Fault Tree Analysis – A History

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ABSTRACT

Fault Tree Analysis (FTA) is a tool for analyzing, visually displaying and evaluating failure paths in a system, thereby providing a mechanism for effective system level risk evaluations. Many people and corporations are already familiar with this tool and use it on a regular basis for safety and reliability evaluations. In some fields it is required for product certification.

FTA is now about 39 years old, and has become a well-recognized tool worldwide. Many improvements have been made since the inception of FTA in 1961 and many people have been involved. This paper provides an overview on the historical aspects of the FTA industry. Topics include important developments through the years, improvements in the process, people involved and contributions made.

FTA has become an important tool in systems design and development, and its history should be recorded and the appropriate people duly recognized. The intent of this paper is to provide a fuller appreciation of the people and events that have contributed to the development of FTA. This is a necessarily incomplete, but hopefully, representative survey of the events, people and literature which have become associated with FTA.

FUNDAMENTAL CONCEPT OF FTA

The fundamental concept of Fault Tree Analysis is the translation of the failure behavior of a physical system into a visual diagram and logic model. The diagram segment provides a visual model that very easily portrays system relationships and root cause fault paths. The logic segment of the model provides a mechanism for qualitative and quantitative evaluation. FTA is based on Reliability theory, Boolean algebra and probability theory. A very simple set of rules and symbols provides the mechanism for analyzing very complex systems, and complex relationships between hardware, software and humans.

EARLY HISTORY

H. A. Watson of Bell Laboratories in connection with an U.S. Air Force contract to study the Minuteman Launch Control System [ref. 1] first conceived fault Tree Analysis. Dave Haasl, then at the Boeing Company, recognized the value of this tool and led a team that applied FTA to the entire Minuteman Missile System. Other divisions within Boeing saw the results from the Minuteman program and began using FTA during the design of commercial aircraft. In 1965 Boeing and the University of Washington sponsored the first System Safety Conference. At this conference, several papers were presented on FTA, marking the beginning of worldwide interest in FTA.

In 1966 Boeing developed a simulation program called BACSIM for the evaluation of multi-phase fault trees. BACSIM could handle up to 12 phases, and included the capability for repair and K-factor adjustment of failure rates. Boeing also developed a program that plotted fault trees on a Calcomp 26-inch wide roll plotter. Both programs ran on an IBM 370 mainframe. These were in-house Boeing programs, developed by Bob Schroeder, that few people were aware of outside Boeing.

Following the lead of the aerospace industry, the nuclear power industry discovered the virtues and benefits of FTA, and began using the tool in the design and development of nuclear power plants. Many key individuals in the nuclear power industry contributed to advancing fault tree theory and fault tree software codes. In fact, the nuclear power industry may have contributed more to the development of FTA than any other single user group. Many new evaluation algorithms were developed, along with software using these algorithms.

FTA has also been adopted by the chemical process industry, the auto industry, rail transportation and is now starting to be utilized by the robotics industry. There are probably many other industries and disciplines using FTA that have not been mentioned here.

UNWANTED RECOGNITION

As is sometimes the case in system safety, a project is not given adequate safety attention until after an accident or incident has occurred. Then, system safety is rigorously applied to solve the accident problem, and any others that might be lurking in the woodwork. The following three accidents were unfortunate and unwanted, but they helped to better establish the FTA process.

After the Apollo 1 launch pad fire on January 27, 1967, NASA hired Boeing to implement an entirely new and comprehensive safety program for the entire Apollo project. As part of this safety effort, fault tree analysis was performed on the entire Apollo system, which helped to bring FTA into national limelight.

Following the Three Mile Island nuclear power plant accident on March 28, 1979, several accident review studies were conducted utilizing FTA. Several years prior to this accident the WASH-1400 study (1976) was conducted to review nuclear power plant design, and to assure the public that the probability of nuclear accidents was very small. This study used fault tree analysis quite extensively, which helped to legitimize the tool and promote its use in the accident investigation..

The Space shuttle Challenger accident occurred on January 28, 1986. Following this accident an independent review team used fault trees to evaluate the main engines to ensure adequate safety in the design. This study showed the applied benefits of FTA.

SUMMARY OF EVENTS

The Beginning Years (1961 – 1970)

1. H. Watson of Bell Labs, along with A. Mearns, developed the technique for the Air Force for evaluation of the Minuteman Launch Control System, circa 1961.
2. Recognized by Dave Haasl of Boeing as a significant system safety analysis tool (1963).
3. First major use when applied by Boeing on the entire Minuteman system for safety evaluation (1964 – 1967, 1968-1999).
4. The first technical papers on FTA were presented at the first System Safety Conference, held in Seattle, June 1965.
5. Boeing began using FTA on the design and evaluation of commercial aircraft, circa 1966.
6. Boeing developed a 12-phase fault tree simulation program, and a fault tree plotting program on a Calcomp roll plotter.

