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FAULT AND EVENT-TREE TECHNIQUES IN OCCUPATIONAL HEALTH-SAFETY SYSTEMS – PART II: STATISTICAL ANALYSIS

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Abstract

Fault-Trees (FT) and Event-Trees (ET) are useful analytic tools for the assessment of reliability and safety of complex technical systems, and occupational health-safety systems (OHSS), as well. In this work we broaden and expand our previous study regarding the features of FT/ET methods. To clarify this further, in the present article we statistically analyzed the results of a literature survey, concentrated on FT/ET techniques applied in risk assessment (RA) of OHSSs, in order to (i) depict the subsistent situation of their application in various occupational fields, and (ii) enhance their handling and usage in RA of OHSS. The paper consists of two parts, including: (i) a literature survey (for years 2000-2012), concentrated on the main categories of FT/ET techniques concerning OHSS RA, and (ii) an examination and statistical analysis of the corresponding scientific papers published by thirteen representative scientific journals of Elsevier_B.V. and IEEE_Inc. The review shows that: (a) FT/ET techniques are classified into three basic categories (qualitative, quantitative, hybrid), (b) in risk assessment of occupational worksites, FT/ET application is not quite expanded and has not been extensively incorporated in the main RA methodologies of OHSSs, despite their significance, (c) the papers with FT/ETs constitute a very small part of the literature (~0.71%), (d) the qualitative methods present the highest relative occurrence-frequency (59%), and (e) the field of "Industry" concentrates the highest percentage of the papers (34%).

Key words: event-tree techniques, fault-tree techniques, occupational health and safety systems, risk assessment

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1. Introduction

Fault-Trees (FT) and *Event-Trees* (ET) are useful analytic tools for the reliability and safety of complex technical systems, and Occupational Health-Safety Systems (OHSS), as well.

Fault-Tree (FT) analysis is a graphical technique that ensures a systematic-description of the combinations of possible occurrences in a system, which can result in an undesirable outcome. A fault tree is constructed by relating the sequences of events, which individually (or in combination), could lead to the top-event (IET, 2010a; Marhavilas and Koulouriotis, 2014).

Moreover, Event-Tree (ET) analysis by using event-trees or "consequence-trees" is based on binary-logic, in which: an event either has (or has not) happened (i), or a component has (or has not) failed (ii). ET is valuable in analysing the consequences arising from a failure or undesired event. The consequences of the event are followed through a series of possible paths, where each path is assigned to a probability of occurrence, while the probability of the various possible outcomes can be calculated. The analysis starts by considering an "initiating event" and then the interaction with other events attributable to the elementary systems, constructs the so-called consequence trees (IET, 2010b; Marhavilas and Koulouriotis, 2014).

Fault-tree and event-tree techniques are widely used by reliability experts, as failure analysis tools, in technical-systems. On the other side, in

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safety science and mainly in risk assessment (RA) concerning occupational worksites, the situation is absolutely different whereas the application of ET and FT techniques is not expanded.

Risk analysis has emerged as an effective and comprehensive procedure that supplements and complements the overall management of almost all aspects of our life. Moreover, it is an essential and systematic process for assessing the impact, occurrence and the consequences of human activities on systems with hazardous characteristics and constitutes a needful tool for the safety policy of a company (Marhavilas and Koulouriotis, 2014; van Duijne et al., 2008).

As far as the occupational-safety and risk-assessment in workplaces are concerned, we can consider that, any company constitutes a simple stochastic system, called OHSS "Occupational Health and Safety System" (Haimes, 2009; Limnios, 2007; Marhavilas et al. 2012a,b,c, Appendix), which (among other techniques) can be implemented by using FT/ETs, subjected to failures (breakdowns).

The variety of risk-analysis procedures is such that there are many appropriate techniques for any circumstance and the selection has become more a matter of taste. We can consider the risk as a physical entity, which can be measured and expressed by a mathematical equation, under the help of real accidents' data. A basic classification of the risk assessment methodologies incorporates the deterministic (DET) and the stochastic (STO) approach. We note that, FTs/ETs are physically embodied in DET techniques (Marhavilas and Koulouriotis, 2008; Marhavilas et al., 2011a, b; Marhavilas and Koulouriotis, 2012a,b,c; Marhavilas et al., 2013).

Taking into account: (i) that FT and ET techniques are very important for risk assessment, concerning occupational health/safety systems and worksites (Marhavilas et al., 2011a, 2012b), and (ii) the fact, FT/ETs have not been incorporated sufficiently, in the main RA-methodologies, by this paper we continue and broaden the work of a recent article of Marhavilas and Koulouriotis (2014), regarding the features of FT/ET methods. More specifically, in Part-I: (i) we reviewed and classified FT/ET methods, and also elaborated their characteristics, and (ii) we presented an alternative risk-evaluation scheme, based on the combination of a FT (or ET) process with a stochastic quantified risk-evaluation model. On the other side, in the current paper, we statistically analyze the results of a literature survey, concentrated on FT/ET techniques applied in risk assessment of OHSSs, in order to (i) depict the subsistent situation of their application in various occupational fields, and (ii) enhance their handling and usage in RA of OHSS. The paper consists of two parts, including: (i) a literature survey (for years 2000-2012), concentrated on the main categories of FT/ET techniques concerning OHSS RA, and (ii) an examination and statistical analysis of the corresponding scientific papers published by thirteen representative scientific journals of Elsevier_B.V. and IEEE_Inc.

2. Summary of FT/ET Techniques

Having in mind the results of a previous paper (Marhavilas and Koulouriotis, 2014), and in particular the classification of the occupational risk assessment techniques, we concentrate, through this work, on FT/ET techniques applied in OHSSs. More specifically, FT/ET techniques are classified into three main categories: (a) the quantitative (QN), (b) the qualitative (QL), and (c) the hybrid techniques (HB). According to QN techniques, the risk can be estimated and expressed plainly by a mathematical relation, under the help of real accidents' data recorded in a work site. The QL techniques are based on analytical estimation processes in association with safety-managers' ability and the analysts' experience. A HB technique mixes in a single framework both a quantitative and qualitative method (Marhavilas and Koulouriotis, 2014). A descriptive summary of the main FT/ET techniques is presented below (Marhavilas and Koulouriotis, 2014).

FTA: Fault-Tree analysis (FTA), is a methodical-analysis that visually models the logical relationships between equipment-failures/ human-errors/ external-events, which cause specific accidents; it models and evaluates the unique interrelationship of events leading to: failure and undesirable (or unintended) states. It focuses on one particular accident event and provides a method for determining causes of that event. FTs are constructed from events and gates. Different kind of FTA techniques are the following: (a) **AFTA** (Augmented FTA), (b) **SMV-FTA** technique, (c) **CBFTA** (Condition-Based FTA), and (d) **QRA-FTA** technique.

ETA: Event tree analysis (ETA) is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event; it is a technique that uses decision trees and logically develops visual models of the possible outcomes of an initiating event.

CHAID: Chi Square Automatic Interaction Detection is a technique that determines how variables can best be combined in order to explain the result in a given dependent variable. The results are displayed as a tree, showing the hierarchical association between variables, using CHAID.

CETA: Concurrent Event Tree Analysis is an accident-analysis technique used not only in identifying but also evaluating the sequence of events in a potential accident scenario following the occurrence of an initiating event.

Bow-tie: Bow-tie is a combination (or an integration) of a fault tree, leading from various hazards to a top event, and an event tree leading from the top event to different sorts of damage.

MORT: Management Oversight and Risk Tree is an analysis technique for identifying safety related oversights, errors, and/or omissions that lead to the occurrence of a mishap.

Probability Trees: Probability tree diagrams allow us to see all the possible outcomes of an event and calculate their probability.

