ISSN 2083-1587; e-ISSN 2449-5999
2023,Vol. 27,No.1, pp. 255-271
Agricultural Engineering
www.wir.ptir.org
DOI: 10.2478/agriceng-2023-0019

REDUCING THE PROBABILITY OF FAILURE IN MANUFACTURING EQUIPMENT BY QUANTITATIVE FTA ANALYSIS

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ARTICLE INFO

Article history:
Received: May 2023
Received in the revised form: August 2023
Accepted: September 2023

ABSTRACT

Fault Tree Analysis (FTA) is a method that directly focuses on the modes of failures. The FTA is a graphical representation of the major faults or critical failures associated with a product, as well as the causes

Keywords:
fault tree;
fault probability;
production technology;
failure mode

for the faults and potential countermeasures. The aim of this research paper is to calculate the probability of the top event – the failure of the process using FTA and propose a technique to prioritize factors for action design and reduce the likelihood of a top event failure based on manufacturers' requirements. We have constructed a qualitative fault tree to produce office components packed and sealed in blister packs using a KOCH KBS-PL machine. We defined the top event G – the production of office components, packed and sealed in blister packs on the machinery KOCH KBS-PL. Then we defined events leading to top events down to individual failure factors. Based on the links between the fault tree and the probability of failure, we performed a quantitative analysis to determine the probability of failure of individual events. We found out that the probability of failure of G is 5.04%. Subsequently, we identified which factors most significantly reduce the resulting probability of failure of factor G. These are the factors: E – feed rate, F – cooling, AL – incorrect setting and D – break. It has been proven that by controlling these 4 factors, we can reduce the probability of failure of top event G to 2.36%, provided that effective measures are taken. The final proposal meets the requirements of several manufacturers for a fast, efficient, and cost-effective solution. We have created a proposal that saves time, has minimal software and hardware requirements, and is easy to use. The efficiency and effectiveness of the proposal was that we identified the weakest points in the fault tree that most significantly cause the top event to fail. This prioritized the factors for the design of the measures.

Introduction

Systems used by manufacturers need to be highly reliable for safety reasons, as well as for the sake of production quality. Kabir defines reliability as the general characteristic (ability) of a product to perform the required functions within a specified time, while maintaining the operating characteristics given by the technical conditions (understood as a set of specifications of the technical and operating characteristics of the equipment, the methods of its operation, maintenance and repair, prescribed for its required function) (Kabir, 2017, Dziki, 2023). In other words, reliability is "the probability that a piece of equipment or component will perform its intended function satisfactorily for a prescribed time and under stipulated environmental conditions" (Kabir et al., 2020).

By end-to-end fault tree analysis, we can improve both system reliability and production quality by determining the probability of failure of a top event. When quantifying the probability of failures, we can start from past events. We should also consider events that have not occurred before (Tanaka et al., 1983, Postnikova et al., 2022). The method that is suitable for assessing causes of critical systems is the Fault Tree Analysis (FTA) method (Markulik et al., 2021a).

FTA is a tool that uses quantitative analysis. The first step is to determine the top event and then systematically assign the causes of the event shown in the tree from top to bottom. The probability of failure is then quantitatively determined (Tavakoli and Nafar, 2021). According to Luo W. et al. FTA computes a large class of system reliability properties and measures based on the fault tree that models failure propagation in a system (Luo et al., 2021).

FTA is also used as a risk assessment method to eliminate risks in industrial processes (Zhu et al., 2021).

In FTA, it is important to go from the top event to the basic events. The frequency of their occurrence will ultimately determine the probability of failure of the top event (Purba et al., 2015; Sallak et al., 2008). This is why the determination of base events as definitive events is so important. (Abdelgawad & Fayek, 2010; Song et al., 2008; Volkanovski & Čepin, 2011). We know two types of uncertainties, which may raise in basic event reliability evaluations, i.e. alleatory and epistemic uncertainties (Aven, 2011). Allative uncertainty is characterized by probability distributions, epistemic uncertainty contains incomplete information, and is characterized by fuzzy solutions.sets (Dubois & Prade, 2012; You & Tonon, 2012).

Many authors have advanced the quality of FTA implementation using various simulations, hybrid models, or tools (Čepin & Mavko, 2002). Together with the Decision Making Trial and Evaluation Laboratory (DEMATEL), the FTA was used in identifying the risk of causality from top to bottom and from left to right (Spalanzani et al., 2020, Kovalenko et al., 2021).

