC) are identified. If the fault in the event box can be caused by component failure, classify the event as an SC fault and it will have an OR gate with P-S-C inputs. And if not by component failure, classify the fault as an SS fault, then the event will be further developed using I-N-S logic to determine the input and gate type. Finally, in P-S-C Concept the question "What are the Primary (P), Secondary (S), and Command (C) causes of the event?" forces the analyst to focus on specific causal factors. The rationale behind this question is that every component fault event has only three ways of failing: a primary failure mode, a secondary failure mode, or a command path fault. An added benefit to this concept is that if more than two of the three elements of P-S-C are present, then an OR gate is automatically indicated.

C. Understanding the Construction Rules

The construction and development of the proposed fault tree follows the construction rules outlined as follows [9]:

i. completing the basic required data for each fault tree,
ii. giving every node a unique identifying name;
iii. no gate-to-gate connection was allowed (always have text box);
iv. placing relevant text in text box;
v. without leaving it blank;
vi. Stating event fault state exactly and precisely;
vii. using state transition wording;
viii. completing the definition of all input to a gate before proceeding;
ix. Keeping event on their relevant level for clarity;
x. Using meaningful naming convention; Not drawing lines from two gates to a single input (use the MOE methodology);
xi. Assuming no miracles (i.e. miraculous component failure blocks other failures from causing undesired event);

Since I-N-S, P-S-C and SS-SC are analysis concept; they are words that are not used in the boxes.

D. Basic Fault Tree Construction Steps

The following basic steps were used to construct the fault tree as shown in Fig. 2.

1. Reviewing and understanding the fault event under investigation (i.e. Bottle not full with content and has particle inside).
2. Identifying all the possible causes of the event through the questions:
a. Immediate, necessary, and sufficient?
b. State of component or state of system?
c. Primary, secondary, and command?
3. Identifying the relationship or logic of the cause-effect events.
4. Structuring the tree with the identified gate input events and gate logic.
5. Double checking logic to ensure that a jump in logic has not occurred.
6. Checking/ looking back to ensure identified events are not repeated.
7. Repeating also for the next event (i.e., gate).
8. Keeping all node wordings clear, precise, and complete.

E. System Failure Analysis of the Production Line/Section of the Soft Drink Bottling Company in Benin Metropolis.

A systems failure analysis to determine the underlying reasons for the nonconformance (failure) to system requirements was performed. The process identified nonconformance root causes and recommended appropriate

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corrective actions [5] taking into account historical records, personnel interviews, development of a "what-if" scenario etc.

In analyzing the failures, structured questionnaires were administered to the personnel in order to find out:

1. why the event "Bottle not full with content and has particle inside" is of interest and the effects (if any) on the system
2. What aspect of the system failures are of concerned to cause the undesired events
3. Failure mechanism on how this failure occurred and the corresponding likelihood of the occurrence.

The data obtained from the analysis, was used to generate the categorization of the failure mode and failure mechanization in Table II.

TABLE II
SYSTEM FAILURE ANALYSIS

S/N	Failure Effect	Failure Mode	Failure Mechanism
1	Sighter error	• E.B.I error or fault • Human error or fault • Conveyor error or fault	• Power failure • Fatigue/ Stress • Power failure
2	Bottle not properly washed in the washer	• Pumps blockage • Low caustic strength • Thick solid particle inside the bottle • Boiler Fault •	• Operator error • Low standard • Low temperature of steam • Power failure • Low pressure reading
3	Filler fault	• Vent tube blockage • Carbo cooler fault • Fault in the mixer tank • Compressor fault	• Power failure • Low CO_2 • Poor mixture standard • Low pressure
4	Crowner fault	• No cork in the crowner • Bottles brok en due to vibration	• Mechanical fault • Power failure

