Knowledge Capitalization to Bus Body Light weight Redesign and Validated by FEM

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Abstract: Bus body manufacturing company in Thailand is recognized as small and medium enterprises. The manufacturing process is performed as a project shop which is rarely modified the process and design. It becomes a lack of competitive enterprise whereas it accumulates huge experiences. This paper proposes the new concept of product redesign using the enterprise experiences. Knowledge capitalization concept is applied to manage the knowledge associated by PCA method in order to extract knowledge from the domain expert particularly on the tacit knowledge. The knowledge is captured, analysed, stored and reused for redesign the bus body structure to accommodate a light weight bus. The final redesign is validated by 3-D FEM in order to ensure that the redesigned model is still met the engineering design conditions.

Key words: Capitalization Knowledge, 3-D Bus Body Light Weight Redesign, PCA, FEM

1- Introduction

Road transportation is the most popular in Thailand which is normally used buses. Local bus constructions are mainly small and medium enterprises. They have huge knowledge and experience which is accumulated by many years. The expertise is transferred from one person to another, from one company to another company, or even from one generation to another generation. However, they have not proved by any scientific method that the bus body design is efficient. It is only concerned to the national transportation regulation in terms on dimensions and safety aspects. The current serious problem is that the bus designed required long manufacturing processes, low efficiency, high fuel consumption, and lack of competitiveness. Therefore, the bus manufacturers request the effective method to improve the existing manufacturing processes and design. In this phase, the bus body redesign is taken into account based on the company expertise instead of using new design which is started by engineering calculation point of view. It follows the concept of sustainability development. Knowledge capitalization method is employed. Existing 3-D CAD model is created by wire frame modelling in order to be compatible with 3-D FEM analysis. The whole bus body structure is subdivided into 7 components. They are bottom side, top or roof side, right side, right side, front side, back side and step floor. Each side is further subdivided into elements. Each element is defined by a certain number in order to be simple for communicating to the shop floor experts. Then, PCA questionnaire is created based on the whole bus body structure and its number. The shop floor expert is asked to give suggestion idea to reduce some elements by its priority. The collection data are analyzed and used to be a guide for redesigning the bus body structure. The new bus body structure is then proved by 3-D FEM analyzed. It is found that the new bus body redesign is more efficient. It is lighter than the previous design, whereas it remains the regulation and engineering safety. This paper is organized by the related paper reviews on the light weight design, capitalization methodology, and FEM procedure in the section 2. Section 3 expresses the research methodology. Section 4 shows the experiment and validation. Section 5 concludes the paper and discussion toward the future works.

2- Literature reviews

The section presents related research studies and then explains the new development in the field of study. First, redesign products are discussed. Secondly, lightweight method is explained. Thirdly, the bus-body structural design is presented.
2.1 – Design and Redesign methodology

