

Modeling and Utilizing Expert's Knowledge, Experience, and Thinking in Automobile Development

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ABSTRACT

Measures were taken to realize the structured knowledge and thinking of experts, personalized in the form of tacit knowledge, for the purpose of enhancing the development efficiency of design work.

In this approach, the words are extracted from procedure manuals, checklists, and so on, that are usually put into written form and managed. Those words are categorized as design information and work procedures, after which they are structured using two types of machine languages. By further extracting both the knowledge and thinking that are the tacit knowledge of an expert directly from statements, the newness and quantity of the information were assured within a short time. At the same time, the thinking that experts perform based on their own empirical values was structured and incorporated in a model. In order to verify the effectiveness of that model in operation, a system for obtaining suggestions not from other people but from machines was constructed and applied to design work on actual crash safety performance. The results confirmed that, by comparison with conventional cases in which only procedure manuals are referred to, cases in which the present model was used to perform work showed that it became possible to advance the work efficiently so that goals could be achieved in approximately one-half the time.

1. Introduction

Keeping up with new technology, as typified by connected, autonomous, shared, and electric (CASE) mobility, is a major challenge for automobile manufacturers. Moreover, regulations relating to environmental protection, as typified by CAFE, as well as safety requirements for the protection of vehicle occupants, grow more rigorous year by year. Engineers, therefore, have to think about such various aspects as safety, regulations, cost, mass productivity, and so on, when developing a vehicle. In order to carry out design work of high quality on a global scale, it is necessary for many engineers at different centers around the world to maintain the same level of design quality. Given this context, AI is used actively in a variety of fields, regardless of the industry, and solutions using big data are being proposed.

In development as it is currently practiced, most engineers actively use simulations as a substitute for actual testing. This shortens the time they spend on investigation. In recent years, however, increases in simulation accuracy have been accompanied by enlargements in model scale, so that the computation time taken for a single cycle has

also increased by the year. Engineers with less experience (beginners) end up needing more time because they go by trial and error, so that securing the time to turn to research and development of next-generation technology, and other such more creative work, becomes an issue. Experts, on the other hand, conduct their investigation very efficiently, without pursuing unnecessary procedures, on the basis of rational hypotheses and theories. They can do this because they have learned lessons from their vast experiences of malfunctions in the past, and they are able to act in an instant to select the appropriate, necessary, and sufficient method for success.

In order to make use of this kind of expert skill to heighten the efficiency of design work, an effort was made to record methods of investigation in design manuals and other such documentation using presentation and other such software employing imagery, graphs, and photographs. However, the thinking process of experts most often deals with tacit knowledge, which has not been put into writing and made into explicit knowledge, so that the structuring of that knowledge is an issue. One method for structuring the thinking and knowledge of experts is by the use of AI. Although there are many cases of the use of AI that

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employs deep learning, however, what these do is process enormous amounts of data by rules that are determined by computer. For that reason, the particulars of how a solution was reached, and what its grounds are, are not understood even by specialists, and there are concerns that the process itself would become a black box. There was MYCIN⁽¹⁾, an expert system for medical use that was developed in the 1970s at Stanford University. MYCIN held knowledge data comprising about 500 rules. When physicians posed questions, the system would respond with a yes or a no, and eventually it would be able to indicate a recommended medical treatment. However, it was not used in actual clinical settings. This was because, if the computer gave a mistaken response, the recommended medical treatment would be of uncertain traceability. When issues arose, it was not possible to look back at the grounds for the judgement, and this was an issue.

In order to make use of AI in the field of vehicle development, where guarantees of quality are important, the developer needs to indicate the basis for conclusions, as in medical, judicial, and other such fields where important conclusions are delivered.

In light of this background, and in order to deal with more issues using fewer resources in the future, it will be necessary to grow out of conventional handling of the experience and knowledge that constitutes an enormous development process based on verification results from the past. What is needed instead is a development-related organization that accumulates that knowhow and utilizes it not in a personalized manner but for the organization as a whole, thereby reducing man-hours of development on already known issues. The present research was, therefore, directed to the construction of a system capable of structuring the thinking and knowledge of experts and utilizing it in design work.

