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Causal Knowledge Integration Method for Product Design Simulation

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제품 디자인 시뮬레이션을 위한 인과 지식 통합 방법 개발

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ABSTRACT

Simulation for product design requires a lot of causal knowledge. Hence, knowledge integration is required for obtaining a new knowledge from existing knowledge. For example, a user requests knowledge for the heating cup. However, the knowledge base only has knowledge for heating and cup, not heating cup. At his situation, knowledge integration can generate a new heating cup knowledge from existing heating and cup knowledge. Therefore, the user can obtain the knowledge for heating cup. Hence, this study aims to propose a novel knowledge integration method for product design.

Key words : Knowledge Integration, Product Design Simulation, Product Development, Knowledge Management System

요 약

제품 설계를 위한 시뮬레이션을 위해서는 다양한 인과지식이 필요하다. 따라서 현존하는 다양한 지식으로부터 새로운 지식을 획득하기 위해서는 이러한 지식들을 통합하는 것이 필요하다. 예를 들어, 사용자가 가열이 되는 컵을 설계하고자 하지만 기존의 설계 지식 베이스에는 가열되는 컵에 대한 설계 지식은 없고 가열 기구에 대한 지식과 컵에 대한 지식이 따로 존재한다. 이러한 상황에서 가열 기구에 대한 지식과 컵에 대한 지식을 통합할 수 있는 자동화된 방법론이 필요하다. 이를 통해 사용자는 가열이 되는 컵을 설계하는 지식을 획득할 수 있다. 따라서 본 연구의 목적은 이러한 제품 설계에 관련한 지식을 통합하여 새로운 지식을 만드는 방법론을 제안 한다.

주요어 : 지식 통합, 제품 설계 시뮬레이션, 제품 개발, 지식 관리 시스템

1. Introduction

Global marketing competition makes manufacturers more conscious about higher quality, lower cost, and time-to-market. This global economical and technological environment poses a challenge of how to realize a true collaborative environment. In the collaborative environment, engineers and product designers needs global cooperation during the overall product development processes. For the cooperation, referring knowledge created by others will enhance the reusability of the knowledge and hence increase the productivity of product development. The product development knowledge will also be used in product modeling and analysis for advanced simulation [2].

However, one survey found that 74% of the respondents believed that their organization's best knowledge was not accessible and reusable, and 68% thought that mistakes were reproduced several times [4]; more than 75% of product design activities have been

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conducted due to the lack of reusing product development knowledge and it has been long recognized as critical in modern product development [3]; According to Boeing Frontiers [1], 80% of a company's knowledge resides only within the minds of its employees. This problem is still recently indicated around industries according to research works, professional meetings and interviews that we have conducted [10, 11, 14, 15, 16]. Such perception of the failure to apply existing knowledge is an incentive for creating and sharing product development knowledge and the method of knowledge integration [9, 12].

To increase the reusability of the knowledge acquired during the product development, how to extract the product development knowledge has been studied [13].

To fully understand knowledge integration, the integration environments should be defined, such as knowledge framework, integration models, and other considerable factors. However, legacy knowledge framework for product development (e.g., [5]) cannot handle recursive product development knowledge since there are only a few methods to capture knowledge from the product development processes. To overcome this problem, new knowledge framework which integrates heterogeneous products is required.

Hence, this study aims to propose an inter-relational product development knowledge framework which handles recursive knowledge based on the theory of causal network integration [8].

Product development knowledge consists of three different knowledge models according to the perspective of knowledge-knowledge relationships: inter-process knowledge, inter-actor knowledge, and inter-product knowledge (Fig. 1). First, inter-actor knowledge acquires and reuses the knowledge in the same domain but developed by different actors (designers, systems, etc.) using causal network belief integration. Second, inter-process knowledge acquires and reuses knowledge created in the different domains, which has different constraints for each domain, using causal network structure integration method during the product development processes. Third, inter-product knowledge acquires and reuses different domains knowledge and different products knowledge using causal network belief integration between different structures.

