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# CLUSTER ANALYTICAL METHOD OF FAULT RISK ANALYSIS IN SYSTEMS

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**Abstract**

*In providing safety functions, the proposal of safety functions of control systems is an important part of a risk reduction strategy. In the specification of security requirements, it is necessary to determine and document individual characteristics and the desired performance level for each safety. This article presents the results of the experiment cluster analysis.*

*The results of the experiment prove that the methods of cluster analysis provide a suitable tool for analyzing the reliability of safety systems analysis. Regarding the increasing complexity of the systems, we can state that the application of these methods in the subject area is a good choice.*

**Key words**

*control systems, safety functions, analyzing reliability, cluster analysis*

## INTRODUCTION

When a constructer develops the strategy of reducing the target fault risks, he should chose an approach for the reduction of risk in security safety systems. Safety parts of control systems have to provide safety functions, which consist of hardware and software. Those elements can be part of control system devices or work itself. The ability of safety components in control systems to carry out the safety function under unpredictable conditions is defined by five performance levels. Performance levels are determined according to the probability of emergence of a non-safety fault per hour (ISO 13849-1, 2006).

The probability of emergence of a non-safety fault depends on many factors – hardware and software architecture, the range of funds of error- detection: diagnostic coverage, reliability of individual components – (mean time of non-safety faults, operational stress, developing process, operating procedures etc.).

Categories of performance levels may be applied to the safety elements of a control system such as:

- Control elements (drives, motors, relays, valves, etc.);
- Protective equipment (various locking devices, two-hand control devices, pressure-responding devices, etc.);
- Processing unit (data processing, logic unit to control functions, monitoring, etc.).

Safety parts of the control system provide safety functions on a performance level in order to reduce risks. In providing safety functions, the proposal of safety functions of control systems is an important part of a risk reducing strategy. In the specification of security requirements, it is necessary to determine and document individual characteristics and the desired performance level for each safety. Safety-related parts of control systems must be designed according to the principles set out in the relevant standards.

The IEC 61511-3 standard describes a method of elaboration of all procedures related to risk. The purpose of the standard is to define the control itself along with safety functions. The strategy for ensuring security must be justified. Simultaneously, determination of all activities and methods of assessment should be an integral part of the strategy. The ETA method is a part of the IEC 62502 standard.

## RISK ANALYSIS METHODS

There is a big group of analysis methods existing in the area of security risk analysis. The choice of each method depends on the range of the analyzed system, time – severity, technical feasibility, etc. The basic risk analysis methods mainly include the index method, revision of security, threat analysis, analysis of the causes and consequences below. One of the key areas of risk analysis is an identification system reliability. The main methodological tool for identifying the system reliability is the fault tree analysis and event tree analysis, or a combination thereof in the form of analysis of cause and effect.

Fault Tree Analysis (FTA) represents a diagram of the logical relationship between a sub-system and component failures and how they combine to cause system failures. Unlike analysis by the tree of faults, analysis by the tree of events focuses on the causes of events and identifies the next possible course. If we combine both methods, we can gain a comprehensive model of non-safety appearances (faults), the reason for this and its predictable effects. Although the use of these methods is suitable for complex systems with increasing complexity of the demands on time and resources increased significantly. Since it is a complex system, it is also very difficult to capture all potentially non-safety appearances, it is important to use methods of due diligence in the process of failure analysis.

## EVENT TREE ANALYSIS (ETA)

The main target of ETA is the identification of the sequence of events in a process leading to a critical event (failure). The result of this analysis is a graphic representation of a logical model - the tree of events which vulnerabilities identified the analysis process. When the ETA method (1, 2, 3) is used often in analysis of difficult processes, there exist faults that have unpredictable occurrence. An appropriate tool for research into the reliability of the safety analysis of complex and wide system seems to be the method of cluster analysis. The advantage of cluster analysis is the possibility of decomposition or a set of elements of the homogeneous set of (clusters) based on the similarity relatedness of objects. The methods of cluster analysis can be used in Event Tree analysis.

## EXPERIMENT

The subject of analysis of fault events was a technological process in the manufacture of semi products in clutch lining which was based on the impregnation of the fabric yarns in a designated chemical solution blended with a dangerous flammable liquid with xylene, an aromatic smell. The dryer is equipped with a gas-warning device. For charging of the underlying dryer fan is a circulating air fan and exhausted air, which drives the winding dryer and flaps. In figure 1 is presented the equipment for heating winding dryers as the part TP. The winding dryers always consist of one circulating air ventilator (M2.2) and one pulling air ventilator (M2.1). The heating regulation of circulated air directs a valve position of heating air (K2.2) and the valve of fresh air (K2.1). The valve of the pulled air (K2.3) is regulated to correspond to a concentration in the interior of the furnace. The combustions can be directly removed from the production hall by the flushing valve (K2.4) in specific situations.