Along with FTA, the Monte Carlo method was used to simulate the effect of the probability of base events on the probability of the top event, simulation to reduce the set of cuts to the minimum set of cuts and also to calculate the reliability of the system (Markulik et al., 2021a; Ruijters & Stoelinga, 2015a). Mostly, the analysis is designed for continuous-time or qualitative models (Aliee & Zarandi, 2013; Durga Rao et al., 2009; Vesely & Narum, 1970). Many authors have used the FTA solution in the fuzzy form (M.R. et al., 2011; Nadjafi et al., 2016; Zadeh, 1965). The fuzzy method has been used to determine the time to failure (TTF) (Baraldi et al., 2010; Flage et al., 2013; Zio & Pedroni, 2010; Zonouz & Miremadi, 2006). FTA is most often used with quantitative analysis for multi-state systems with high complexity (Dugan et al., 1992; Rao et al., 2010).

The goals of the paper are:

– to calculate the probability of the top event – the failure (early termination) of the process using the FTA
– to propose a prioritization of factors used to design measures and to reduce the probability of failure of a top event based on manufacturers' requirements.

The goal of the paper was defined based on the manufacturer's request for prioritization or selection of factors for efficient and effective proposal of measures. Please note that a concrete proposal of measures was not the research goal.

Materials and methods

The procedure for creating an FTA analysis is as follows. A successful fault tree analysis requires the following steps (da Costa et al., 2020; Plura, 2012):

1. Identify the objective – for the purpose of analysis, in our research paper, we have chosen the production of office components packed and sealed in blister packs using a KOCH KBS-PL machine (Fig. 1).
2. Define the top event –the top event is selected by stratification of possible failures in the production process/technology using KOCH KBS-PL (G) considering the highest risk.

3. Define the scope – at the start of production, prefabricated trays (with dimensions of the manufactured component) are inserted into the plate by the blister foil loader. The plate is then moved at a set speed along the belt to a set position, where the automated loader inserts the first batch of components into the trays. Another batch of components is inserted, then the components are arranged. At the end of the belt, the loaded blister trays relate to the relevant card (contains labelling, description and function of a specific component, and the sealing technology). The cover card, which follows the exact shape of the tray with components, is inserted onto the blister plate by the card loader and sealed along with the blister. A visual inspection is performed by the end operator and the component is placed into a cardboard box, then it is marked, and a data label is attached. The last step is packaging, automatic strapping, manual storage, and transport.
4. Define the print resolution – external dispenser (G1), blister foil (G2), pressing (G3), labelling (G4) and forming trays (G5).
5. Define basic rules.
6. Construct the fault tree (FT).
7. Evaluate the fault tree.
8. Interpret and present the results.

KOCH KBS-PL machine

The blister packing machine produces blisters from foil, which are sealed with a cover card. KOCH KBS-PL consists of several components which are described below.

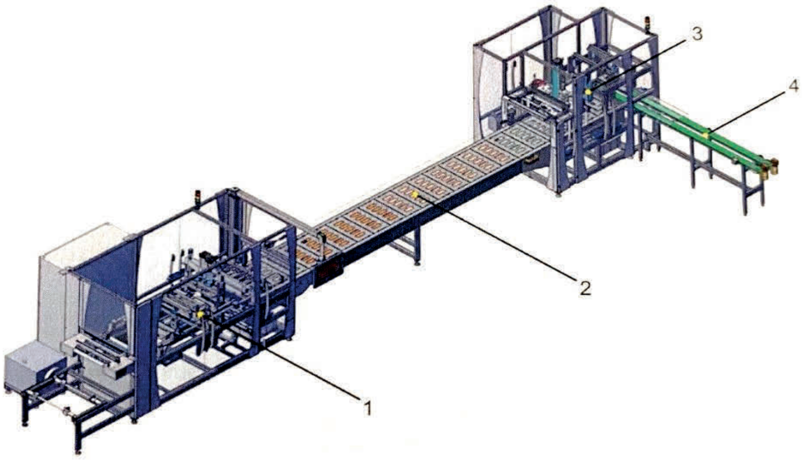


Figure 1. Schematic representation of a KOCH KBS-PL machine: Key: 1 - Forming machine, 2 - Plate transport, 3 - Welding machine, 4 - Product delivery

Furthermore, the machine is divided into two basic units, which process components from the initial to the final form. These units have their specific names and subgroups and are interconnected to fulfill the prescribed function as well as to ensure the smooth operation of both the equipment and the production process. The blister packing machine produces blisters from foil and seals them with a cover card. KOCH KBS-PL consists of several components which are described in the following lines.

Constructing the qualitative FTA

In FTA, a fault tree is created – a logical model of the relationship of an adverse event to a number of underlying events. The FT (fault tree) is deductive in nature, which means that the analysis starts with the top event (system fault) and proceeds backwards from the top of the tree to the leaves of the tree in order to determine the root causes of the top event.