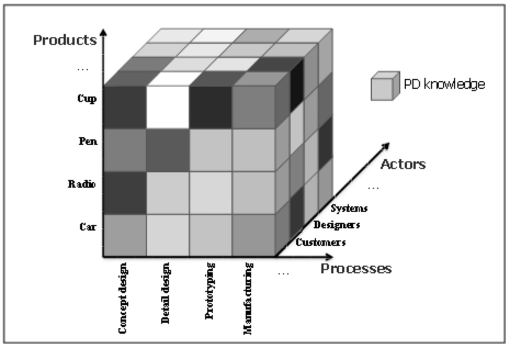


Fig. 1. Knowledge relationship for product development

2. Types of Inter-relational Knowledge

2.1 Inter-actor knowledge

Inter-actor knowledge acquires and reuses the same domain knowledge with different actors (designers, systems, and etc.) using causal network integration (Fig. 2). In this case, one basic assumption is that a causal network structure is the same in each domain. Inter-actor knowledge framework integrates actors' knowledge in the same domain, because different actors have different knowledge with the same process and product in the domain. Main function of this framework is that the accuracy of the knowledge is improved by knowledge integration with weights, which are based on experiences, positions,

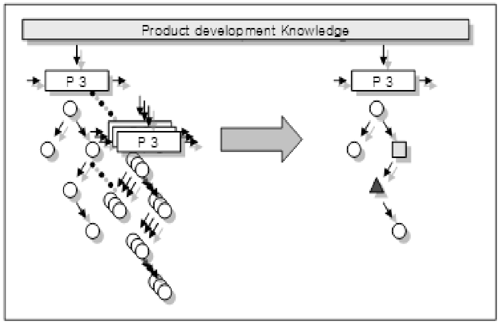


Fig. 2. Inter-actor knowledge integration for product development

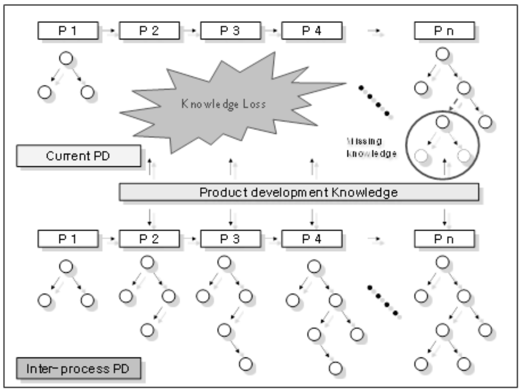


Fig. 3. Inter-process knowledge framework vs. current knowledge framework for product development

number of same project completion, and other considerable factors.

In the Fig. 2, inter-actor knowledge framework is integrated one single framework, which is the same of the inter-process knowledge framework. Also, this single framework will be able to use for inter-process knowledge framework. The inter-actor knowledge framework can acquire and reuse the same domain knowledge with different actors (designers, systems, etc.) using causal network integration during the product development processes. The next step is applying this result to inter-process knowledge framework, which include heterogeneous domains.

2.2 Inter-process knowledge

Inter-process knowledge framework acquires and reuses different domains knowledge, which has different constraints for each domain, using causal network structure integration method during the product development processes. Inter-process knowledge framework is showing in Fig. 3. Compared with current product development knowledge, inter-process knowledge framework is evolutional increasing the knowledge process-by-process. Current knowledge framework has loosed product development knowledge during the product development processes.

For example, a product development has six processes: Detailed Requirements, Conceptual Development, System-level Design, Detail Design, Testing and Refinement, and Production Ramp-up. Each of process has different constraints. These constraints affect product development knowledge to add or delete knowledge to apply constraints. Because conceptual development process does not require a detail design aspect, the causal network structure of conceptual development process is slightly smaller than detail design process's one. Process is moved from system-level design process to detail design process. The knowledge from system-level design to detail design will be added, deleted, or updated, which means causal network structure will be added, deleted, or updated. Finally, production ramp-up process will have more informative causal network structure than any other processes. Via current framework, production ramp-up process has almost the same causal network structure with other processes. Therefore, the result of production in inter-process knowledge framework will be significantly improved.

