CONCURRENT ENGINEERING: Research and Applications

Concurrent Decisions on Design Concept and Material Using Analytical Hierarchy Process at the Conceptual Design Stage

A. Hambali,[1,]* S. M. Sapuan,[2] A. S. Rahim,[3] N. Ismail[4] and Y. Nukman[5]

[1,3]Department of Manufacturing Design, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia, Melaka, Karung Berkunci No. 1752, Pejabat Pos Durian Tunggal, 76109, Durian Tunggal, Melaka

[2,4]Department of Mechanical and Manufacturing, Faculty of Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

[5]Department of Engineering Design and Manufacture, University of Malaya, Malaysia

Abstract: There is an increased study for considering the precise decisions on the design concept (DC) and material concurrently at the early stage of development of product. Inappropriate decisions on DC and material always lead to huge cost involvement and ultimately drive toward premature component or product failure. To overcome this problem, concurrent engineering (CE) is an approach which allows designers to consider early decision making (EDM) need to be implemented. To illustrate the use of CE principle at the early stage of design process, a concept selection framework called concurrent DC selection and materials selection (CDCSMS) was proposed. In order to demonstrate the proposed CDCSMS framework, eight DC s and six different types of composite materials of automotive bumper beam have been considered. Both of these decisions were then verified by performing various scenarios of sensitivity analysis by using analytical hierarchy process through utilizing Expert Choice software.

Key Words: concurrent engineering, analytical hierarchy process, early decision making.

1. Introduction

Concurrent engineering (CE) has been widely recognized as an effective approach for reducing development time and cost of products, improve product quality, and fulfill customers' demand. Thus, a CE principle in product development process is essential. One of its principles that allows designers to consider and making the right decision at the early stage of product development process is called an early decision making [1]. Considering early decision making is important due to improper decision can be disastrous from both performance and economic perspectives. The level of success of product design achieved depends significantly on the right decisions on the design concept (DC) and material during early stage of development process. An early stage of product development process is called conceptual design stage. Conceptual design is an early stage of the product development process which involves the generation of solution concepts in order to satisfy the functional or design requirements of a design problem [2]. Conceptual design can be described as a stage where design objectives are defined, functional requirements are specified, and concepts are generated, evaluated, and selected [3]. Conceptual design is the preliminary stage of design process in which both well-defined problem specifications and high-level design solutions are developed [4]. The conceptual design plays a critical part in the overall success of the product as once the conceptual design process has been completed, the majority of product cost and quality has been fixed by selecting particular concepts. Therefore, the conceptual design stage is more important than to the other design stages in product development process. The implementation of an early decision making and considering design problems at the early design stage is essential in developing a new product. To achieve the development of a new product under CE environment, integration between early decision making and tools and technology need to be addressed. The interrelated each aspect in the product development process is illustrated in Figure 1.

The importance of considering concurrent decision on design and material has been addressed. Edwards [5] and Lu and Deng [6] have addressed the importance of making concurrent decision on material and design at the early stage of product development process. It contributes to the benefits such as shorter time to market, reduced development costs, and higher quality products. However, there are a few researches that clearly addressed the implementation of concurrently

*Author to whom correspondence should be addressed.
E-mail: hambali@utem.edu.my
Figures 2 and 4–9 appear in color online: http://cer.sagepub.com

1063-293X/11/02 0111–11 $10.00/0 DOI: 10.1177/1063293X11408138

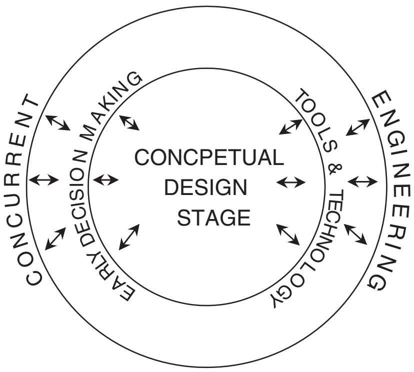

Figure 1. Conceptual design stage under CE environment.

decisions on material and design in the literature. Ewards and Deng [7] suggested a multiple-mapping strategy and an inter-level behavioral modeling strategy. The designers can concurrently consider both design and material solutions in supporting design decision-making at the early design stage.

Lu and Deng [6] proposed a system modeling methodology to support the integration between materials design (including materials selection) and engineering systems design at the early design stage. It consists of a generic framework to develop the relationships between the required system performances and their related system loadings and attributes, where the attributes include both the structural attributes of an engineering system (thus for engineering systems design) and the material properties (thus for materials design and selection). Ljungberg and Edwards [8] developed an integration system called integrated product materials selection (IPMS) model, which has highlighted the importance of integrated design of product and materials selection, and market-oriented design. Moreover, various computer aided systems have been developed which allow designers to consider various decision tasks in the literature [9–12]. In this article, the concurrent decision task for both materials selection and DC selection is proposed during concept selection at the conceptual design stage. The proposed selection framework provides several steps which allow designers to consider concurrently decisions during concept selection process at the conceptual design stage. The purpose of the selection framework is to assist designers or engineers to evaluate and determine the most appropriate decisions on DC and material concurrently at the early stage of the product development process. Analytical hierarchy process (AHP) through utilizing Expert Choice software is addressed in this article to show the importance of addressing CE tools in product development process. Many product development frameworks have been developed which only provide a guideline or design flow to assist designers or engineers in performing designing activities, but they still are lacking in terms of addressing the CE tools, which is a key factor to success in developing a new product under CE environment [13].

