Integrating knowledge-based engineering in body-in-white lightweight design

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Abstract. During the vehicle design process, the body-in-white (BIW) lightweight design needs to consider factors from multiple aspects, such as topology, mechanical properties of the material, thickness parameters, BIW stiffness, modality and crashworthiness. At present, the commonly used BIW lightweight technology around the world includes the application of high-strength lightweight material, the optimization of vehicle structure as well as application of new molding and connection technology. The optimization of vehicle structure changes the mechanical properties of the components by selecting shape parameters of the components (such as the geometric characteristics of the components), in order to achieve lightweight design or performance optimization design. Since BIW contains a large number of structural components and design variables, designing BIW is always time-consuming and knowledgeable-extensive, which requires the collaboration of multidisciplinary engineers. This paper reviews the main methods of lightweight design of BIW and focuses on the application of knowledge engineering. Additionally, the paper introduces the effectiveness of knowledge reuse in practical cases.

1. INTRODUCTION
The automotive industry had been suffering from unremitting technology advancements since the day Henry Ford transformed the industry forever by introducing first assembly line in his Ford factory, which enabled a colossal growth in production. Accompanied by the prosperity of vehicles, carbon dioxide emissions became a major issue. Entering 21st Century, especially, with the rising of public’s awareness and concerns for the pollution and global warming, vehicle engineers and scientists have been continuously making great efforts to come up with effective methods to reduce energy consumption as much as possible. Among these attempts, vehicle lightweighting has becoming extremely essential. The fact is body-in-white structure takes up around 40% of the total mass. Also, it accounts for about 60% of the cost. Moreover, 70% of the fuel is spent by body-in-white structure under no-load condition. Therefore, reducing the weight of body-in-white fixture is of great importance [1-4]. Vehicle lightweighting not only plays an important role in reducing emissions and energy consumption, and enhancing performance, but also makes a great contribution to national energy strategy, serving to promote sustainable development and mitigate the contradiction between society and nature [2]. Lightweight design may also alleviate energy shortages and environmental pollution on the premise of increasing vehicle ownership.

As the best representative of developed country, United States, has always been getting ahead on the cutting-edge of light weighting application. A typical vehicle for the US family weighs from 1585 kg in 1970s to 1375kg in 1980s, then to about 1275kg in 1995. According to a national study, a 10% decrease in weight accounts for a 5% increase in its miles per gallon. This may not seem a lot in percentage, but
with a build of millions of vehicles annually all over the world, this will save the petroleum and reduce the energy emissions beyond count.

2. Main approaches of BIW lightweight design

It is possible to achieve light weighting by material substitution, optimization of bodywork, advanced molding technology, as well as a combination of all these methods [5-10]. Although the key goal is aimed to reduce the vehicle weight, the driving performance has to be kept at a proper level to ensure the safety and other requirements. The automotive body is expected to serve many purposes from reducing noise and vibration to protecting occupants in the event of an accident. As a matter of fact, lightweight design is such a complicated engineering process that involves many factors such as static stiffness, dynamic stiffness, crashworthiness Noise-Vibration-Harshness (NVH) and cost. Also, in the meantime, one may not ignore the fact that the automotive industry is suffering from rapid technological change and global wide competition.

Lightweight material, as the name itself suggests, is the lower density material which can substitute the original one without the sacrifice of performance. Formerly with iron and steel accounting for the majority of the weight, a higher degree of low-density material such as plastics and aluminum are being introduced to the automotive industry. Based on the data given by United States EPA, the amount of plastics used in a typical US passenger vehicle increased from about 4.6% in 1980 to about 10% to 12% in 2009. A significant usage of high-strength steel, using all the potential of steel technology, is also highly encouraged and promoted. Recent years The World Steel Association have organized researches towards Ultra-Light Steel Automotive Suspension (ULSAS) and Ultra-Light Steel Auto Closure (ULSAC), which has made noteworthy progress in the automotive fields [1].

Another technique to achieve lighter body-in-white is structural optimization. With the significant development of Finite Element Method, two main methods --- topology optimization and size optimization, are universally applied in the design [3-4]. Topography optimization is an advanced form of structural optimization that avoids unnecessary repetition design in the early stage. Its key idea is to maximize the stiffness of components without increasing mass and thus determining the best material distribution. Size optimization, on the other hand, can decide specific component parameters like thicknesses and cross-section dimensions. Most of the time in a design cycle, topography optimization is first used in concept developing phase to determine structural outline, and then engineers would be able to use size optimization to decide the specific structure and dimensions of interested part [5].