3. Statistical analysis and results of the scientific literature review

The objective of this work was the statistical analysis, classification, and comparative study of the scientific papers with as main aim the usage of FT/ET techniques in OHSS. This target was achieved by the investigation of 13 representative scientific journals published by **Elsevier B.V.** and **IEEE Inc.** during the years 2000-2012 (Table 1). The journals #1-11 are published by Elsevier B.V., while the journals #12-13 are published by IEEE Inc. More specifically, we studied and investigated all the published papers of the above referred journals, gathering a total number of N=31793 papers, concerning 2000-2012. The reviewing of the scientific literature: (i) revealed a plenty of M=225 published technical articles that include FT/ETs, or more specifically, S=112 papers with FT/ET techniques which are associated with occupational health and safety science (OHSS) in the work-sites, and concern many different fields (like engineering, computer science, high-technology, transportation, chemistry, medicine, biology etc.) and (ii) showed that RA techniques are classified into three main categories, i.e. the qualitative, the quantitative and the hybrid (qualitative-quantitative). These articles address concepts, tools, technologies, and methodologies that have been developed and practiced in such areas as planning, design, development, quality control and maintenance, in association with occupational risk assessment.

In the Appendix (Table A) we depict the classification results of the 112 papers including FT/ET techniques concerning OHSS, under the basic classification of section 2, which are associated with RA of occupational health and safety science, and they were determined by the investigation of 31793 papers of thirteen representative scientific journals covering the period 2000-2012. Table A uses eight columns e.g. the number (or numerical code) of the paper (A), the paper's citation information (B), the FT/ET technique's name (C), its method's type (D), the kind of the paper's data or material (E), the field of application (F), the general field (G), and the source or the journal acronym e.g. AAP, ApE, IJIE, JLPPI, JSR, RESS, SS, JHM, EAAI, ESwA, StS, ToR, IaM (column H).

Table 1 illustrates the statistical results of the investigation including the following:

(i) the absolute frequency N_i i.e. the number of investigated papers per journal (col. C, i.e. **AAP:**1979, **ApE:**1152, **IJIE:**1241, **JLPPI:**1145, **JSR:**816, **RESS:**1906, **SS:**1228, **JHM:**10089, **EAAI:**1199, **ESwA:**5392, **StS:**467, **ToR:**1078, **IaM:**4101),

(ii) the relative frequency $F_i=N_i/N$ of the thirteen journals, concerning the total amount of their published papers during 2000-2012 (column D, i.e. **AAP:**6.22%, **ApE:**3.62%, **IJIE:**3.9%, **JLPPI:**3.6%, **JSR:**2.57%, **RESS:**6.00%, **SS:**3.86%, **JHM:**31.73%, **EAAI:**3.8%, **ESwA:**16.96%, **StS:**1.47%, **ToR:**3.4%, **IaM:**12.9%),

(iii) the number of papers with FT/ET techniques $n_{FT(i)}$ (column E, **AAP:**10, **ApE;**6, **IJIE:**2, **JLPPI:**32, **JSR:**3, **RESS:**50, **SS:**61, **JHM:**20, **EAAI:**21, **ESwA:**6, **StS:**1, **ToR:**10, **IaM:**3),

(iv) the relative frequency of occurrence concerning FT/ET techniques $f_{FT(i)}=n_{FT(i)}/N$ (column F, **AAP:** 0.031%, **ApE:** 0.019%, **IJIE:** 0.006%, **JLPPI:** 0.101%, **JSR:** 0.009%, **RESS:** 0.157%, **SS:** 0.192%, **JHM:** 0.063%, **EAAI:** 0.066%, **ESwA:** 0.019%, **StS:** 0.003%, **ToR:** 0.031%, **IaM:** 0.009%),

(v) the number of papers $n_{SS(i)}$ with FT/ET techniques concerning OHSS (column G, i.e. **AAP:**3, **ApE:**2, **IJIE:**1, **JLPPI:**17, **JSR:**2, **RESS:**26, **SS:**29, **JHM:**10, **EAAI:**8, **ESwA:**4, **StS:**1, **ToR:**6, **IaM:**3),

(vi) the relative frequency of occurrence concerning OHSS, $f_{SS(i)}=n_{SS(i)}/N$ (column H, i.e. **AAP:**0.009%, **ApE:** 0.006%, **IJIE:** 0.003%, **JLPPI:** 0.053%, **JSR:** 0.006%, **RESS:** 0.082%, **SS:** 0.091%, **JHM:** 0.031%, **EAAI:** 0.025%, **ESwA:** 0.013%, **StS:** 0.003%, **ToR:** 0.019%, **IaM:** 0.009%),

(vii) the normalized (per journal) frequency of occurrence $f_i^*=n_{FT(i)}/N_i$ which has been used in order to weigh up the contribution of each journal to FT/ET techniques (col. I, i.e. **AAP:** 0.51%, **ApE:** 0.52%, **IJIE:** 0.16%, **JLPPI:** 2.79%, **JSR:** 0.37%, **RESS:** 2.62%, **SS:** 4.97%, **JHM:** 0.20%, **EAAI:** 1.75%, **ESwA:** 0.11%, **StS:** 0.21%, **ToR:** 0.93%, **IaM:** 0.07%)

(viii) the normalized (per journal) frequency of occurrence $f_i^{**}=n_{SS(i)}/N_i$ which has been used in order to weigh up the contribution of each journal to FT/ET in OHSS (column J, i.e. **AAP:** 0.15%, **ApE:** 0.17%, **IJIE:** 0.08%, **JLPPI:** 1.48%, **JSR:** 0.25%, **RESS:** 1.36%, **SS:** 2.36%, **JHM:** 0.10%, **EAAI:** 0.67%, **ESwA:** 0.07%, **StS:** 0.21%, **ToR:** 0.56%, **IaM:** 0.07%),

(ix) the relative occurrence-frequency of papers with FT/ET techniques $f^{M}_{FT(i)}=n_{FT(i)}/M$ referred to M (column K, i.e. **AAP:** 4.44%, **ApE:** 2.67%, **IJIE:** 0.89%, **JLPPI:**14.22%, **JSR:**1.33%, **RESS:**22.22%, **SS:** 27.11%, **JHM:** 8.89%, **EAAI:** 9.33%, **ESwA:** 2.67%, **StS:** 0.44%, **ToR:** 4.44%, **IaM:** 1.33%), and

(x) the relative occurrence-frequency of papers with FT/ET techniques concerning OHSS $f^{S}_{SS(i)}=n_{SS(i)}/S$ referred to S (column L, i.e. **AAP:** 2.68%, **ApE:** 1.79%, **IJIE:** 0.89%, **JLPPI:** 15.18%, **JSR:** 1.79%, **RESS:** 23.21%, **SS:** 25.89%, **JHM:** 8.93%, **EAAI:** 7.14%, **ESwA:** 3.57%, **StS:** 0.89%, **ToR:** 5.36%, **IaM:** 2.68%).

Moreover, Fig. 1 depicts for the period of 2000-2012 the following: (a) the relative frequency $F_i=N_i/N$ of the thirteen journals, concerning the total amount of their published papers, (b) the relative occurrence frequency of the thirteen journals, concerning FT/ET techniques $f_{FT(i)}=n_{FT(i)}/N$, (c) the normalized (per journal) frequency of occurrence $f_i^*=n_{FT(i)}/N_i$ concerning published papers with FT/ET techniques, (d) the normalized (per journal) frequency of occurrence $f_i^{**}=n_{SS(i)}/N_i$ concerning papers with FT/ET techniques in OHSS, (e) the relative occurrence-frequency of papers with FT/ET techniques $f^M_{FT(i)}=n_{FT(i)}/M$ referred to the total number M=225, and (f) the relative occurrence-frequency of papers with FT/ET techniques in OHSS $f^S_{SS(i)}=n_{SS(i)}/S$ referred to the total number S=112.

The examination of the above referred, 13 journals, showed (according to Table 1) that the papers with FT/ET techniques are very few (i.e. only ~0.71%, and only ~0.35% for FT/ET techniques in OHSS), while the majority is represented by papers with subject different from FT/ET (i.e. ~99.3%). Taking into account the illustrations of Fig. 1, we note that although JHM is the journal with the most published papers during 2000-2012 (Fig. 1a), SS, RESS and JLPPI are the journals with the greatest number of published papers, concerning FT/ET techniques (Fig. 1, b,c).