2. Analytical Hierarchy Process

The AHP is a systematic approach developed in late 1970s to structure the experience, intuition, and heuristics-based decision making into a well-defined methodology on the basis of sound mathematical principles [14]. AHP is also categorized as a multi-attribute decision-making method [15]. The AHP is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria [16]. AHP is a method which can be used to establish a systematic approach for a single decision maker or a group decision maker to solve decision making problems [17]. AHP is a decision-making tool that can assist describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives [18]. AHP can be employed in making decisions that are complex, unstructured, and contain multiple criteria [19]. Owing to its simplicity and ease of use, the AHP has been implemented in many areas such as manufacturing, government, social studies, research and development (R&D), defence and other areas involving decisions in which choice, prioritization, or forecasting is required. AHP is a powerful and flexible multi-criteria decision-making tool for dealing with complex problems where both qualitative and quantitative aspects need to be considered. AHP helps decision makers to organize the critical aspects of a problem into a hierarchy rather like a family tree [20].

The AHP is used in order to handle both qualitative and quantitative factors and sub-factors influencing DC selection and materials selection in the context of CE in which these selection problems are addressed in early stage of product development process or conceptual design stage. The selection of the AHP is based on the characteristics of the problem and the consideration of the advantages and disadvantages of other techniques as discussed above. Therefore, the main research in this study has focused on formulating an AHP-based model to determine the most appropriate decisions on DC and material concurrently at early stage of product development process or conceptual design stage.

3. The Proposed Selection Framework During Concept Selection at the Conceptual Design Stage

Basically, the research flow used in this research is based on total design method [21]. The design flow used

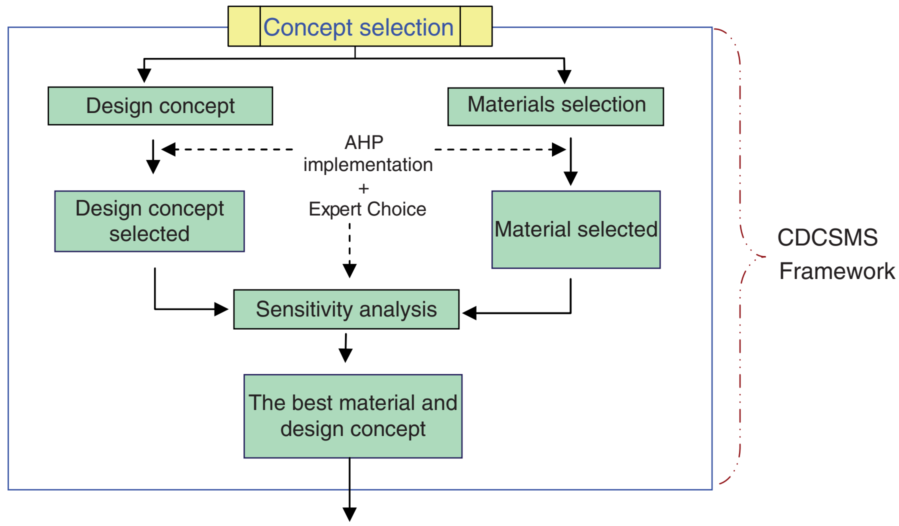

Figure 2. The proposed of CDCSMS framework.

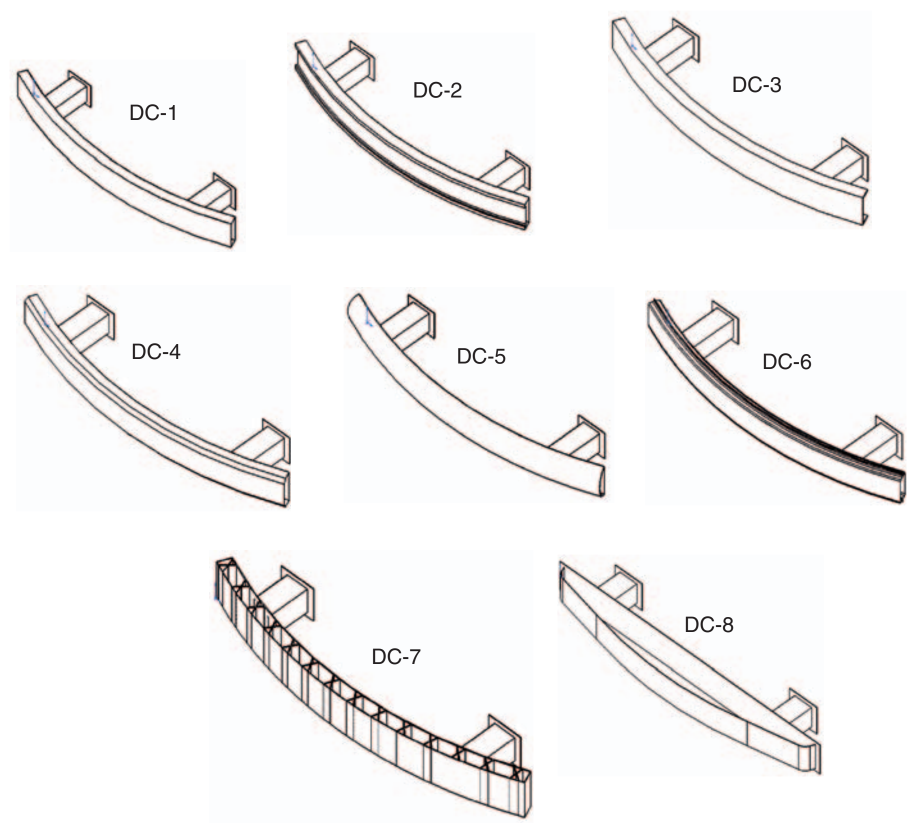

Figure 3. Various DC.

in this research is only covered the development of a product which is initially started from, market investigation, product design specification stage and ends at conceptual design stage.

Development of bumper beam is considered at the conceptual design stage. Bumper beam is a complex shape, thus, all the proposed conceptual design or DCs are assumed as curve flat-faced (a zero (0) sweep). It is because the actual shape of bumper beam is based on the shape of bumper fascia, energy absorber, and bumper stay and how they are attached each other. To design automotive bumper beam, generally, a convenient way of defining the degree of roundness is to use the concept of sweep [22]. At the conceptual design stage, there is only concept selection is considered in which the proposed selection framework was developed.