Continuous improvement is recognized as a key successful factor for any manufacturing enterprise particularly on the design phase. It can be developed by different strategies such as variant management, fixed redesign, product modification, and new design. In the case of a large and complex product together with a long life cycle such as the bus-body manufacturing, the fixed redesign is more suitable than other strategies. Although the bus structure has a small variety, companies usually have an ability to make unique models to create their own identity. Since the market demand is changed, product redesign and modification is necessary. However, design experts usually do not modify the product in the way of engineering redesign. Mostly, they do minor modification according to customer requirements. This section explains the methods, concepts, applications of bus body design and redesign. Butdee and Vignat (2008) study the bus body design which is mainly divided into three parts; the chassis and engine, the body structure, and the interior including light and sound system in general. Recognized as the major part of the bus, the chassis must be approved by the accreditation agency such as MAN, Mercedes-Benz, Volvo, Isuzu, Daewoo, Hino, Scania and so on. The second part of the bus is its body structure, which consists of six major parts: the front, the back, the left, the right, the top, and the bottom. Each part supports different functional components. The front part supports the windshield, the console, main front lights, and the top part. The back part supports the rear window and the top part. The left part supports the front door, a middle door or/and a back door, windows, the left side panel made of sheet metal with primer coats and paints, and the top part. The right part supports the driver door, an emergency door, windows, the right side panel, and the top part. The top part supports both fixed and varying loads. Fixed loads consist of an air conditioner, an LPG or NGV vessel, lights, and stereo system; and varying loads consist of bags and luggage. The bottom part also supports both fixed and varying loads. Fixed loads are the wooden floor, seats, and the other five parts; and vary loads are passengers and carry-on objects. Designer experts must consider all functional components for appropriate structural strength and safety. Ning et al., (2009) present a design and development of thermoplastic composite roof door for mass transit bus which aims to meet light weight, high strength and modulus. Replacing metallic components with reinforced composites in mass transit helps to lower weight and therefore increase fuel efficiency and decrease maintenance cost without compromising performance. Weight savings of 39% and reduction of free-standing deflection of 42% were realized using the composite approach compared to the metallic counterpart. Chang and Van (2003) study trend design for the redesign of product form. They illustrate how to conduct pre-design research properly before redesigning a product form. Gautam and Singh (2008) study lean product development by maximizing the customer perceived value through design change (redesign). They present an application of optimization model for perceived value and change trade-off in general. Salhieh (2007) study a methodology to redesign heterogeneous product portfolios as homogeneous product families. The methodology proposed to homogenize the portfolio begins by analyzing the current product offerings to determine customer needs and functions.

2.2 - Lightweight methods

This section reviewed the light weight methods in order to apply to bus body improvement. Lan et al. (2004) study lightweight structure in bus-body design. A new common medium-sized bus-body structure is modeled and analyzed using the computer-aided design (CAD) package, UG, and finite element (FE) solver, ANSYS. They do a basis for structural design optimization with bus-body weight reduction. Junbo and Ulfvarson (2004) study the static and dynamic structural behavior of a lightweight deck, as lightweight structures are increasingly used for high-speed ships. A theoretical model is studied the interaction between the car on the ship and the ship deck, indicates that the car chassis is the significant part of the problem and influences the solution. As a result, a FE model of the ship deck is generated and special parameters, such as the material of panels and the numbers and the locations of loaded cars, were studied. Results obtain from the finite element analysis (FEA), show how a conventional steel structure can be improved by introducing lightweight material. Asnafi et al. (2000) study a new developed lightweight metal-composite-metal (MCM) panel. The MCM panel exhibits slightly smaller stiffness than the aluminum panel but larger dent resistance than the aluminum and the carbon steel panels. Although the MCM panel is 46% heavier than the aluminum panel, it is 60% lighter than the carbon and stainless steel panels. This new panel is expected to have many applications in manufacturing of parts for car, train and bus bodies, appliances, and household machines. Zhang et al. (2007) study lightweight design of automotive front-side rail based on robust optimization with the consideration of the variation in sheet gauge, geometrical size, and material parameters, caused by environmental factors and other uncertainties. The response surface method (RSM) coupled with the design-of-experiment (DOE) technique is employed to create the approximate functions of structural performances. The lightweight design, considering the impact of the tolerance in sheet gauge, mechanical parameters of material, and structural performances are presented. The weight reduction achieves by using robust optimisation reaches 29.96%. Cui et al. (2008) study an optimal design method of lightweight automotive body assembly using multi-material construction with low cost penalty. Unlike current constructions of automotive structures that use single types of material, e.g., steel or aluminium, the multi-material construction selects suitable material for an intended function. A multi-objective genetic algorithm is used to solve the problem whereas, an artificial neural network is employed to approximate the constraint functions and reduce the number of FE runs. Wu and Cheng (1997) study the advanced development of explicit FEA in automotive applications. They present the selected applications in safety simulations and other CAE activities using by Ford in-house crash simulation code FCRASH. Hwang et al. (2005) develop a fuel cell system and integrated to the lightweight vehicle which is known as the Mingdao hydrogen vehicle (MHV). The MHV performs
satisfactorily over a hundred-kilometre drive thus validating the concept of a fuel cell powered zero-emission vehicle. Measurements show that the fuel cell system has an efficiency of over 30% at the power consumption for vehicle cruise, which is higher than the typical internal combustion engine. Chan et al. (2000) study a parallel design method for optimising lightweight structures. The gradient-based approach to ending the optimum structural design is not naturally suitable for parallelisation by the ‘divide and compute’ strategy, which simultaneously computes different independent designs, used by the random search based approach. Duijne van et al. (2007) study how designers respond to information about users’ perspectives and use patterns, when redesigning a consumer product. They develop three experimental conditions for designers, which vary the presentation format and the type and availability of in-depth information (tabular data vs. narratives vs. audio/video descriptions). They describe the usage of the information by the designers in the design process. Eldonk van et al. (1996) study redesign of technical systems. They describe a systematic approach to support the redesign process which is the adaptation of a technical system in order to meet new specifications. The system applies model-based diagnosis research. The essence is to find the part of the system which causes the discrepancy between a formal specification of the system to be designed and the description of the existing technical system.