The top event of the fault tree (G) is the adverse event. The intermediate events are the intermediate events (G1, G2, ..., G_n) and there can be multiple levels of them. We then denote them as follows (G11, G12, ... , $G1_n$; G21, G22, ..., $G2_n$; G_n1, G_n2, ... , G_{nn}) The bottom of the fault tree is the cause of the top event or base events. We also refer to them as the underlying factors. The logical relationships of the events are represented by logical symbols or gates (AND - OR). The results of the analysis show how different component failures or certain environmental conditions can combine to cause a system failure (Kang et al., 2019).

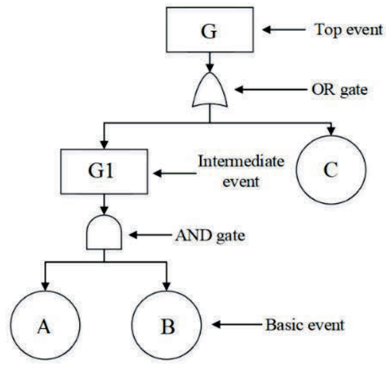


Figure 2. Structure of the fault tree (Kang et al., 2019)

The qualitative analysis is based only on the structure of the fault tree and the causal relationships of the events leading to the top event (Xu et al., 2021).

Evaluation of the quantitative FTA

The purpose of this analysis is to calculate the occurrence probability of the top event (Xu et al., 2021). In quantitative analysis, it is mathematically computed (Ruijters & Stoelinga, 2015b). Once the qualitative analysis is established, the fault tree can be evaluated quantitatively. The key is to know the number of occurring adverse events and calculate the probability for each gate separately (Kang et al., 2019). It is also important to consider the type of gate (Kang et al., 2019).

The gate "AND", i.e. A, is used if an event occurs after at least one of the upcoming events, or mutually in all of them, that affect the event that is connected to this gate (eq. 1). The gate "OR", that is, OR, is used if the input event occurs when any of the outgoing events occur. It is a logical sum (Eq. 2).

$$P(G) = \prod_{i=1}^{n} P(A_i) \tag{1}$$

$$P(G) = 1 - \prod_{i=1}^{n} (1 - P(A_i)) \tag{2}$$

In solving the quantitative analysis, we will use the bottom-up approach. That is, we start by determining the probabilities of the underlying factors, then determine the probability of the intermediate events, and finally the probability of the top event (Markulik et al., 2021a).

Proposal to reduce the probability of failure

The chosen proposal to reduce the probability of failure based on quantitative analysis of the FT will respect the requirements of production organizations. Based on this, we defined 5 proposal requirements: 1) timesaving; 2) minimum software requirements; 3) minimum hardware requirements; 4) easy to use; 5) efficient and effective.

The design will be based on quantitative analysis calculations. The aim is to identify which gates of the fault tree need to be addressed as a priority and what effect this will ultimately have on reducing the probability of failure of a top event. Then, based on the constraints and FT gates, we will create a complex system, in which by reducing the probability of each single factor, we will also see a change in the probability of the top event G. We will do this by gradually reducing the level of each single factor to a minimum (at the failure probability 1) and see how this affects the overall potential reduction in the failure probability of the top event in the fault tree. We repeat the procedure for every failure mode. To simulate the probability of a top event failure mode, many authors have used the Monte Carlo method (Baraldi et al., 2010; da Costa et al., 2020; Markulik et al., 2021b; Zio & Pedroni, 2010; Zonouz & Miremadi, 2006), the critical cuts method (Barozzi et al., 2021; Hu et al., 2021; Xu et al., 2021).

Evaluation team

The created team consisted of three university researchers (authors of the paper), 5 employees of a manufacturing company, in which the research was carried out, and another three employees from three different manufacturing companies who participated in solving the research task.

Results

Constructing the qualitative FT

The selected top event were the failures in the process of production of office components, packed and sealed in blister packs using a KOCH KBS-PL machine (gate G).

Based on brainstorming, the identified number of failure modes, and the described work process we defined the events leading to the top event, of which we selected the 5 most serious ones – external dispenser (G1), blister foil (G2), pressing (G3), labelling (G4) and forming trays (G5) (Fig. 3).