The Early Years (1971 – 1980)

1. Adopted for use by the Nuclear Power industry.
2. Many new evaluation algorithms were developed.
3. Many new fault tree evaluation software codes were developed. Some of the more recognized software includes Prepp/Kitt, SETS, FTAP, Importance and COMCAN.

The Mid Years (1981 – 1990)

1. Usage started becoming international, primarily via the Nuclear Power industry.
2. More evaluation algorithms and codes were developed.
3. A large number of technical papers were written on the subject.
4. Usage of FTA in the software (safety) community.

The Present (1991 – 1999)

1. Continued use on many systems in many countries.
2. High quality fault tree construction and evaluation software developed that operates on PC's.
3. Usage of FTA adopted by the Robotics industry.

HIGHLIGHTS

The following provides some of the highlights of individuals and their contributions over the years. Dave Haasl devised a construction methodology and construction rules that have been followed almost implicitly by everyone in the industry [training classes and Table 3-1]. Jerry Fussell initiated automatic FT construction with his Synthetic Tree Model (STM) [Table 5-3]. Powers and Tompkins developed an automated fault tree construction method for chemical systems [Table 2-9]. Lapp and Powers developed the Fault Tree Synthesis (FTS) program, which utilizes a di-graph model [Table 2-12]. In 1970 W. Vesely developed the Kinetic Tree Theory (KITT) and the PREPP/KITT computer program [Table 4-1 and 4-3]. Fussell and Vesely developed the top down cut set generation algorithm called MOCUS (Method of obtaining Cut Sets) [Table 5-1 and 5-4]. A bottom up cut set algorithm call MICSUP (Minimal Cut Sets Upward) was developed by P. Pande, M. Spector and P. Chatterjee [Table 2-11]. The FATRAM algorithm was developed by D. Rasmuson and N. Marshall to improve upon the MOCUS algorithm [Table 2-14]. S. Semanderes developed a cut set algorithm using prime numbers in his ELRAFT program, which efficiently stored cut sets and eliminated super sets. [Table 2-8]. Randall Willie developed the ever-popular computer program call FTAP [Table 2-13]. Dick Worrell developed the SETS computer program, which is still in usage in various versions [Table 2-10]. Howard Lambert extensively developed importance measures, and developed the program called IMPORTANCE [Table 6-4, 6-7].

IMPORTANT CONTRIBUTORS

Through out the years many individuals have contributed to the development of FTA, some more than others. The following is a short list of some of the individuals who have made significant contributions to the field. This list is derived from both the literature available and personal knowledge. Although this list is not complete, it is an attempt to recognize those who made valuable contributions. Each of these individuals has carried the banner and been a major spokesperson for FTA.

1. H. Watson and A. Mearns
   Developed FTA methodology [Table 2-1, 2-2]
2. Dave Haasl
   Developed FT construction techniques, training [Table 2-3, 3-1]
3. Robert Schroeder
   BACSIM simulation program, AFTD program (Boeing)
4. William Vesely
   Kinetic tree theory, Kitt/Prepp, technical papers from 1969-1994 [Table 4]
5. Jerry Fussel
   Synthetic FTA, MOCUS, technical papers from 1972-1994 [Table 5]
6. Howard Lambert
   Developed Importance program, technical papers from 1973-1994 [Table 6]
7. Dick Worrel
   SETS program [Table 1-10]
8. Randall Willie
   FTAP program [Table 1-13]
9. Ernst Henely
   Technical papers and books from 1973-1996 [Table 7]
10. John Andrews
    Research, technical papers and books from 1986-1999 [Table 8]

PRODUCT APPLICATIONS

Since its inception, FTA has been applied to many different types of systems and hardware, on many different projects. The following list shows many areas that have used FTA. This list may not be complete, but it is fairly representative of systems that have received FTA.