Furthermore, in order to weigh up the contribution of each journal to FT/ET in OHSS, we depict in Fig. 1d the normalized (per journal) occurrence-frequency of papers, which newly confirms that SS, JLPPI and RESS produced the highest plethora of publications as far as (FT/ET)/OHSS techniques are concerned. The same results (for SS, JLPPI and RESS) are concluded in Fig. 1(e,f) by the study of the relative occurrence-frequency with reference to numbers M=225 and S=112. In Fig. 2 we illustrate the yearly variation of the number (n_{ss}) of papers with FT/ET techniques in OHSS, published by the 13 journals during 2000-2012, which shows the existence of a long-term trend factor with positive inclination (i.e. n_{ss}=0.31t-608.61). In particular, there is a gradual decreasing for the period 2000-2006 ($Y_1=-0.033\ t+74.24$), while for the yrs 2007-2010, an abrupt increasing with an intensive inclination of 4.1 (i.e. $Y_2=2.7t-5411.7$), with a maximum in year 2010.

The "pie"-chart of Fig. 3 displays the distribution of papers including (FT/ET)/OHSS techniques in association with the various fields of application (Industry: 34%, Transportations: 13%, Computer Science: 10%, Chemistry: 8%, High Technology: 6%, Environment: 2%, Medicine: 3%, Other Fields: 24%). The main discernible feature of this pie-chart is that the field of "Industry" concentrates the greatest number of the papers with (FT/ET)/OHSS methods.

Fig. 4a depicts the percentage distribution of the papers with FT/ET techniques concerning OHSS, relatively to the three main FT/ET classes (qualitative, quantitative, hybrid), which have been determined by the 13 journals reviewing, covering the period of 2000-2012. The graph shows that the "qualitative" methods present the highest relative frequency (qualitative: 59%, hybrid: 9%, quantitative: 32%). Moreover, taking into account that some papers have applied in a discernible way, both the quantitative and qualitative mode, we present in Fig. 4b, another distribution, which includes a fourth category, i.e. the quantitative and qualitative one. In Table 2 we compare the main FT/ET techniques focusing on the advantages (col. a) and disadvantages (col. b), and we highlight as well, areas of future improvements (col. c). The comparison of FT/ET techniques, and as a consequence, the structuring of Table 2, was achieved by using the scientific literature (Marhavilas and Koulouriotis, 2008; Marhavilas et al., 2011a, 2013; Reniers et al., 2005; Zheng and Liu, 2009) and taking into account the advantages/disadvantages of these techniques, in association with future improvements.

4. Discussion and results

4.1. Discussion

Taking into account: (i) that FT and ET techniques are very important for risk assessment, concerning occupational health/safety systems and worksites (Marhavilas et al., 2011a, 2012b), and (ii) the fact, FT/ETs have not been incorporated sufficiently, in the main RA-methodologies, by this paper we continue and broaden the work of a recent article of Marhavilas and Koulouriotis (2014), regarding the features of FT/ET methods.

More specifically, in the current paper, we statistically analyze the results of the literature survey, concentrated on FT/ET techniques applied in risk assessment of OHSSs, in order to (i) depict the subsistent situation of their application in various occupational fields, and (ii) enhance their handling and usage in RA of OHSS. The paper consists of two parts, including: (i) a literature survey (for years 2000-2012), concentrated on the main categories of FT/ET techniques concerning OHSS RA, and (ii) an examination and statistical analysis of corresponding scientific papers published by thirteen representative scientific journals of Elsevier_B.V. and IEEE_Inc.

4.2. Main results

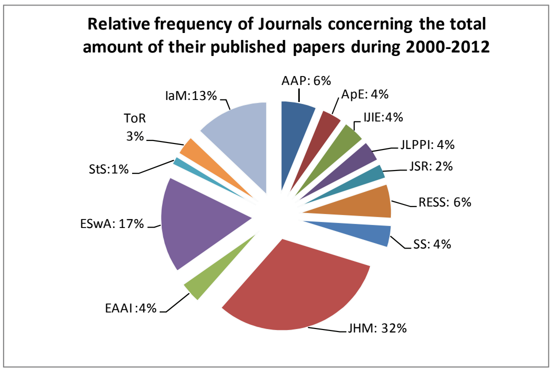
The main results of this work are summarized to the following points: (i) Our reviewing of the scientific literature, revealed for the occupational health/safety science and risk assessment, a plenty of published technical articles with FT/ET techniques, which are associated with OHSSs and their work-sites, and concern many different fields (like engineering, computer science, transportation, chemistry, medicine, biology etc.). (ii) The papers with FT/ET techniques constitute a very small part of the scientific literature.

The investigation of the above referred thirteen journals, which covers the period 2000-2012, shows that the papers with FT/ET techniques are very few (~0.71%), while the majority is represented by papers with subject different from FT/ET (~99.3%). Moreover, the percentage of the papers with FT/ET techniques concerning OHSS is only ~0.35%. (iii) The distribution of the papers with FT/ET techniques referred to OHSS, determined by the 13 journals reviewing, during 2000-2012, shows that the "qualitative" methods present the highest relative frequency (QL: 59%, QN: 32%, HB: 9%). (iv) Although JHM is the journal with the most published papers (during 2000-2012), SS, RESS and JLPPI are the journals with the greatest number of published papers, concerning FT/ET techniques. (v) The normalized (per journal) occurrence-frequency of papers, newly confirms that SS, JLPPI and RESS produced the highest plethora of publications as far as (FT/ET)/OHSS techniques are concerned.

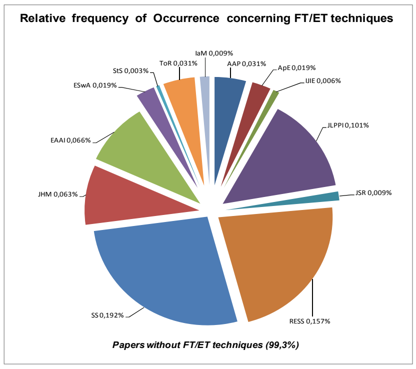
Table 1. Statistical results of 13 journals investigation, concerning papers with as main aim FT/ET techniques (during 2000-2012)

Nr	Journal	Acronym	Number of investigated papers *(Absolute frequency N_i)*	Relative frequenc ($F_i=N_i/N$ [%]	Number of papers with FT/ET techniques ($n_{FT(i)}$)	Relative freque-ncy of occur-rence (<u>*referred to N)*</u> ($f_{FT(i)}=n_{FT(i)}/N$) [%]	Number of papers with FT/ET techniques concerning OHSS ($n_{SS(i)}$)	Relative frequency of occurrence (<u>*referred to N)*</u> ($f_{SS(i)}=n_{SS(i)}/N$) [%]	Normalized (per journal) frequency of occurrence for FT/ET techniques ($f_i^*=n_{FT(i)}/N_i$) [%]	Normalized (per journal) frequency of occurrence for FT/ET in OHSS ($f_i^{**}=n_{SS(i)}/N_i$ [%]	Relative occurrence frequency of papers with FT/ET techniques (<u>*referred to M)*</u> ($f^M_{FT(i)}=n_{FT(i)}/M$) [%]	Relative occurrence frequency of papers with FT/ET techniques concerning OHSS (<u>*referred to S)*</u> ($f^S_{SS(i)}=n_{SS(i)}/S$) [%]
	(A)	(B)	(C)	(D)= C/N	(E)	(F)= (E)/N	(G)	(H)= (G)/N	(I)= (E)/(D)	(J)=(E)/(C)	(K)=(E)/M	(L)= (G)/S
1	Accident Analysis and Prevention	AAP	1979	6.22%	10	0.031%	3	0.009%	0.51%	0.15%	4.44%	2.68%
2	Applied Ergonomics	ApE	1152	3.62%	6	0.019%	2	0.006%	0.52%	0.17%	2.67%	1.79%
3	International Journal of Industrial Ergonomics	IJIE	1241	3.90%	2	0.006%	1	0.003%	0.16%	0.08%	0.89%	0.89%
4	Journal of Loss Prevention in the Process Industries	JLPPI	1145	3.60%	32	0.101%	17	0.053%	2.79%	1.48%	14.22%	15.18%
5	Journal of Safety Research	JSR	816	2.57%	3	0.009%	2	0.006%	0.37%	0.25%	1.33%	1.79%
6	Reliability Engineering and System Safety	RESS	1906	6.00%	50	0.157%	26	0.082%	2.62%	1.36%	22.22%	23.21%
7	Safety Science	SS	1228	3.86%	61	0.192%	29	0.091%	4.97%	2.36%	27.11%	25.89%
8	Journal of Hazardous Materials	JHM	10089	31.73%	20	0.063%	10	0.031%	0.20%	0.10%	8.89%	8.93%
9	Enginnering Application of Artificial Intelligence	EAAI	1199	3.77%	21	0.066%	8	0.025%	1.75%	0.67%	9.33%	7.14%
10	Expert Systems with Application	ESwA	5392	16.96%	6	0.019%	4	0.013%	0.11%	0.07%	2.67%	3.57%
11	Structural Science	StS	467	1.47%	1	0.003%	1	0.003%	0.21%	0.21%	0.44%	0.89%
12	Transactions on Reliability (IEEE)	ToR	1078	3.39%	10	0.031%	6	0.019%	0.93%	0.56%	4.44%	5.36%
13	Trans. on Instrumen. & Measurement (IEEE)	IaM	4101	12.90%	3	0.009%	3	0.009%	0.07%	0.07%	1.33%	2.68%
	TOTAL		31793	100%	225	0.708%	112	0.352%	0.71%	0.35%	100.00%	100.00%