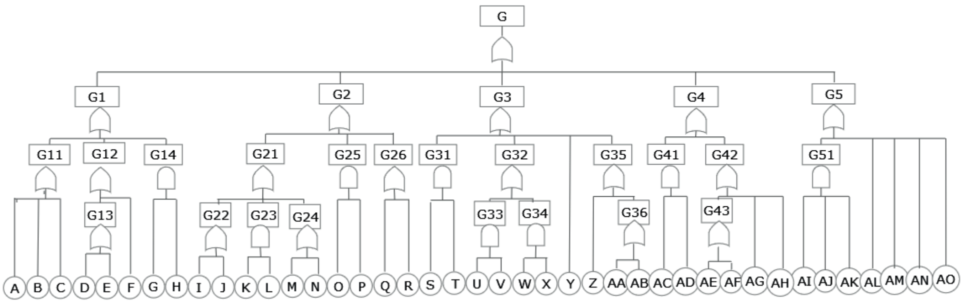


Figure 3. A FT constructed by means of FTA analysis

Evaluating the quantitative FTA

Using MS Excel and equations 1 and 2 (Chapter 2.2), we calculated the probability of failure at each gate and determined the highlight. We assumed the probability of failure of factors A, B, ..., AO. Their names are listed in Table 1. For calculations, we used the bottom-up analysis, shown in the table as from left to right.

The probability of the basic events and factors (A,B, ... , AO) was evaluated based on data collected over a period of four years, i.e. since the machine was put into production. Below is the proportion of the factors as failure modes to the total number of operating cycles. These data were supplied by the manufacturer (Table 2).

Table 1.
A quantitative fault tree analysis.

Factor			3. resolution		2. resolution		1. resolution		Top event	
F	Factor	P	G	P	G	P	G	P	G	P
A	Low Rpm	0.0054								
B	Low Speed	0.0040			G11	0.0000				
C	Stopping the Dispenser	0.0054								
D	Break	0.0047	G13	0.0147			G1	0.0223		
E	Feed Rate	0.0100			G12	0.0222				
F	Cooling	0.0077								
G	Setting	0.0057			G14	0.0001			G	0.05040
H	Visibility	0.0120								
I	Deformation	0.0007	G22	0.0010						
J	Break	0.0003								
K	Reduced Sharpness	0.0017	G23	0.0000	G21	0.0037	G2	0.0073		
L	Crack	0.0007								
M	Deformation	0.0010	G24	0.0027						
N	Crack	0.0017								

Factor			3. resolution		2. resolution		1. resolution		Top event	
F	Factor	P	G	P	G	P	G	P	G	P
O	Pump	0.0013			G25	0.0000				
P	Injector	0.0030								
Q	Equipment Conversion	0.0010			G26	0.0037				
R	Foil Replacement	0.0027								
S	Jam	0.0007			G31	0.0000	G3	0.0013		
T	Dirty Plate	0.0007								
U	Crack	0.0007	G33	0.0000	G32	3E-07				
V	Scratch	0.0003								
W	Break	0.0003	G34	0.0000						
X	Deformation	0.0003								
Y	Cooling	0.0000								
Z	Suction	0.0003								
AA	Crack	0.0003	G36	0.0010	G35	0.0013				
AB	Sliding Out of the Cover	0.0007								
AC	Emergency Setting	0.0010			G41	0.0000	G4	0.0060		
AD	Revision of El. Parts	0.0007								
AE	Poor Quality Material	0.0010	G43	0.0033	G42	0.0060				
AF	Dirt	0.0023								
AG	Guide Rollers	0.0013								
AH	Cooling	0.0013								
AI	Dirt	0.0013			G51	0.0000	G5	0.0143		
AJ	Insufficient Pressure	0.0027								
AK	Jam	0.0007								
AL	Incorrect Setting	0.0067								
AM	Blackout	0.0033								
AN	Suction Cups	0.0017								
AO	Dimensions of Trays	0.0027								

Key: G – gate, P – probability of failure

Based on the bottom-up FTA analysis (Table 1), we have found that the probability of failure of the top event G is 5.04%, i.e., 0.0504. The probability value of the top event was determined from the probability of the basic factors by considering the logical relations and the fault tree structure using formulae 1 and 2.

Gate G1 (external dispenser) is the most important contributor to the occurrence of the top event (G). The probability of gate G1 is 0.0223, i.e., 2.23%.

Events G1 participate in G11 (incorrect machine settings), G12 (technical errors) and G14 (software errors). Although G14 has the most numerous representations, from the point of view of the evaluation of ties G12 (P = 0.0222) is the main contributor to the total failure of the top event. Here we have defined factor F and gate G13 (feed plates) caused by factors D and E. By software simulation we have found out that only by solving the failure of factor E we can reduce the resulting probability of top event G by 0.93%.

Gate G2 (blister foil) is also involved in the occurrence of the top event G. The probability of gate G2 is 0.0073. The events involved in G2 are G21 (incorrect setting), G25 (cooling), and G26 (other factors). Gate G26 contributes to the overall failure of event G1 by factor R. By proposing measures to eliminate the occurrence of factor R, we can reduce the probability of failure of the top event G by 0.18%.