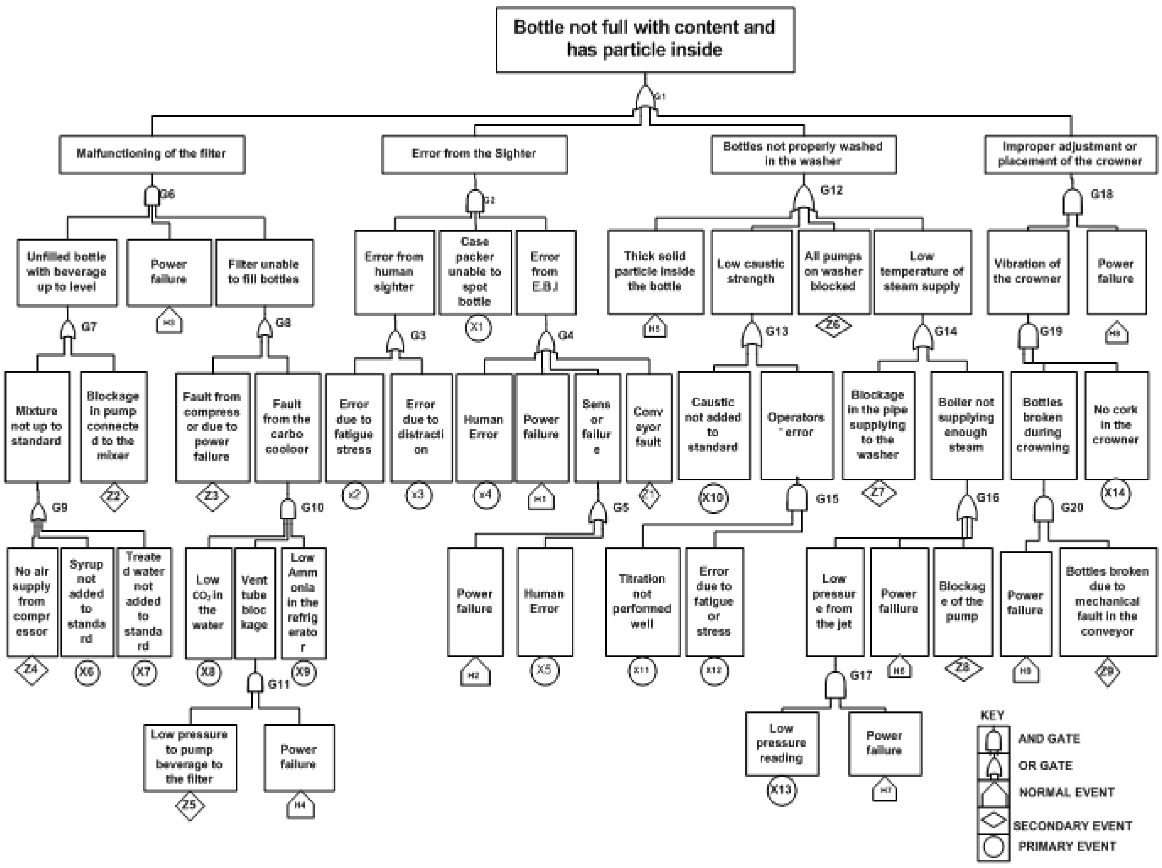

Fig. 2 Complete Fault Tree Diagram of the production section of the Bottling Company

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F. Probability evaluation methods:

Mean Time Between Failure (MTBF): This is the mean or average time between successive failures of the system. Mathematically it is given as;

$$MTBF = \frac{Total\ Operating\ \ hours\ of\ \ the\ \ items}{Total\ \ numbers\ of\ \ Failures\ that\ occured} \quad (1)$$