Annotations: The total absolute frequency (i.e. the total Number of Investigated Papers) is: N=31793; The number of papers with FT/ET techniques is: M=225 ; The number of papers with FT/ET techniques concerning OHSS is: S=112



(a)



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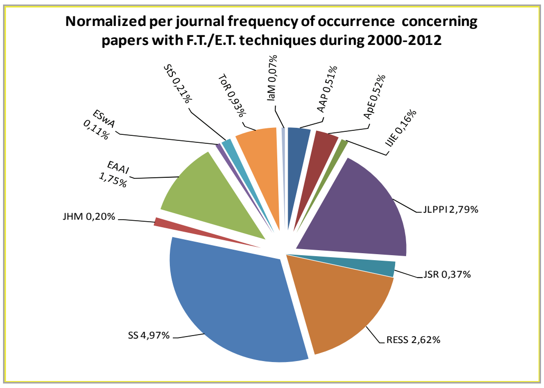

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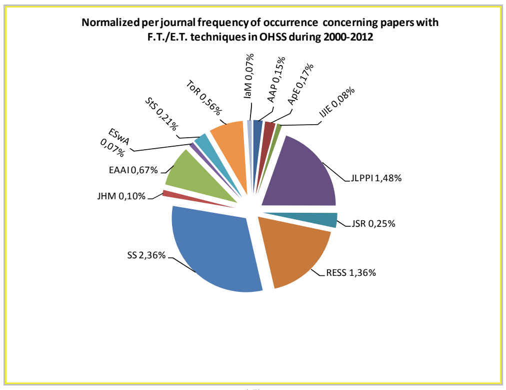

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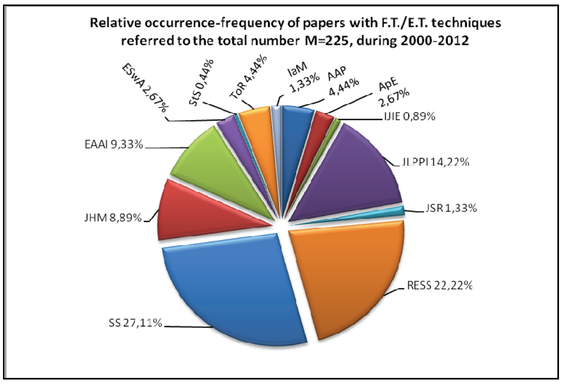

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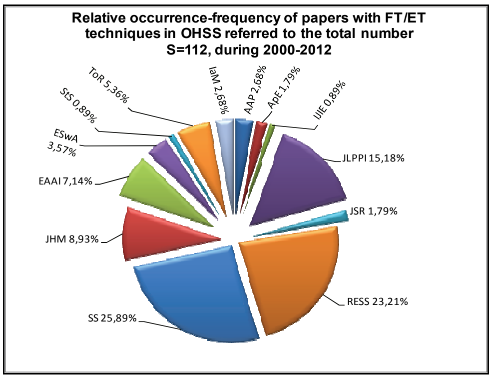


(f)

Fig. 1. (a) The relative frequency $F_i=N_i/N$ for 13 journals concerning the total amount of their published papers, (b) the relative occurrence freq. of the 13 journals, concerning FT/ET techniques $f_{FT(i)}=n_{FT(i)}/N$, (c) the normalized (per journal) freq. of occurrence $f_i^*=n_{FT(i)}/N_i$ concerning published papers with FT/ET techniques, (d) the normalized (per journal) freq. of occurrence $f_i^{**}=n_{SS(i)}/N_i$ concerning papers with FT/ET techniques in OHSS, (e) the relative occurrence-freq. of papers with FT/ET techniques $f^M_{FT(i)}=n_{FT(i)}/M$ referred to the total number M=225, (f) the relative occurrence-freq. of papers with FT/ET techniques in OHSS $f^S_{SS(i)}=n_{SS(i)}/S$ referred to the total number S=112

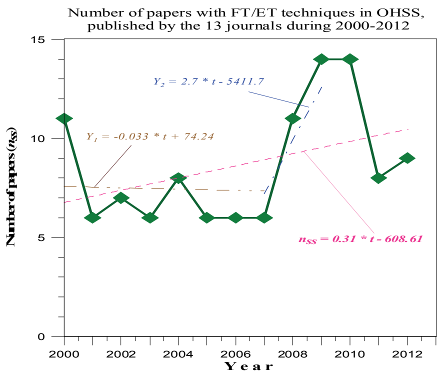


Fig. 2. Yearly variation of the number (nss) of papers with FT/ET techniques in OHSS, published by the 13 journals during 2000-2012, which shows the existence of a long-term trend factor with positive inclination

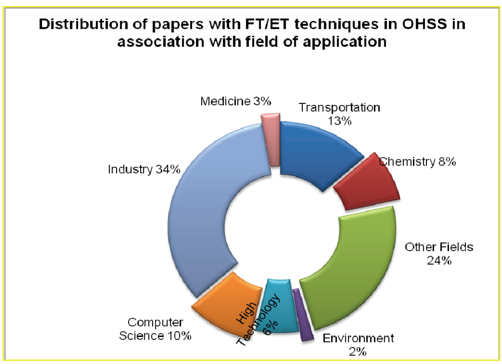
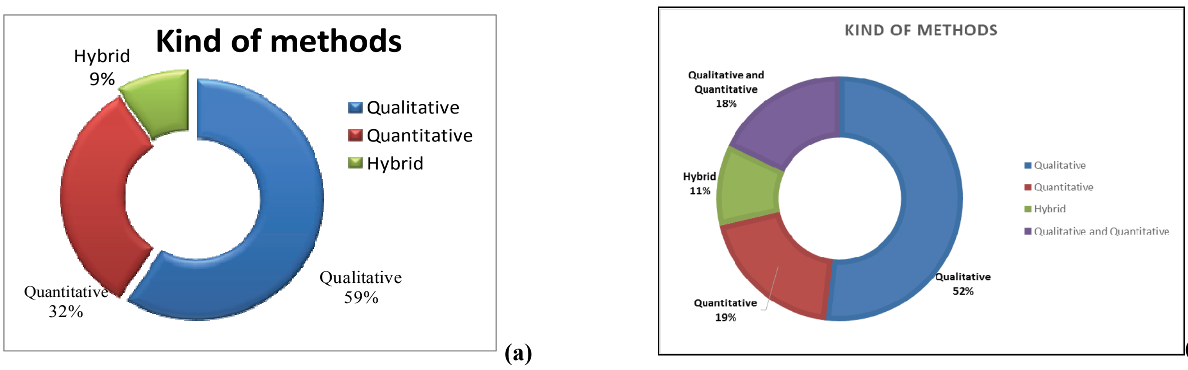


Fig. 3. The "pie"-chart displays the distribution of papers including FT/ET techniques concerning OHSS in association with the various fields of application

Table 2. Comparison of FT/ET techniques, taking into account the advantages (a), disadvantages (b), and future improvements (c)