The main order of this experiment is the identification of chains of fault events of the device for heating of the dryers, which leads to the critical event (fault). This event can have an unacceptable influence on the safety functions of the device. The database for analysis consisting of a constellation of faults (archive of faults), which is a result of monitoring of fault-messages. All fault-events are placed into an archive of faults in the sequence of events plus additional parameters such as date and time of occurrence of an event, the level of gravity of the fault condition solutions etc. The fragment archive is shown in Tab. 1.

For the purposes of analysis, a set of 5000 error events consisting of 32 Error conditions (P1 - P32) were chosen. The error events were transformed into a neighboring matrix A={aij}, with elements of the matrix representing the average distance (distance ordinal) disorders (4). The fragment of a neighboring matrix is shown in Fig. 2. The transformed data was analyzed by the methods of cluster analysis in the STATISTIKA software (5).

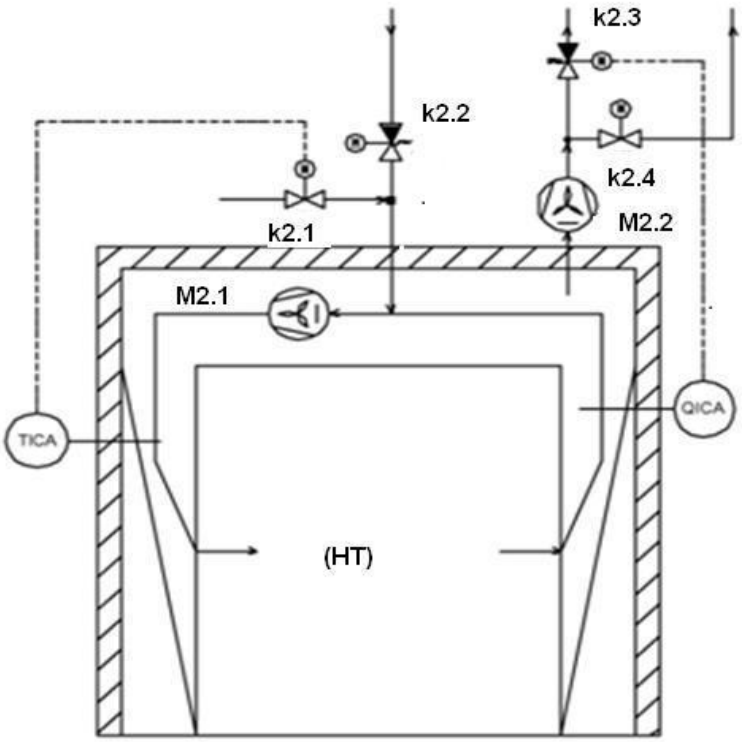


***Fig. 1***

**Table 1** Archive of faults

| | | |
|---|---|---|
| 16:15:02 | 16.01.14 | Failure of a solution in xylene |
| 10:03:51 | 20.01.14 | CO sensor failure in the pipe conveying the hot clean air |
| 14:06:21 | 20.01.14 | Wrong password or login name. Login failed. |
| 11:02:00 | 21.01.14 | Failure of low blood sodium xylene |
| 17:24:16 | 23.01.14 | Failure of the door of the winding dryer |
| 17:24:17 | 23.01.14 | Failure of the control computer |
| 17:24:18 | 23.01.14 | Engine cooling fan to circulate air in the dryer |
| 9:48:20 | 24.01.14 | Failure of the temperature sensor |
| 13:18:09 | 25.01.14 | Failure of a curing oven door |