2. Aims of the Present Research

2.1. Overview

For the present research, the structured knowledge of an expert is defined as a knowledge model and a model structured with the thinking of an expert is defined as an expert model.

First, a method for combining the two machine languages of Goal Structuring Notation (GSN)⁽²⁾ and System Modeling Language (Sys ML)⁽³⁾ was verified as a method for structuring knowledge in design. Words extracted from information materials were structured by the two machine languages and the two were linked together in order to construct a knowledge model. Next, a method to enable structuring knowledge directly from an expert's statement even when information materials in documentary form are not available was investigated and steps were taken to speed up the construction of a model. Policy was then further extracted from the tacit knowledge possessed by an expert, and the expert's thinking was structured

using the concept of reward. Finally, the constructed model was applied to actual design work and its effectiveness in workload reduction was evaluated. Figure 1 shows the ideal state of an expert model being utilized globally. There are large numbers of people engaging in work while being transferred to and from large numbers of centers where they come and go. Therefore, the issue of passing on and accumulating technology becomes greater when considered on a global scale. The aim here, by contrast, is to aggregate structured knowledge and experience of experts at a single location so that anyone anywhere can make active use of that expert knowledge and experience.

2.2. Approach to the Ideal State

Figure 2 shows an approach to the ideal state. Beginners do not have the knowledge and experience needed for development work, so they tend to carry out extra tasks. The approach taken to make it possible for beginners also to advance their work effectively was to structure knowledge and thinking of experts in the form of a model. By making use of the model, beginners can reduce the time they need for development work, and with the extra time they create, they can pursue more creative work.

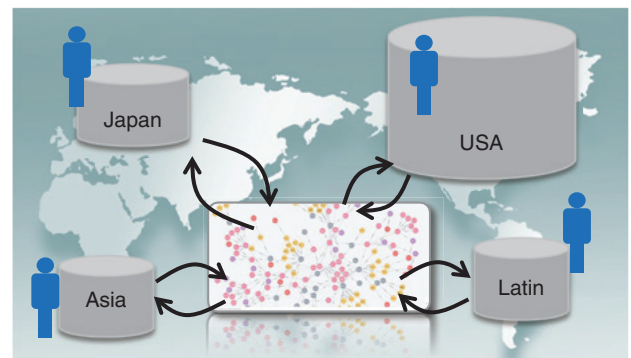


Fig. 1 Expert model utilized globally

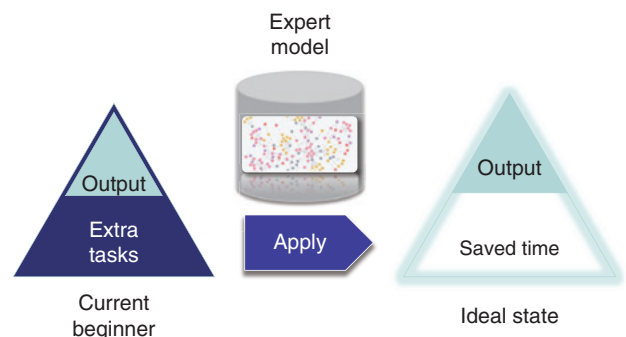


Fig. 2 Concept of expert model

Figure 3 shows the dialogue with an expert model. As shown in Fig. 3(a), the knowledge and experience in conventional work is personalized, so that the passing on of knowledge and experience and education in it is carried on from person to person by analog communication of information. The proposal here, as shown in Fig. 3(b), was conceived to have users engage in dialogue with the system to obtain the suggestions they need to promote development.

2.3. The Four Steps of the System

The system presented in this research is conceived as being implemented in four steps, as shown in Fig. 4.

“Educating”

Knowledge, experience, and thinking are extracted from experts and technical documents and structured in a language that can be input to machines. By providing that structured model to the system as sequential input, the system is placed in a state that allows engineers to obtain suggestions from it.

