MODELING OF PERFORMANCE OF PACKING EQUIPMENT UNITS

DainaKanaska, GunarsVerdins, RobertsVanags
Latvia University of Agriculture, Faculty of Engineering, Institute of Motor Vehicles
daina.kanaska@llu.lv, gunars.verdins@llu.lv

Abstract. There are analyzed experimental data of operating of packing equipment, identified refusal - non-correspondence with the quality requirements, as well as worked out a model of performance of the researched equipment by using the methods of Boolean algebra. There are identified events as well as causal relationships, which caused denial of the equipment performance, as well as effectiveness of variouspreventivesteps are examined.

Keywords: eventchainmodeling, Boolean algebra, truth trees, effectiveness of equipment.

Introduction

Testing of new equipment, launch of modernized facilities, upgrading of the existing equipment with new elements, as well as solving of other technical problems associated with achieving the desired results by eliminating a number of unexpected factors are discussed. The number of factors may be so large that by using experimental or traditional mathematic predictive methods (probability theory, combinatory etc.) the result cannot be reached in short terms and with low investment. As well as nowadays concurrent engineering is becoming increasingly popular instead of the traditional designing and manufacturing process; concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers from the outset, to consider all elements of the product life cycle from conception to disposal, including the quality, cost, schedule, and user requirements. A continuing trend is taking place to bring products to the market place as rapidly as possible [1; 2].

One of the possible solutions is to use the methods of Truth trees and Boolean algebra for appreciation of the working quality of the designed equipment in the phase of testing and commissioning.

Boolean algebra is the subarea of algebra in which the values of the variables are the truth values true and false, usually denoted 1 and 0 respectively. Instead of elementary algebra where the values of the variables are numbers and the main operations are addition and multiplication, the main operations of Boolean algebra are conjunction AND, denoted $\cap$, disjunction OR, denoted $\cup$, and negation NOT, denoted $\bar{x}$.

The basic operations of Boolean algebra are the following:

AND (conjunction), denoted $x \cap y$ (sometimes x AND y), satisfies $x \cap y = 1$ if $x = y = 1$ and $x \cap y = 0$ otherwise;

OR (disjunction), denoted $x \cup y$ (sometimes x OR y), satisfies $x \cup y = 0$ if $x = y = 0$ and $x \cup y = 1$ otherwise.

If the truth values 0 and 1 are interpreted as integers, this operation may be expressed with the ordinary operations of the arithmetic: $x \cap y = xy$; $x \cup y = x + y - xy$ and $\bar{x} = 1 - x$ [3].

In order toexplore howto apply the logical mathematics methods: Truth trees and Boolean algebra for solution of practical design problems we made researchofoperatingdenials of packing equipment elements. The study aims are to identify operating denials of packing equipment items that cause the system non-compliance to the quality requirements, as well as approbation of the methods of Boolean algebra for testing of the designed equipment to accelerate the testing and implementation process.

The researched object is a system, included: glazing, transfer and packaging machines, Fig.1. The aim of this system is to deliver the product for packing at the right time, location, orientation and shape without damaging. Re-transfer facility was designed to combine glazing and packing equipment in a unified system.

After testing of the transfer node prototype, it was concluded that the expected result is not achieved; the facility is operated unstable and does not fulfill its intended designing task on behalf of the independent clause. The equipment in its operations after a certain cycle performance went out of order and made an error operation. We decided to carry out a theoretical study of the process by using a mathematical model.

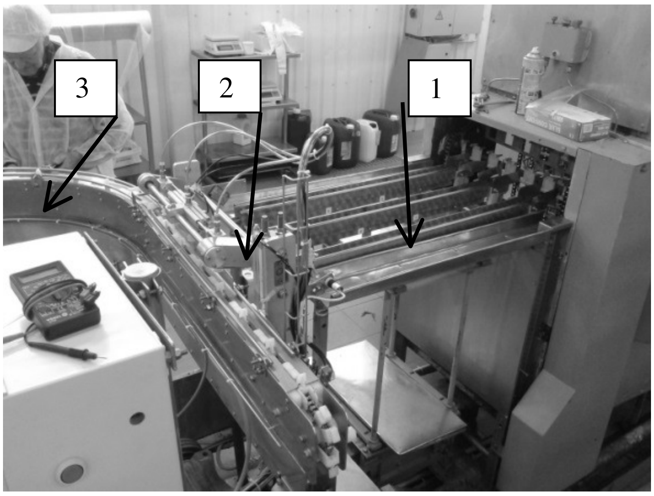

Fig. 1. **Packing line:** 1 – glazing; 2 – transfer; 3 – packaging machines

Materials and methods

Understudy aims were to install and run on packaging line, made footage admission of the line performance process, as well as of the refusal identification of elements of equipment, forming of the packing line, Fig. 1.The new facility designed was only a transfer unit, but launching of technological line is connected with coherent working of glazing and packing machines.