Major industries and technologies utilizing FTA include:
1. Aircraft – commercial, fighters, bombers, tankers, UAV's, AWACS, helicopters
2. Power Systems – nuclear, solar, electric
3. Transit Systems – trains, MPRT (Morgantown Personal Rapid Transit), BART
4. Space –Apollo, Space Shuttle, satellites, launch vehicles, Space Station
5. Robotic Systems
6. Auto Systems
7. Missile Systems – Minuteman, SRAM, ALCM, Tomahawk
8. Oil Platforms
9. Torpedoes
10. Hydrofoil

APPLICATION PURPOSES

FTA tends to be used in high-risk applications where a probability of occurrence assessment is needed. However, FTA has proven its worth for both quantitative and qualitative applications. Some of the most typical reasons why FTA has been used include the following.

Major applications of FTA include:
1. Numerical requirement verification
2. Identification of safety critical components
3. Product certification
4. Product risk assessment
5. Accident/incident analysis
6. Design change evaluation
7. Visual diagrams of cause-consequence events
8. Common cause analysis

MAJOR IMPROVEMENTS

FTA construction and evaluation is a relatively simple and straightforward process. However, when trees become large and complex, they become much more difficult to solve. The ability to evaluate fault trees is directly correlated to size, complexity and computer capability. In the early day's, computer power and capacity was much more limited than it is today, which meant that much research went into developing tractable FTA algorithms. Many algorithms and computer software codes were developed to efficiently take advantage of various FT parameters.

Early FT computer software was limited by computer power – memory and speed. Current codes have the advantage of a) early algorithms and b) improvements in computer power. FTA evaluation programs have become decentralized and user friendly. They now operate on PC's sitting on an analyst's desk, rather than a mainframe computer.

Probably the two most major advances in FTA technology are 1) improved user interface, and 2) improved user computational power. And, both of these advances are the direct result of improvements in computer technology. If the computer industry had not improved, these gains would not likely have been achieved for FTA.

Major improvements in the FTA process include:
1. Progressed from drawing trees manually using templates to using computers
2. Transition from mainframe computers to desktop PC's

3. Transition from large mainframe plotters to desktop printers
4. Decentralized – moved the computer and FTA tools to the user's desk
5. Software has become user friendly
6. Graphical user interface rather than ASCII text files with no visuals
7. Software packages have become relatively inexpensive
8. Improved computation – algorithms, size, speed

PHILOSOPHIES AND TRENDS

Over the years there have been various trends and philosophies in FTA, some have come and gone, others are still with us. Some of these trends have even competed with each other.

1. Analytical solution vs. Simulation
2. Top down vs. Bottom up algorithms
3. Dynamic FTA vs. Static FTA
4. SFTA (Software FTA)
5. Fuzzy FTA
6. FT Synthesis (automated FT construction)
7. Single phase vs. multi phase fault trees
8. Various evaluation methods
    - Boolean reduction
    - BDD (Binary Decision Diagram)
    - Min terms
    - Genetic algorithms
    - Approximations

TECHNICAL ARTICLES

FTA is a topic that almost everyone wants to write about, and almost everyone feels qualified to do so. To date I have cataloged 775 technical articles and books on the subject of FTA. The list of authors ranges from experienced practitioners, to dedicated researchers, to neophytes that just learned how to perform FTA the week before. Table 1 shows a graph of the number of items on FTA per year since its inception. The quantity of items indicates that FTA is an important and valuable subject, with widespread interest. This chart shows the continued, and somewhat constant, interest in FTA. Table 2 lists some of the early articles on FTA. Table 3 lists the most used books on FTA. Tables 4 through 8 contain technical articles written by five different authors. Each of these authors have individually contributed the most research and technical articles on FTA, and have proudly carried the FTA banner for many years. Although other individuals have made important contributions, these five have been the most consistent.

SUMMARY

FTA was conceived circa 1961, and as such is a relatively new tool compared to many other technical tools and disciplines. Special recognition should go to H. A. Watson as the Father of Fault Tree Analysis and Dave Haasl as the God Father of Fault Tree Analysis. Watson of Bell Labs invented fault tree analysis (along with assistance from M. A. Mearns). Haasl, while at Boeing saw the benefits of FTA and spearheaded the first major application on the Minuteman program. As a private consultant he has helped train most of the industry in FTA, and consulted on many projects utilizing FTA.

Algorithms and software codes received the most research attention in the early years (and still does). Less research has been spent on improving construction methods and training methods. Advancements and improvements in computer technology have provided concomitant advances in FTA. FTA analysts can today visually construct fault trees on desktop computers with relatively inexpensive software

Synthetic FTA is the process of using computers to automatically construct fault trees from electrical schematics and drawings. Synthetic FTA has been an elusive goal. Researchers have been trying to achieve this objective since 1970, yet there are still no commercial products available.