“Listening”

Users ask the expert model questions, using the system



Fig. 3 Interaction with expert's knowledge

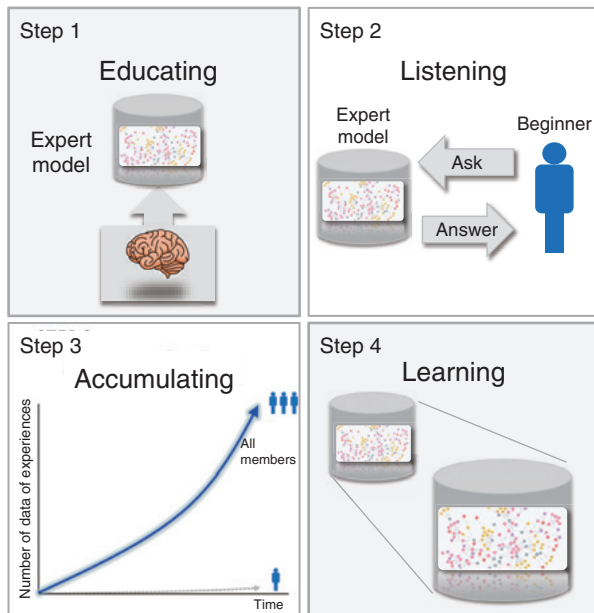


Fig. 4 Four step approach

as intermediary, and obtain suggestions from the expert model regarding investigation policy.

“Accumulating”

As the expert model is utilized more and more, so that history, including the responses, is accumulated in the model as empirical values. When it is utilized by more users, then it can accumulate a dramatically greater number of empirical values. This makes it possible to maintain a constantly up-to-date newness of information.

“Learning”

The model itself engages in self learning that uses knowledge together with cause-and-effect relationships, and in this way evolves into a model that goes beyond human experience.

The actual sites of design and development are spread around the whole world. As more users employ this model, the knowledge in it accumulates and the model undergoes further growth by engaging in self learning. The expert model can be thought of as evolving while going through the four steps described above. This paper will explain the structuring method used and the verification results obtained for the “Educating” of the expert model that becomes the core of this approach by means of the four steps.

3. “Educating”

3.1. The Modeling Process

Figure 5 shows the procedure for construction of the model. Tacit knowledge is extracted from information materials from the past that record knowledge and experience of experts, verification results, words spoken by experts, and other such sources, and the knowledge model is constructed. Next, policy is extracted from experts and combined with the knowledge model to construct the expert model.

Figure 6 shows the visualization and structurization of tacit knowledge.

The knowledge based on experiences contained in the brain of an expert is tacit knowledge that is invisible

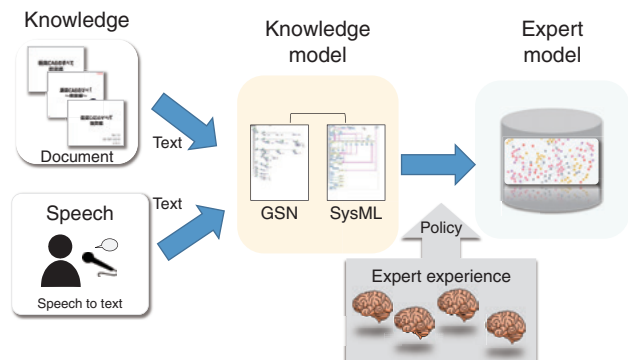


Fig. 5 Model construction process

and cannot be seen by other people (bottom left). That knowledge is extracted from procedure manual and statements in a state that is made visible using text data (top left). Then, it is further structured so that it can be interpreted by machine (top right) and a knowledge model is constructed. However, the work of creating procedure manuals takes considerable time, so it is possible that information will be updated during that interval. For present purposes, therefore, it was decided to construct the knowledge model directly from statements without going through the conversion of tacit knowledge into information materials. Following this kind of process makes it possible to create the model in a shorter time. The knowledge model constructed by extracting knowledge and experience directly from the expert's tacit knowledge is grounded in the expert's experience, and suggestions obtained from it can be formed so that they are based in past development experience and verification results as their grounds.

3.2. Modeling Knowledge

A design procedure manual used in actual work is easy for people to understand, but it is written down on the assumption that people will have the ability to comprehend some amount of specialized knowledge and the meanings of the words. It is also sometimes the case that the definitions of words and work procedures that are accepted as a matter of course in that field are omitted, in which case only people who have knowledge of that field will be able to understand the meaning of the what is written. The machine, however, has not been equipped with the meanings and definitions of the various words in that text, so it cannot readily interpret them. The written procedure manual, therefore, needs to be structured using a language that the machine is able to interpret. For that purpose, the writing in information materials is extracted in the form of text and broken down into words. A dictionary of specialized terminology is, then, used to categorize the words by their parts of speech.