The inter-process knowledge framework can acquire and reuse the different domains knowledge, which has different constraints for each domain, using causal network structure update method during the product development processes. The next step is applying this result to inter-product knowledge framework, which include heterogeneous products.

2.3 Inter-product knowledge

Inter-product knowledge framework acquires and reuses different domains knowledge and different products knowledge using causal network and structure integration between different structures. The Fig. 4 is showing inter-product knowledge framework, which integrates heterogeneous products' knowledge to general knowledge. However, this framework is not visible because heterogeneous products do not have the same structures, even not similar. If we integrate these heterogeneous products' knowledge, we will have huge general knowledge, which may not be represented by any network. Therefore, we propose unsupervised learning to categorize this heterogeneous products' knowledge to similar products' knowledge. First, classify this knowledge with similar products and then integrate this similar knowledge in categories (Fig. 5).

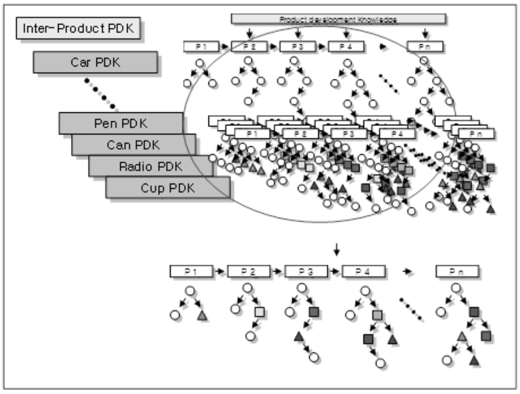


Fig. 4. Heterogeneous product development knowledge framework

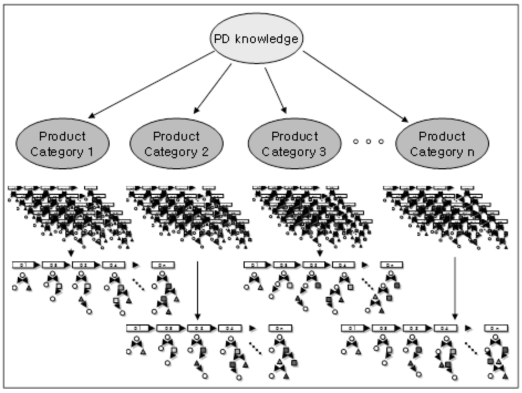


Fig. 5. Inter-product knowledge framework with unsupervised learning

The inter-product knowledge framework can acquire and reuse different domains knowledge and different products knowledge using causal network and structure integration between different structures during the product development processes. The next chapter represents the causal network integration with inter-relational knowledge framework for the recursive product development knowledge in product development processes.

3. Integration of Causal Knowledge

3.1 Integration Cases

Knowledge integration is an intelligent knowledge acquisition method from existing knowledge. Based on inter-relational knowledge framework, knowledge integration

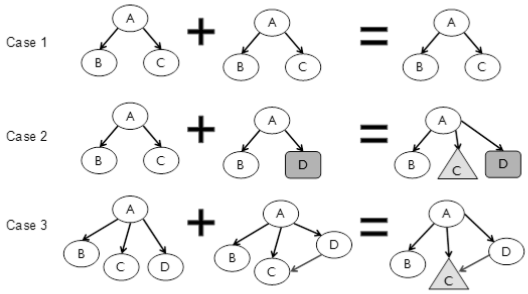


Fig. 6. Knowledge integration cases

includes three different cases (Fig. 6). Case 1 is from inter-actor knowledge framework and is only belief integration in the same structure. Case 2 is from inter-process knowledge framework and is added the knowledge structures for integration and is updated belief between the structures. Case 3 is from inter-process knowledge and inter-product knowledge framework and integrates the knowledge structures and is integrated the knowledge structures and belief. The combination of these three cases can cover all possible integration cases in product development knowledge.