In addition, advanced molding technology, such as Variable-thickness Rolled Blank, thermos-forming, hydro-forming are introduced into the industry. Especially, Variable-thickness Rolled Blank technique, primarily consisting of Tailor Weld Blank, Tailor Rolled Blank, Tailor Rolled Tube, is rather popular. Because it translates the original flat surface into curved surface and makes the design three-dimensional. Hence structural spacing is better utilized. In fact, cost for technique used accounts for more than 30% of the total manufacturing cost. Therefore, applying advanced molding technology can not only achieve light weighting but may also lower overall expense afforded by the automotive companies.

In order to find the best techniques for better reducing the weight of body-in-white fixture design without sacrificing the performance, integrating knowledge Based Engineering might be a viable option [11-13].

3. Knowledge reuses in BIW lightweight design

Knowledge-based Engineering, as the name itself suggests, is a technology that deals with the method of extracting the process and solving problems into computer-processable knowledge to build knowledge models through advanced technology such as artificial intelligence, and then use the models constructed to solve real problems automatically.

Product design is a complicated, knowledge-intensive process, which involves especially a great amount of design knowledge. In engineering design, around 70% of the design work is adaptive design and variant design, and about 60% of the work of new product design is based on past experience.
However, currently during the entire design process, design engineers would spend up to 70% of their time trying to sort out existing design data and knowledge, and spend only 30% of the time on design activities. In order to improve efficiency, enterprises must standardize existing design knowledge, promote the integration between design knowledge, new product design processes as well as designers, thereby optimizing resource allocation, improving product design quality, significantly reducing design rework and product design cycle.

At the moment, the research on knowledge engineering mainly focuses on the management of knowledge, including the acquisition, the representation and the reuse of knowledge.

3.1. The Acquisition of Knowledge
In modern manufacturing environments, large amounts of data are stored in the data warehouses. The data contains all sorts of information regarding to product and process design, material planning, quality control, maintenance, scheduling and diagnostics. Because knowledge acquisition is based on the data stored, the data mining related methods have become important tools, which commonly includes concept extraction, association analysis, classification, prediction, clustering and evolution analysis.

The acquisition of knowledge in the manufacturing system includes the following steps: firstly, in the process of knowledge acquisition, understand the manufacturing domain, and analyze the manufacturing assignments and objectives through the learning of related knowledge; Second, collect the data and focus on the set of variables that can impact the manufacturing; Then, pre-process the data, such as eliminating noise, replacing missed values and cleansing data, which can transform the data into a form more suitable for mining; Next choose the appropriate functions such as clustering and rule extraction based on the type of knowledge required, and select relevant data mining algorithms to find specific patterns included in the data; Combine the extracted knowledge with manufacturing problems, assist the decision-making process and correct the knowledge content based on feedback; Consequently, knowledge will be stored, updating the knowledge base.

3.2. The Representation of Knowledge
Establishing an effective knowledge representation model has always been the focus of knowledge management research in engineering and manufacturing in order to achieve sharing and integration among various enterprises. There are two types of knowledge generally: explicit knowledge and tacit knowledge. Nowadays engineers have mastered the use of explicit knowledge, including the reuse of different forms of knowledge such as drawings, CAD models, calculation results and simulation results. However, those great decisions often rely on experienced engineers’ accumulated problem-solving strategy, often referred as internal knowledge or tacit knowledge. In fact, the representation of knowledge allows combination of multiple fields of study such as study of logic, ontology and computational technology. At present, the knowledge representation models proposed by scholars are mainly divided into the following categories:

3.2.1. Function-based representation model
The research on knowledge representation model started in the 1990s. The typical model is the function-behavior-structure (FBS) model proposed by Gero. The FBS model describes the main elements in engineering design and related activities. It uses function as the main carrier, integrating knowledge of expert design experience into the product model. Similar to the FBS model, there are FR models, SBF models and so on.

3.2.2. Process-based representation model
Process-based representation model is a model that uses the product life cycle as the main line. It achieves the knowledge representation and reuse in the manufacturing process by describing the data and information associated with the product objects at each stage. For instance, according to different manufacturing products and objectives, Process-based representation model is able to define the design resources required for different design phases and associate the resources with the manufacturing
process. Burge and others introduced how to use FBS ontology to represent the product design process and provided a unified framework to classify different processes, uniformly representing the design process and design objects, and contained high-level semantic information.