The contents of the procedure manual have accounts

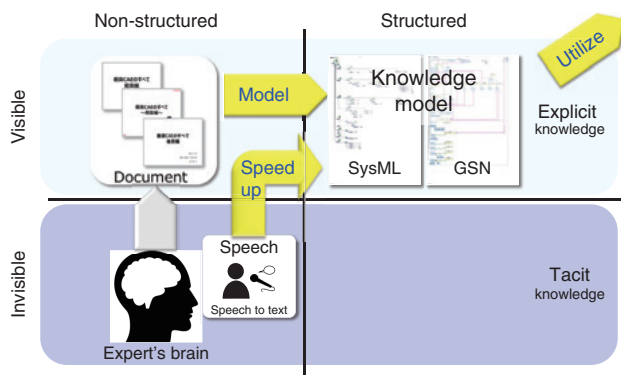


Fig. 6 Visualization and structurization of invisible knowledge

of design information and accounts of design procedures mixed together, so they need to be structured using different methods respectively. For the present research, therefore, the design information was structured using SysML. SysML has a syntactical construction used to express system structure, and it is capable of expressing components as a tree structure, expressing relationships between those components, and so on. For this reason, it is suited to structuring information for the purpose of designing parts. The structuring of design procedures, on the other hand, was handled using GSN. GSN is a syntactical construction that is used for visualization of design quality. GSN can express a top goal by breaking it down into sub goals. By using this GSN, the validity of sub goals can be explained on the basis of evidence regarding the goals they belong to, and the satisfaction of characteristic criteria for a top goal can be explained. For this reason, it is suited to structuring design procedures for the purpose of satisfying the goals for parts. When GSN and SysML are used in these ways for their respective structuring and then further linked together, it becomes possible for the first time to tie design procedures together with parts structure, and the structuring of knowledge becomes possible.

As a specific example, Fig. 7 shows the method for making crispy pizza of a kind only a first-rate chef can make, structured using SysML and GSN. In SysML, the makeup of the pizza is structured. The pizza is made up of dough, tomato sauce, and topping. The dough is further made up of flour, salt, dried yeast, and water.

In GSN, on the other hand, the design procedures for making crispy pizza are structured. With the dough, the top goal (1) is to make crispy pizza, and for that purpose (2) the flour, water, salt, and dried yeast are thoroughly stirred together. Next, the sub goal (3) is to beat the dough against a board until its surface is smooth. In SysML, the action of beating the dough until its surface is smooth becomes a

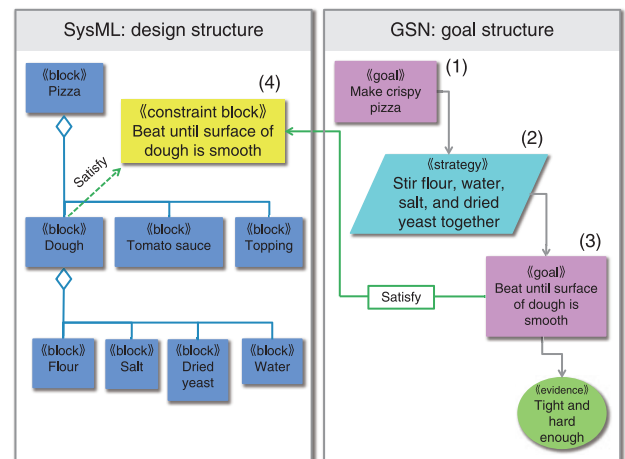


Fig. 7 SysML-GSN model of making crispy pizza

condition of constraint with regard to the dough, and this serves the purpose of (4) linking GSN and SysML together. When GSN and SysML are linked together in this way, the pizza makeup and procedure is clarified for the first time, and the recipe for pizza is completed. When the recipe is available, even beginners can successfully make crispy pizza, and this method can, therefore, be considered to have successfully structured the knowledge of a first-rate chef.