Based on knowledge integration cases, two main function is required, knowledge network identifier and integrator. The network identifier analyzes number of vertices, matching of vertices, structure of the knowledge network, and other considerable factors in knowledge. For the matching of vertices' name, ontological knowledge mapping, which will be addressed in the next section, can be used. After analyzing the knowledge, network identifier can select the combination of knowledge integration cases (Fig. 6). Based on the selected combination cases for knowledge integration, knowledge network integrator generates a new knowledge using structure and probability integration.

3.2 Ontological Knowledge Mapping

To integrate heterogeneous design knowledge, which includes different knowledge name for the same knowledge, this research proposes the ontological causal network representation to match different knowledge name. The ontology is one of the ways to represent product development knowledge and is explicit formal specifications

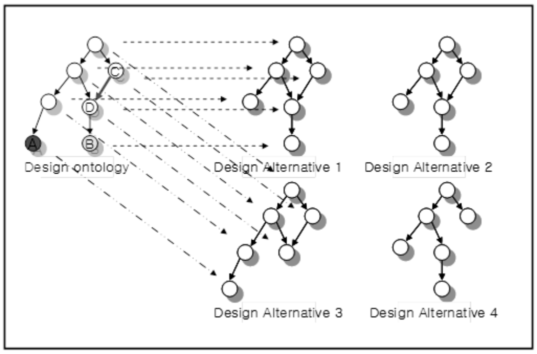


Fig. 7. Ontological BBN design knowledge

of the terms in the domain and relations among them [7]; a formal, explicit specification of a shared conceptualization. This research uses Bayesian belief network and Ontology to represent product design knowledge, which means the network is BBN and the nodes are defined by ontology (Fig. 7).

In the Fig. 7, the design alternatives are somewhat different, but the design ontology is the same for the specific product or part. Design alternative 1 inherits all of the nodes except node A. Design alternative 2 is the same with design alternative 1, but the probability of nodes are may vary. Design alternative 3 inherits all of the nodes except node B. Design alternative 4 is almost same with design alternative 1 and 2 except the arc from node C to node D. The ontological BBN is able to use for product development knowledge reasoning and mapping.

4. Implementation: Utilization of Causal Knowledge Integration

We developed web-based causal product design knowledge management system under .net framework. The detail developing environment is as follows: 1) the computer is PC based, 2) operating system is Microsoft Windows XP Professional SP2, 3) the database management system is MS SQL Express with ODBC for database connection, 4) programming languages used are C++, C#, and HTML/ASP, 5) web server is Microsoft Internet Information Service, and 6) developing platform

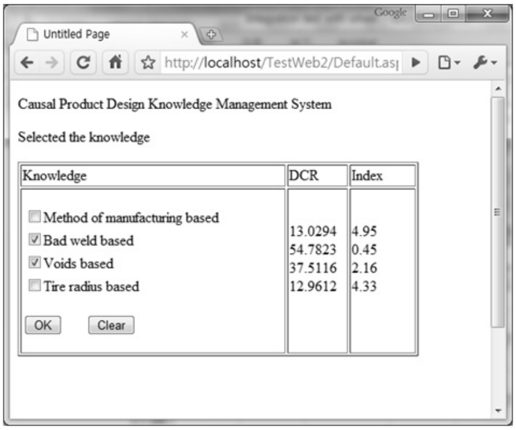


Fig. 8. Snapshot of causal product design knowledge management system for knowledge integration

is Microsoft Visual Studio 2008. This developing environment is one of the most popular configurations in web-based client/server architecture. The Visual Studio developing platform can easily connect C++ functions and C# web page development. In this platform, also, the Internet Information Service is ready to deploy the web service because all developing software is based on Microsoft applications.

