

Method of Computer-Aided FTA (Fault Tree Analysis) in Reliability Design and Development; Using Knowledge Management Based on Quantity Dimension Indexing and Block Diagram

Youji Hiraoka and Katsunari Yamamoto
JATCO, Ltd.

Tamotsu Murakami
The University of Tokyo

Yoshiyuki Furukawa, Hitoshi Tokunaga and Hiroyuki Sawada
AIST

ABSTRACT

In this paper the authors propose computerized support for Fault Tree Analysis (FTA) based on new knowledge management in product design. FTA is a method of analyzing and visualizing the causes of a fault event by Fault Tree diagram (FT diagram) that has a tree structure with logical step. When we develop the new product, we use FTA to analyze the fault events, to extract design parameters, and to plan test programs in Jatco's development process. Although FTA is an effective analytical tool for resolving problems, improving design quality and planning test programs, it is not easy to complete the FT diagram of a fault on Automatic Transmission and the component system without a mistake. To solve this problem, we propose the following approach using Computer-Aided knowledge management based on Quantity Dimension Indexing and block diagram. We classify FT diagrams into component failure, system failure, and control failure diagrams. An FT diagram of component failure is created with a computerized support tool based on quantity dimension indexing that was proposed [9] [10]. An FT diagram of system failure and control failure is created with a computerized support tool utilizing block diagrams that were created with design engineers. We developed this software of Computer-Aided FTA for design engineers by the collaborative research group (Jatco Ltd, The University of Tokyo and National Institute of Advanced Industrial Science and Technology (AIST)). We report the efficiency and effectiveness of this support method (software) for FTA based on evaluating results in actual development process, and describe the possible feasibility and future study for proposal methods in complex system development.

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INTRODUCTION

Product design is defined as a process to seek a design solution that can meet the functional requirements under many constraint conditions (cost, layout, weight, manufacturing conditions, etc.) [1]. In practical product design, due to diversified functional requirements, complicated product systems and many constraints, an optimal design solution has been difficult for design engineers and their groups, and required significant efforts. Therefore, many computerized design support systems which

can be used to organize design data and share the data among the related engineer groups, are studied. Tamura et al.[2] proposes a design support system based on the knowledge-structured database established using Stress-Strength Model (SSM) to reuse failure data as design knowledge, and they put the software in practical use. Kitamura et al. [3] defined the ontology of faults in detail and proposed knowledge structuring applications. These methods are the design support systems that require the database to be established correctly according to the defined notations. Converting

enormous amounts of corporate design data into the notations to establish the database requires a lot of labor hours and days of work.

On the other hand, Fault Tree Analysis (FTA) [4] is a method to analyze a cause event of faulty phenomenon based on Fault Tree diagram (FT diagram), which visualizes the causes of fault events by expanding a fault event hierarchically to its possible cause events and representing the entire structure of the problem. FTA is used for fault analysis in many technological fields (automotive, aircraft, nuclear power, etc.) and is a general analyzing tool in problem resolution of products. Miyamura [5] reported that the knowledge management of design information using FTA is possible and effective in product design. Jatco also makes use of FTA in problem resolution of product and design stage processes: the P-FTA-D-QFD (Perfect · Fault Tree Analysis - Design · Quality Function Deployment) method [6] (Fig. 1) which was developed by the power train development division of Nissan Motors. Therefore the knowledge management based on FTA is practically effective in problem resolution of products and design stage processes. Many methods of support for FTA are studied [7] [8], but they do not confirm the accuracy of an FT diagram itself.