Figure 8 shows an example of this structuring method applied to the design of frame structure intended to achieve the stable absorption of crash energy as designed by an expert in charge of crash safety.

The vehicle body component parts in the engine room that absorb crash energy during a collision are structured in SysML. The engine room is made up of the side frame, lower member, and subframe. There are also component parts that make up the side frame, namely the main plate, back plate, patch, and bulkhead. In GSN, on the other hand, the design procedures for the purpose of stable absorption of crash energy are structured. The top goal (1) is the stable absorption of crash energy, and in order to achieve that, then (2) the side frame has to be made to collapse in a stable manner. Next, in order to cause stable collapse, the sub goal (3) is to configure three bending points where collapse is to occur, as shown in Fig. 9. The configuration of three bending points for collapse is a condition of constraint with respect to the side frame in SysML, and this serves the purpose of (4) linking GSN and SysML together. In other words, the procedure and structure needed to realize the stable absorption of crash energy are clarified, meaning that the recipe for achieving the top goal, which is the expert's knowledge, has been structured using GSN and SysML.

3.3. Increasing the Speed of the Modeling Method

There is a history of research that used to be carried out on expert systems to handle the knowledge of experts using

computers. That was during the second AI boom from the 1980s to the 1990s. From the 1990s on, however, this faded away. The rules for the if statements used at that time to solve complex issues are not easy to understand, and the programming itself was not a simple task. Consequently, the input work done in order to use that system could only be carried out by engineers who had learned those skills. Input, therefore, took huge amounts of time, and this combined with the challenges involved in acquiring those limited skills meant that the quantity and newness of the needed information could not be maintained. This was a factor in the decline of that approach.

Now that programming has advanced to its present level, it is possible to extract words from procedure manuals, as described in Section 3.2., in those fields that have procedure manuals and other such documentary data. It is, therefore, easier, by comparison, to create a model. In fields that do not have procedure manuals and other such documentary data presenting knowledge, however, the documentation has to be created before structuring can be done. Some of the work that has been done to date in creating documentation of certain functionalities took approximately three years, so that by the time it was published, the information already needed to be updated. Creating the documentation successfully achieved the goal of centralizing the knowledge, but it did not enable use of the most up-to-date information in development. Meanwhile, new knowledge is being generated day by day in the discussions conducted by experts at the sites where development is being done, in lectures, and so on. If it became possible to extract and structure the knowledge from those spoken words, therefore, then the newness of information could be maintained. For these reasons, the method adopted for the present research to speed up the process was to construct the technology to create models directly from statements without going through information

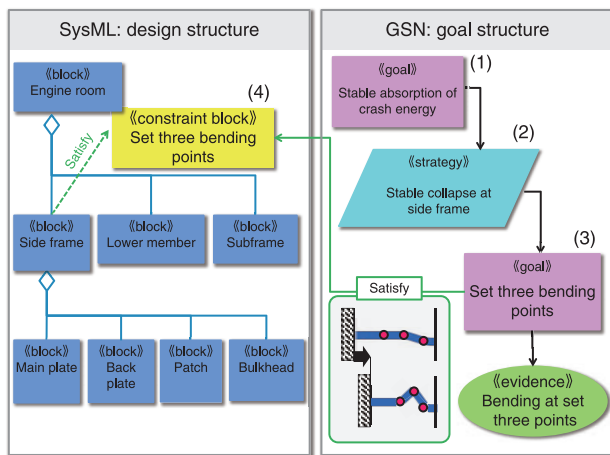


Fig. 8 SysML-GSN model of side frame design

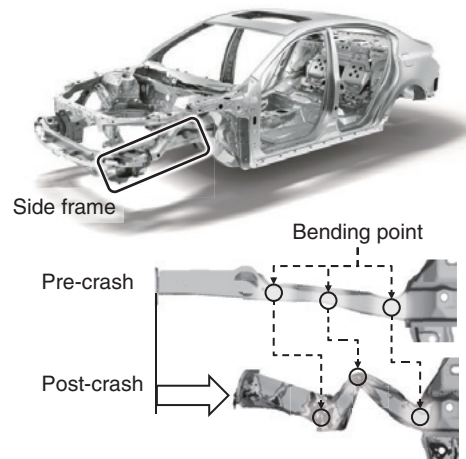


Fig. 9 Three bending points of side frame

materials, as shown in Fig. 10. The procedure followed was first to hold interviews with experts and have them talk about their knowledge. Their spoken statements would be recorded and converted to text by voice recognition. This differs from the procedure followed when extracting text from written documents because statements made in natural conversation involve some amount of ambiguity. The statements were, therefore, subjected to context analysis and anaphoric analysis in order to remove the ambiguities before structuring.