2.3 Knowledge Capitalization

Knowledge capitalization is a type of knowledge management. The cycle is to capture knowledge, analyze, formulate, store, reuse and retain. The concept is suitable for a huge expertise. The bus body manufacturing company is one of the high accumulated knowledge. However, the knowledge is mostly in the type of tacit knowledge which is hard to extract. PCA method is employed to associate the communication way between knowledge engineers and the shop floor expert via questionnaire. This section presents the related papers of the knowledge capitalization. The process of knowledge engineering (KE) plays an important role in management of industrial knowledge. It means an engineering discipline that involves integrating knowledge into computer systems in order to solve complex problems normally requiring a high level of human expertise [1]. The KE involves various activities; assessment problem, acquiring and structuring the general and specific knowledge, testing and validating of the stored knowledge, integration and maintenance of the system, revision and evaluation of the system. The KE principles have been developed in order to manage different types of knowledge, different types of experts and expertise, different ways of representing knowledge which can support validation and re-use of knowledge, different way of using knowledge. Knowledge is a set of precise and concise information that could induce a change or arouse more effective actions in a broader context capable of triggering a new learning and new knowledge. The knowledge of an organization can be classified into two parts; explicit knowledge and tacit knowledge. The former refers the expressed knowledge in a document form, whereas the latter refers to an unwritten know-how and keep in deep worker’s mind. Knowledge management is presently well-known in anywhere. However, knowledge sharing and transferring is still a question for many people and organizations in order to use knowledge effectively. Knowledge management can be divided into four steps; knowledge formulation, knowledge capitalization, knowledge re-textualization and knowledge sharing. Nowadays, Industrial knowledge is managed by a capitalization concept and become more and more important. To capitalize knowledge means to reuse the knowledge of a given domain previously stored and modeled in order to perform a new task. The knowledge is stored in the database called corporate memory to the industrial experience in a given domain [2]. Knowledge capitalization aims to build a capital from existing information or knowledge in an organization in order to enhance them through their dissemination to other institutions or stakeholders as well as to serve he group in a context of knowledge sharing [3], [4], [5].

3- Research methodology

This section explains the research methodology. Firstly, the existing environment of the bus body manufacturing is studied and explained in terms of process design. Secondly, the bus body is created on CAD modeling. The model must be suit and completely transferred to CAE analysis using FEM. In this case, wire frame modeling is selected and a beam mate as the method for FE analysis is used. The PCA method is used to create questionnaire based on domain expert and use to communicate with knowledge engineers. Figure 1 shows the bus body redesigns process and validation. The existing 3-D bus body model is retrieved from the product database. Wire frame modeling is used. It is compatible with the CAE of FEA using beam strategy. Then the 3-D model is divided into 7 parts. Then, the interview questionnaire is created which refers to the 7 subdivided parts. PCA method is applied to make the questionnaire. Knowledge is represented by semantic adjectives. The third step is knowledge capitalization process. It consists of knowledge collection, knowledge analyst, knowledge reuse and knowledge retain. The capitalized knowledge is reused by the designer in order to modify and redesign the bus body based on the shop floor expert recommendation. Finally, the redesign structure is validated by FEM. The new acceptable design is retained back to the knowledge capitalization. Otherwise, it can redesign until the ultimate satisfactory occurs.