FTA has earned its place as a valuable tool for safety, risk assessment, accident investigation, reliability, etc. The number of papers graphed over time show that the interest in FTA has not declined, but has actually remained constant over the years. There have been criticisms of FTA over the years, but the benefits and strengths of FTA have proven to out weight the detractors arguments, and FTA has become an internationally recognized and used tool.

BIOGRAPHY

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Mr. Ericson works in system safety on the Boeing 767 AWACS program. He has 34 years experience in system safety and software design with the Boeing Company. He has been involved in all aspects of fault tree development since 1965, including analysis, computation, multi-phase simulation, plotting, documentation, training and programming. He has performed Fault Tree Analysis on Minuteman, SRAM, ALCM, Apollo, Morgantown Personal Rapid Transit, B-1, AWACS and 737/757/767 systems. He is the developer of the MPTREE, SAF and FTAB fault tree computer programs. In 1975 he helped start the software safety discipline, and has written papers on software safety and taught software safety at the University of Washington. Mr. Ericson holds a BSEE from the University of Washington and an MBA from Seattle University. He is currently Executive Vice President of the System Safety Society, and is on the technical review committee for the Hazard Prevention journal.

Table 1—Fault Tree Articles Per Year

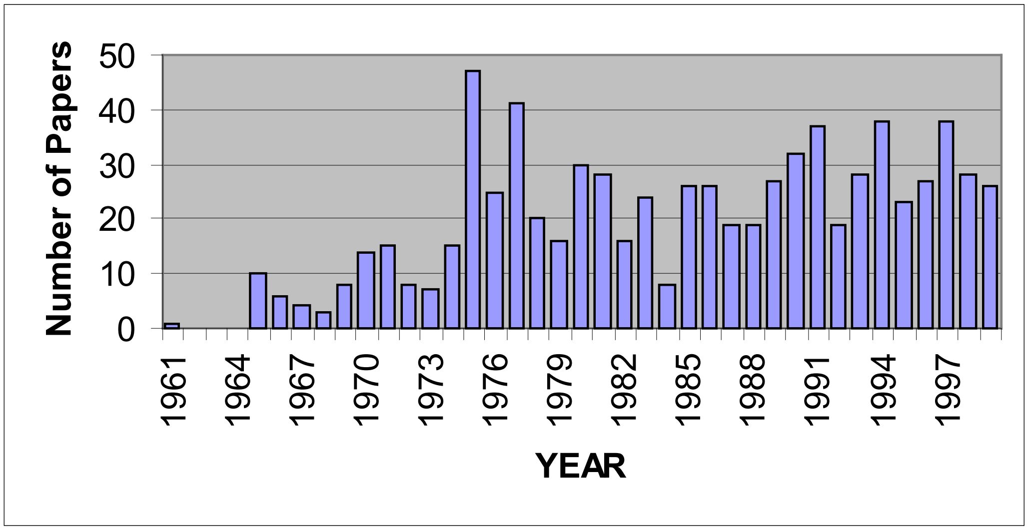

Table 2 – Early Works

	Year	Title
1.	1961	*Launch Control Safety Study*, Section VII Vol 1; Bell Labs; Murray Hill, NJ, 1961, H. A. Watson
2.	1965	*Fault Tree Analysis : The Study Of Unlikely Events In Complex Systems*, Boeing/UW System Safety Symposium, 1965, A. B. Mearns
3.	1965	*Advanced Concepts In Fault Tree Analysis*, Boeing/UW System Safety Symposium, 1965, D. F. Haasl
4.	1965	*Computer Evaluation Of The Safety Fault Tree Model,* System Safety Symposium (Boeing/UW), 1965, J. M. Michels
5.	1965	*A Monte Carlo Method To Compute Fault Tree Probabilities,* System Safety Symposium (Boeing/UW), 1965, P. M. Nagel
6.	1965	*The Application of Fault Tree Analysis to Dynamic Systems,* System Safety Symposium (Boeing/UW), 1965, R. J. Feutz & T. A. Waldeck
7.	1965	*Concept of System Safety Mathematics*, System Safety Symposium (Boeing/UW), 1965, K. Kanda
8.	1971	*ELRAFT: A Computer Program For The Efficient Logic Reduction Analysis Of Fault Trees*, 1971, IEEE Transactions On Nuclear Science (NS-18 No 1), p481-487, S. N. Semanderes
9.	1974	*Fault Tree Synthesis for Chemical Processes*, G. J. Powers and F. C. Tompkins, AICHE Journal, Vol 20, 1974, p376-387
10.	1974	*Set Equation Transformation System (SETS)*, 1974, SLA-73-0028A Sandia National Laboratories, R. B. Worrell
11.	1975	*Computerized Fault Tree Analysis: TREEL and MICSUP*, 1975, Univ. of California ORC-75-3, P. K. Pande & M. E. Spector & P. Chatterjee
12.	1977	*The Synthesis of Fault Trees*, S. A. Lapp and G. J. Powers, in Nuclear Systems Reliability and Risk Assessment , 1977, p778-799
13.	1978	*Computer Aided Fault Tree Analysis: FTAP*, 1978, Univ. of California Operations Research Center; OC 78-14, R. R. Willie