By examining the process closer it can be concluded that the denials of the system have occasional characteristics.The problems are based on correlations, which lead to a refusal. This refusal is characterized by Truth tree – reliability block diagram, which characterized the possibleoperations of the system, in the diagram the following expressions are used:

□ – main event of system;

○ – events that are not analyzed further, as they have enough empirical data;

⬭ – is used to describe the logical operation "OR" (logicaladdition); for the outgoing event to be true it is necessary that at least one header would be true.

The quality requirement for operation of the system isto deliver the product for packing at the right time, location, orientation and shape without damaging. As "*A*" the main event (the refusal) of the operation of the investigated system is denoted.

Event *A* is the case that is the result of the interactionof events *B*, *C*, *D*. Events are denoted by the symbols: *B* – represents glazing unitrefusal; *C* – represents transfer node refusal; *D* – represents packing machine refusal.

During the experiment it was found, that: B is sum of events*B*1, *B*2, *B*3, *B*4, *B*5; *C* is sum of events *C*1, *C*2, *C*3, *C*4, *C*5; *D* is sum of events *D*1, *D*2, *D*3, *D*4, *D*5.

The events *A*, *B*, *C*, *D* havecertain probability of occurrence; to compare events according to their degree of probability it is necessary to associate them with the figures, which are the greater, the greater is the likelihood of occurrence of the event (probability). It is a true statement, that any of the events *A*, *B*, *C*, *D* can take two fixed values: true and false.

Assume that *B*, *C*, *D* are Booleanvariable parameters, but A is variable Boolean function $A = F(B, C, D)$. For example, $A = 1$ (True), is refusal in operation of packing line, but $A = 0$ (false), if the packing line operated without refusal.

The location area of Boolean variable parameters *Bi*, *Ci*, *Di*, (*i* numbers can be from 1 to *N*) can be represented: $Bi = \{0, 1\}$; $Ci = \{0, 1\}$; $Di = \{0, 1\}$, but the location area of Boolean function A: $A = \{0, 1\}$.

$$A = F(B,C,D) = (B \cup C \cup D) = (B1 \cup B2 \cup B3 \cup B4 \cup B5) \cup (C1 \cup C2 \cup C3 \cup C4 \cup C5) \cup \\ \cup (D1 \cup D2 \cup D3 \cup D4 \cup D5) \tag{1}$$

Expression (1) is a normal disjunctive form, which is represented as disjunction of elementary disjunctives;disjunctive can be considered as elementary, if each variable parameter occurs not more than once.

In accordance with the expression (1) the function A (refusal in operation of packing line) takes value 1in the cases, when even one from ($B1$, $B2$, $B3$..., $B5$); ($C1$, $C2$, $C3$.., $C5$); ($D1$, $D2$.., $D5$) takes the value 1. To turn A function into 0 it is necessary to ensure that all Boolean variable parameters take the value 0^{th}.

The chosen methodology can help predict possible development of events, depending on the input parameters. The research and analysis of refusals is required not only for describing of the investigated refusal, but it is also the basis for analyzing and choosing the most effective methods of prevention.

As one of the refusal probability quantification methods analysis of all possible combinations of n Boolean variables can be used.It is known that n Boolean variables give 2^n various combinations of these variables, but when $n > 6$ there it is practically impossible to analyze all possible combinations. We have $n = 15$ Boolean variables, so in our case, the method is not applicable.

Probability of refusal can be appreciated by any other method: by calculation of the number of combinations of n Boolean variables, where function $A = F(B, C, D)$ becomes equal to zero (zero combination – T_0) or by calculation of the number of combinations, where $A = 1$ (solitary combinations – T_1). Equation is true:

$$T_a = T_0 + T_1, \tag{2}$$

where $T_a = 2^n$ – number of all possible combinations of n Boolean variables;
T_0 – number of zero combination;
T_1 – number of solitary combinations.