Causal knowledge integration method is utilized for a new product design using existing one. For example, a cup with heating/cooling function, a pen with special logo on it, and a can with zip lock. These examples are modified existing design or are generated by knowledge integration. The utilization of causal knowledge integration is presented with a wheel design scenario. Suppose that a designer wants to design a newly designed automotive wheel, which is modified from existing design. Also assume that current design knowledge is not enough to completely design the new wheel. Thus, an appropriate design knowledge should be generated from existing one. In other words, the design knowledge integration is required. The designer opens web-based causal product design knowledge management system in order to find existing wheel designs. Fig. 8 shows existing design in the system repository. Also, the knowledge evaluation results are provided for support designer’s decision as shown in the right hand side of Fig. 9 (DCR and

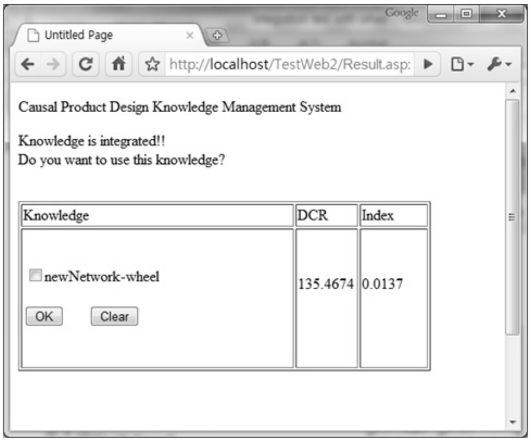
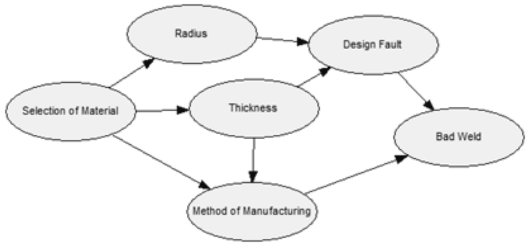


Fig. 9. Result of knowledge integration with DCR evaluation

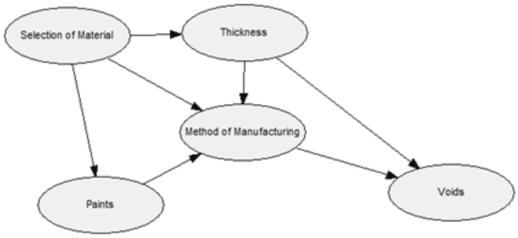
DRC index). In the prior works, Degree of Causal Representation (DCR) is developed for comparing knowledge networks with each other to confidently apply causal knowledge representation instead of procedural knowledge in the product knowledge management [6, 7]. DCR-index is developed for resolving one of the DCR's limitation, which is biased by network connectivity. It will be reported by a separate paper.

Among the existing designs, the designer selects two alternatives for the new wheel design: bad weld based and voids based knowledge. The selected alternatives are integrated to generate a new design knowledge, which is called newNetwork-wheel. The integration result is presented in Fig. 8. The result of integration provides the new design knowledge with DCR evaluation result, which includes DCR and DCR index (Fig. 9). Finally, the designer can select the new and integrated knowledge, which provides the designer with knowledge of two original ones for the new wheel design.

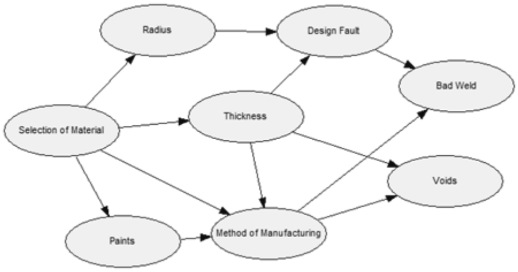
DCR of bad weld based knowledge is higher than voids based knowledge, but the DCR index shows that voids based knowledge is higher than Bad weld based knowledge. It can be explained that voids based knowledge has more degree of causal representation than the other one. Fig. 10(c) shows a new generated knowledge, newNetowrk-wheel, which is analyzed that DCR is 135.4674, causality is 45.3893, network connectivity is 2.9845, and DCR index is 0.0137. This generated