3.2.3. Object-oriented knowledge representation model
Object-oriented programming languages can also be used to represent knowledge models. The foretype is the Modelica language. It defines the data and behavior of objects through classes, which use fields to represent solution results and equations to represent solution processes, converting the rules, principles, documents in the database into multi-field knowledge. Therefore, Modelica language can effectively describe the knowledge in the product development process.

3.2.4. Ontology-based representation model
The ontology model consists of conceptual entities, entity attributes and relationship between entities. It represents the associations between entities through conceptual inclusion, attribute association, constraints, and axiom definitions. Based on the ontology model, scholars are able to represent product concepts, functional relationship and technical principles into a semantic network, greatly promoting the sharing and reuse of knowledge.

3.3. The Reuse of Knowledge
The research on the reuse of knowledge mainly includes knowledge retrieval, knowledge matching and knowledge reasoning. Based on the above analysis of knowledge modeling methods, existing knowledge retrieval methods include concept-based retrieval, vector space-based retrieval, and ontology-based retrieval.

Concept-based retrieval, matches the keywords of text information in the perspective of functional requirements, constraints and product attributes, expresses knowledge topics through a combination of keywords. For instance, Peng uses feature sets to represent product requirements and match existing cases in the knowledge base by calculating similarity between semantics and numerical values. Vector space-based retrieval, however, generally uses cosine distance to measure similarity between vectors, in which the vector consists of a feature set. The above two retrieval methods are mainly based on keywords formed by features or concepts, hence cannot accurately reflect the contextual semantic information.

Ontology-based retrieval uses the semantic information contained in the ontology language to retrieve the knowledge model. This method of retrieval can obtain an accurate association relationship using the context background and can also perform the reasoning of related concepts. During the product concept design process, Setchi and others retrieved useful product design images by sorting out the importance of keywords and key sentences around images, associating them with the ontology concept and finally matching ontology concept. Zhu Haiping used the concept map to represent the knowledge in his doctoral dissertation. On this basis, he proposed ontology matching method based on concept similarity and relationship similarity. In the design of mechanical products, based on the mechanical design ontology domain modeling, through steps of ontology design, semantic similarity calculation and ranking scores, Ma achieved efficient retrieval of ontology semantics. Ke transformed the requirement-description document and service-description document models established by OWL-S language into the form of ontology tree, then he used taxonomy and layering method to compare conceptual similarity, attribute similarity and structural similarity of corresponding nodes in the tree, and finally acquired the matching relationship between services.
4. Case studies and Conclusions

In this paper, a Web-based prototype system is developed using ASP.net technology to verify the effective support of knowledge engineering method for lightweight design of white body. The software and hardware environment of the system implementation is summarized as follows: (1) Application server, IBM desktop with Intel Core i7 CPU (3.40 GHz) and 8GB memory, 512GB SCSI HD and Windows 10 operating system; (2) Programming platform, Microsoft Visual Studio Premium 2012,.net Framework 4.0 and C#; (3) Database: MySQL 6.0, the Web service used to access explicit knowledge records is deployed in the application server; (4) Network configuration: The use of 100M Ethernet network connection is tested between the client and the application server. The graphical user interface (GUI) of the system is shown in the figure above.

The left of the GUI is the design requirements and matching candidate cases of the product, and the model and available resources for the collaborative design are shown on the right, and the middle is the design variable of the inference process and the current state. Specifically, all design requirements are presented in the Design task table in the form of indicator names and numeric values. According to the similarity calculation method, the two-dimensional model and similarity value corresponding to the similar knowledge records obtained in the previous design cases are listed. The figure above shows the design process corresponding to the available design knowledge, as well as the part diagram of BIW, which provides engineers with a way to understand the design object in all directions.

Based on the premise that the performance of the car has to be unchanged, the purpose of BIW lightweighting is to reduce the mass of the vehicle bodywork in order to reduce fuel consumption and pollution, and make the cost as low as possible. This paper reviews the main methods of related design techniques including the use of lightweight materials, advanced molding technology and structural optimization. Among them, structural optimization is a multi-parameter, multi-constrained and multi-disciplinary optimization problem for a complex system. Using the knowledge-based engineering can effectively improve the efficiency of potential optimization design. Therefore, this paper gives an introduction of knowledge-based engineering including its three steps: the acquisition of knowledge, the representation of knowledge and the reuse of knowledge. In the end, a prototype system verifies the effectiveness of the knowledge-based engineering.

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