The proposed selection framework for DC and material is depicted in Figure 2. During concept selection at the concept selection stage, the decision tasks can be divided into two main tasks. The first task is called the DC selection and the second task is called the materials selection. Both of these parts are concurrently performed by implementing AHP. This concurrent system is called concurrent DC selection and material selection or CDCSMS framework. It is a model that provides specific steps to assist designers to consider and determine the best DC and materials concurrently during concept selection process at the conceptual design stage. After the ranking of decisions have been determined (called design or material selected), then various scenarios of sensitivity analysis are performed to verify the results of the decision and to see how sensitive the decision options which will change with the importance of the criteria. Thus, the proposed CDCSMS framework provides a systematic approach for designers to determine the most optimum decision during concept selection at the conceptual design stage.

Table 1. Materials used in automotive bumper beam design.

No	Composite materials
1	Glass fiber epoxy (M-1)
2	Carbon-fiber epoxy (M-2)
3	Carbon fiber-reinforced polypropylene (10%) (M-3)
4	Glass fiber-reinforced polypropylene (40%) (M-4)
5	Glass fiber-reinforced polyester (30%) (M-5)
6	Glass fiber vinylester SMC (60%) (M-6)

4. Selection Process of Determining Concurrently Decision: Case Study

Based on CDCSMS framework, AHP was used to determine the most appropriate decisions. AHP is linked to the framework to show that the selection process is

Table 2. Factors consideration in materials selection for polymeric composite automotive bumper beam.

Factors	Description
Energy absorption (EA)	Bumper beam is a main structure for absorbing the energy of collisions. The property of material that shows the ability of the material to absorb energy is impact toughness
Impact toughness (ITH)	Impact toughness is defined as a measure of the ability of material to absorb energy during impact
Performance (PR)	Performance is defined as the ability of a bumper beam to stay intact or rigid at high-speed impact and prevent damage to the bodywork in minor impacts. There are two factors of material properties should be considered, namely, *flexural strength* and flexural modulus
Flexural strength (FS)	Flexural strength is defined as a measure of a material's ability to withstand failure due to bending
Flexural modulus (FM)	Flexural modulus is also known as stiffness. It is defined as a capability of materials to resist against bending or deflection
Cost (CS)	Cost plays a very significant role to determine the best material at the early stage of product development process
Raw material cost (RMC)	Raw material cost is defined as the cost of raw material that will be used in fabricating the product
Weight (W)	Select a material which enables to reduce the weight of vehicle is very important
Density of materials (DS)	The density of a material is defined as its mass per unit volume. Low density of material can contribute to weight reduction
Service conditions (SC)	A service condition is defined as to satisfy the resistance to weather conditions. Two material properties need to be considered are corrosion resistance and water absorption (WA)
Corrosion resistance (CR)	Corrosion resistance is defined as the ability of a material to resist corrosion
Water absorption (WA)	Water absorption is defined as the amount of water absorbed by a material
Manufacturing process (MP)	Manufacturing process is also need to be considered when determining the best material at the early stage of the product development process
Shape (SH)	Shape is defined as the ability of a material to be shaped into the finished product. As bumper beam is a very complex shape, whether the materials to be formed or shaped according to design requirements need to be considered
Environment consideration (EC)	Due to increasing environmental demands, especially on dealing with products end of life phase, it is important to select the material which is easily to be recycled and disposed of for a better environment
Recycling (RY)	Recycling is defined as the ability of a material to be recycled at the end of life phase
Disposal (DP)	Disposal is defined as the ability of a material to be disposed of in an environmental way such as landfill and incineration
Availability of material (AVM)	Availability of material can be categorized into two factors, namely availability of raw material (AM) and availability of materials information (AI)
Availability of raw material (AM)	The availability of raw material means that an existence of the raw material in the place of manufacturing
Availability of materials information (AI)	The availability of materials information is defined as the materials information readily available to designers during the design process

Table 3. Factors influencing the selection of a DC.