(a) Knowledge network for Bad weld based



(b) Knowledge network for Voids based

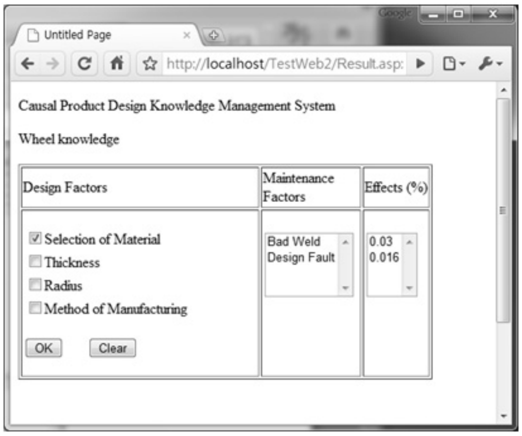


(c) Knowledge network for newNetwork-wheel

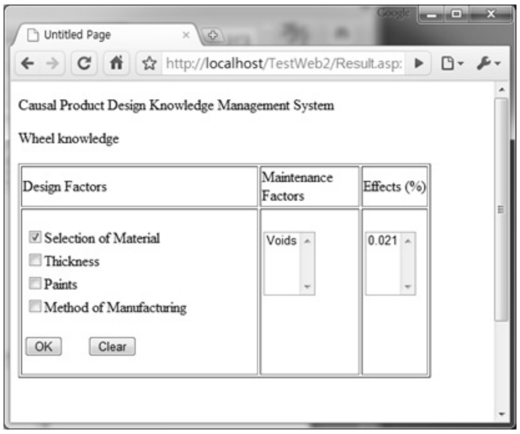
Fig. 10. Knowledge network for integration with the same domain

knowledge can represent two knowledge with updated their beliefs for wheel design. Based on the integrated knowledge, causal product design knowledge management system can provide the effects of the design modification.

Fig. 11 presents the effects of design modification with two wheel knowledge, bad weld based and void based. If a designer modifies the Selection of Material among the design factors, the effects of maintenance factors are predicted. Two maintenance factors for bad weld based wheel knowledge are predicted, Bad Weld (0.03) and Design Fault (0.016). For the voids based wheel knowledge, Voids (0.021) is predicted. The numbers for maintenance factors represent the effects of the



(a) Bad Weld based wheel knowledge



(b) Voids based wheel knowledge

Fig. 11. Effects of design modification

modification depended on each knowledge network structure and belief.

Fig. 12 illustrates the effects of design modification (Selection of Material) in the integrated wheel knowledge. The integrated wheel knowledge includes five design factors and three maintenance factors. Comparison with original knowledge and integrated knowledge indicates that 1) integrated knowledge provides more design factors to modify a design for a new product, 2) integrated knowledge predicts more maintenance factors to indicate the effects of the design modification, 3) integrated knowledge is enough to include the original knowledge in the representation of the effects of the modification.

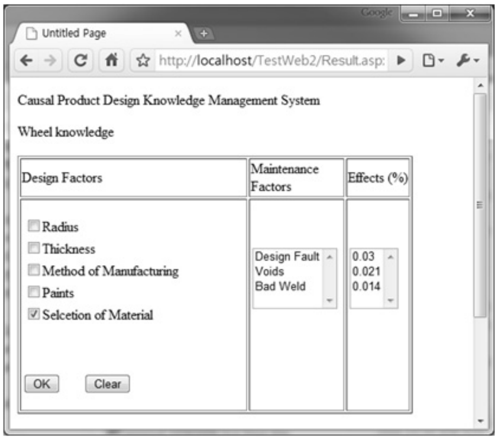
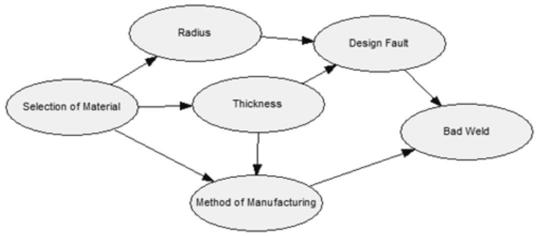


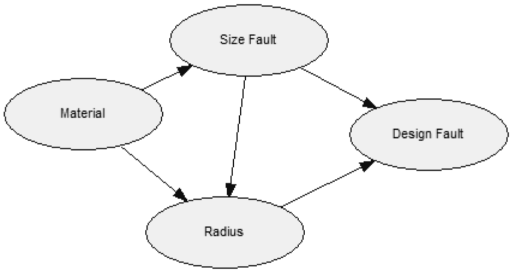
Fig. 12. Effects of design modification in integrated wheel knowledge

The integrated wheel knowledge provides more knowledge to a designer and the designer can make better decision for a new product design. This is one objective of using causal product design knowledge management system.