14.	1978	*FATRAM – A Core Efficient Cut Set Algorithm*, 1978, IEEE Transactions On Reliability (R-27 No 4), p250-253, D. M. Rasmuson & N. H. Marshall

Table 3 – Most Significant Books

	Year	Title
1.	1981	*Fault Tree Handbook*, NUREG-0492, 1981, N. H. Roberts, W. E. Vesely, D. F. Haasl & F. F. Goldberg
2.	1993	*Reliability and Risk Assessment*, Longman Scientific & Technical, 1993, J. D. Andrews & T. R. Moss
3.	1996	*Probabilistic Risk Assessment And Management For Engineers And Scientists*, IEEE Press (2nd edition), 1996, E. J. Henley & H. Kumamoto

Table 4 – Articles by W. E. Vesely

	Year	Title
1.	1969	*Analysis Of Fault Trees By Kinetic Tree Theory*, Idaho Nuclear Corp IN-1330, 1969, W. E. Vesely
2.	1970	*A Time- Dependent Methodology For Fault Evaluation*, Nuclear Engineering and Design (Vol 13 No 2), 1970, p337-360, W. E. Vesely
3.	1970	*PREPP & KITT: Computer Codes For The Automatic Evaluation Of A Fault Tree*, IN-1349; Idaho Nuclear Corp, 1970, W. E. Vesely & R. E. Narum
4.	1971	*Reliability And Fault Tree Applications At The NRTS*, IEEE Transactions On Nuclear Science (NS-18 No 1), 1971, p472-480, W. E. Vesely
5.	1972	*A New Methodology For Obtaining Cut Sets For Fault Trees,* Transactions American Nuclear Society (Vol 15 No 1), 1972, p262-263, J. B. Fussell & W. E. Vesely
6.	1975	*Reliability Quantification Techniques Used In The Rasmussen Study,* Reliability And Fault Tree Analysis: SIAM, 1975, p775-804, W. E. Vesely
7.	1976	*Important Event Tree And Fault Tree Considerations In The Reactor Safety Study,* IEEE Transactions On Reliability (R-25 No 3, 1976, p132-139, S. Levine & W. E. Vesely
8.	1977	*FRANTIC – A Computer Code For Time dependent Unavailability Analysis,* NUREG 0193, 1977, W. E. Vesely & F. F. Goldberg
9.	1983	*The Façade Of Probabilistic Risk Analysis: Sophisticated Computation Does Not Necessarily Imply Credibility,* Proceedings Annual R & M Symposium, 1983, p49-51, W. E. Vesely
10.	1985	*Two Measures of Risk Importance and their Application*, Nuclear Technology (Vol 68 No 2), 1985, p226-234, W. E. Vesely
11.	1988	*Utilizing Probabilistic Risk Analyses (PRA) in Decision Support Systems*, Engineering Risk and Hazard Assessment; Volume II; editors A. Kandel & E. Avni; CRC Press, 1988, p101-116, W. E. Vesely
12.	1994	*PRA Importance Measures For Maintenance Prioritization Applications*, Reliability Engineering And System Safety 43, 1994, p307-318, W. E. Vesely, M. Belhadj & J. T. Rezos

Table 5 – Articles by J. B. Fussell

	Year	Title
1.	1972	*A New Methodology For Obtaining Cut Sets For Fault Trees,* Transactions American Nuclear Society (Vol 15 No 1), 1972, p262-263, J. B. Fussell & W. E. Vesely
2.	1973	*A Formal Methodology For Fault Tree Construction,* Nuclear Science and Engineering (Vol 52), 1973, p421-432, J. B. Fussell
3.	1973	*Synthetic Tree Model – A Formal Methodology For Fault Tree Construction,* ANCR-1098, 1973, J. B. Fussell