Factors	Description
Energy absorption (EA)	EA is defined as the ability to absorb enough energy to meet the original equipment manufacturer's (OEM's) internal bumper standard
Structure of bumper beam (SC)	Structure of bumper beam is important in determining the capability of the beam to absorb kinetic energy when it collides. To provide excellent EA, there are four factors that have to be considered in designing bumper beam
Curvature structure (CST)	Curvature structure of bumper beam determines the level of energy to be absorbed. The bumper beam is curved in plan so as to keep a constant offset to the front bumper skin providing a consistent level of protection to vulnerable road users across the vehicle front. The bumper beam straightens and as a consequence, the beam mounts are pushed outwards. This outward motion puts the energy absorbing structure into bending and so energy may not be absorbed efficiently. The bumper beam is curved or bent for several reasons
Ribbing pattern (RP)	The structure of bumper beam can be strengthened by ribs in specific places in order to form a more rigid and stabilized structure. The ribs are strengthening plates mainly placed along the vertical direction for preventing deflection of lateral surfaces and creating a rigid structure and reduce deflection
Cross-section (CS)	The cross-sectional shape of the bumper beam is important that it influences the EA rate. Various cross-sectional shape of the bumper beam have been developed in order to provide effective deformation resistance such as circular type, square, square + rib, C-section, I-section, B-section, D-section, etc.
Thickness (TH)	By increasing the material thickness of bumper beam, it will greatly improve the bumper beam strength. The bumper beam part which has thinner material such as central portion provides effective energy absorbing characteristics
Cost (CT)	Cost is defined as a cost reduction without sacrificing its safety and impact performance characteristics. There are three most important costs required to be considered in designing bumper beam
Material cost (MC)	The cost of the material for bumper beam is based on its weight and the price of material per unit weight
Manufacturing cost (MFC)	Manufacturing cost is based on the size and complexity of the product, the manufacturing process employed for making the shape and finish, the material used to make the product, etc. The cost of manufacturing is estimated based on the material-manufacturing-selling 1-3-9 rule
Repair cost (RC)	The repair cost is roughly estimated assuming when bumper beam involved in low-speed impact
Manufacturing process (MP)	Manufacturing process is defined as how easy product would be fabricated
Easy to fabricate (EF)	The easy to fabricate by simplifying the shape is important when designing bumper beam
Weight consideration (WE)	Reducing the weight of the structure without sacrificing performance of the bumper can provide manufacturing cost savings
Strength (ST)	Strength is defined as an ability of bumper beam to stay intact or rigid at the high-speed impact, provide dimensional stability, and prevent damage to the other components. The strength of the bumper beam is determined by its deflection during impact
Deflection (DF)	During impact bumper beam absorb all kinetic energy through deflection. Low deflections during impact shows bumper beam is not easy to bent and absorb impact. High deflections can cause bumper beam breakage allowing damage to the vehicle
Styling (SL)	The current styling trend for vehicles is toward rounded and aerodynamic shapes. It is essential to consider roundness and aerodynamic shape of bumper beam
Roundness (RN)	Roundness on bumper beam surface is needed to consider in designing bumper beam. Bumper beam which is having a good roundness formed can be improved impact-absorbing performance
Aerodynamic shape (AD)	An aerodynamic shape helps direct air flow to the engine compartment. Creating an excellent aerodynamic shape for bumper beam can cut fuel consumption and emissions
Material (MT)	There are two factors must be considered by designers in determining the best DC namely, recyclability of materials and formability of materials
Formability of materials (FM)	Formability is defined as the easy or difficulty level of materials involved in a forming process. A material with good formability requires less applied force, consumes less energy, and can be formed into required shapes without failure
Recyclability of materials (RM)	Recyclability is defined as the material which is easily recycled at the end of their useful life
Maintenance (MTN)	There are three main factors that influence the selection of the composite bumper beam related to maintenance consideration
Easy to repair (ER)	Repairability measures how easily, quickly, and cost-effectively the damaged structure and components can be repaired or replaced
Easy to dismantle (ED)	How easy component can be separated or removed for maintenance or repairing purposes is also needed to be considered in determining the best DC
Easy to install (EI)	Easy to install means that how easy component can be assembled and integrated to the other components such as bumper stay, energy absorber, etc. during installation or maintenance purposes

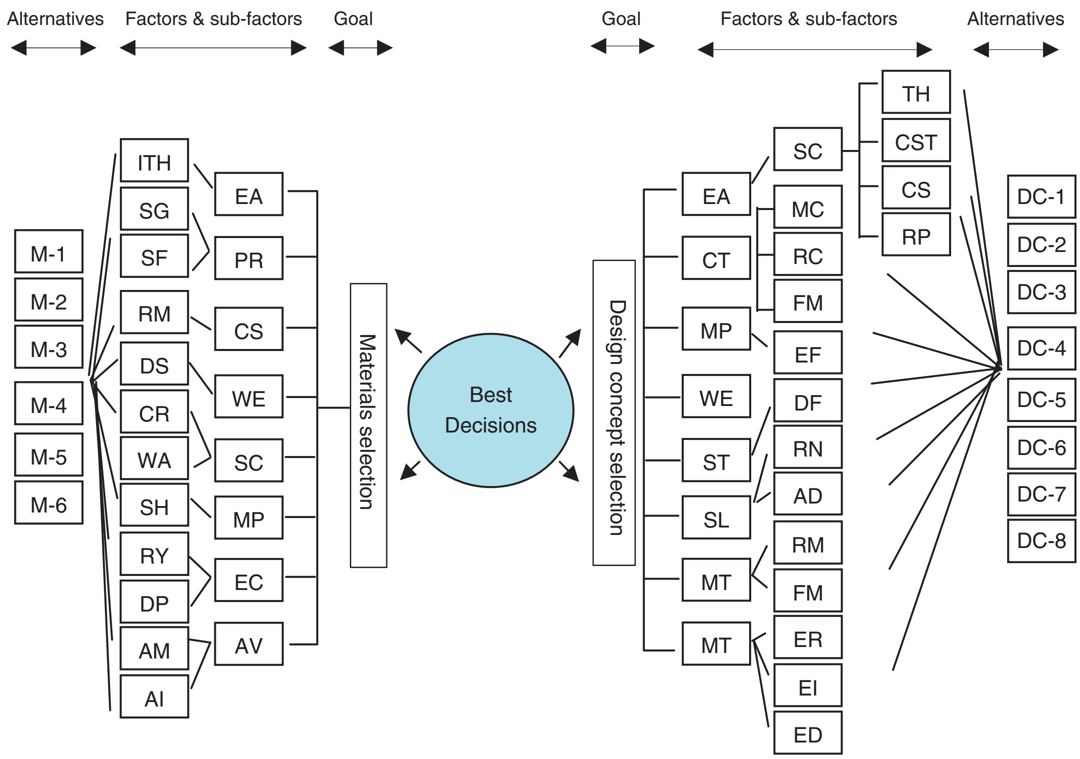

Figure 4. Hierarchy structure of AHP model.