4- Case study

The case study presents the selected existing bus body model to redesign processes according to the flowchart in Figure 1. Firstly, the existing design and manufacturing process is expressed. Secondly, load data is collected. Thirdly, the process of capitalization and PCA tool are presented. Fourthly, the redesign process is shown the result following with the FEM is presented in the fifth step.
4.1-Existing 3-D Bus Body Model

The bus body is created by 3-D wireframe modeling as shown in Figure 1. The dimensional size is 3.15 meter height, 11.8 meter length, and 2.4 meter width. The total weight is 1,429 kg. There are 507 elements with 555 joints. Mostly, there are the T-joint. The assembly model can be divided of seven frames; left side, right side, front side, back side, bottom side, top side and floor step. The material type is AISI 1020 with variety shapes as shown in the Figure 2.

4.2-Load data collection

Load data are necessary and important. It can be point loads or distribution loads. This research mainly considers the vertical loads such as an air conditioner, windows, and the top or the roof part. In this case the collection data from the sample bus's company is the followings. The roof load is 2,893.5 N. The air conditioner load is 2,452.5 N. The total window with mirror load is 2354.5 N. In addition, the yield strength of the material obtained from the supplier is 351.571 N/mm².

4.3-Capitalization knowledge using PCA

Capitalization knowledge is a process of utilization or reuse
previous knowledge. As mentioned above, the Thai’s bus companies build or develop buses by experiences. They occasionally redesign without proving by scientific method. However, the knowledge and experiences are valuable. Therefore, this research intends to capture expertise, analyze and reuse to redesign the bus body model. PCA method is adopted to communicate with the shop floor expert. Drawing and manufacturing process are used to ask the expert. Then, the data is analyzed by STATBOX. The knowledge captured is mapped into two axes based on the weight priority. Figure 1 shows the bus body subdivision elements of the left side. There are 53 elements. All of the elements are used to be the reference of the PCA questionnaire. Figure 5 shows the example of the PCA questionnaire. It concludes three major parts: the picture, the semantic adjectives with scale, the elements. The semantic adjectives are linked to the particularly element which is shown in the picture. The scale is assigned into 5 levels (2,1,0,1,2) modified from liker scale. The semantic adjectives express two sides; the positive and the negative feelings. The scale of 2 or 1 shows the significant or more significant feelings in each semantic adjective. The scale 0 represents the moderate feeling which is not in the negative or positive side. The semantic adjectives are collected from the expertise. There are, for example, the element is used for the main functional part or use for the fashion style. This is because there are two sides of design and manufacturing. One is for the functional part which is used for engineering point of view (design for strength and safety), whereas the other side is design for emotion (beauty, modern fashion style).

Figure 4: Subdivision Elements for the Left Side Bus Body.

Figure 5: PCA Questionnaire.

Figure 6: The Bus Body Principle Component Mapping

Figure 6 shows the PCA mapping to the bus body elements. After the collected data from the domain experts, the data is analyzed by the STATBOX program. The most important expertise’s are selected and assigned as the vertical and the horizontal axes. From the analysis, the main significant of the bus body design and manufacturing are priority and loads. The loads are placed on the left and right of the map, heavy and light load respectively. On the other hand, the priority included first and last priority. The variable factors are the element position and shapes. From the PCA mapping, the designer can start to redesign based on the expert feelings as their expertise.

4.4 Redesign Model Process

The bus-body model is redesigned based on the capitalization knowledge. The process is to check each element and arrange in priority. Then, the unnecessary elements are taken into account. It is discarded or replace by the new lighter materials. The priority consists of four groups. They are [1] the functional element for heavy load, [2] the functional element with light load, [3] the fashion element with heavy
load, and [4] the fashion element with light load. The group 1 must be considered to keep as the main structure elements, whereas the group 4 can be discarded. Table 2 shows the comparison between the existing structure and redesign structure. From the existing components to redesign components, there are 39 elements reduction. It is 69.912 kg of the reduction. As the concept of knowledge capitalization to redesign the bus body, it needs to ensure that the new structure is still in the acceptable boundary of the national transportation regulation. Therefore, it is validated by the FEM.