In terms of failure rate and system reliability, $MTBF$ is expressed as

$$MTBF = 1/\lambda \quad (2)$$

$$where\ \ \lambda = failure\ \ rate\ \ and\ \ is\ related\ \ to\ the\ system\ \ reliability\ by\ R = e^{-\lambda T}$$

$$and\ \ T = Specified\ \ period\ \ or\ Exposure\ Time\ (1\ \ year)$$

Hence, the system unreliability (P) is the probability of failure of a component defined by

$$P = 1 - R = 1 - e^{-\lambda T} \quad (3)$$

$$And\ \ when\ \ \lambda T < 0.001$$

$$then\ \ P \approx \lambda T \quad (4)$$

Boolean algebra of Union and Intersection events A and B as OR and AND gate respectively is used in evaluating the various inputs and with the probability expansion for an OR gate with N inputs is given as

$$P = (\Sigma 1st\ \ terms) - (\Sigma 2nd\ \ terms) + (\Sigma 3rd\ \ terms) - (\Sigma 4th\ \ terms) + (\Sigma 5th\ \ terms).....$$

$$P = (P_A + P_B + P_C) - (P_{AB} + P_{BC} + P_{AC}) + (P_{ABC}) << if\ \ we\ take\ a\ 3-input\ \ AND\ \ gate \quad (5)$$

while the probability expansion for a AND gate with N number of inputs to the gate if

$$P = P_A P_B P_C P_D P_E ,..., P_N \quad (6)$$

III. CONSTRUCTION AND ANALYSIS

Fault tree construction is an iterative process that begins at the tree top and continues down through all the tree branches. In this study, the same set of questions and logic was applied on every gate moving down the tree. After identifying the top undesired event, sub-undesired events were also identified and structured into what is referred to as the top fault tree layers. Deductive reasoning was use to determine the type of gate and the particular input to this gate at each gate level of the fault tree [12], [13]. Table III identifies some undesirable events that may occur in the production line of the bottling company to aid in the analysis of the developed fault tree.

IV. CALCULATION OF BASIC EVENTS

Using eqs. (1) and (2), and assuming an operating time of year of 8760 hours and the total of 38 failures observed for the operating year in 2011 , with $\lambda = 4.3 \times 10^{-3}$, the probability of occurrence is calculated as shown in Table IV for the identified basic events. Note a "Not common" event (NC) has an assumed frequency of 10^{-5}, a "Very rare" event (VR) is assumed to have an assumed frequency of 10^{-4}, a "Rare" event (R) has an assumed frequency of 10^{-3}, and a "Frequent" event (F) has an assumed frequency of 10^{-2}.

V. CALCULATION OF THE TOP / MAJOR UNDESIRED EVENT

The Bottom-Up algorithm was used to calculate the probability of occurrence of the top undesired event (Bottles not full with content and has particles inside). The computational process is as follows:

G_1 is an OR gate with 4 inputs gates (G6, G2, G12 and G18).

i.e. $P_{G1} = P_{G6} + P_{G2} + P_{G12} + P_{G18} - (P_{G6G2} + P_{G6G12} + P_{G6G18} + P_{G2G12} + P_{G2G18} + P_{G12G18}) + (P_{G6G2G12} + P_{G6G2G18} + P_{G6G12G18} + P_{G2G12G18}) - (P_{G6G2G12G18})$ (7)

And applying the Upper bound rule, therefore the Probability of the occurrence of the Top undesired event is:

P_T = Probability of the Top undesired event.

$P_T \approx G_1 = P_{G6} + P_{G2} + P_{G12} + P_{G18}$ (8)

Starting from bottom: where G_5 = OR gate with 2 inputs,

$G_5 = P_{H2} + P_{X5} = 3.8\text{x}10^{-3} + 3.8\text{x}10^{-4} = 4.18\text{x}10^{-3}$

For G_4 = OR gate with 4 inputs, we have:

$G_4 = P_{X4} + P_{H1} + P_{G5} + P_{Z1} - (P_{X4H1} + P_{X4G5} + P_{X4Z1} + P_{H1G5} + P_{H1Z1} + P_{G5Z1}) + (P_{X4H1G5} + P_{X4H1Z1} + P_{X4G5Z1} + P_{H1G5Z1}) - (P_{X4H1G5Z1})$

Using the upper bound rule, and solving, yields:

$G_4 = 8.74\text{x}10^{-3}$

For G_3 = OR gate with 2 inputs:

$G_3 = P_{X2} + P_{X3} = 3.8\text{x}10^{-3} + 3.8\text{x}10^{-3} = 7.6\text{x}10^{-3}$

Hence, for G_2 =AND gate with 3 inputs, we have:

$G_2 = P_{G3} \cdot P_{X1} \cdot P_{G4} = 2.52\text{x}10^{-8}$

G_{11} = AND gate with 2 inputs, gives

$G_{11} = P_{Z5} \bullet P_{H4} = 1.44\text{x}10^{-5}$

For G_{10} = AND gate with 3 inputs, we have:

$G_{10} = P_{X8} \bullet P_{G11} \bullet P_{X9} = 2.08\text{x}10^{-12}$

And G_8 = OR gate with 2 inputs, gives:

$G_8 = P_{Z3} + P_{G10} = 3.8\text{x}10^{-4}$

For G_9 = OR gate with 3 inputs, we have:

$G_9 = P_{Z4} + P_{X6} + P_{X7} - (P_{Z4X6} + P_{Z4X7} + P_{X6X7}) + (P_{Z4X6X7}) = 3.9\text{x}10^{-2}$

For G_7 = OR gate with 2 inputs, yields:

$G_7 = P_{G9} + P_{Z2} = 3.9\text{x}10^{-2}$

Hence, $G_6 = PG7 \bullet P_{H3} \bullet P_{G8} = 5.63\text{x}10^{-8}$

For, G_{17} = AND gate with 2 inputs, we have:

$G_{17} = P_{X13} \bullet P_{H7} = 1.44\text{x}10^{-5}$

For G_{16} =OR gate with 3 inputs, we have:

$G_{16} = P_{G7} + P_{H6} + P_{Z8} - (P_{G7H6} + P_{G7Z8} + P_{H6Z8}) + (P_{G7H6Z8}) = 0.38$

For G_{14} = OR gate with 2 inputs, we have:

$G_{14} = P_{Z7} + P_{G16} = 3.8\text{x}10^{-1}$

For G_{15} = AND gate with 2 inputs, we have:

$G_{15} = P_{X11} \bullet P_{X12} = 1.44\text{x}10^{-5}$

For G_{13} = OR gate with 2 inputs, we have:

$G_{13} = P_{X10} + P_{G15} = 3.9\text{x}10^{-4}$

For G_{12} = OR gate with 4 inputs, we have:

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$G_{12} = P_{H5}+P_{G13}+P_{Z6}+P_{G14}-P_{H5G13} + P_{H5Z6} + P_{H5G14} + P_{G13Z6} + P_{G13G14}+P_{Z6G14}) + (P_{H5G13Z6}+P_{H5G13G14}+P_{H5Z6G14}+P_{G13Z6G14}) - (P_{H5G13Z6G14}) = 0.38$

For G_{20} = AND gate with 2 inputs, we have:

$G_{20} = P_{H1} \bullet P_{Z9} = 0.14$

For G_{19} = AND gate with 2 inputs, we have:

$G_{19} = P_{G20} \bullet P_{X14} = 5.\ 5\text{x}10^{-4}$

For G_{18} = AND gate with 2 inputs, we have:

$G_{18} = 2.\ 09\ \text{x}10^{-4}$

From eq. 8, we have

$P_T \approx G_1 = P_{G6} + P_{G2} + P_{G12} + P_{G18}$

$P_T = 2.52\text{x}10^{-8} + 5.63\text{x}10^{-8} + 3.\ 8\text{x}10^{-1} + 2.09\text{x}10^{-4} = 0.38$

Summarized qualitative and quantitative occurrence rate of undesirable events is shown in Table V.

TABLE III
IDENTIFIED UNDESIRED EVENTS IN THE SYSTEM (THE PRODUCTION LINE/SECTION OF THE BOTTLING COMPANY) AND THEIR CLASSIFICATIONS.