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | & | 12,7 | 2,5 | 14,6 | 6,2 | 6,6 | 136,4 | 135,5 | 21,8 | 44,3 | 84,4 | 20,5 | 11,1 |
| 2 | 7,8 | 0 | 3,4 | 11,9 | 5,5 | 7,4 | 153,2 | 152,4 | 15 | 37,9 | 102,1 | 19,1 | 5,8 |
| 3 | 5,9 | 11,2 | 0 | 15,5 | 6,5 | 8,3 | 136,6 | 135,7 | 22 | 44,8 | 84,3 | 20,4 | 10,2 |
| 4 | 8,7 | 4,1 | 1,3 | 0 | 6,7 | 6,7 | 125 | 124,3 | 23,4 | 51,1 | 73,3 | 21,4 | 7,1 |
| 5 | 6,8 | 11,9 | 2,7 | 16,4 | 0 | 8,9 | 157,6 | 156,7 | 17,5 | 42,4 | 102,7 | 24,1 | 10,4 |
| 6 | 4,7 | 10,2 | 3,1 | 12,1 | 8,3 | 0 | 117,6 | 116,7 | 16,5 | 40,5 | 71,4 | 16,1 | 6,3 |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 | 5 |
| 9 | 6,5 | 9,6 | 3,3 | 18,6 | 4,8 | 9,1 | 195 | 194 | 0 | 41,3 | 136,3 | 17 | 11,3 |
| 10 | 6 | 12 | 3,7 | 18,3 | 5,3 | 4 | 71,7 | 70,7 | 8 | 0 | 46,7 | 13,3 | 9 |
| 11 | 9,7 | 8,7 | 2 | 7 | 6 | 6,7 | 25,7 | 24,7 | 23,7 | 18,3 | 0 | 12,7 | 4,7 |
| 12 | 5,9 | 9,4 | 2,9 | 17,1 | 6,7 | 8,3 | 108,3 | 107,3 | 9,1 | 33,9 | 68,6 | 0 | 9,6 |
| 13 | 8,3 | 8 | 2,6 | 16,7 | 6,3 | 6,3 | 129,3 | 128,3 | 18,6 | 41,6 | 78,6 | 18 | 0 |
| 14 | 7 | 14,3 | 3,6 | 17,7 | 4,7 | 6 | 122,1 | 121,1 | 19,4 | 49 | 73,4 | 16,3 | 9,7 |
| 15 | 8,5 | 14 | 2,4 | 16,4 | 5,1 | 9,1 | 140,1 | 139,1 | 16,9 | 50,4 | 83 | 22,1 | 10,6 |
| 16 | 3,4 | 11,8 | 3,6 | 24,8 | 5,2 | 7,4 | 124,4 | 123,4 | 7,4 | 6,4 | 82,4 | 22,8 | 11,2 |
| 17 | 7,5 | 7,3 | 4,3 | 18,8 | 8,3 | 4,5 | 131 | 130 | 15,8 | 33 | 89,3 | 14,5 | 6,5 |
| 18 | 6,7 | 11,2 | 2,6 | 18,9 | 5,1 | 7,9 | 130,8 | 129,8 | 22,1 | 41,3 | 77,3 | 20,5 | 7,3 |
| 19 | 8,3 | 7,8 | 1 | 14,3 | 6,3 | 8,8 | 159,3 | 158,3 | 9,5 | 41,3 | 109 | 17 | 14,3 |
| 20 | 8,6 | 10,4 | 3,4 | 21,2 | 3,4 | 7,4 | 146 | 145 | 16,6 | 46,8 | 93 | 21 | 6,8 |
| 21 | 6,6 | 12 | 2,4 | 17,2 | 5,7 | 8,5 | 162,8 | 161,8 | 19,6 | 47,2 | 102,9 | 23,2 | 10,6 |
| 22 | 6,4 | 8,8 | 3,3 | 17,1 | 6,4 | 7,1 | 157,7 | 156,7 | 18,8 | 46,6 | 101,6 | 22,2 | 8,7 |
| 23 | 7,1 | 12,3 | 2,2 | 14,5 | 5,1 | 9,5 | 156,3 | 155,3 | 22,4 | 48,4 | 95,2 | 26,5 | 11,7 |
| 24 | 2,6 | 15,9 | 2,9 | 16,9 | 4,4 | 7,9 | 143 | 142 | 25,5 | 45,5 | 84,8 | 26,8 | 13,6 |
| 25 | 1,7 | 13,7 | 3 | 15,3 | 3,7 | 5 | 101 | 100 | 28 | 51,7 | 51 | 16,7 | 9,3 |
| 26 | 3 | 9 | 1 | 5 | 13 | 4 | 52 | 51 | 50 | 36 | 12 | 21 | 3 |
| 27 | 9 | 3 | 1 | 1 | 7 | 10 | 58 | 57 | 56 | 42 | 6 | 27 | 3 |
| 28 | 6,3 | 14 | 1,3 | 24 | 6,3 | 12,3 | 166,3 | 165,3 | 24,7 | 47 | 102,3 | 17,7 | 14,3 |
| 29 | 6,4 | 13,4 | 4 | 18,2 | 5,4 | 8,2 | 191,4 | 190,4 | 8,6 | 59,4 | 127,4 | 16,2 | 14,2 |
| 30 | 3,8 | 8,5 | 3,3 | 15,5 | 2,3 | 5,8 | 225,8 | 224,8 | 7,8 | 53,3 | 161,8 | 14,3 | 10,5 |
| 31 | 10 | 23 | 1 | 23 | 3 | 10 | 203 | 202 | 8 | 7 | 139 | 41 | 26 |
| 32 | 6,5 | 11 | 1 | 15,5 | 2 | 7 | 261 | 260 | 5 | 65 | 197 | 13 | 15,5 |