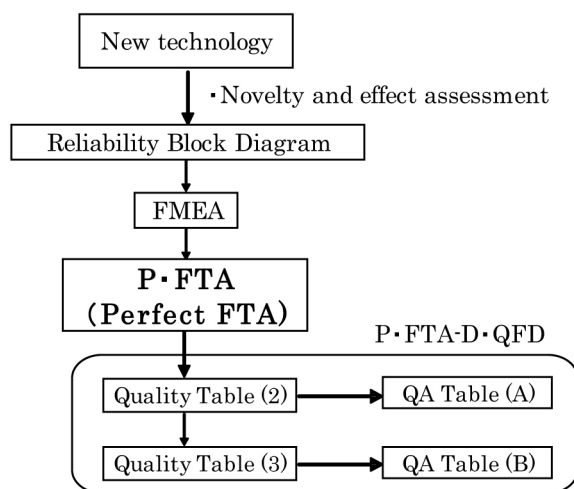


Fig.1. P-FTA-D-QFD method [6]

This paper proposes a new approach of computerized support for FTA. We classify FT diagrams into component failure, system failure, and control failure diagrams. An FT diagram of component failure is created with a computerized support tool based on quantity dimension indexing that was proposed [9] [10]. An FT diagram of system failure and control failure is created with a computerized support tool utilizing block diagrams that were created by design engineers. We develop this software of Computer-Aided FTA for design engineers by the collaborative research group (Jatco Ltd, The University of Tokyo and AIST). We report that the engineer's working hours of creating an FT diagram decrease by 50 % with this support software, while the accuracy of an FT diagram is improved in actual

development process, and describe the possible feasibility and future study for proposal methods in complex system development.

FTA IN JATCO PRODUCT DEVELOPMENT PROCESS

Jatco uses the P-FTA-D-QFD method [6] (Fig. 1) for the standard development process of new design products. In the process we analyze a design parameter based on P-FTA; a kind of FTA, and plan a experiment and a computer simulation required for unit system, component, and control system using the design parameter and Quality Table (2). For solving a problem of prototype and product units, Jatco uses a process of a method to analyze problem causes based on FTA and verify the cause. In these methods FTA is most important and effective analysis tool for product design and solving problems, but the following issues exist in creating an FT diagram of FTA:

- Since technical knowledge and profound expertness are required to create an FT diagram, it is difficult for younger design engineers.
- Since an experienced design engineer's thought is affected by past designs, problems, and experiments in products, it is difficult for an experienced design engineer to create an FT diagram without a mistake.
- Since an FT diagram in actual work is complicated and the scale is large, check and correction of misunderstandings and oversight are not possible with manpower.
- Since during a process of creating new FT diagram, feedback from senior engineers, and correction must be repeated until the FT diagram is completed, so it takes many working hours and days.

Experienced design engineers are much more likely to describe only the failure in the events of the FT diagram that they experienced, and then the FT diagram has some mistakes. They receive much feedback from senior engineers and repeats trial and error. This is a phenomenon [12] that a thought is affected by the past experiences, which is called "cognitive bias" by psychology, and is frequently found in experienced design engineers. We consider that the improvement that a design engineer can efficiently create an accurate FT diagram is a big challenge in development process.

STRUCTURE OF FT DIAGRAM AND SUPPORT METHOD

Fault tree analysis (FTA) is one of such systematic method in which the possible causes of fault events can be analyzed and visualized during a product design and development process in the form of an FT diagram called a "fault tree". Even with the fault analysis of a single component, the scale of FT diagram frequently becomes large, since it follows through the logicity. Therefore, the

FT diagram of such a system product is on the much larger scale, and check and correction of development of an event with human power is difficult. Actually, the FT diagrams are classified as follows, divided and created, so that they can be easily handled by design engineers:

- FT diagram of system failure
- FT diagram of component failure
- FT diagram of control failure

The FT diagram of system failure is defined as a tree diagram of failure which occurs between multiple components and controls, and an event occurring at the end is defined as a component failure or a control failure. With an FT diagram of component failure, the breakage, wear, etc. of a component is defined as a top event. The FT diagram of control failure is defined a failure in the control system, such as a hydraulic system and an electronic system, and the control logic, its input (sensor, etc.), etc. are factors of failure. According to the definition, the FT diagram of system failure is composed of a complicated combination of top events in the FT diagrams of component failure and control failure, as shown in Fig.2.