4.	1974	*MOCUS – A Computer To Obtain Minimal Sets From Fault Trees*, Aerojet Nuclear Corp; ANCR-1156, 1974, J. B. Fussell & E. B. Henry & N. H. Marshall
5.	1974	*Fault Trees – A State Of The Art Discussion*, IEEE Transactions On Reliability (Vol R-23 No 1), 1974, p51-55, J. B. Fussell & G. J. Powers & R. G. Bennetts
6.	1975	*Fault Tree Analysis – Concepts And Techniques,* NATO Advanced Study Institute On Generic Techniques Of System Reliability Assessment; Nordhoff Netherlands, 1975, J. B. Fussell
7.	1975	*How to Hand Calculate System Reliability Characteristics,* IEEE Transactions On Reliability (R-24 No3), 1975, p169-174, J. B. Fussell
8.	1975	*Reliability And Fault Tree Analysis,* Conference On Reliability And Fault Tree Analysis; UC Berkeley; SIAM Pub, 1975, R. E. Barlow & J. B. Fussell & N. D. Singpurwalla
9.	1975	*Computer Aided Fault Tree Construction For Electrical Systems*, Reliability And Fault Tree Analysis ; SIAM, 1975, p37-56, J. B. Fussell
10.	1975	*Fault Tree Analysis – The Secondary Failure Anomaly,* Operations Research Society Of America, 1975, J. B. Fussell
11.	1976	*Fault Tree Analysis : Concepts And Techniques,* Generic Techniques In Systems Reliability Assessment; E.J.Henley & J.W.Lynn editors; Noordhoff Pub, 1976, p133-162, J. B. Fussell
12.	1976	*A Collection Of Methods For Reliability And Safety Engineering,* ANCR-1273; Idaho National Engineering Lab, 1976, J. B. Fussell & G. R. Burdick & D. M. Rasmuson & J. C. Wilson
13.	1976	*On The Quantitative Analysis Of Priority AND Failure Logic,* IEEE Transactions On Reliability (R-25 No 5), 1976, p324-326, J. B. Fussell & E. F. Aber & R. G. Rahl
14.	1976	*Quantitative Evaluation Of Nuclear System Reliability And Safety Characteristics,* IEEE Transactions On Reliability (R-25 No3), 1976, p178-183, J. B. Fussell & H. E. Lambert
15.	1977	*Nuclear Systems Reliability and Risk Assessment,* SIAM Pub; International Conference on Nuclear Systems Reliability Engineering and Risk Assessment, 1977, J. B. Fussell & G. R. Burdick
16.	1977	*Common Cause Failure Analysis Methodology For Complex Systems,* Nuclear Systems Reliability and Risk Assessment; edited by J. B. Fussell & G. R. Burdick; SIAM, 1977, p289-313, D. P. Wagner & C. L. Cate & J. B. Fussell
17.	1977	*BACFIRE – A Computer Program For Common Cause Failure Analysis,* Univ. Tennessee NERS-77-02, 1977, C. L. Cate & J. B. Fussell
18.	1977	*Phased Mission Analysis: A Review Of New Developments And An Application,* IEEE Transactions On Reliability (Vol R-26 No 1), 1977, p43-49, G. R. Burdick & J. B. Fussell & D. M. Rasmuson & J. R. Wilson
19.	1977	*Fault Tree Analysis As A Part Of Mechanical System Design*, National Bureau Of Standards NBS-SP-487 NTIS, 1977, J. B. Fussell & D. P. Wagner
20.	1980	*A Methodology for Calculating the Expected Number of Failures of a System Undergoing a Phased Mission,* Nuclear Science Engineering (Vol 74), 1980, D. F. Montague & J. B. Fussel
21.	1981	*System Reliability Engineering Methodology For Industrial Application*, Loss Prevention Vol 14; AICE, 1981, p18-28, J. S. Arendt & J. B. Fussell
22.	1994	*Probabilistic Safety Analysis For Systems With Standby Subsystems With Sequentially Used Standbys,* Reliability Engineering And System Safety 44, 1994, p67-76, Q. Zhang & H. M. Paula & J. B. Fussell

Table 6 – Articles by Howard Lambert

	Year	Title
1.	1973	*System Safety Analysis And Fault Tree Analysis*, UCID-16238; Lawrence Livermore Labs, 1973, H. E. Lambert
2.	1975	*Fault Trees For Decision Making In Systems Analysis*, Lawrence Livermore Labs UCRL-51829; PhD Thesis; Univ. California, 1975, H. E. Lambert
3.	1975	*Introduction To Fault Tree Analysis,* Reliability And Fault Tree Analysis ; SIAM, 1975, p7-36, H. E. Lambert
4.	1975	*Measures Of Importance Of Events And Cut Sets In Fault Trees,* Reliability And Fault Tree Analysis ; SIAM, 1975, p77-100, H. E. Lambert
5.	1976	*Quantitative Evaluation Of Nuclear System Reliability And Safety Characteristics,* IEEE