S/N	AREA AFFECTED	POSSIBLE UNDESIRED EVENT	CLASSIFICATION STATE
1	Filler	Unfilled or Unlevel Bottle with beverage.	State of the system
2	Washer	Bottles with particles inside after being filled and crowned.	State of the system
3	Crowner	Bottles broken due to vibration of the crowner.	State of the system
4	Crowner	Filled bottles broken during crowning.	State of component
5	Washer	Bottles not properly wash as they leave the washer.	State of the system
6	Sighters	Sighter unable to spot unclean bottles that leaves the washer.	State of component
7	Boiler / Washer	Blockage in the pipe supplying steam to the washer.	State of component
8	Washer	All pumps on the washer blocked.	State of component
9	Boiler	Low pressure from the jets.	State of the system
10	Boiler	Boiler not supplying enough steam to the washer.	State of the system
11	Boiler	Power failure on the boiler due to power supply.	State of the system
12	Boiler	Blockage of the pump in the boiler.	State of component
13	Boiler	Low pressure reading in the boiler.	State of component
14	Washer	Low caustic strength during bottle washing.	State of the system
15	Washer	Caustic not added to standard.	State of the system
16	Mixer	Titration not performed well.	State of the system
17	ALL	Human error due to stress and fatigue.	State of the system
18	E.B.I	Electronic Bottle Inspector (EBI) error due to power failure.	State of the system
19	E.B.I	E.B.I unable to spot unclean bottles due to human error.	State of the system
20	Sensors	Sensors unable to spot unclean bottle due to power failure.	State of the system
21	Sensors	Sensors unable to spot unclean bottle due to conveyor fault.	State of component
22	Conveyor	Broken bottles due to mechanical faults in the conveyor.	State of the system
23	Mixer	Syrup not added to standard in the mixing tank.	State of the system
24	Mixer	Treated water not added to standard in the mixing tank.	State of the system
25	Carbo Cooler	Poor cooling of the beverage in the carbo cooler.	State of the system
26	Compressor	Compressor affected by power failure.	State of the system
27	Compressor	Compressed air not sent to the mixing tank.	State of component
28	Mixer	Low pressure to pump beverage from the mixing tank to the carbo cooler.	State of component
29	Carbo Cooler	Low CO2 in the carbo cooler.	State of the system
30	Refrigerator /Carbocooler	Low Ammonia supply to the carbo cooler.	State of the system
31	Filler	Blockage in the pump that supply the beverage from cooler to the filler.	State of component
32	Filler	Vent tube in the filler is not working well.	State of component
33	Filler	Filler affected by power supply.	State of the system
34	Filler	Filler unable to fill bottles due to blockage in the pump.	State of component

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35	Crowner	No crown cork in the crowner capper.	State of the system
36	Crowner	Human sighter unable to spot bad bottles that were filled and crowned.	State of the system
37	Sensor	Sensors unable to spot bad bottles that were filled and crowned.	State of component
38	Case packer	Case/crate packer unable to spot bad bottles.	State of the system
39	Conveyor	Bottles broken after leaving the washer.	State of component

TABLE IV
IDENTIFIED EVENTS AND THEIR CALCULATED PROBABILITY OF OCCURRENCES.