Gate G3 represents a failure in the pressing process. The probability of gate G2 is 0.0013. G31 (suction cups), G32 (fixed machine parts), factor Y and G35 (other failures) are responsible for event G3. Gate G3 currently does not represent an event that would cause the failure of the top event G. Therefore, in terms of prioritizing the setting of measures, we suggest addressing it last.

Gate G4 represents a failure in the labeling process. The probability of gate G2 is 0.0060. G4 is caused by gates G41 (blackout) and G42 (gluing device). G2 may cause the failure of G43 (suction) or G44 (protective cover). The AF factor is the most important contributor to the failure of the top event G. By proposing measures to eliminate the occurrence of the AF factor, we can reduce the probability of failure of the top event G by 0.19%.

Gate G5 represents failures in the formation of trays. The probability of gate G2 is 0.0143. G51 (low pressure) and factors AL (incorrect setting), AM (blackout), AN (suction cups), AO (tray dimensions) are involved in the G5 event. A G51 failure occurs when the AI, AJ and AK factors fail at the same time. The AL factor is most involved in the failure of the top event G. By proposing measures to eliminate the occurrence of factor AL, we can reduce the probability of failure of the top event G by 0.61%. From this point of view, it is the second most important factor after the E factor.

Proposal to reduce the probability of failure

To achieve the second objective, we simulated how a potential reduction in the probability of failure of each factor would affect the reduction in the probability of failure of the top event G. Based on the quantitative analysis (based on formulas 1 and 2; results in Table 1), we found that the factors listed in Table 2 contribute most significantly to reducing the probability of failure of the G top event. The design and application of corrective actions for a factor is a fundamental prerequisite. We assigned a frequency probability with a value of 1 for each factor in Table 2.

If we only dealt with the basic probabilities (based on the frequency) without taking into account the FTA methodology, the solution would be simpler and we would propose measures for the factors with the highest probabilities. But FTA also takes into account the relations between factors and events. Therefore, in the proposal we observed how the probability of failure of the top event G will be affected if a particular factor (A, B, ..., AO) is always reduced to a minimum level.

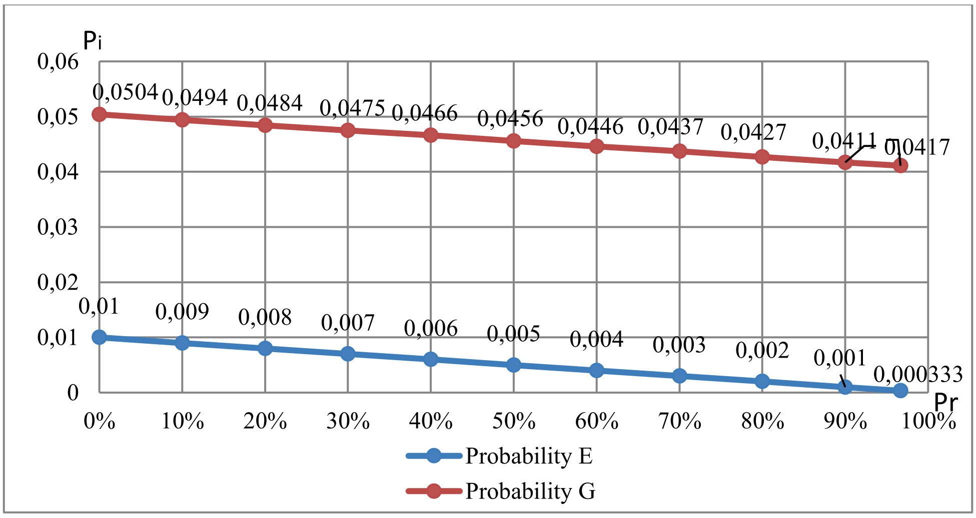
Table 2.
Simulation of the reduction of the probability of the top event G failure.

Factor	Probability G	New probability G	Classification
D	0.0504	0.0462	4
E		0.0411	1
F		0.0434	2
AF		0.0485	7
AG, AH		0.0494	9/10
AL		0.0443	3
AM		0.0475	5
AN		0.0491	8
AO		0.0481	6

Table 2 shows the classification of the 10 factors that, based on the proposal, will most significantly reduce the probability of failure of the top event G. According to Table 2, factor E (external dispenser plate feed rate) contributes the most significantly to reducing the probability of failure of the top event G. The following factors are F (external dispenser cooling), AL (incorrect set tray setting), D (external dispenser plate break).