The content of natural conversation is often not understandable to a third party because, for someone who was not present at the time, it may not be clear what the statements are referring to. The knowledge cannot readily be structured in such cases. In order to identify the context of statements, therefore, context analysis was conducted as shown in Fig. 11.

When a statement with the content, “the force generated at the side frame did not reach the target,” is subjected to context analysis, it becomes clear that the words “did not reach the target” show that this is a statement about goals. As a result, the words making up this sentence can be properly structured according to their parts of speech in GSN, which records goals.

Next, the anaphoric analysis shown in Fig. 12 is carried out in order to deal with terms such as “it” and “that” that indicate correspondences between different parts of the text. With statements made in natural conversation, it is common for multiple sentences using anaphor to become broken off and disconnected. If those statements are structured just as they are, the structure will also become broken off and disconnected, and the result will end up inadequate as knowledge. In order to help prevent this, anaphoric analysis was used to make connections between antecedents and anaphors so that structuring could be done without causing the relationships between words to become broken

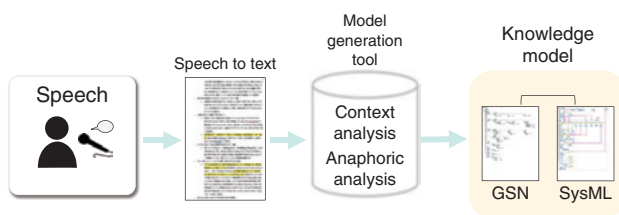


Fig. 10 Speech-to-knowledge model process

Speech	Context analysis
Force generated at the side frame did not reach the target.	➡ About goal
He was the president of this company.	➡ About person
Higher the deformation, higher the injury value.	➡ About collision

Fig. 11 Context analysis

off and disconnected. In this way, anaphoric analysis and context analysis were included in the tools for generating knowledge structure, and structuring was successfully accomplished without going through the process of creating information materials from spoken utterances.

3.4. Structuring Expert Thinking

Figure 13 shows differences between the thinking of beginners and experts. Beginners, who have less knowledge and experience, tackle a task without knowing the pathway to achieving a solution. Experts, on the other hand, have structured their experience and thinking within their own brains. Therefore, not only do they possess it in the form of knowledge, but they can also build the pathway to achieving a solution appropriately for the circumstances. Experts possess this kind of thinking as the result of long years of experience. When they experience a malfunction, they identify the causes of it and remember them and make use of them in their brain in the form of a policy expressing their essence. A policy is a statement that can be expressed in the form “in other words...is what it means.” It is generalized, with specific attributes removed, so that it can be used as a choice for action to help prevent malfunctions