S/N	CODE USED	EVENTS	Assumed frequency (f)	Probability of occurrence $P = 1 - e^{-\lambda t}$
1	X1	Case packer unable to spot bottle	$NC/10^{-5}$	$3.8x\ 10^{-4}$
2	X2	Error due to fatigue or stress	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
3	X3	Error due to distraction	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
4	X4	Human error from E.B.I	$NC/10^{-5}$	$3.8x\ 10^{-4}$
5	H1	Power failure	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
6	Z1	Conveyor fault	$NC/10^{-5}$	$3.8x\ 10^{-4}$
7	H2	Power failure	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
8	X5	Human error from sensor failure	$NC/10^{-5}$	$3.8x\ 10^{-4}$
9	H3	Power failure	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
10	Z2	Blockage in pump connected to the mixer	$NC/10^{-5}$	$3.8x\ 10^{-4}$
11	Z3	Fault from compressor due to power failure	$NC/10^{-5}$	$3.8x\ 10^{-4}$
12	Z4	No air supply from compressor	$NC/10^{-5}$	$3.8x\ 10^{-4}$
13	X6	Syrup not added to standard	$NC/10^{-5}$	$3.8x\ 10^{-4}$
14	X7	Treated water not added to standard	$R/\ 10^{-3}$	$3.8x\ 10^{-2}$
15	X8	Low Co_2 in the cooler	$NC/10^{-5}$	$3.8x\ 10^{-4}$
16	X9	Low Ammonia in the Refrigerator	$NC/10^{-5}$	$3.8x\ 10^{-4}$
17	Z5	Low pressure to pump beverage to the filler	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
18	H4	Power failure	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
19	H5	Thick solid particle inside the bottle	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
20	Z6	All pump on the washer blocked	$NC/10^{-5}$	$3.8x\ 10^{-4}$
21	X10	Caustic not added to standard	$NC/10^{-5}$	$3.8x\ 10^{-4}$
22	Z7	Blockage in the pipe supplying steam to washer	$NC/10^{-5}$	$3.8x\ 10^{-4}$
23	X11	Titration not performed well	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
24	X12	Error due to fatigue	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
25	H6	Power failure	$F/\ 10^{-2}$	$3.8x\ 10^{-1}$
26	Z8	Block of the boiler pump	$NC/10^{-5}$	$3.8x\ 10^{-4}$
27	X13	Low pressure reading	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
28	H7	Power failure	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
29	H8	Power failure	$F/\ 10^{-2}$	$3.8x\ 10^{-1}$
30	X14	No cork in the crowner	$VR/\ 10^{-4}$	$3.8x\ 10^{-3}$
31	H9	Power failure	$F/\ 10^{-2}$	$3.8x\ 10^{-1}$
32	Z9	Bottles broken due to Mechanical fault in the conveyor	$F/\ 10^{-2}$	$3.8x\ 10^{-1}$

Note: X: represent primary failures or basic events (circles), Z: represents secondary failures or undeveloped events, (diamonds), H: represents normal or initiating events (houses)

TABLE V
THE CALCULATED EVENTS OCCURRENCE RATE

S/N	Code	Undesired Event [10]	Probability (Quantitative)	Occurrence rate (Qualitative)
1	G5	**Sensor failure** (i.e. sensor unable to spot bad bottles before and after filling)	4.18×10^{-3}	Moderate (Rare)
2	G4	**Error from the E.B.I** (i.e. Electronic bottle inspector fault)	8.74×10^{-3}	Moderate (Rare)
3	G3	**Error from Human sighter** (i.e. Human sighter unable to spot unclean bottle that leaves the washer)	7.6×10^{-3}	Moderate (Rare)
4	G2	**Error from the sighter** (i.e. all possible faults from all the sighters in the production line)	2.52×10^{-8}	Not common
5	G11	**Vent tube blockage** (i.e. the tube in the filler is not working well)	1.44×10^{-5}	Very low
6	G10	**Fault from the carbo cooler** (i.e. poor cooling and carbonation of the beverage)	2.08×10^{-12}	Not common
7	G8	**Filler unable to fill bottles** (i.e due to blockage in the pump)	3.8×10^{-4}	Low (very rare)
8	G9	**Mixture not up to standard** (i.e. beverage mixture not up to standard)	3.9×10^{-2}	High (frequent)
9	G7	**Unfilled bottle with beverage not up to level** (i.e. no beverage in the bottle)	3.9×10^{-2}	High (frequent)
10	G6	**Malfunctioning of the filler**	5.63×10^{-8}	Not common
11	G17	**Low pressure from the jet** (i.e. no pressure force to push the beverage to from the Mixer to the C.C)	1.44×10^{-5}	Very low
12	G16	**Boiler not supplying enough steam** (i.e. No steam in the washer)	3.8×10^{-1}	Very high (very frequent)
13	G14	**Low temperature of steam supply**	3.8×10^{-1}	Very high (very frequent)
14	G15	**Operator's error** (i.e. due to stress and fatigue)	1.44×10^{-5}	Very low
15	G13	**Low caustic strength** (i.e. caustic not added to standard in the washer)	3.9×10^{-4}	Low (very rare)
16	G12	**Bottles not properly wash in the washer**	3.8×10^{-1}	Very high
17	G20	**Bottles broken during crowning**	1.4×10^{-1}	Very high (very frequent)
18	G19	**Vibration of the crowner**	5.5×10^{-4}	Low (very rare)
19	G18	**Improper adjustment or placement of the crowner**	2.09×10^{-4}	Low (very rare)
20	G1	**Bottles not full with content and has particle inside.**	3.8×10^{-1}	Very high (very frequent)