If we reduce the number of failure modes of factor E to 1, we will reduce the probability of failure of this factor by 0.01 to 0.0003 and subsequently the probability of failure from 0.0504 to 0.0411. If we reduce the number of failure modes of factor F to 1, the probability of failure of this factor will decrease from 0.0077 to 0.0003 and subsequently the probability of failure from 0.0504 to 0.0434. If we reduce the number of failure modes of the AL factor to 1, the probability of failure of this factor will decrease from 0.0067 to 0.0003 and subsequently the probability of failure from 0.0504 to 0.0443. If we reduce the number of failure modes of factor D to 1, the probability of failure of this factor will decrease from 0.0047 to 0.0003 and subsequently the probability of failure from 0.0504 to 0.0462. If we reduce the number of failure modes of the AM factor to 1, the probability of failure of this factor will decrease from 0.0033 to 0.0003 and subsequently the probability of failure from 0.0504 to 0.0475.

Figure 3 shows the impact of changing the factor E while gradually reducing the probability by 10% on the top event G.



Legend: P_i - Probability of failure of the i-th factor, P_r - Percentage reduction in probability of failure.

Figure 3. Reducing the probability of failure of a top event G based on reducing the probability of failure of a factor E

Figure 4 shows how the overall failure probability of top event G is reduced based on a successive 10% reduction in the failure probability of factors E, F, AL and D.

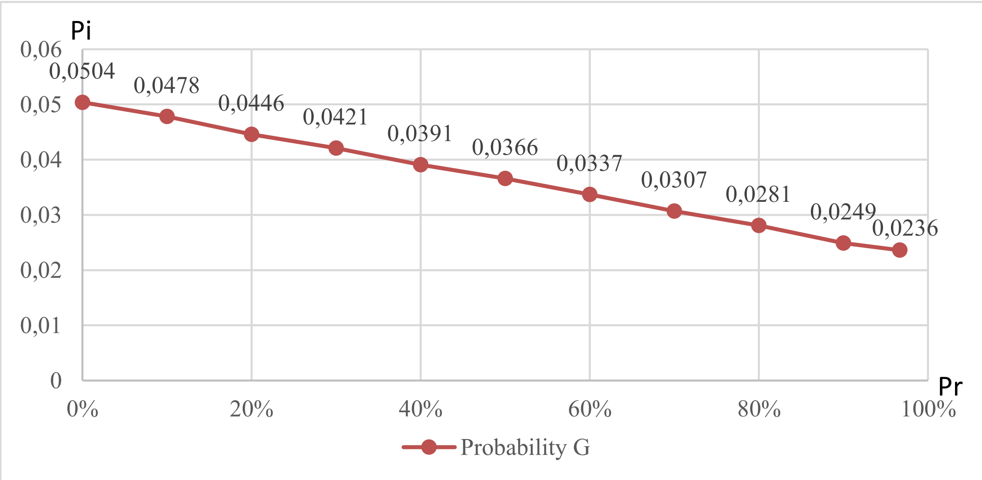
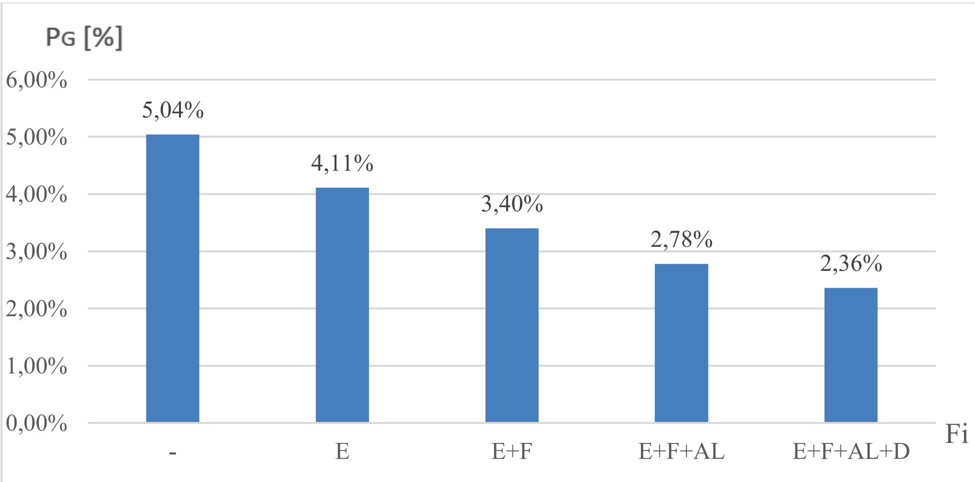


Figure 4. Reducing the probability of failure of the top event G based on the reduction in the probability of failure of factors E, F, AL and D

Figure 5 shows how we can reduce the probability of failure of the top event G. It is important to note that we can only achieve this by using high efficiency measures, namely those that will reduce the occurrence of factors such as failure modes to the level defined by the proposal conditions. The resulting probability of failure of the top event G after the combination of factors is shown in Tab. 5, Figs. 3 and 4.