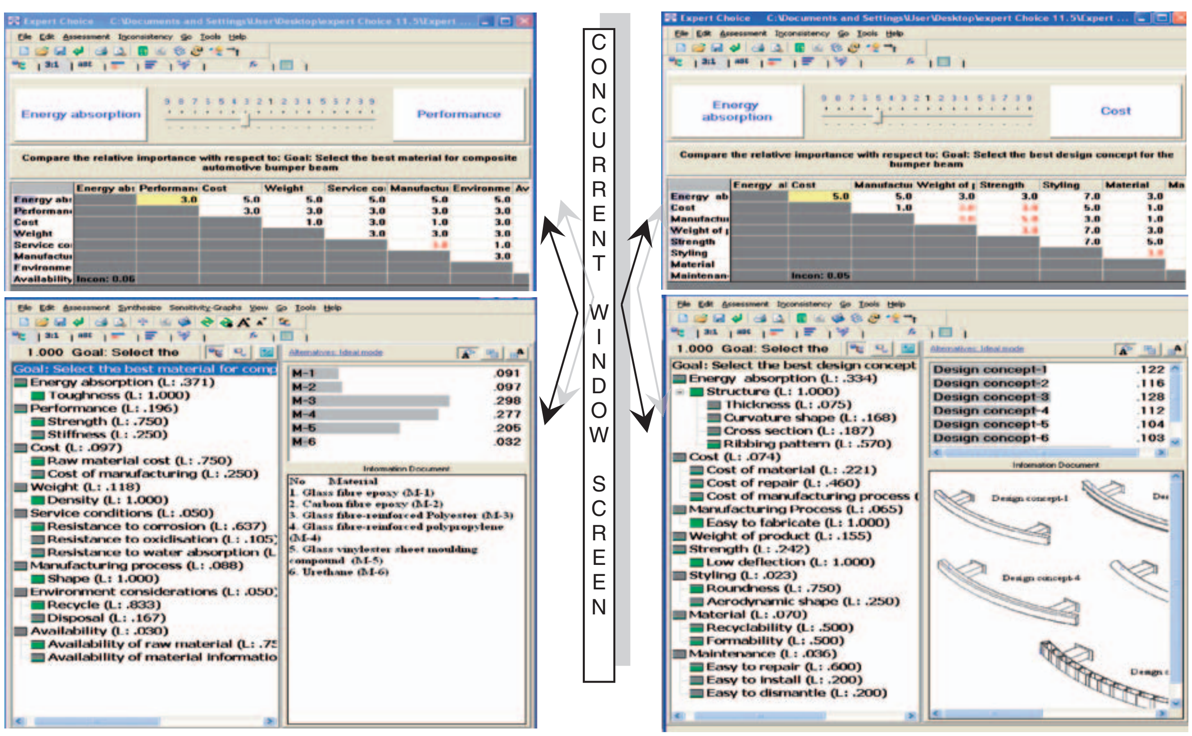

Figure 5. Concurrent windows for pairwise comparison and all priority vector for criteria, sub-criteria, and alternatives.

carried out by employing AHP. Basically, AHP method consists of three main steps namely decomposition of the hierarchy structure, comparative judgments, and synthesis of priorities [15,16]. These steps can be elaborated by structuring them in a more encompassing nine-step process [17]. To illustrate the CDCSMS framework and the use of AHP in the context of CE environment, EIGHT (8) DC (Figure 3) and SIX (6)

Table 4. Scale for pairwise comparisons [19].

Relative intensity	Definition	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals	Reciprocals for inverse comparison	

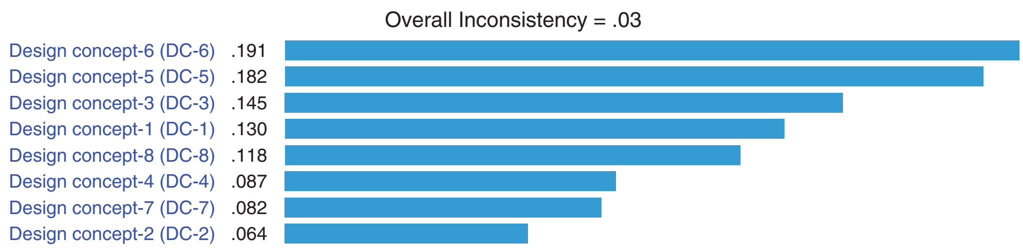

Figure 6. Result of selection of DC.

Table 5. Consistency ratio and priority vectors for the main factors, sub factors, and alternatives (DC selection).

	Priority vectors																
Main factor		EA 0.434 CR = 0.04				CT 0.062		MP 0.062	WE 0.131	ST 0.131	SL 0.025		MT 0.131			MTN 0.025	
Sub-factor		SC			MC	RC	MFC	EF		DF	RN	AD	RC	FM	ER	EI	ED
Sub-sub-sactor	TH 0.095	CST 0.249 CR = 0.02	CS 0.560	RP 0.095	0.258	0.105 CR = 0.04	0.637	1.0		1.0	0.750 CR = 0.0	0.250	0.250 CR = 0.0	0.750	0.238	0.625 CR = 0.02	0.137
Alternative																	
DC-1	0.100	0.136	0.132	0.100	0.053	0.125	0.053	0.218	0.053	0.157	0.086	0.083	0.125	0.218	0.125	0.125	0.125
DC-2	0.100	0.136	0.037	0.100	0.033	0.125	0.033	0.078	0.034	0.034	0.036	0.083	0.125	0.078	0.125	0.125	0.125
DC-3	0.100	0.136	0.092	0.100	0.229	0.125	0.229	0.218	0.217	0.108	0.086	0.083	0.125	0.218	0.125	0.125	0.125
DC-4	0.100	0.136	0.052	0.100	0.078	0.125	0.078	0.078	0.090	0.073	0.223	0.250	0.125	0.078	0.125	0.125	0.125
DC-5	0.100	0.136	0.227	0.100	0.130	0.125	0.130	0.218	0.135	0.227	0.223	0.250	0.125	0.218	0.125	0.125	0.125
DC-6	0.100	0.136	0.385	0.100	0.052	0.125	0.052	0.078	0.053	0.327	0.036	0.083	0.125	0.078	0.125	0.125	0.125
DC-7	0.300	0.136	0.055	0.300	0.019	0.125	0.019	0.078	0.023	0.050	0.086	0.083	0.125	0.034	0.125	0.125	0.125
DC-8	0.100	0.045	0.020	0.100	0.406	0.125	0.406	0.033	0.396	0.024	0.223	0.083	0.125	0.078	0.125	0.125	0.125
CR	0.0	0.0	0.06	0.0	0.05	0.0	0.05	0.01	0.02	0.03	0.01	0.0	0.0	0.01	0.0	0.0	0.0

different types of composite materials (Table 1) of automotive bumper beam are considered.