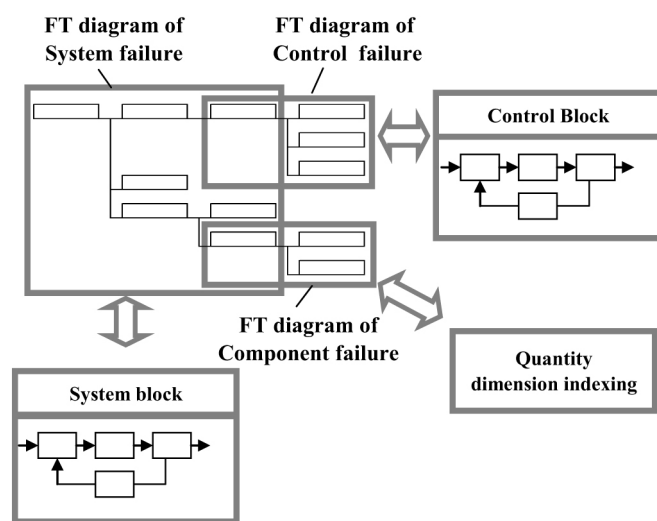


Fig.2. The structure of FT diagram and support method

In this study, we propose a support method of creating FT diagrams by the bidirectional arrows in Fig. 2, because of the characteristics of the FT diagrams in the above classification. Since the FT diagram of component failure follows the physical phenomena in many cases, we supports the FT diagram created based on the quantity dimension indexing method. Since the engineers majoring the system and control use a block diagram to analyze the behaviors of system and control, we support the making FT diagrams based on the block diagram for the FT diagrams of system failure and control failure. It is possible in this way to support creating the FT diagrams of a large-scale system product, by combining these support methods.

THE METHOD OF SUPPORT CREATING FT DIAGRAMS

As the method of support creating FT diagrams, we set the concepts of the software to be developed as follows:

< The concepts of software developed for support creating FT diagrams. >

- The design engineers shall be users.
- The software can point out mistakes in newly creating FT diagrams.
- The software can show some correction lists of a mistake, and the correction is easy for users.
- The software has system extensibility in the future (generally available software, Internet, etc.).

The concept target the compatibility of accuracy and efficiency while the support system is based on the judgment of designer engineers.

Method of support creating an FT diagram of component failure

Physical Quantity Representation for Design Knowledge Management [9]

Nowadays, the design of an advanced engineering product includes an increasing number of issues such as product liability and environmental impact as well as the functionality and performance of artifacts. Knowledge management is a promising approach for supporting such complicated design processes, by which design knowledge and information are compiled using information technology and used.

Although many knowledge management techniques for literal expression have been developed, they are not necessarily suitable for managing the engineering design knowledge of physical phenomena. For example, a design engineer may store knowledge about a faulty state of a machine as "...the temperature of the part is too high...", whereas another design engineer may search for relevant knowledge about a failure of a machine with the description "...the part becomes too hot...". The relevance between these two descriptions, however, cannot be estimated from their literal expressions and a thesaurus or concept dictionary must be prepared in advance (e.g., [13] [14] [15] [16]).

On the other hand, a physical quantity approach to knowledge management has been mentioned in some studies (e.g., [17]). If we select the physical quantities appearing in these two descriptions and represent them using SI units (the International System of Units) [18], we can estimate their possible relevance because they have a common physical quantity: temperature (K). This suggests a possible advantage of physical quantity representation as an index for estimating the relevance between design knowledge descriptions. On the

basis of this observation, the authors propose quantity dimension indexing for design knowledge management [11].

Quantity dimension indexing [9]

In SI Units, all physical quantities describing physical phenomena can be defined by a combination of seven base quantities (and their units): length (m), mass (kg), time (s), electric current (A), thermodynamic temperature (K), amount of substance (mol) and luminous intensity (cd). The unit of a quantity is represented as a seven-dimensional vector in such a space:

$$\mathbf{a} = [a_m \ a_{kg} \ a_s \ a_A \ a_K \ a_{mol} \ a_{cd}]$$

For example, Force [N] = [kg · m/s²] = [m¹ · kg¹ · s⁻²] is expressed as [11-20000]. We call this seven-dimensional vector a “quantity dimension vector”. Examples of quantity dimension vectors for various quantities are listed in the Appendix.