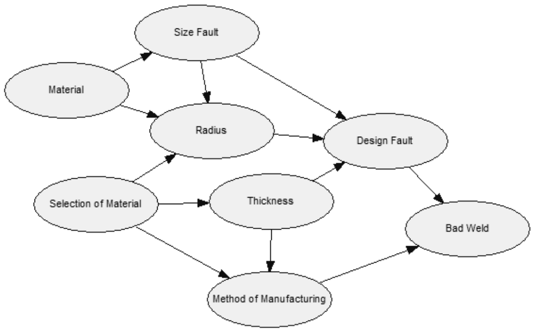
The utilization of knowledge integration in the same domain is presented and a utilization of knowledge integration in the different domain is following. Fig. 12 (a) and (b) illustrate bad weld based wheel knowledge and tire knowledge, which are in different domains. Two of knowledge vertices for each knowledge are identical and others are totally different. The analysis of these knowledge networks are as follows: for bad weld based knowledge, DCR is 54.7822, causality is 23.3331, network connectivity is 2.3178, and DCR index is 0.45; for Tire knowledge, DCR is 15.4235, causality is 7.7007, network connectivity is 2, and DCR index is 5.8669. DCR of bad weld based knowledge is higher than tire knowledge, but the DCR index shows that tire knowledge is higher than bad weld based knowledge. It is explained that tire knowledge has more degree of causal representation than the other. The integrated wheel tire knowledge is presented in Fig. 13 (c). It is integrated by knowledge network structure and beliefs. It shows a new generated knowledge, newNetowrk-wheel-tire, which is analyzed that DCR is137.485, causality is 41.7467, network connectivity is 3.2933, and DCR index is 0.14.