VI. Evaluation and Validation of the Fault Tree

The input of the resultant Fault tree into a fault tree analysis computer program, such as FTAP (Fault Tree Analysis Program), IRRAS (Integrated Reliability and Risk Analysis System) would yield a list of Minimum Cut-Sets (MCS) which cause the top event to occur [7]. However, determination of the minimum Cut-sets which shows the smallest combination of events that would lead to the occurrence of the top event is carried out to check if these are indeed valid failure paths to the top event. The total number of cut set was determined using the Bottom-Up Algorithm for generating cut set. Also, the probability of occurrence of the top event was calculated from the fault tree using the probabilities that are inputs for the basic events, taking into consideration failure rate and exposure time or straight probability.

Applying the MUCOS Algorithm; which is a matrix reduction method. [1],[2],[3] and [4]), the following steps would determine the minimum cut-set.

1. Replace the **OR** gate **G1** with its input gates **G6, G2, G12** and **G18.**
2. Replace the **OR** gate **G12** with its input **H6, G13, Z6** and **G14.**
3. Replace the **OR** gate **G13** with its input **X10** and **G15.**
4. Replace the **OR** gate **G15** with its input **X11** and **X12.**
5. Replace the **AND** gate **G6** with its input **G7, H3** and **G8.**
6. Replace the **OR** gate **G7** with input **G9** and **Z2.**
7. Replace the **OR** gate **G9** with input **Z4, X6** and **X7.**
8. Replace the **OR** gate **G8** with input **Z3** and **G10.**
9. Replace the **AND** gate **G10** with input **X6, X9** and **G11.**

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10. Replace the **AND** gate **G11** with input **Z5** and **H4.**
11. Replace the **AND** gate **G11** with input **G3, G4** and **X1.**
12. Replace the **OR** gate **G3** with input **X2** and **X3.**
13. Replace the **OR** gate **G4** with input **X4, H1, Z1** and **G5.**
14. Replace the **OR** gate **G5** with input **H2** and **X5.**
15. Replace the **AND** gate **G18** with input **G19** and **H8.**
16. Replace the **OND** gate **G19** with input **G20** and **X14.**
17. Replace the **AND** gate **G20** with input **H9** and **Z9.**
18. Replace the **OR** gate **G14** with input **Z7** and **G16.**
19. Replace the **OR** gate **G16** with input **G17, H6,** and **Z8.**
20. Replace the **AND** gate **G17** with input **X13** and **H7.**

This would generate ten first-order cut sets **(H6, H7, H8, Z6, Z7, Z8, X6, X10, X11,** and **X13)** among other higher order cut sets.

VII. Conclusion

Fault tree analysis has become important in determining system behavior and probabilities of occurrence of undesirable event(s) that can impede production processes, increase downtime, reduce product quality and profitability of a company.

In this study (using the Kristen model as reference) we have drawn the fault tree diagram for the Production Line of a Soft Drink Bottling Company in Benin City, Nigeria. We have also analyzed the system to obtain the probabilities of the identified events leading to the occurrence of the top event. Even though probabilities of all the events were qualitatively calculated, events G1, G12, 14 and G16 would require additional attention to avoid the occurrence of "Bottles not full with content and has particle inside". Furthermore, the minimum cut sets would help in both managerial and maintenance decision of the company.