***Fig. 2*** *The fragment of neighboring matrix*

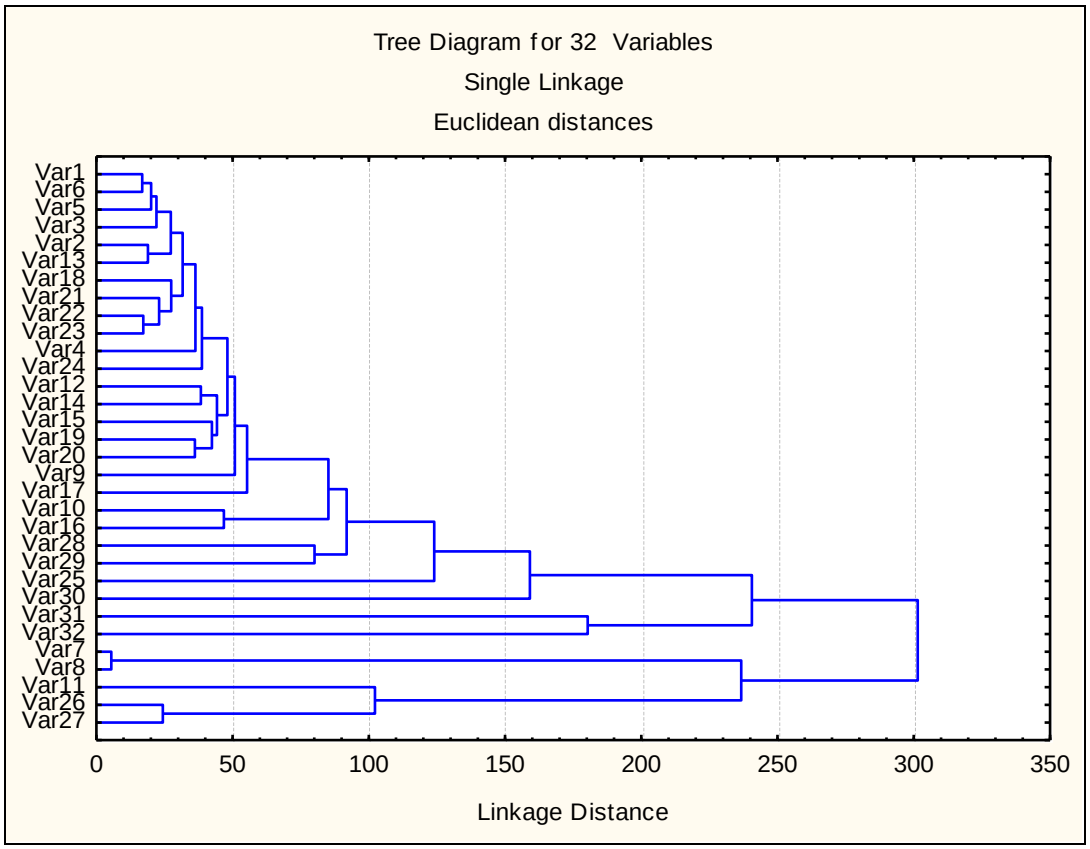


***Fig. 3*** *The tree of fault conditions*

If the failure is a part of a common cluster, we can predict that, where one of the faults occur, then there are also other error events. We can predict the appearance of a critical (peak) event by this approach. The tree of fault conditions of the analyzed device is shown in Fig.3.

**Table 2** The result of cluster analysis

| Case | 10 Clusters | 9 Clusters | 8 Clusters | 7 Clusters | 6 Clusters | 5 Clusters | 4 Clusters | 3 Clusters |
|---|---|---|---|---|---|---|---|---|
| P1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| P8 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| P9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P10 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P11 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| P12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P15 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P16 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P17 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P19 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P23 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P25 | 5 | 4 | 4 | 4 | 1 | 1 | 1 | 1 |
| P26 | 6 | 5 | 5 | 3 | 3 | 3 | 3 | 2 |
| P27 | 6 | 5 | 5 | 3 | 3 | 3 | 3 | 2 |
| P28 | 7 | 6 | 1 | 1 | 1 | 1 | 1 | 1 |
| P29 | 7 | 6 | 1 | 1 | 1 | 1 | 1 | 1 |
| P30 | 8 | 7 | 6 | 5 | 4 | 1 | 1 | 1 |
| P31 | 9 | 8 | 7 | 6 | 5 | 4 | 4 | 3 |
| P32 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 |

## CONCLUSION

Table 1 can be used to identify the interdependence between the following groups of faults: {P7, P8}, {P10, P16}, {P26, P27} & {P28, P29}. If error P7 happens with the device, we can expect a high probability of the P8 error emergence, which allows us to react correctly to the situation in advance. Since the coefficient of faults significance was not established at the beginning of the experiment, i.e. errors were considered as equally important; we have to prepare a crisis scenario for all variants.

Results of the experiment prove that the methods of cluster analysis provide a suitable tool for analyzing reliability of safety systems analysis. Regarding the increasing complexity of the systems, we can state that the application of these methods in the subject area is a good choice.

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