Tech-niques	***Advantages (a)***	***Disadvantages (b)***	***Future Improvements (c)***
FTA	It is easy to read and understand It can handle multiple failures or combinations of failures It exposes the needs for control or protective actions to diminish the risk It quickly exposes critical paths The results can provide either qualitative or quantitative data for the risk assessment process It identifies and models combinations of equipment failures, human errors, and external conditions that can result in an accident It is performed primarily by an individual working with system experts through interviews and field inspections It is a deductive modeling approach It produces quantitative and qualitative results It is a highly structured method It determines accidents causes in depth It is generally applicable for almost every type of risk assessment application It can be used as an effective root cause analysis tool in several applications	It is very complicated and difficult It requires a lot of time consuming in its application It is expensive It is used most often as a system-level risk assessment technique It requires detailed knowledge of the design, construction and operation of the system Significant training and experience is necessary to use this technique properly It is not practical on systems with large numbers of safety critical failures	It could be combined with other accident scenario analysis techniques (ETA, Petri-Nets) in order to achieve the accident reconstruction, where the human factor is involved It should be used to the development of accident analysis techniques which thoroughly investigates the accidents
ETA	Identifies various sequences of events, both failures and successes that can lead to an accident It is a graphical representation of the logic model that identifies and quantifies the possible outcomes following the initiating event It is an inductive modeling approach It produces quantitative and qualitative results It is applicable not only to design, construction, and operation stages, but also to the change of operation and the analysis of accident causes	It is complicated and difficult It requires a lot of time consuming in its application	It could be combined with other accident scenario analysis techniques (FTA, Petri-Nets) in order to achieve the accident reconstruction, where the human factor is involved It should be used to the development of accident analysis techniques which thoroughly investigates the accidents
BOW-TIE	It is a structured method to assess risk It is simple and easy for the non-specialist to understand It can be used for any type of hazard analysis, from major accidents, through occupational and environmental to business The graphical representation of the bow tie diagram can give a clear picture of what are often complex safety management systems Clear links between management systems and safety are shown	Bow Tie analysis requires a high level of knowledge regarding a system and the components of the system that relate to its safety Training is required It is difficult to link to quantitative techniques It doesn't use Boolean logic	Some degree of quantification should be incorporated, possibly with a relative ranking/risk indexing approach An integrated risk analysis scheme, which will incorporate and combine a well-considered selection of techniques (including Bow-Tie) could be developed, achieving more efficient results on the risk analysis
CHAID	An exceptional advantage is the capability to visualize the relationship between the dependent variable and the related factors with a tree image It is an ideal solution for survey studies concerning data in finding out the statistical relationship concerning continuous values The ability to analyze employee satisfaction and risk analysis The advantage in looking for patterns in complicated datasets The availability of such analysis can be useful to the sales and marketing, team of company in realizing the type of person who is most likely to buy the company's products and/or services It is useful in identifying major data trends	It is primarily a step-forward modeling fitting method. It is a sequential fitting algorithm and its statistical tests are sequential with later effects being dependent upon earlier ones, and not simultaneous as would be the case in a regression model or analysis of variance where all effects are fit simultaneously	Some degree of quantification should be incorporated
MORT	Very effective in identifying underlying management root causes of hazards It is a reactive analysis tool for mishap investigation, but It can be used for the proactive evaluation and control of hazards. It can be applied to all types of systems and equipment, with analysis coverage given to systems, subsystems, procedures, environment, and human error Its primary application is in mishap investigation to identify all of the root causal factors and to ensure that corrective action is adequate The theory behind its analysis is fairly simple and straightforward Highly detailed. A full MORT diagram or tree contains more than 10,000 It has a pictorial benefit that aids analysts in visualizing hazards It can be quantified (but usually is not) Commercial software is available to assist the analyst.	It is a time-consuming and difficult technique Proper training and an ability to logically identify energy sources and track flows in systems, are demanded for the analyst The analyst must have the ability to understand energy flow concepts, for which at least a rudimentary knowledge of the behaviors of each of the basic energy types is necessary It is not recommended for the general system safety program as there are other techniques available which provide more effective results Though simple in concept, the process is labor intensive and requires significant training Tree size can become too large for effective comprehension by the novice	It could be combined with more rigorous quantitative techniques such as fault tree analysis or quantitative risk analysis Some degree of quantification should be incorporated

PROBABILITY TREE	It allows us to see all the possible outcomes of an event and calculate their probability It offers a way to visually see all of the possible choices, and to avoid making mathematical errors Easy application of the technique It is a quantitative technique The mathematical risk evaluation Safe results, based on the recorded data of undesirable events or accidents It can be incorporated in data-bases It can help with their numerical results other risk assessment techniques It can be applied to any company/corporation or productive procedure	It requires efficient safety managers to record the undesirable events It is a time-consuming technique	It could be incorporated in data bases, where statistic information of accidents are being registered, in order to help other risk assessment techniques It could be incorporated in computer automated toolkits It could be incorporated to an integrated quantitative risk analysis scheme, which will combine a well-considered selection of widespread quantitative techniques It could be combined with stochastic (like time-series (TSP)) and quantitative risk assessment (like PRAT, SRE) methodologies, achieving a more realistic forecasting and risk-assessment process in the worksites (see the proposed PRAT-TSP-SRE scheme of Marhavilas & Koulouriotis, 2011)
CETA	It is very easy to be learnt and understood It is ideal in modeling an entire system and it can be conducted at different abstraction level • Useful in identifying control measures • Useful in situations with varied outcomes • It can be extended into QRA if data is available	Its proper application depends on the complexity of the system and how skillful the analyst is • Trees can grow quickly • It can miss possible branches in the tree	It could be combined with other accident scenario analysis techniques It should be used to the development of accident analysis techniques which thoroughly investigates the accidents
AFTA	It augments the traditional fault tree analysis with potential human and computer working contexts	It is complicated and difficult It requires a lot of time consuming in its application It is expensive It requires detailed knowledge of the design, construction and operation of the system Significant training and experience is necessary to use this technique properly	It should be used to the development of accident analysis techniques which thoroughly investigates the accidents
CBFTA	It starts with a known FTA A tool for updating reliability values of a specific system A tool for calculating the residual life according to the system's monitored conditions It is for use during the systems operational phase, including maintenance	It is complicated and difficult It requires a lot of time consuming in its application	Its use during the systems operational phase, and maintenance as well, have to be extended in the design phase
SMV-FTA	Highly accessible in many safety applications An important principle implemented by SMV to produce the legal inputs is the non-determinism. Using this concept, the finite state machines generating the inputs are able to produce the whole area of values.	It is complicated and difficult It requires a lot of time consuming in its application The exhaustive verification model is appropriate for small size circuits To verify a circuit, the user has to decompose it in small enough modules, which can be explored exhaustively with model checking	SMV could integrate some other techniques to adjust complex circuits in order to verify them both by model checking: symmetry reduction, temporal case splitting, data type reduction, induction, etc
QRA-FTA	It identifies the dominant contributors to the total risk It quantifies the benefits of possible changes The first step is to analyze the total risk associated with the base case and to calculate the contributions. These findings lead naturally to the specification of possible measures to improve reliability or reduce the damage potential. Results can be compared with criteria for risk acceptance Results for different types of facilities can easily be compared	Expensive and cumbersome analysis, which requires expert knowledge The "probabilistic" element in the result is hard to communicate Result suggests large accuracy, but it includes large uncertainty The presence of accept criteria (hard political decision) is necessary beforehand	It could be incorporated in computer automated toolkits in order to identify the weak spots in an industrial area It could be incorporated to an integrated quantitative risk analysis scheme, which will combine a well-considered selection of widespread quantitative techniques



(a) (b)

Fig. 4. The percentage distribution of papers with FT/ET techniques concerning OHSS (for 2000-2012), that have been determined by 13 journals reviewing, relatively to: (a) 3 main classes (QL, QN, HB), and (b) 4 categories (QL, QN, HB, QL-QN)

The same results (for SS, JLPPI and RESS) are concluded by the study of the relative occurrence-frequency with reference to numbers M=225 and S=112. (vi) The field of "Industry" concentrates the greatest number of the papers with (FT/ET)/OHSS methods. In particular, the distribution of papers including (FT/ET)/OHSS techniques in association with the various fields of application is: (a) Industry: 34%, (b) Transportations: 13%, (c) Computer Science: 10%, (d) Chemistry: 8%, (d) High Technology: 6%, (e) Environment: 2%, (f) Medicine: 3%, (g) Other Fields: 24%. (vii) The yearly variation of the number (n_{ss}) of papers with FT/ET techniques in OHSS, published by the 13 journals during 2000-2012, shows the existence of a long-term trend factor with positive inclination (i.e. n_{ss}=0.31t-608.61). In particular, there is a gradual decreasing for the period 2000-2006 ($Y_1 = -0.033\ t + 74.24$), while for the years 2007-2010, an abrupt increasing with an intensive inclination of 4.1 (i.e. $Y_2 = 2.7t - 5411.7$), with maximum in year 2010.