		Transactions On Reliability (R-25 No3), 1976, p178-183, J. B. Fussell & H. E. Lambert
6.	1977	*Fault Trees For Diagnosis Of System Fault Conditions,* Nuclear Science And Engineering (Vol 62), 1977, p20-34, H. E. Lambert & G. Yadigaroglu
7.	1977	*The IMPORTANCE Computer Code,* UCRL-79269; Lawrence Livermore Lab, 1977, H. E. Lambert & F. M. Gilman
8.	1978	*The Results Of A Directed Graph Fault Tree Assessment Of A MCA System,* UCRL-80802 Lawrence Livermore Labs, 1978, F. M. Gilman & H. E. Lambert & J. J. Lim
9.	1979	*Comments On The Lapp-Powers Computer Aided Synthesis Of Fault Trees,* IEEE Transactions On Reliability (R-28 No 1), 1979, p6-9, H. E. Lambert
10.	1981	*The Use Of The Computer Code IMPORTANCE With SETS Input,* Sandia SAN81-7068; USNRC Report NUREG/CR-1965, 1981, H. E. Lambert & B. J. Davis
11.	1983	*Interval Reliability For Initiating And Enabling Events,* IEEE Transactions On Reliability (R-32 No 2), 1983, p150-163, C. Dunglinson & H. Lambert
12.	1996	*The Impact Of Improved Vehicle Design On Highway Safety,* Reliability Engineering And System Safety 54, 1996, p65-76, J. S. Eisele & Y. Y. Haimes & N. J. Garber & D. Li & J. H. Lambert & P. Kuzminski & M. Chowdhury

Table 7 – Articles by Ernst Henley

	Year	Title
1.	1973	*Generic Techniques In Systems Reliability Assessment,* Proceedings Of The NATO Advanced Study Institute On Generic Techniques In Systems reliability July 1973; Noordhoff Pub, 1976, E. J. Henley & J. W. Lynn
2.	1976	*Systems Analysis By Sequential Fault Trees,* Microelectronics And Reliability 15, 1976, p247-248, E. J. Henley
3.	1976	*Process Failure Analysis By Block Diagrams And Fault Trees,* Industrial & Engineering Chemistry Fundamentals 15, 1976, p128-134, S. Caceres & E. J. Henley
4.	1977	*Comments On: Computer Aided Synthesis Of Fault Trees,* IEEE Transactions On Reliability (R-26 No 5), 1977, 316-318, E. J. Henley & H. Kumamoto
5.	1978	*Top Down Algorithm For Obtaining Prime Implicant Sets Of Non-Coherent Fault Trees,* IEEE Transactions On Reliability (R-27 No 4), 1978, p242-249, H. Kumamoto & E. J. Henley
6.	1980	*Author Reply #2,* IEEE Transactions On Reliability (R-29), 1980, p133-134, H. Kumamoto & E. J. Henley
7.	1980	*Dagger Sampling Monte Carlo For System Unavailability Evaluation,* IEEE Transactions On Reliability (R-29 No 2), 1980, p122-125, H. Kumamoto & K. Tanaka & K. Inoue & E. J. Henley,
8.	1980	*State Transition Monte Carlo For Evaluating Large Repairable Systems,* IEEE Transactions On Reliability (Vol R-29 No 5), 1980, p376-380, H. Kumamoto & K. Tanaka & K. Inoue & E. J. Henley
9.	1980	*Probabilistic Evaluation Of Prime Implicants And Top Events For Non-Coherent Systems,* IEEE Transactions On Reliability (Vol R-29 No 5), 1980, p361-367, T. Inagaki & E. J. Henley
10.	1981	*Reliability Engineering and Risk Assessment,* Prentice Hall Pub, 1981, E. J. Henley & H. Kumamoto
11.	1981	*Signal Flow Based Graphs For Failure Mode Analysis Of Systems With Control Loops,* IEEE Transactions On Reliability (Vol R-30 No 2), 1981, p110-116, H. Kumamoto & E. J. Henley & K. Inoue,
12.	1986	*Automated Fault Tree Synthesis By Disturbance Analysis,* Industrial & Engineering Chemistry Fundamentals 25, 1986, p233-239, H. Kumamoto & E. J. Henley
13.	1988	*On Digraphs – Fault Trees And Cut Sets,* Reliability Engineering And System Safety (Vol 20 No 2), 1988, p35-61, T. Kohda & E. J. Henley
14.	1989	*Finding Modules in Fault Trees,* IEEE Transactions on Reliability (R-38 No 2), 1989, p165-176, T. Kohda & E. J. Henley & K. Inoue
15.	1990	*An Action-Chain Model For The Design Of Hazard-Control Systems For Robots,* IEEE Transactions on Reliability (R-39 No 2), 1990, p151-157, Y. Sato & E. J. Henley & K. Inoue
16.	1995	*Automated Fault Tree Synthesis By Semantic Network Modeling Rule Based Development And*