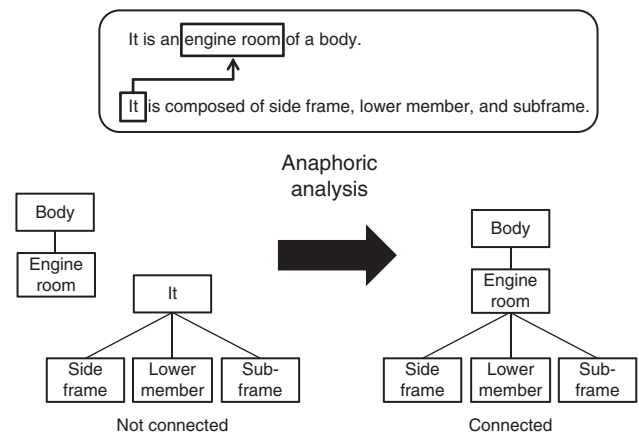


Fig. 12 Anaphoric analysis

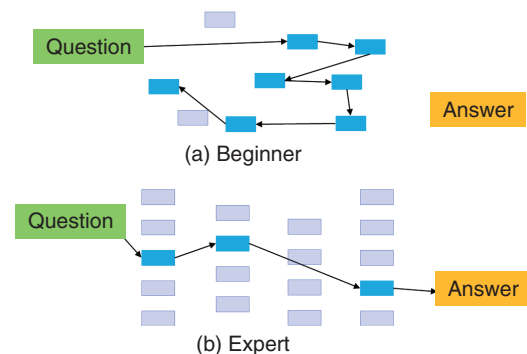


Fig. 13 Comparison of beginner's and expert's thinking

even in different cases. The science of failure⁽⁴⁾ was used for visualization of this policy. The science of failure is a systematized method for working from factor analysis of faults that occur to arrive at factors that present their essence. It is used for extracting policy. First, cases of faults from actual past work were gathered together and interviews were conducted with the people involved. Next, a collection of troubles in the past was created according to the science of failure, and policies were collected.

The policies extracted from malfunctions in this way constitute guidelines to help prevent faults before they can occur, or in other words, they are actions that experts would select. In order to suggest these actions to beginners, a method for reward scoring matched to the action was investigated. Figure 14 shows an example of reward scoring according to policy. The rewards were determined as point scores matched to actions. Action that is in accordance with policy is assigned a higher reward, and action that is instead counter to policy is assigned a negative reward. When users choose a procedure that gains them the highest reward, they are able to choose the procedure with the higher priority.

Figure 15 shows the concept of using reward to suggest priority. Here, what should be done first in order to achieve the crash performance target that is the goal is shown in an example using GSN. Next, in the case of tasks to be carried out that are presented in parallel, beginners will end up carrying out an incorrect task unless they receive suggestions about priority. When making use of rewards in this situation, the higher reward is assigned to the procedure that sets goals based on policy, and users are able to

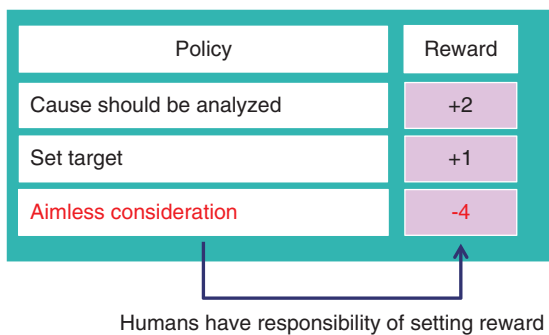


Fig. 14 Description of policy and reward

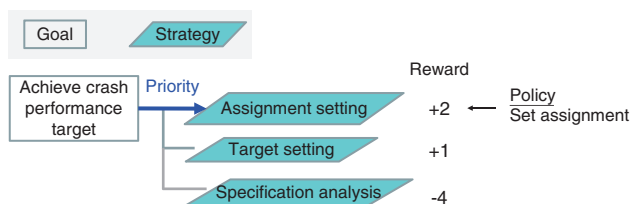


Fig. 15 Reward suggesting correct strategy

understand why that procedure has a higher priority.

The rules for this reward scoring shown in Fig. 14 constitute the grounds for the correctness of suggestions made by the expert model. Therefore, these grounds need to be valid in a way that human beings can understand, such as in terms of their experience, logic, and so on. Thus, the system is predicated on human beings taking responsibility for upholding the rules. The substance of the approach explained up to this point was used to incorporate knowledge and thinking in a structure, and an expert model was constructed that structures 29,429 items of design information relating to performance design of a vehicle frame.

3.5. Verification of Effectiveness

The following scenario was formulated for crash safety work in order to verify that using the expert model is effective in reducing man-hours: "In an offset deformable barrier crash mode where the vehicle has a weight 100 kg greater than the base vehicle, carry out a design whereby the force generated at the side frame is increased from 100 kN to 150 kN while achieving the target mode of collapse." For verification, two younger engineers at approximately the same skill level who were inexperienced in development were selected and a comparison was made of the extent to which they achieved the goal with and without use of the expert model. One engaged in the work while referring only to a procedure manual. The other used the expert model to obtain suggestions while engaging in the work. Figure 16 shows the results for verification of effectiveness by comparison of the extent to which the two subjects achieved their goal and the work time required to do so. Where the expert model was not used, it took 142 hours to achieve the target for the force generated at the side frame. However, the target for mode of collapse was not achieved. Where the expert model was used, on the other hand, the target for force generated and for mode of collapse were both successfully achieved in 62 hours. The effect was to shorten the work time by 56%.