5. Conclusions and future work

General conclusions: (i) The usage of FT/ET techniques referred to occupational safety science is not considerably expanded, and all the knowledge about FT/ET has not been fully shared among the various scientific fields, so we believe that the scientific community faces with the challenge to duplicate and transfer the commonalities from one field to another. (ii) In fact, the development of an integrated risk assessment scheme, which will combine a well-considered selection of widespread techniques (including FT/ET techniques), would enable companies to achieve efficient results on RA. (iii) We could illustrate the relation between the different kinds of FT/ET techniques (qualitative, quantitative, hybrid) as far the ways of risk-modeling are concerned, by a linear curve in Fig. 10, where the slope $tan(\hat{\phi}) = \frac{QL}{QN}$ of the line (*L*) can define method's hybrid-making level. A practical problem is that it is not clear which is the optimum level of hybrid-making in any situation.

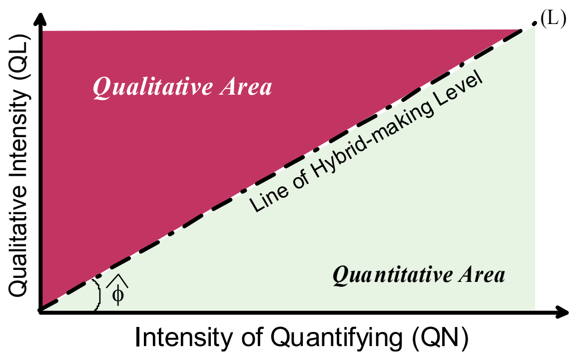


Fig. 10. The relation between the different classes (QL/QN/HB) of FT/ET techniques as far as method's hybrid-making level is concerned

Future work: Further research on the topic of defining the optimum level of hybrid-making in any FT/ET method, by determining the finest slope (i.e. the best value of angle $(\hat{\phi})$) is interesting and very important.

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Appendix

Table A presents the classification results of 112 papers including fault-tree techniques (FT/ET), which are associated with risk analysis and assessment in the work-sites (or occupational health and safety science), and they were determined by the investigation of 31793 papers of thirteen scientific journals, covering the period of 2000-2012.

Table A. The classification results of the 112 papers including FT/ET techniques

Nr	*Paper Citation*	*Tech-nique*	*Method's type*	*Type of paper data or material*	*Field of application*	*General Field*	*Journal*
A	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Aggregate nonparametric safety analysis of traffic zones (Siddiqui et al., 2012)	FTA	Qualitative	Case study	Transportation	Transportation	AAP
2	Hierarchical task analysis: Developments, applications and extensions (Stanton 2006)	FTA	Qualitative	Theoretical analysis	General Use	Other Fields	ApE
3	Towards a framework to select techniques for error prediction: Supporting novice users in the healthcare sector (Lyons, 2009)	Probability Tree	Qualitative	Theoretical analysis	Medicine	Medicine	ApE
4	Accident sequence analysis for sites producing and storing explosives (Papazoglou, 2009)	ETA	Qualitative	Theoretical analysis	Power Energy	Chemistry	AAP
5	Combining task analysis and fault tree analysis for accident and incident analysis: A case study from Bulgaria (Doytchev and Szwillus, 2009)	FTA	Hybrid	Case study	Computer Science	Computer Science	AAP
6	A novel genetic programming approach to nonlinear system modeling: application to the DAMADICS benchmark problem (Metenidis et al., 2004)	FTA	Qualitative	Theoretical foundations	Medicine	Medicine	EAAI
7	Modeling and inference for troubleshooting with interventions applied to a heavy truck auxiliary braking system (Pernestal et al., 2012)	FTA	Hybrid	Methodological Analysis	Sport Formula 1	Transportation	EAAI
8	Development of an intelligent technique for traffic network incident detection (Srinivasan et al., 2000)	FTA	Qualitative	Methodological Analysis	Computer Science	Computer Science	EAAI
9	Assessing -classifying risk of pipeline third-party interference based on FT & SOM (Liang et al., 2012)	FTA	Qualitative	Case study	Sport Formula 1	Transportation	EAAI
10	An intelligent hybrid system for surface coal mine safety analysis (Lilic et al., 2010)	FTA	Hybrid	Case study	Coal mine	Industry	EAAI
11	A modular approach to generating fuzzy rules with reduced attributes for the monitoring of complex systems (Shen et al., 2000)	FTA with RIA	Quantitative	Theoretical foundations	Fuzzy logic	Computer Science	EAAI
12	Real-time transaction processing for autonomic Grid applications (Tang et al., 2004)	Petri net with FTA	Qualitative	Mathematic types	Computer Science	Computer Science	EAAI
13	CAD for fault tree-based diagnosis of industrial processes (Kavčič and Juričić, 2000)	Probability Tree	Quantitative	Mathematic types	Computer Science	Computer Science	EAAI
14	Fault diagnosis of induction motor based on decision trees & adaptive neuro-fuzzy inference (Tran et al., 2009)	FTA	Hybrid	Methodological Analysis	Computer software	Computer Science	ESwA
15	MatCarloRe: An integrated FT and Monte Carlo Simulink tool for the reliability assessment of dynamic fault tree (Manno et al., 2012)	FTA	Qualitative	Case study	Industry	Industry	ESwA
16	Design and implementation of a quantitative risk assessment software tool for Singapore road tunnels (Qu and Wong, 2011)	FTA with QRA	Quantitative	Case study	Road tunnels	Transportation	ESwA
17	Fault-tree analysis for liquefied natural gas terminal emergency shutdown system (Cheng et al., 2009)	FTA-ESD	Quantitative	Methodological Analysis	LNG	Industry	ESwA
18	Organizing learning processes on risks by using the bow-tie representation (Chevreau et al., 2006)	Bow-tie	Qualitative	Case study	Pharmaceutical production plant	Chemistry	JHM
19	Risk based methodology for safety improvements in ports (Trbojevic and Carr, 2000)	Bow-tie (SMS)	Qualitative	Case study	Application methods	Transportation	JHM
20	Risk-based process safety assessment and control measures design for offshore proc. Facil. (Khan et al., 2002)	FTA	Qualitative	Case study	Oil and gas platforms	Industry	JHM
21	Two-dimensional fuzzy fault tree analysis for chlorine release from a chlor-alkali industry using expert elicitation (Renjith et al., 2010)	FTA	Qualitative/ Quantitative	Theoretical analysis	Chlor-alkali Industry	Industry	JHM
22	Safety and reliability analysis in a *polyvinyl chloride* batch process using dynamic simulator-case study: Loss of containment incident (Rizal et al., 2006)	FTA	Qualitative	Case study	Polyvinyl chloride (PVC) production	Industry	JHM
23	Risk-based maintenance of ethylene oxide production facilities (Khan et al., 2004)	FTA (develop)	Qualitative/ Quantitative	Theoretical analysis	Strategy develop	Industry	JHM
24	Modified risk graph method using fuzzy rule-based approach (Nait-Said et al., 2009)	FTA	Quantitative	Graph method	Computer Science	Computer Science	JHM
25	Underestimation of language issues in frequently used accident investigation Methods A new taxonomy problem found in Dutch accident data (Lindhout, et al., 2011)	FTA	Qualitative	Theoretical analysis	methods comparison	Other Fields	JHM
26	The use of generic failure frequencies in QRA: The quality and use of failure frequencies and how to bring them up-to-date (Beerens et al., 2005)	Bow-tie	Quantitative	Case study	Industry	Industry	JHM
27	SCAP: a new methodology for safety management based on feedback from credible accident-probabilistic fault tree	FTA	Qualitative	Methodological Analysis	Safety measures	Other Fields	JHM