Legend: P_G - Probability of failure of the factor G, F_i - I-th factor and its combination with other factors.

Figure 5. Reduction of the failure probability of the top event G

Figure 5 shows that by managing the 4 factors (E, F, AL, D) we can reduce the failure probability of G from 5.04% to 2.36%. In Figure 5, we can see in the first column the initial state of the top event failure probability. The other columns contain the predicted reduction in the top event failure probability by successively applying the measures under the conditions defined by the design.

Discussion

The correct construction of the fault tree is the basis for the successful implementation of the research. It forms the basis for a correctly performed quantitative analysis.

Ruiters and Stoelinga (Ruijters & Stoelinga, 2015b) discuss sensitivity analysis techniques, which determine how sensitive an analysis is with respect to the values (i.e., failure probabilities) in the leaves. The proposal in the paper demonstrates the sensitivity to proper fault tree construction. If the links between the factors and the gates of the fault tree are incorrectly determined, the design results will not be relevant. Baig et al. (Baig et al., 2013) say that FTA can be very time consuming and vulnerable to human error. If we want the qualitative and quantitative analysis of FTAs to be at a high level, we must pay close attention to their elaboration and carry out thorough control within the team with regard to the mentioned sensitivity of the system. Only in this way is it possible to ensure that the prediction proposal achieves professional results even in practical application within the production technology. Vesely (Stamatelatos et al., n.d.) indicates the correctly selected top event and the definition of the analysis boundary in depth. Determining the depth of the analysis was also a very difficult task in our research. Too much depth of analysis increases the expertise and time required to apply FTA, but it also increases the accuracy and decreases the sensitivity of the analysis.

Markulík et al. (Markulik et al., 2021a) their research states that when the variability of the probability of basic events increases by 10%, the probability of a top event increases to 15.7% according to the Monte Carlo method. Reducing the probability of the highest event is practically difficult to achieve without interfering with the technology. In this paper, we have analyzed in detail how reducing the probability of occurrence of each factor will affect the reduction of the probability of occurrence of a top event. Specific results are included in Table 2 and Figure 5.

Rao (Rao et al., 2010) states that to simplify the complex reliability problems, conventional approaches make many assumptions to create a simple mathematical model. We say that it was the requirements of manufacturers that were directed to our research. At the same time, the proposal answers the questions that manufacturers face in everyday practice. The proposal is simple, timesaving and software-friendly. This is especially important because in times of economic crisis, manufacturers demand fast, simple, clear and inexpensive solutions.

The actual proposal is the original work of the authors of the paper. As mentioned earlier, the simplicity of the proposal takes into account the requirements of the manufacturers. However, the result must be a clear demonstration of the increase in production efficiency and effectiveness (by reducing the number of top event failure modes), as shown by the diagram in Figure 5.

Chemweno et al. (Chemweno et al., 2015) described the importance of the assessment team in compiling a qualitative and quantitative FTA. It is the team of evaluators who guarantees the objectivity and usability of the results and the proposal itself. The team of evaluators in this paper represented a combination of university research and practice.

For future research, we propose to apply the DEMATEL technique to increase efficiency and effectiveness for perfect identification of relational links between individual factors in terms of importance and relational intensity. Although this proposal will fulfill the need for increased efficiency and effectiveness, manufacturers will also need to reconsider the other design requirements mentioned above. Flage et al. (Flage et al., 2013) compared the results of the different approaches (hybrid, probabilistic and possibilistic) with respect to the representation of uncertainty about the probability of a top event (marginal relative frequency). They critically examined the rationale underpinning the approaches as well as the computational effort they require.

Conclusions

The purpose of the paper was to calculate the probability of the top event – a failure (premature termination) of the process using FTA and the developed proposal to determine the prioritization of factors for the proposal of measures and to reduce the probability of failure of the top event in the production process on the KOCH KBS-PL machinery.

The constructed qualitative failure tree defines the events that lead to the top event from the lowest level of each factor. The relationships between the individual factors and gates allowed us to quantify the probability of their failure as well as the failure of the top event G (5.04%).

We found that event G1 (P = 2.23%) is the most significant contributor to the top event G.