Because of the generality, objectivity and universality of SI, this covers all physical quantities that may appear in any design knowledge or design problem in the past, present and future, and the same physical quantities are represented as the same vectors regardless of the differences between people, products, domains, organizations, nations and languages. This is expected to be a promising method of indexing design knowledge from the viewpoint of physical phenomena.

Application of quantity dimension indexing and the FT diagram for component failure

The FT diagram for component failure places a faulty event of component in the top event. Since a faulty event of component occurs following the physical phenomenon, the events developed from the top event are mostly expressed by a physical amount. In the development of an event expressed by physical amount, unless the quantity dimension of an upper event is expressed by the quantity dimension of a lower event, the requisites of logical development cannot be satisfied. That is, the development with a mistake can be said if the quantity dimension of an upper event can not be expressed by multiplying or dividing the quantity dimension of a lower event, or both are not equal (see Fig. 3). Therefore, by using the quantity dimension indexing for each event of the FT diagram, it can be judged whether the FT diagram can correctly be developed, by calculating the quantity dimension vectors of upper and lower events. Furthermore, since the indexes based on the quantity dimension vectors of each event makes search easy on computer, a design engineer can show the candidates of development patterns from the database and select the correct pattern.

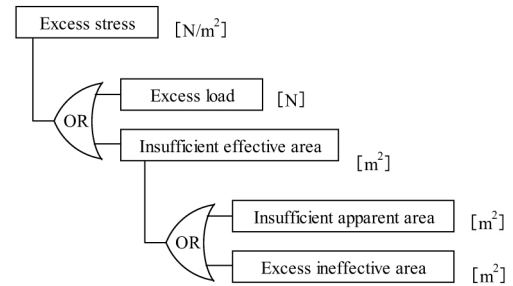


Fig.3. Example of an FT diagram

Processes of support created the FT diagram of component failure

Fig. 4 shows the computer-aided support processes the FT diagram creation support software. After this software first runs quantity dimension indexing of a newly created FT diagram on computer, user checks and corrects it to determine the quantity dimension indexing of each event. The software judges the logicity of event developed by quantity dimension indexing of each event, and displays the results. At a mistaken point, the software searches for a development pattern similar to the event of FT diagrams on the database. It calculates the similarity[9] [10] between the mistaken event and the quantity dimension of the patterns registered in the database, and presents the patterns in the order from the highest similarity to the user. The user selects the pattern judged to be correct among the presented the candidates, and corrects the event developed.

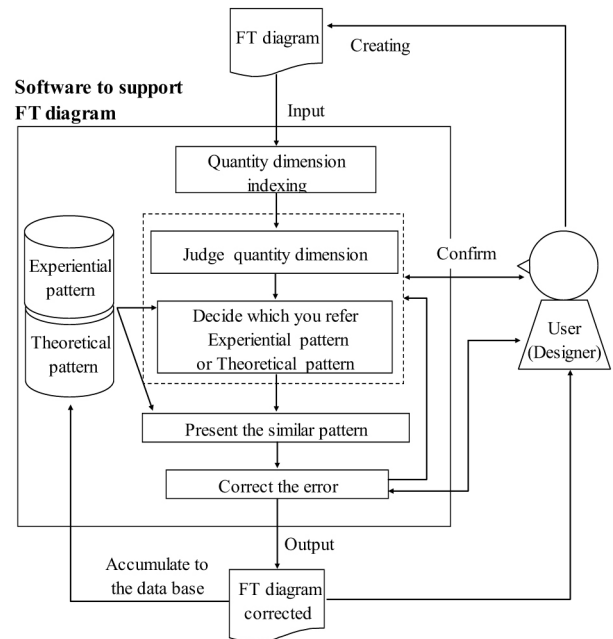


Fig.4. Support process creating an FT diagram