	analysis system (Khan et al., 2001)						
28	A comparison of accident analysis techniques for safety-critical man machine systems (Kontogiannis et al., 2000)	FTA	Qualitative	Critical technique	Man-machine systems	Mechanics	IJIE
29	Importance & uncertainty analysis of flue gas scrubber systems with extreme reliab. Param. values (Jin et al., 2002)	FTA	Qualitative Quantitative	Empirical data	Scrubber system	Industry	JLPPI
30	Dynamic management of human error to reduce total risk (Jo and Park, 2003)	FTA	Qualitative/ Quantitative	Theoretical foundations	Human Error	Industry	JLPPI
31	Calibrate failure-based risk assessments to take into account the type of chemical processed in equipment (Keren et al., 2006)	FTA	Qualitative/ Quantitative	Case study	Chemistry	Chemistry	JLPPI
32	Recursive Operability Analysis as a decision support tool for Risk-Based Maintenance (Marmo et al., 2009)	FTA	Qualitative/ Quantitative	Theoretical foundations	Industry	Industry	JLPPI
33	A novel method to apply Importance and Sensitivity Analysis to multiple Fault-trees (Contini et al., 2010)	FTA	Quantitative	Algorithmic model	Other Fields	Other Fields	JLPPI
34	Study and application of Reliability-centered Maintenance considering Radical Maintenance (Li and Gao, 2010)	FTA	Qualitative	Theoretical foundations	Model's Analysis	Chemistry	JLPPI
35	Uncertainty aspects in process safety analysis (Markowski et al., 2010)	FTA	Qualitative	Theoretical foundations	Model's Analysis	Other Fields	JLPPI
36	Accident modeling approach for safety assessment in an LNG processing facility (Rathnayaka et al., 2012)	FTA	Qualitative	Case study	Gas transmission pipelines	Chemistry	JLPPI
37	Safety analysis and risk assessment in a new pesticide production line (Rigas et al., 2003)	FTA, HAZOP	Qualitative	Theoretical foundations	Industry	Industry	JLPPI
38	Risk analysis and assessment methodologies in the work sites: on a review, classification and comparative study of the scientific literature of the period 2000-2009 (Marhavilas et al., 2011a, b)	FTA	Quantitative	Methodolo-gical Analysis	Model's Analysis	Industry	JLPPI
39	A risk estimation methodological framework using quantitative assessment techniques and real accidents' data: application in an aluminum extr. industry (Marhavilas & Koulouriotis, 2008)	FTA	Quantitative	Case study	Aluminum industry	Industry	JLPPI
40	On the development of a new hybrid risk assessment process using occupational accidents' data: Application on the Greek Public Electric Power Provider (Marhavilas et al., 2011a, b)	FTA	Quantitative	Case study	Power Energy	Industry	JLPPI
41	Automatic generation of accident scenarios in domain specific chemical plants (Kim et al., 2003)	Bow-tie	Qualitative	Accident scenario	Industry	Industry	LPPI
42	Handling and updating uncertain information in bow-tie analysis. (Ferdous et al., 2012)	Bow-tie	Quantitative	Mathematic types	Industry	Industry	JLPPI
43	Comparison of techniques for accident scenario analysis in hazardous systems (Nivolianitou et al., 2004)	ETA	Qualitative	Theoretical foundations	Industry	Industry	LPPI
44	Risk modeling of maintenance work on major process equipment on offshore petroleum installations (Vinnem et al., 2012)	ETA	Qualitative	Theoretical foundations	Oil extraction	Industry	JLPPI
45	Estimation of failure probability of oil and gas transmission pipelines by fuzzy fault tree analysis (Yuhua and Datao, 2005)	FTA	Quantitative	Probability models	Gas transmission pipelines	Industry	JLPPI
46	Condition-based fault tree analysis (CBFTA): A new method for improved fault tree analysis (FTA), reliability and safety calculations (Shaleva and Tiran, 2007)	FTA	Qualitative/ Quantitative	Theoretical foundations	Industry	Industry	RESS
47	Accident sequence analysis of human–computer interface design (Fan and Chen, 2000)	FTA	Qualitative	Theoretical foundations	Human fault in computer	High Technology	RESS
48	A logical model for quantification of occupational risk (Papazoglou and Ale, 2007)	ETA	Qualitative and Quantitative	Theoretical foundations	Industrial	Industry	RESS
49	Accidents in the construction industry in the Netherlands: An analysisof accident reports using Storybuilder (Ale et al., 2008)	Bow tie	Qualitative and Quantitative	Case study	Hazard to human	Other Fields	RESS
50	Quantification of sequential failure logic for fault tree analysis (Long et al., 2000)	FTA	Quantitative	Probability models	Computer Science	Computer Science	RESS
51	Safety analysis of autonomous excavator functionality (Seward et al., 2000)	FTA	Qualitative	Empirical data	Autonomous excavator	Computer Science	RESS
52	Application of the cause – consequence diagram method to static systems (Andrews and Ridley, 2002)	FTA	Qualitative and Quantitative	Case study	Industry	Industry	RESS
53	Fault-tree structures of override control systems (Ju et al., 2003)	FTA	Qualitative	Theoretical foundations	Chemical plants	Industry	RESS
54	Posbist fault tree analysis of coherent systems (Huang et al., 2004)	FTA	Quantitative	Theoretical foundations	Mathematical modelling	Other Fields	RESS
55	Fault tree construction of hybrid system requirements using qualitative formal method (Lee and Cha, 2005)	FTA	Hybrid	Theoretical foundations	Engineering	Industry	RESS
56	Software safety analysis of function block diagrams using fault trees (Oha et al., 2005)	FTA	Qualitative	Theoretical foundations	Nuclear Accident	Industry	RESS
57	An analytic solution for a fault tree with circular logics in which the systems are linearly interrelated (Lim and Jang, 2007)	FTA	Quantitative	Theoretical foundations	Other Fields	Other Fields	RESS
58	Criteria for evaluating protection from single points of	FTA	Qualitative and	Methodolo-	Hazard to human	Other Fields	RESS