4.1 Determination of Right Decisions

Various selection factors that influence the selection process are considered as illustrated in Tables 2 and 3. The factors that consider are then translated into a hierarchy form as depicted in Figure 4. AHP steps are conducted through utilizing Expert Choice software. The software developed by Forman et al. [11], is a multi-attribute decision-support software tool based on the AHP methodology, and it is easy to use and understand, as well as providing visual representations of overall ranking on a computer screen. DC and material window screen are concurrently open and the judgments of pairwise comparison can be performed simultaneously as illustrated in Figure 5. Pairwise comparisons are fundamental to the AHP methodology [18]. Designers have to perform the judgment of pairwise comparison by using pairwise numerical comparisons or relative scale pairwise comparison as shown in Table 4.

***Table 6.** Consistency ratio and priority vectors for the main factors, sub factors, and alternatives (materials selection).*

						GOAL						
Criteria	EA	PR		CS	WE	SC		MP	EC		AV	
	0.364	0.223		0.122	0.122	0.038		0.070	0.038		0.022	
						CR = 0.05						
sub-criteria	ITH	FS	FM	RMC	DS	RC	WA	SH	RY	DP	AM	AI
		0.750	0.250			0.667	0.333		0.750	0.250	0.750	0.250
		CR = 0.0				CR = 0.0			CR = 0.0		CR = 0.0	
Alternatives												
M-1	0.430	0.254	0.254	0.086	0.254	0.167	0.071	0.167	0.083	0.167	0.167	0.167
M-2	0.149	0.435	0.426	0.031	0.088	0.167	0.071	0.167	0.083	0.167	0.167	0.167
M-3	0.030	0.029	0.088	0.051	0.426	0.167	0.430	0.167	0.250	0.167	0.167	0.167
M-4	0.051	0.086	0.052	0.427	0.150	0.167	0.143	0.167	0.250	0.167	0.167	0.167
M-5	0.087	0.049	0.031	0.179	0.052	0.167	0.037	0.167	0.250	0.167	0.167	0.167
M-6	0.253	0.147	0.150	0.225	0.031	0.167	0.249	0.167	0.083	0.167	0.167	0.167
CR	0.07	0.07	0.08	0.01	0.08	0.0	0.05	0.0	0.0	0.0	0.0	0.0

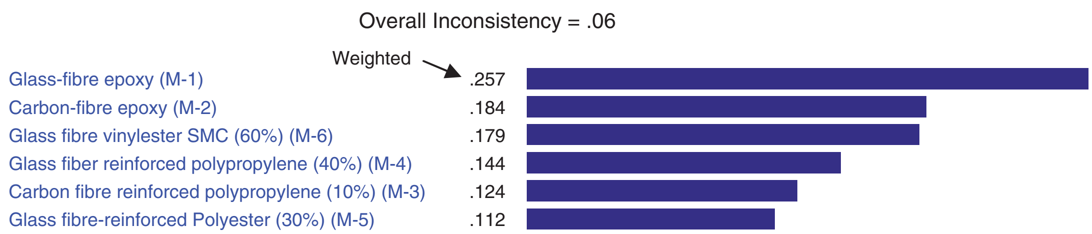

Figure 7. Results of selection of materials.

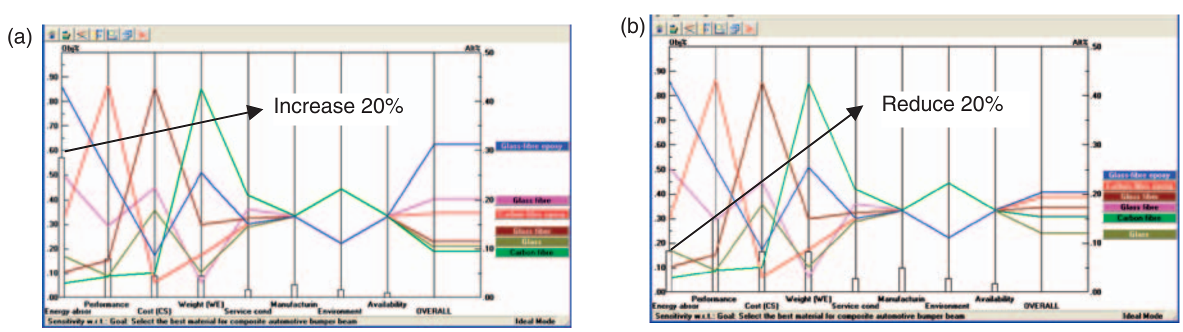

Figure 8. Priority vectors of EA are increased and reduced by 20%.

The judgments or assigned values as shown in Figure 6 are based on the authors' experience and knowledge. All the judgments for the DC selection and materials selection are acceptable due to consistency ratio (CR) for each pairwise comparison is less than 0.1 as depicted in Tables 5 and 6, respectively.

4.2 Results of the Best Selection

AHP reveals that the DC-6 with a weight of 0.191 (19.1%) as a first choice as shown in Figure 6, and the glass fiber epoxy (M-1) is the most appropriate composite material with a weight of 0.257 (25.7%) as shown in Figure 7.