	Result	Required time
Without model	Target missed	142 h
With model	Target achieved	62 h

-80 h
-56%

Fig. 16 Verification result of analysis time reduction effect

Figure 17 shows a breakdown of the reduction effect. It is clear that where the expert model was used, a smaller number of analysis cycles was executed. This is particularly notable in the more time-consuming analysis using a large-scale CAE model, where the number of cycles executed was held down to four cycles compared to seven cycles without the system.

Figure 18 shows the results from verification of the process. The engineer who used only a procedure manual did not succeed in defining phased aims for analysis and actions. Consequently, the work of investigating specific specifications for the side frame to be derived from that process was executed by an analysis using a large-scale CAE model. Many hours were, therefore, expended on the work, and the result did not succeed in achieving the target for mode of collapse.

On the other hand, the engineer who used the expert model was able to obtain suggestions for necessary and sufficient procedures. By means of those suggestions, a grasp of the current state of the base vehicle was obtained, on which basis targets were defined, each stage was configured for the issues involved, and investigation of specific specifications was successfully executed. This made it possible even for someone without experience of their own to successfully achieve all the set targets. The development time shortening effect of using the expert model was, therefore, confirmed.

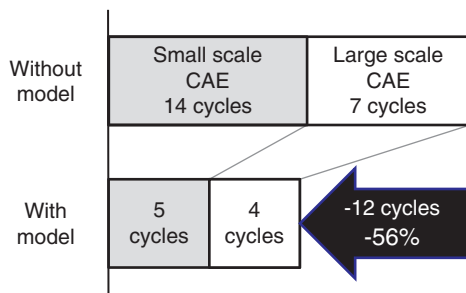


Fig. 17 Breakdown of analysis reduction

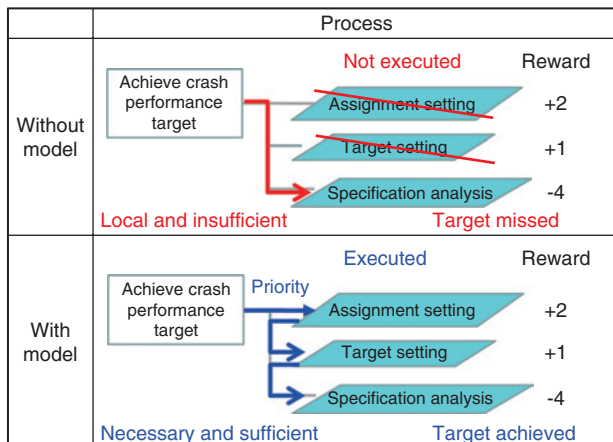


Fig. 18 Verification result of design process

4. Conclusion

A method was established for structuring the thinking and knowledge of experts, which had been in the form of tacit knowledge, and an expert model that is needed for the “Educating” step of an expert system was constructed.

- (1) Knowledge was constructed as a knowledge model by using GSN and SysML linked together.
- (2) A method of rapidly structuring the knowledge model from statements without going through information materials was constructed.
- (3) An expert model was constructed that is capable of reproducing an expert’s thinking process by assigning higher rewards in the knowledge model to actions that are accordance with the expert’s policy.
- (4) It was confirmed that use of the expert model constructed in the present research had the effect of shortening the work time.

The methods established in the present research will be used in the future to engage in accumulating and collecting recorded data with the aim of expanding the scale of the expert model. System development for the purpose of utilizing the model in regular work on the basis of “Listening” and “Accumulating” steps will be promoted. Compatibility with analysis, mining, accumulation, and machine learning technologies for the purpose of linking with “Learning” will also be considered within the scope of this effort in order to continue the research with a view to enabling use of the model across a broader range of application.

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