	failure for partially expanded fault trees (Aswani et al., 2007)		Quantitative	gical Analysis			
59	An enhanced component connection method for conversion of fault trees to binary decision diagrams (Remenyte-Prescott and Andrews, 2008)	FTA	Qualitative and Quantitative	Methodolo-gical Analysis	Binary system	Industry	RESS
60	Component-based modeling of systems for automated fault tree generation (Majdara and Wakabayashi, 2009)	FTA	Qualitative	Theoretical foundations	Fire accident	Other Fields	RESS
61	Application of the fault tree analysis for assessment of power system reliability (Volkanovski and Mavko, 2009)	FTA	Qualitative and Quantitative	Theoretical foundations	Power system	High Technology	RESS
62	A frame work for evaluating the effects of maintenance-related human errors in nuclear power plants (Heo and Park, 2010)	FTA	Qualitative	Theoretical foundations	Nuclear plant	Industry	RESS
63	Quantification of risk to company's incomes due to failures in food quality (Domenech et al., 2010)	FTA , ETA	Qualitative	Theoretical foundations	Food quality	Industry	RESS
64	Improving the analysis of dependable systems by mapping fault trees into Bayesian networks (Bobbio et al., 2001)	FTA	Hybrid	Probability models	Methods comparison	Other Fields	RESS
65	Hydroxylamine production: will a QRA help you decide? (Krishna et al., 2003)	FTA, ETA	Qualitative and Quantitative	Case study	Industry	Chemistry	RESS
66	Analysis and synthesis of the behaviour of complex programmable electronic systems in conditions of failure (Papadopoulos et al., 2001)	FTA, FFA	Qualitative	Case study	Programmable electronic systems	Other Fields	RESS
67	Mechanical system reliability analysis using a combination of graph theory and Boolean function (Tang, 2001)	FTA, FMECA	Quantitative	Probability models	Boolean Tree	Other Fields	RESS
68	Phased mission modeling of systems with maintenance-free operating periods using simulated Petri nets (Chew et al., 2008)	Petri net with FTA	Hybrid	Theoretical foundations	Rocket Accident	High Technology	RESS
69	Comparing safety analysis techniques (Rouvroye and Bliek, 2002)	Probability Tree	Qualitative	Theoretical foundations	Methods comparison	Other Fields	RESS
70	SMV model-based safety analysis of software requirements (Koh and Seong, 2009)	SMV-FTA	Qualitative and Quantitative	Algorithmic model	Nuclear plant	Industry	RESS
71	Storybuilder—A tool for the analysis of accident reports (Bellamy et al., 2007)	Bow tie	Quantitative	Case study	Hazard to human	Other Fields	RESS
72	Development of a loading dock safety evaluation tool (Gauthier et al., 2007)	FTA	Qualitative	Empirical data	Upload truck accident	Transportati on	JSR
73	An examination of the characteristics and traffic risks of drivers suspended/revoked for different reasons (DeYoung and Gebers, 2004)	FTA	Qualitative	Theoretical foundations	Driver Safety	Transportati on	JSR
74	An application of data mining tools for the study of shipping safety in restricted waters (Kokotos and Linardatos, 2011)	(FTA)	Hybrid	Methodical analysis	Sea accidents	Transportati on	SS
75	Risk assessment practices in The Netherlands (Ale, 2002)	Bow-tie	Qualitative	Theoretical foundations	Nuclear Accident in Netherlands	Industry	SS
76	Analysis of hazard scenarios for a research environment in an oil and gas exploration and production company (Bruin and Swuste, 2008)	Bow-tie	Qualitative	Theoretical foundations	Oil extraction	Environment	SS
77	Risk + barriers = safety? (Hollnagel, 2008)	Bow-tie	Qualitative	Theoretical foundations	Barriers to safety	Other Fields	SS
78	Process indicators: Managing safety by the numbers (Hudson, 2009)	Bow-tie	Qualitative	Theoretical foundations	Other Fields	Other Fields	SS
79	A semi-quantitative assessment of occupational risks using bow-tie representation (Jacinto and Silva, 2010)	Bow-tie	Qualitative	Case study	Steel Industry	Industry	SS
80	Reanalyzing occupational fatality injuries in Taiwan with a model free approach (Chi and Chen, 2003)	CHAID	Qualitative	Theoretical foundations	Fatal Accidents	Industry	SS
81	Flow diagram analysis of electrical fatalities in construction industry (Chi et al., 2012)	CHAID	Qualitative	Case study	Power Energy	Industry	SS
82	A conceptual model for the analysis of mishaps in human-operated safety-critical systems (Hall and Silva, 2008)	FTA	Qualitative	Theoretical models	Different models	Computer Science	SS
83	An experimental comparison of conservative versus optimal collision avoidance warning system thresholds (Lehto et al., 2000)	FTA	Qualitative	Empirical data	Driver Safety	Transportati on	SS
84	A fail-safe dual channel robot control for surgery applications (Laible et al., 2004)	FTA	Qualitative	Theoretical foundations	Robot control system	High Technology	SS
85	Suicide prevention in railway systems: Application of a barrier approach (Radbo et al., 2008)	FTA	Qualitative	Case study	Railway accidents	Transportati on	SS
86	Risk assessment tools incorporating human error probabilities in the Japanese small-sized establishment (Moriyama and Ohtani, 2009)	FTA	Qualitative and Quantitative	Case study	Small establishments	Industry	SS
87	A risk-based modeling approach to enhance shipping accident investigation (Celik et al., 2010)	FTA	Qualitative Quantitative	Case study	Mathematic model	Other Fields	SS
88	Incident tree model and incident tree analysis method for quantified risk assessment: An in-depth accident study in traffic operation (Wang et al., 2010)	FTA	Hybrid	Methodolo-gical Analysis	Transportation	Transportati on	SS
89	A tool for safety officers investigating ''simple'' accidents (Jorgensen, 2011)	FTA	Qualitative	Theoretical foundations	Human Accident	Industry	SS

90	Not just rearranging the deckchairs on the Titanic: Learning from failures through (Labib and Read, 2012)	FTA	Qualitative	Case study	Oil extraction	Transportation	SS
91	Incorporating human factors into a simplified ''bow-tie'' approach for workplace risk assessment (Targoutzidis, 2010)	FTA, Bow-tie	Qualitative	Theoretical foundations	Human factors	Other Fields	SS
92	Risk assessment in the aerospace industry (Altavilla and Garbellini, 2002)	FTA	Qualitative/ Quantitative	Case study	Aerospace	High Technology	SS
93	HRA in China: Model and data (Dai et al., 2011)	HRA event tree	Hybrid	Case study	Nuclear plant	Industry	SS
94	Learning from Tabasco's floods by applying MORT (Santos-Reyes et al., 2010)	MORT	Qualitative	Methodological Analysis	Other Fields	Other Fields	SS
95	The accident process preceding back injuries among Australian nurses (Engkvist, 2004)	Probability Tree	Qualitative/ Quantitative	Dataset	Nurses' Accidents	Medicine	SS
96	A framework for estimating the safety effects of roadway lighting at intersections (Donnell et al., 2010)	Probability Tree	Qualitative/ Quantitative	Statistic data	Road Lighting	Transportation	SS
97	Towards a causal model for air transport safety—an ongoing research project (Ale et al., 2006)	Probability Tree	Qualitative	Theoretical foundations	Transport safety	Transportation	SS
98	Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models (Katsakiori et al., 2009)	Probability Tree	Qualitative	Methodological Analysis	Methodological Analysis	Other Fields	SS
99	The software tool storybuilder & the analysis of the horrible stories of occup. accidents (Bellamy et al., 2008)	Bow tie	Hybrid	Case study	Application methods	Other Fields	SS
100	Towards a causal model for air transport safety—an ongoing research project (Ale et al., 2006)	FTA	Qualitative	Case study	Theoretical analysis	Transportation	SS
101	Developing a new alternative risk assessment framework in the work sites by including a stochastic and a deterministic process: a case study for the Greek Public Electric Power Prov. (Marhavilas & Koulouriotis, 2012b)	FTA	Quantitative	Case study	Power Energy	Industry	SS
102	Towards risk assess. crane activities (Aneziris et al., 2008)	Bow tie	Quantitative	Method.Anal.	Crane activities	Other Fields	SS
103	Bayesian networks for system reliability reassessment (Mahadevan et al., 2001)	FTA	Qualitative	Math. types		Other Fields	StS
104	Carbohydrate Detection Failure Analysis via Biosensoring (Siontorou and Batzias, 2008)	FTA	Qualitative	Methodological Analysis	Carbohydrate biosensor	Chemistry	ToIaM
105	Investigating the Causes of Biosensor SNR Decrease by Means of Fault Tree Analysis (Batzias & Siontorou, 2005)	FTA	Qualitative	Methodological Analysis	Carbohydrate biosensor	Chemistry	ToIaM
106	A Knowledge-Based Approach to Online Fault Diagnosis of FET Biosensors (Siontorou et al., 2010)	FTA	Qualitative	Methodological Analysis	Carbohydrate biosensor	Chemistry	ToIaM
107	Event-Tree Analysis Using Binary Decision Diagrams (Andrews and Dunnett, 2000)	ETA-BDD	Hybrid	Methodological Analysis	Other Fields	Other Fields	ToR
108	Choosing a Heuristic for the "Fault Tree to Binary Decision Diagram" Conversion, Using Neural Networks (Bartlett and Andrews, 2002)	ETA-BDD	Qualitative	Methodological Analysis	Industrial Systems	Industry	ToR
109	Combined m-Consecutive-k-Out-of- n: F and Consecutive kc-Out-of-n: F Systems (Mohan et al., 2009)	FTA	Quantitative	Mathematic types	Other Fields	Other Fields	ToR
110	Interval Methods for Fault-Tree Analysis in Robotics (Carreras and Walker, 2001)	FTA	Quantitative	Mathematic types	Robotics	High Technology	ToR
111	Stochastic Fault Tree Analysis With Self-Loop Basic Events (Jenab and Dhillon, 2005)	FTA and MGF	Quantitative	Mathematic types	Other Fields	Other Fields	ToR
112	Constructing Fault Trees for Advan.Proc.Control Syst.- Appl. to Cascade Control Loops (Ju et al., 2003)	Loop tree (FTA)	Qualitative	Mathematic types	Other Fields	Other Fields	ToR