5. Verification of the Decisions Through Sensitivity Analysis

The final decisions were verified by simulating various scenarios by increasing or decreasing the values of the priorities vector of the main criteria. The purpose of performing the sensitivity analysis is to verify the results of the decision and to study the effect of the different factors on deciding the best decision option. The final selection of the DC is highly dependent on the priority vectors attached to the main criteria. The minor changes in the priority vectors might contribute to the major changes in the final ranking [20]. The stability of the

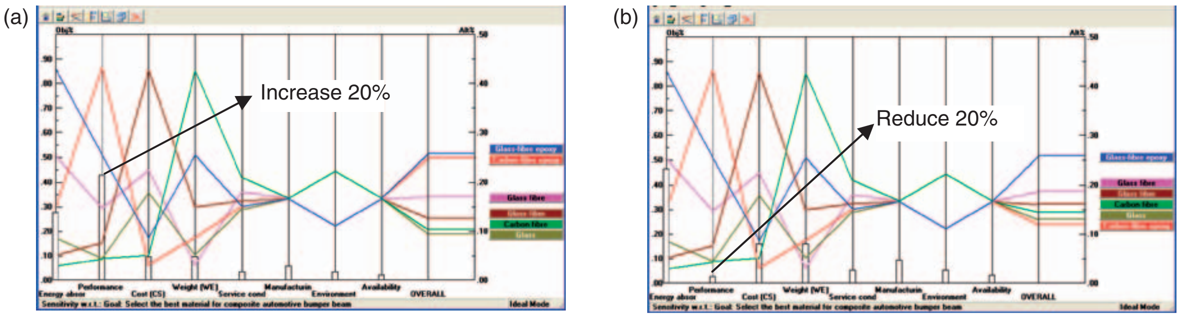

Figure 9. Priority vectors of performance (PR) are increased and reduced by 20%.

Table 7. The results obtained after simulating four scenarios of sensitivity analysis.

Criteria	EA		PR	
Rank	Reduced (20%)	Increased (20%)	Reduced (20%)	Increased (20%)
1	M-1	M-1	M-1	M-1
2	M-6	M-2	M-2	M-6
3	M-2	M-4	M-6	M-4
4	M-4	M-6	M-4	M-3
5	M-5	M-3	M-3	M-5
6	M-3	M-5	M-5	M-2

ranking under varying criteria weights has to be tested as these priority vectors are usually based on highly subjective judgments. The sensitivity analysis is performed by increasing or decreasing the priority vector of individual criterion, the resulting changes of the priorities and the ranking of the decision can be observed.

The 15% and 20% were selected to perform various scenarios of sensitivity analysis in order to observe how alterations of priority vector of the criteria can affect the overall alternatives or decision option scores and ranking. If less or more than these percentages, the decision option scores and ranking were not changed.

For the materials selection:

1. Priority vectors of energy absorption (EA) are increased and reduced by 20% (Figure 8(a) and (b))
2. Priority vector of performance (PR) is increased and reduced by 20% (Figure 9(a) and (b))

The ranking of the early decisions (Figure 8) was compared with the results obtained after performing four scenarios of sensitivity analysis as given in Table 7.

If the priority vectors of EA are increased and reduced by 20% and priority vectors of performance (PR) are increased and reduced by 20%, the results show that glass fiber epoxy (M-1) is the most appropriate material. It can be concluded from the sensitivity analysis, the final result of proposed AHP model is mainly based on increasing or decreasing the values of the priorities vector of the main criteria. In this study, final decision of the most appropriate material was glass fiber epoxy after various scenarios of sensitivity analysis have been conducted.

Table 8. The results obtained after simulating two scenarios of sensitivity analysis.

Main criteria	Energy absorption	Strength
Rank	Decreased (15%)	Increased (15%)
1	DC-6	DC-6
2	DC-5	DC-5
3	DC-3	DC-3
4	DC-1	DC-1
5	DC-8	DC-8
6	DC-4	DC-4
7	DC-7	DC-7
8	DC-2	DC-2

For the DC selection:

1. Priority vector of EA is decreased by 20%
2. Priority vectors of strength (ST) are increased and reduced by 15%

The ranking of the early decisions (Figure 6) was compared with the results obtained after performing four simulated scenarios as given in Table 8. If the priority vectors of EA is decreased by 15% and priority vector of strength (ST) is increased by 15% the ranking results of the best DC would not change which is same as the previous one. In this study, final decision of the most appropriate one was DC-6 after various scenarios of the sensitivity analysis have been conducted.

6. Conclusions

Determine the right selection of DC and material during concept selection at the conceptual design stage is very important. The proposed CDCSMS framework provides a systematic guide to designers to perform DC selection and materials selection concurrently during concept selection stage. The use of AHP through utilizing Expert Choice software for solving DC and materials selection at early stage of product development process was explored in this research. Various scenarios of sensitivity analysis scenarios were conducted to verify the final decisions. The AHP and sensitivity analysis reveals that the glass fiber epoxy (25.7%) and concept-6 (19.1%) are the most appropriate decision for the material and DC, respectively. It is indicated that the proposed selection framework and the linked AHP approach through utilizing Expert Choice software to the model is a useful method to solve decision problems in selection of material and DC during concept selection stage. Concurrently decisions on design and material at the conceptual design stage can lead to the products to be manufactured in shorter time and higher quality.

Acknowledgement

The authors thank Universiti Teknikal Malaysia Melaka (UTeM) for supporting this research.