Table 2: The Comparison between the Before and After Redesign Bus Body Structure

<table>
<thead>
<tr>
<th>Components</th>
<th>Elements (pieces)</th>
<th>Weight (Kg)</th>
<th>Reduction (pieces)</th>
<th>Weight reduction (Kg)</th>
<th>Reduce (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Front side</td>
<td>13</td>
<td>41.019</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. Left side</td>
<td>65</td>
<td>248.358</td>
<td>9</td>
<td>35.73</td>
<td>6.729</td>
</tr>
<tr>
<td>3. Back side</td>
<td>22</td>
<td>31.231</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Right side</td>
<td>62</td>
<td>247.681</td>
<td>6</td>
<td>0.942</td>
<td>3.062</td>
</tr>
<tr>
<td>5. Top side</td>
<td>69</td>
<td>203.929</td>
<td>20</td>
<td>28.458</td>
<td>14.145</td>
</tr>
<tr>
<td>6. Front step</td>
<td>87</td>
<td>122.901</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7. Bottom side</td>
<td>186</td>
<td>483.591</td>
<td>182</td>
<td>10.860</td>
<td>2.235</td>
</tr>
<tr>
<td>Total</td>
<td>507</td>
<td>1,420.646</td>
<td>468</td>
<td>1,350.73</td>
<td>69.912</td>
</tr>
</tbody>
</table>

4.5-FEM Validation

The redesign structure is validated by FEM. As the structure model is created by wireframe, it can transfer to the FE software (Ansys) directly. The process contains six steps. The first step is to set properties of analysis. Then, the material used is defined. The third step is to assign the joint position between the body structure and the chassis. Next, all loads are set in the certain positions. The fifth step is to assign the gravity force. The last step is to set and divide the mesh. Once, the six step is completely prepared, the FEM can be performed.

Figure 7 shows the finite element analysis for the redesign bus body model. Figure 7(a) presents the load applications which referred to the load collection in the section 4-2. Table 3 shows the result of the comparison between traditional and redesign model. It is investigated that the yield strength remains the same (3.515x10^2 N/mm^2). The maximum stress is slightly increased, whereas the compressive stress is slightly decreased.

5- Conclusion

This paper presented the concept of knowledge capitalization in order to use for redesign existing bus body structure. The research methodology is explained. The capitalization is associated by PCA method. The domain experts give the expertise via the PCA questionnaire. The knowledge data is analyzed and used to guide the redesign procedures. Finally, the new bus body model, redesigned model, is validated by FEM.

Figure 7: The Finite Element Analysis for the Redesign Bus Body Model; (a) load applications, (b) analysis result

Table 3: The Comparison between Traditional model and Redesign model

<table>
<thead>
<tr>
<th>Items</th>
<th>Traditional Model</th>
<th>Redesign Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus body structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elements (pieces)</td>
<td>507</td>
<td>468</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>1,420.646</td>
<td>1,350.73</td>
</tr>
<tr>
<td>Element reduction (pieces)</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Weight reduction (Kg)</td>
<td></td>
<td>69.912</td>
</tr>
<tr>
<td>Total weight reduction (%)</td>
<td></td>
<td>0.492</td>
</tr>
<tr>
<td>Yield Strength (N/mm^2)</td>
<td>3.515 e+002</td>
<td></td>
</tr>
<tr>
<td>Stress Max. (Tensile stress) (MPa)</td>
<td>2.271e+002</td>
<td>2.817e+002</td>
</tr>
<tr>
<td>Stress Min. (Compressive stress) (MPa)</td>
<td>-2.880e+002</td>
<td>-2.434e+002</td>
</tr>
<tr>
<td>Displacement (mm.)</td>
<td>7.021e+001</td>
<td>7.439e+001</td>
</tr>
</tbody>
</table>

6- References

Achievements in Materials and Manufacturing Engineering, 31(2), 456-462.