(a) Bad weld based wheel knowledge

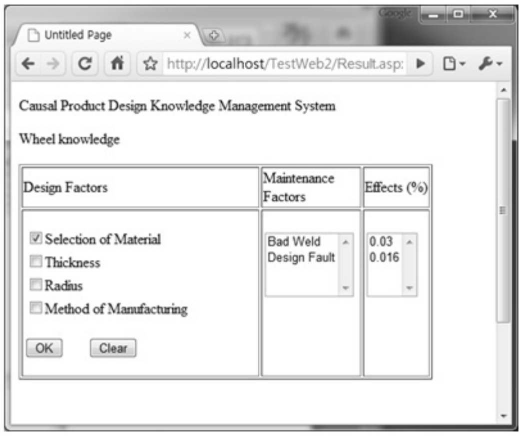


(b) Tire knowledge

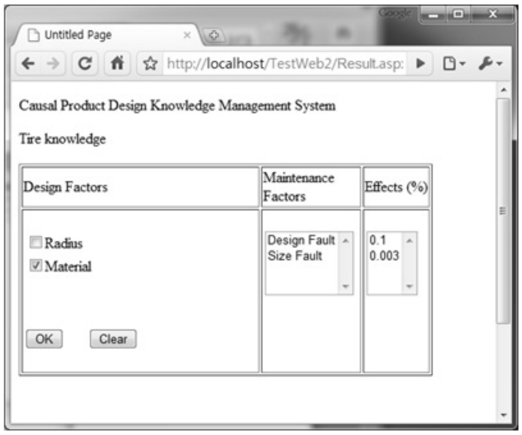


(c) Integrated wheel tire knowledge

Fig. 13. Knowledge network for integration with different domains



(a) Bad weld based wheel knowledge

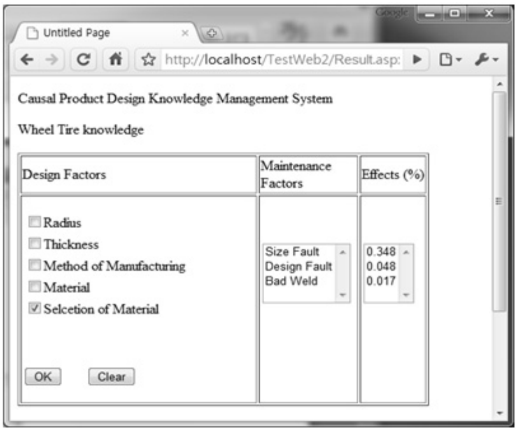


(b) Tire knowledge

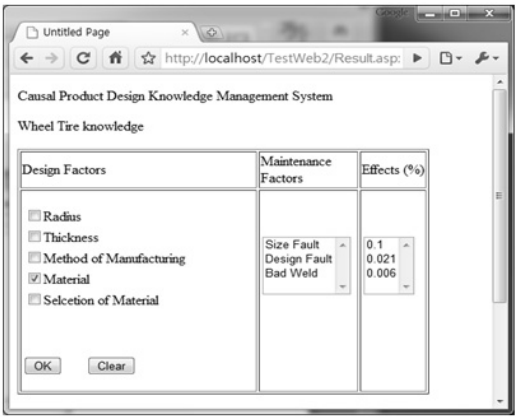
Fig. 14. Effects of the design modification

Fig. 14 presents the effects of design modification with two original knowledge with different domains, bad weld based wheel and tire knowledge. If a designer modifies the Selection of Material for bad weld based wheel knowledge and Material for tire knowledge among the design factors, the effects of maintenance factors are predicted. Two maintenance factors for bad weld based wheel knowledge are predicted, Bad Weld (0.03) and Design Fault (0.016). For the tire knowledge, Design Fault (0.1) and Size Fault (0.003) are predicted.

Fig. 15 illustrates the effects of design modification (Selection of Material and Material) in the integrated wheel knowledge. The integrated wheel knowledge includes five design factors and three maintenance factors. To compare between original knowledge and integrated knowledge, Selection of Material is selected for bad weld based wheel knowledge, Material is selected for tire knowledge, and Selection of Material or Material is selected for integrated knowledge. For the bad weld based wheel knowledge and integrated knowledge (Fig. 14 (a) and 15 (a)), the effects of integrated knowledge provide more knowledge to make better decision; 1) Size Fault (0.348) has more effects than others (0.048, 0.017) in integrated knowledge, but Bad Weld (0.03) has more effects than Design Fault (0.016) in bad weld based wheel knowledge, 2) even Bad Weld (0.03) has



(a) For bad weld based wheel knowledge



(b) For tire knowledge

Fig. 15. Effects of design modification in integrated wheel-tire knowledge

more effects than Design Fault (0.016) in bad weld based wheel knowledge, Design Fault (0.48) has more effects than Bad Weld (0.017) in integrated knowledge. For the tire knowledge and integrated knowledge (Fig. 14 (b) and 15 (b)), the results of comparison is similar with the ones between bad weld based wheel knowledge and integrated knowledge.

The integrated knowledge, which is within the same domain and in different domain, represents more knowledge than original knowledge. These results indicate that the integrated knowledge includes additional knowledge from tire knowledge and bad weld based wheel knowledge to provide better design decision for a new product design.

6. Conclusion

The reproduction rate may be significantly decreased and the new product design process will be faster and have less steps if the best knowledge of the organization is properly managed. However, the current product knowledge is not properly managed. To overcome this problem, a new knowledge management method is required and one of the knowledge management method is the knowledge integration. The developed integration method is able to be utilized for various domain such as information science, quality control, enterprise resource planing, manufacturing, etc.

In this research, based on knowledge relationship, the new knowledge integration method is developed. The knowledge relationship classifies product development knowledge into three categories: inter-process, inter-actor, and inter-product knowledge in order to integrate heterogeneous existing product development knowledge. Based on these categories, the cases of the causal knowledge integration is developed. Finally, the innovative knowledge integration method is validated with wheel case.

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