However, it is of importance to note that a Fault Tree is only a model of reality, whose estimate is a perception of reality which cannot be duplicated. This is as a result of lack of proper planning and foresight that might necessitate the restructure of the entire tree, renaming of events in the tree, gates over confidence, gates calculation errors and incorrect time implications.

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REFERENCES

[1] G.O. Ariavie, G.C. Ovuworie and S.S. Ariavie, "Fuzzy Failure Probability of Transmission Pipelines in the Niger Delta Region of Nigeria: The case of Third Party Activities". *Journal of the Nigerian Association of Mathematical Physics.* Volume 18. (May 2011), pp 445 – 450. 2011a.

[2] G.O Ariavie, G.C. Ovuworie and S.S. Ariavie, "Clark and Reza-Latif-Shabgahi Algorithm for the Determination of the Minimal Cut-Sets of the Fault Tree of Pipeline Failure in the Niger Delta Region of Nigeria". *Journal of the Nigerian Association of Mathematical Physics*. Volume 18. (May,2011) pp 451 – 458. 2011b.

[3] G.O. Ariavie, S.S. Ariavie and G.C Ovuworie, "Eliciting Expert Judgment for Determination of Failure Probability of Transmission Pipeline in the Niger Delta region of Nigeria". *Journal for Science, Engineering and Technology*. (JSET) Volume 18 Number 2 of June, 2011. Pp 10162 – 10177. 2011c.

[4] G.O Ariavie and R. Edokpia, "MOCUS Algorithm for the Determination of the Minimal Cut-Sets of Fault Tree of Pipeline Failure in the Niger Delta Region of Nigeria". *Journal for Science, Engineering and Technology*. (JSET) Vol. 18 No. 2 of June, 2011. pp 10011 – 10019. 2011.

[5] J.H. Berk, "Systems Failure Analysis: A Fault-Tree-Driven, Disciplined Failure Analysis Approach". Accessed online on 13th January 2012. http://www.jhberkandassociates.com/systems_failure_analysis.htm

[6] P.L. Clemens, " Fault Tree Analysis". 4th Edition, Sverdrup Publication. May 1993. Accessed Online on 13th January, 2012. www.fault-tree.net

[7] DOE-HDBK-1100-96. "Chemical Process Hazards Analysis Handbook". A United States of American Department of Energy Publication. 1996.

[8] C.A. Ericson, "Fault Tree Analysis: A History". *Proceeding Of The 17th International System Safety Conference* 1999.

[9] C.A. Ericson, "Hazard Analysis Techniques for System Safety II". John Wiley and Sons Inc. Copyright (c) 2005.

[10] H. Kirsten, " Workshop on Evaluation of Risk as Decision Making with the Criterion", Denver, Co.1999.

[11] NUREG-0492. "Fault Tree Handbook". Edited by Roberts N.H., Vesely W.E., Haasi D.F., and Goldberg, F.F. U.S *Nuclear Regulatory Commission.* 1981

[12] R. M. Sinnamon and J.D. Andrews, "Improved Efficiency in Qualitative Fault Tree Analysis". *Quality and Reliability Engineering International*" Vol. 13, 1997. pp 293 – 298. 1997a

[13] R.M. Sinnamon and J.D. Andrews, " New Approaches to Evaluating Fault Trees". *Reliability and System Safety*, Vol. 58 No. 02, 1997. 1997b

[14] M. Stamatelatoes, W. Vesely, J. Dugan, J. Fragola, J. Minarick, and J. Railsback, " Fault Tree Handbook with Aerospace Application*". Prepared FOR NASA Office of Safety and Mission Assurance, NASA Headquarters, Washington, DC 20546. August* 2002

[15] Y. Wang, "Development of a Computer-Aided Fault Tree Synthesis Methodology for Quantitative Risk Analysis in the Chemical Process Industry" *A Ph.D Dissertation Submitted to the Office of Graduate Studies of Texas A and M University.* 2004