Consequently, we developed a proposal that shows how reducing the failure of the selected factors achieves a reduction in the probability of failure of the top event G. The proposal is a simple guide to how to manage failure modes in practice. It is easy for manufacturers to understand and easy to implement into the process; it is not software intensive or time and cost intensive.

We found that by controlling factor E (applying measures to minimize the occurrence of the failure mode), we can reduce the probability of failure of G from 5.04% to 4.11%. By controlling factors E and F, we can reduce the probability of failure of G to 3.4%. By controlling factors D, E, F, AL, we can reduce the occurrence of the highest G failure modes to 2.36%.

Development teams of manufacturing organizations can easily design corrective measures for individual factors causing failure modes. The challenge is to identify which failure modes need quickly and correctly to be tackled as a priority to have the greatest effect. Our proposal is a response to these recurring demands.

Thus, the main result of the paper is a proposal that respects the manufacturers' requirements. We have created a design that is timesaving, has minimal software and hardware requirements (MS Excel) and is easy to use. The efficiency and effectiveness of the design was that we identified the weakest points in the fault tree that most significantly affect the failure of a top event. This prioritized the factors for designing the measures.

Conflicts of Interest: The authors declare no conflict of interest.

Authors Contribution: The entire article is the work of the first author, Marián Bujna. Miroslav Prístavka, Chia Kuang Lee, Andrzej Borusiewicz, Ivan Beloev and Urszula Malaga-Toboła participated in the interpretations and Marián Bujna worked on the quantitative analysis calculations.

Acknowledgements

This paper was created with financial support of the grant project VEGA no. 1/0102/21 - Reducing chemical loads and degradation of agricultural and forestry soils by selecting appropriate agri-technology with regard to climate change.

This paper was created with financial support of the grant project KEGA no. 016SPU-4/2021 - Implementation of modern educational approaches and tools to enhance creativity and practical skills of graduates with special focus on agricultural and forestry science using.

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ZMNIEJSZENIE PRAWDOPODOBIEŃSTWA WYSTĘPOWANIA AWARII URZĄDZEŃ PRODUKCYJNYCH DZIĘKI ILOŚCIOWEJ ANALIZIE FTA

Streszczenie. Analiza Drzewa Usterek (Fault Tree Analysis, FTA) to metoda opracowana z myślą o rozwiązywaniu usterek maszyn produkcyjnych. Umożliwia ona graficzne przedstawienie głównych usterek lub krytycznych awarii oraz ich przyczyn, a także potencjalnych środków zaradczych. Celem artykułu jest obliczenie prawdopodobieństwa wystąpienia głównego zdarzenia – awarii procesu – za pomocą FTA oraz zaproponowanie techniki priorytetyzacji czynników w projektowaniu działań naprawczych i zmniejszenia prawdopodobieństwa awarii głównego zdarzenia bazując na specyfikacji producenta. W toku badań skonstruowaliśmy jakościowe drzewo usterek do produkcji komponentów biurowych pakowanych i zabezpieczanych w opakowaniach blisterowych na maszynie KOCH KBS-PL. Zdefiniowaliśmy główne zdarzenie G – produkcję komponentów biurowych. Następnie zdefiniowaliśmy zdarzenia prowadzące od głównych zdarzeń aż do indywidualnych czynników awarii. Na podstawie powiązań między drzewem usterek a prawdopodobieństwem awarii przeprowadziliśmy analizę ilościową, by określić prawdopodobieństwo awarii poszczególnych zdarzeń. Okazało się, że prawdopodobieństwo awarii G wynosi 5,04%. Następnie ustaliliśmy, które czynniki najbardziej przyczyniają się do zmniejszenia wynikowego prawdopodobieństwa awarii czynnika G. Są to: E – prędkość podawania, F – chłodzenie, AL – nieprawidłowe ustawienie i D – przerwa. Udowodniliśmy, że kontrolując te cztery czynniki możemy zmniejszyć prawdopodobieństwo awarii głównego zdarzenia G do 2,36%, pod warunkiem, że zostaną podjęte skuteczne działania. Ostateczna propozycja spełnia wymagania wielu producentów, którzy oczekują szybkiego, wydajnego i niedrogiego rozwiązania. Stworzyliśmy propozycję, która oszczędza czas, ma minimalne wymagania sprzętowe i programowe oraz jest łatwa w użyciu. Efektywność i skuteczność proponowanego rozwiązania polegała na tym, że zidentyfikowaliśmy najsłabsze punkty w drzewie usterek, które w największym stopniu powodują awarię głównego zdarzenia. To pozwoliło priorytetyzować czynniki do projektowania środków zaradczych.

Słowa kluczowe: drzewo usterek; prawdopodobieństwo usterek; technologia produkcji; tryb awarii.