Each disjunctive in expression (1) is some set of Boolean variables, for calculation of the number of zero combinations T_0 can use the expression, analogous to the formula for calculation of the combination number of summarizing of sets. Formula for calculation of the combination number of n sets summarizing [4] is as follows:

$$N(A_1 \cup .. \cup A_n) = N(A_1) + ..N(A_n) - \left(N(A_1 \cap A_2) + N(A_1 \cap A_3) + .. + N(A_{n-1} \cap A_n)\right) + \\ + \left(N(A_1 \cap A_2 \cap A_3) + N(A_1 \cap A_2 \cap A_4) + .. + N(A_{n-2} \cap A_{n-1} \cap A_n)\right).. + (-1)^{n-1} N(A_1 \cap A_n), \tag{3}$$

where n – amount of sets summarizing;
$A_1,..., A_n$ – sets;
$N(A_i)$ – number of elements in set A_i.

Analogous with expression (3), formula for calculation of the number of zero combinations T_0 of Boolean function [5] is as follows:

$$T_0 = \left(2^{n-m_1} + 2^{n-m_2} + .. + 2^{n-m_k}\right) - \left(2^{n-(m_1+m_2)} + 2^{n-(m_1+m_3)} + .. + 2^{n-(m_{k-1}+m_k)}\right) + \\ + \left(2^{n-(m_1+m_2+m_3)} + 2^{n-(m_1+m_2+m_3)} + .. + 2^{n-(m_{k-2}+m_{k-1}+m_k)} - .. + (-1)^{k-1} 2^{n-(m_1+..+m_k)}\right), \tag{4}$$

where n – total number Boolean variables in model, $n = \Sigma m_i$;
m_i – number of members of i^{th} elementary disjunctive;
k – number of disjunctives in the expression.

In percentage $T_0\%$ value in model (Fig. 2) can be as follows:

$$T_0\% = \frac{T_0}{T_A} \cdot 100\,\%. \tag{5}$$

Further, in order to assess the efficiency of one or another method for prevention of refusal, compare the value of $T_0\%$ in the initial model and analogic values in models, formed due allowance of the impact of the prevention method on the initial model. The higher the value, the more efficient is the method for preventing. The value of T_0% on the original modelserves as a reference criterion for assessing the effectiveness.

Results and discussion

In the experimentfixed mainrefusals and probability of occurrence % are set in Table1.

Table 1

Experimentally fixed refusals in packaging line

A – main event (refusal)					
Glazing unit	*B*	Transfer node	*C*	Packing machine	*D*
Product has changed the orientation	*B*1	Product is not inflated	*C*1	Product has changed the orientation	*D*1
Dimensions of the product going out of requirement	*B*2	Product is inflated, but falls off in motion	*C*2	Product is not positioned at the right end position	*D*2
Product step is shifted from the given	*B*3	Product falls before reaching the end position	*C*3	Product step is shifted from the given	*D*3
Product falls from the grab-type node	*B*4	Product step is shifted from the given	*C*4	Product no date is required	*D*4
Product passes over the lifting of the transfer zone	*B*5	Long time before putting down product has to wait	*C*5	Dimensions of the product going out of requirement	*D*5

Casual events and links leading to the main event "*A*" referred to expression (1) are shown in the scheme in Fig. 2.

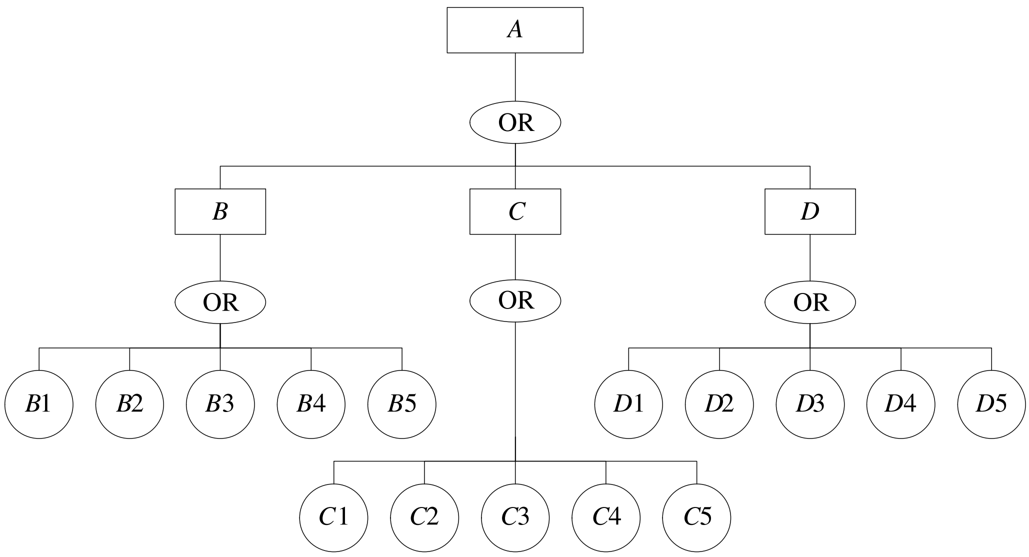

Fig. 2. **Reliability block diagram of casual events, affecting operation of packing line (initial model)**