References

1. Prasad, B. (1996). *Concurrent Engineering Fundamentals: Integrated Product and Process Organization*, Michigan: Prentice Hall.
2. Chakrabarti, A. and Bligh, T.P. (1994). An Approach to Functional Synthesis of Solutions in Mechanical Conceptual Design. Part I: Introduction and Knowledge Representation, *Research in Engineering Design*, **16**(3): 127–141.
3. Fung, R.Y.K., Chen, Y. and Tang. J. (2007). A Quality-Engineering-Based Approach for Conceptual Product Design, International, *Journal of Advanced Manufacturing Technolology*, **32**(11): 1064–1073.
4. Lin, Y.J., Huang, C.W., Tseng, J.C. and Shiau, J.Y. (2004). Issue Resolution for Conceptual Design Using AHP, In: *Proceedings of the SPIE-Volume 5605, Intelligent Systems in Design and Manufacturing*, Philadelphia, PA, 25–26 October, pp. 47–53.
5. Edwards, K.L. (2007). Supporting Design Decision-Making when Applying Materials in Combination, *Materials and design*, **28**: 1288–1297.
6. Lu, W.F. and Deng, Y.M. (2004). A System Modelling Methodology for Materials and Engineering Systems Design Integration, *Materials and Design*, **25**: 459–469.
7. Edwards, K.L. and Deng, Y.M. (2007). Supporting Design Decision-Making When Applying Materials in Combination, *Materials and Design*, **28**(4): 1288–1297.
8. Ljungberg, L.Y. and Edwards, K.L. (2003). Design, Materials Selection and Marketing of Successful Products, *Materials and Design*, **24**: 519–529.
9. Sapuan, S.M. (2001). A Knowledge-Based System for Materials Selection in Mechanical Engineering Design, *Materials and Design*, **22**: 687–695.
10. Ashby, M., Shercliff, H. and Cebon, D. (2007). *Materials Engineering, Science Processing and Design*, London: Butterworth-Heinemann.
11. Forman, E.H., Saaty, T.L., Selly, M.A. and Waldron, R. (2000). *Expert Choice 1982–2000*, McLean, VA, Pittsburgh, USA: Decision Support Software Inc.
12. Okudan, G.E. and Tauhid, S. (2008). Concept Selection Methods – A Literature Review from 1980 to 2008, *International Journal of Design Engineering*, **1**(3): 243–277.
13. Hambali, A., Sapuan, S.M., Ismail N. and Nukman, Y. (2009). The Important Role of Concurrent Engineering in Product Development Process, *Pertanika Journals of Science and Technology*, **17**(1): 9–20.
14. Bhushan, N. and Rai, K. (2004). *Strategic Decision Making Applying the Analytic Hierarchy Process*, New York: Springer.
15. Ho, W. (2008). Integrated Analytic Hierarchy Process and Its Applications- A Literature Review, *European Journal of Operation Research*, **186**(1): 211–228.
16. Saaty, T.L. and Vargas, L.G. (2001). *Models, Methods, Concepts & Applications of the Analytical Hierarchy Process*, Boston: Kluwer Academic Publishers.
17. Chen, C.F. (2006). Applying the Analytical Hierarchy Process (AHP) Approach to Convention Site Selection, *Journal of Travelling Research*, **45**(2): 167–174.
18. Huan, S.M., Sheoran, S.K. and Wang, G. (2004). A Review and Analysis of Supply Chain Operations Reference (SOR) Model, *Supply chain management: An International Journal*, **9**(1): 23–29.
19. Partovi, F.Y. (1994). Determining What to Benchmark: An Analytic Hierarchy Process Approach, *International Journal of Operations and Production Management*, **14**: 25–39.
20. Bevilacqua, M., D'Amore, A. and Polonara, F. (2004). A Multi-Criteria Decision Approach to Choosing the Optimal Blanching-Freezing System, *Journal of Food Engineering*, **63**(3): 253–263.
21. Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*, Wokingham: Addison Wesley Limited.
22. Bernert, W., Bulych, S., Cran J., Egle, D., Henseleit, K., Hersberger, T., Kantner, C., Koch, M., Kudelko, C., Mihelich, M., Mohan, R., Stokfisz, S., Tang, M., Vikstrom, T., Welte, E. and Zabik, B. (2006). American Iron and Steel Institute: Steel Bumper Systems for Passenger Cars and Light Trucks, Revision number three, June 30, 2006. Available at: http://www.bumper.autosteel.org (accessed February 6, 2008).

A. Hambali

Dr Hambali Ariff is a senior lecture at the Department of Manufacturing Design, FKP, UT*e*M. He obtained his PhD in 2010 at the University Putra Malaysia (UPM). His research area is focused on Concurrent Engineering, New Product Development (NPD), Product Design and CAD/CAE.

S. M. Sapuan

Professor Dr Mohd Sapuan is Head and Professor of Composite Materials, Department of Mechanical and Manufacturing Engineering, University Putra Malaysia (UPM). He obtained his PhD from De Montfort University, UK in 1998. He has contributed to the field of mechanical engineering particularly in polymer composite and concurrent engineering. He is an international leader in concurrent engineering for composite materials. His research area is focused on concurrent engineering for composites, automotive composites, composite materials selection and natural fibre composites.

A. S. Rahim

Rahim Samsuddin is a lecture at the Department of Manufacturing Design, FKP, UT*e*M. He obtained his MSc from University of Technology Malaysia in 2003. His research area is focused on Concurrent Engineering and Product Design.

N. Ismail

Dr Napsiah Ismail is an Assoc. Prof from Department of Mechanical and Manufacturing Engineering, University Putra Malaysia (UPM), Malaysia. She obtained her PhD from University of Technology Malaysia in 2000. Her research areas of interest: Advanced Manufacturing Technology, Intelligent Manufacturing, Automation and Robotics.

Y. Nukman

Dr Nukman Yusof is a senior lecturer from Department of Engineering Design and Manufacture, University Malaya (UM), Malaysia. He obtained her PhD from University of Loughborough, UK in 2007. His research area is focused on material Processing Technology, Control Technology and CAD/CAM.