		Recursive 3-Value Procedure, Reliability Engineering And System Safety (Vol 49 No 2), 1995, p171-188, H. Kumamoto & E. J. Henley
17.	1996	*Probabilistic Risk Assessment And Management For Engineers And Scientists*, IEEE Press (2nd edition), 1996, E. J. Henley & H. Kumamoto

Table 8 – Articles John Andrews

	Year	Title
1.	1986	*Application Of The Digraph Method Of Fault Tree Construction To Process Plant,* Reliability Engineering And System Safety (Vol 14 No 2), 1986, p85-106, J. D. Andrews & J. M. Morgan,
2.	1988	*The Propagation Of Faults In Process Plants: Fault Tree Synthesis For A Butane Vaporiser System (Part 5),* Reliability Engineering And System Safety 23, 1988, p31-49, J. S. Mullhi & M. L. Ang & B. E. Kelly & F. P. Lees & J. D. Andrews
3.	1990	*Application Of The Digraph Method Of Fault Tree Construction To A Complex Control Configuration,* Reliability Engineering And System Safety (Vol 28), 1990, p357-384, J. Andrews & G. Brennan
4.	1991	*Quantitative Safety Assessment of the Ventilation Recirculation System in an Undersea Mine*, Quality And Reliability Engineering International (Vol), 1991, p497-510, J. D. Andrews
5.	1993	*Fault Tree Analysis,* Reliability And Risk Assessment; Longman Scientific & Technical Publishers, 1993, 144-200, J. D. Andrews & T. R. Moss
6.	1994	*Optimal Safety System Design Using Fault Tree Analysis,* Proceedings ImechE (Vol 208), 1994, p123-132, J. D. Andrews
7.	1995	*New Approaches To Evaluating Fault Trees,* Proceedings Of ESREL 95 Conference, 1995, p241-254, R. M. Sinnamon & J. D. Andrews
8.	1996	*Fault Tree Analysis And Binary Decision Diagrams,* Annual R & M Symposium, 1996, p215-222, R. M. Sinnamon & J. D. Andrews
9.	1996	*Improved Efficiency (Accuracy) In Quantitative Fault Tree Analysis,* Proceedings Of 12th ARTS: Manchester, 1996, R. M. Sinnamon & J. D. Andrews
10.	1997	*Optimal Safety System Performance,* Proceedings Annual R & M Symposium, 1997, p76-83, J. D. Andrews & R. L. Pattison
11.	1997	*Computerized Fault Tree Construction For A Train Braking System,* Quality And Reliability Engineering International (Vol 13), 1997, p299-309, J. J. Henry & J. D. Andrews
12.	1997	*Improved Efficiency In Qualitative Fault Tree Analysis,* Quality And Reliability Engineering International (Vol 13), 1997, p293-298, R. M. Sinnamon & J. D. Andrews
13.	1997	*Improved Accuracy In Quantitative Fault Tree Analysis,* Quality And Reliability Engineering International (Vol 13), 1997, p285-292, R. M. Sinnamon & J. D. Andrews
14.	1997	*New Approaches To Evaluating Fault Trees,* Reliability Engineering And System Safety (Vol 58 No 2), 1997, p89-96, R. M. Sinnamon & J. D. Andrews
15.	1997	*A Computerized Fault Tree Construction Methodology,* Journal of Process Mechanical Engineering (Vol 211 No E3), 1997, p171-183, J. D. Andrew & J. J. Henry
16.	1998	*Efficient Basic Event Orderings for Binary Decision Diagrams,* Proceedings Annual Reliability and Maintainability Symposium, 1998, p61-68, J. D. Andrews & L. M. Bartlett
17.	1998	*Analysis of Systems With Standby Redundancy,* Proceedings of the 16th International System Safety Conference, 1998, p80-89, J. D. Andrews & L. M. Ridley