At first define T_0 in the initial model in Fig. 2, which is characterized by expression (1) – $n = 15$, $k = 3$, $m_1 = 5$, $m_2 = 5$, $m_3 = 5$; under formula (4) T_{0A}:

$$T_{0A} = \left(2^{15-5} + 2^{15-5} + 2^{15-5}\right) - \left(2^{15-(5+5)} + 2^{15-(5+5)} + 2^{15-(5+5)}\right) + (-1)^{3-1} \cdot 2^{15-(5+5+5)} =$$
$$= \left(2^{10} + 2^{10} + 2^{10}\right) - \left(2^{5} + 2^{5} + 2^{5}\right) + (-1)^{2} \cdot 2^{0} = 3027 - 99 + 1 = 2977 \quad .$$

Define T_A in the initial model**:** $T_A = 2^n = 2^{15} = 32768$**;** define $T_{0\%}$ in the initial model:

$$T_{0A}\,\% = \frac{T_{0A}}{T_A} \cdot 100\,\% = \frac{2977}{32768} = 9\,\% \,.$$

So, in the initial model the number of zero combination, meaning operation of the system without refusals constitutes 9 % from the total number of combinations.

After improvements of operation of the elements of the packing line, the test was repeated. For example, for refusal *C*4 there were identified technical reasons, connected with design decisions and the followed steps were done: preventedundesirable movement of universal joint transmission of the glazing machine, mounted self-fusing bearings, enhanced strength of the clamshell design. In Table 2 the refusals, fixed in the repeated test are set.

Table 2

Refusals, fixed in the repeated test

*A*1	Experimentally fixed refusals		
B	Glazing unit	*C* – transfer node	*D* – packing machine
*B*1	Product step is shifted from the given	Transfer denial is not observed	Packing machine refusals have not been observed
*B*2	Dimensions of the product going out of requirement		

According to Tab.2 a new model is created, where improvements are taken into account.

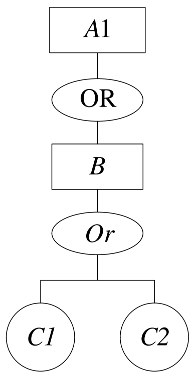

Fig. 3. **Reliability block diagram of casual events, affecting operation of packing line after improvement in performance**

Define T_0 in the second model in Fig. 3, where *A*1 – main event, after improvements in the systems which is characterized by expression (6):A1 ($B1 \cup B2$), (6)

According to expression (6) $n = 2$, $k = 1$, $m_1 = 2$, under formula (4):

$$T_{0A1} = \left(2^{2-2}\right) - \left(2^{2-2}\right) + (-1)^{1-1} \cdot 2^{2-2} = \left(2^{0}\right) - \left(2^{0}\right) + (-1)^{0} \cdot 2^{0} = 1 - 1 + 1 \cdot 1 = 0 + 1 = 1$$

Define T_A in the second model: $T_{A1} = 2^2 = 4$; define $T_0\%$ in the second model:

$$T_{0A1}\,\% = \frac{T_{0A1}}{T_{A1}} \cdot 100\,\% = 25\,\%$$

The result obtained means that thenumber of zero combinations (system operated without refusals) is 25 % from all possible combinations. Compared with the analogical value of the initial model $T_{0A} = 9$ % – the rate of possibility that the system operates without refusals increased 2.8 times.

In addition, from the model in Fig. 3 we see that the refusals that affect the performance of the system are not related to the Transfer node operation.

Conclusions

1. For successful analysis of information, obtained in the process of testing of the designed transfer node and packing line it was expediently to use the method of Boolean algebra.
2. By using the method of Truth treesdevelopment (reliability block diagrams of casual events) it is simply and quickly toobtain qualitative and quantitative data that characterize the accordance of the operation of the packing linewith the initialtask for design.
3. The example described in the paper characterizes practical using of the method and demonstrates that after removing of technical reasons of refusals there is achieved improvement of the system operation, characterized with increasing of the ratio of T_0 % from 9 to 25 %, it is 2.8 times.

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