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A KNOWLEDGE MODEL FOR AUTOMOTIVE ENGINEERING DESIGN

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ABSTRACT
Within the competitive environment of the automotive industry, increasing the efficiency of the engineering design process and shortening the time to market of a product becomes a key to the success of an automotive firm. Apart from applying design tools and strategies, undertaking knowledge management is also of significant importance as there are always huge amount of data and information generated during a design project. This has driven researchers to study knowledge management and devise a knowledge management system to assist the engineering design process. This paper is based on the study of a Formula Student racing car design project and presents a development of a Project-Process-Product (P3) Model as the core of a knowledge management system. The P3 Model aims to identify the information structure of automotive design knowledge as well as exploring the way to organize the data and information generated during an automotive design project. The preliminary work shows that, the model helps designers, especially novices, gain a clear overview of the project and recognise what data and information may be required for their design as well as how to access the information when necessary.

Keywords: design engineering, automotive engineering design, information management, knowledge management, knowledge model

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1 INTRODUCTION

With the increasingly severe competition in the automotive industry, shortening the design cycle of a vehicle is one of the most significant factors for a company's success. Certainly, both good designing tools and effective design strategies can speed up the design process (Ahmed et al., 2003). However, the large amount of data and information generated during the engineering design process can also greatly affect the efficiency of a design project. In this case, knowledge management for assisting the engineering design process becomes significant. At present, there are some developed knowledge management systems mainly focused on managing the data of a project in a general scope. These systems, however, cannot capture the knowledge and rationale within an engineering design process which is important for reuse in future design. Consequently, an information system which can not only manage product and process knowledge, but also capture the informal knowledge (e.g. the rationale behind the design) will be required to improve the design efficiency of automotive engineering design processes.

This paper presents the authors' preliminary work on the development of a Project-Process-Product (P3) Knowledge Model which acts as the foundation of the information systems assisting for automotive engineering design. The authors' research is initially based on a Formula Student racing car design project, which is a complete design and manufacture project delivered by universities students. In this design project, as the lack of efficient and effective knowledge management, there are obvious difficulties in locating, retrieving and reusing previous information & knowledge. The research on the project is to develop an information system for efficient information & knowledge organization, storage and reuse. The P3 knowledge model is the basis of this system, which provides the users with guidance throughout the automotive design projects by incorporating the perspectives at the Project, Process and Product levels.

This paper is organized as follows. Section 2 reviews the literature on knowledge management for engineering design. Section 3 investigates the engineering design process of this racing car design project as well as the information flow throughout the whole project. In Section 4, details of the P3 Knowledge Model is analysed in terms of Project Model, Process Model, Product Model and the integration of them. Then, the application of the P3 Model will be described in Section 5, as well as the whole discussion on this preliminary work. The conclusions and future work will be discussed in Section 6.

2 LITERATURE REVIEW

Knowledge management has become a research topic in the past decades, and it has been affected significantly by information technologies since 1995 (Liao, 2003). These fast-growing information technologies (e.g., the Internet, intranets, extranets, browsers, data warehouses, data mining techniques, and software agents) are used to systematise, enhance and expedite knowledge management (Alavi and Leidner, 2001). Subsequently, development of computer software and systems is the trend in fulfilling the functions of knowledge management. Many researchers, at the meantime, are investigating knowledge models which support these computer software and systems. This section presents a review focusing on the issues of identifying the basic concept of knowledge management as well as the suitable approaches to achieving its function. The major existing software and systems as well as some supporting knowledge models will also be reviewed, with discussion on the challenges in using them.

Knowledge management is based on management theory and concentrates on the systematic creation, leverage, sharing and reuse of knowledge resources in a company (Awad and Ghaziri, 2003). Knowledge management has been considered as one of the key enabling technologies for distributed engineering enterprises in the 21st century (McMahon et al., 2004), as it affects the efficiency in a design project. A good knowledge management can accelerate the design process and shorten the lead time of delivering a new product to market. There are two different approaches to knowledge management: one approach tends to have a technical focus on managing the information in the form of tangible documents and the other promotes the exploitation of an organization's intelligent assets (McElroy, 2002). These two approaches indicate that knowledge management helps to organize data, information and knowledge in projects and allow designers to find and reuse information effectively. In order to achieve that, it is important to define, manage and exploit the relationships between the

different representations of product data and structure (Briere-Cote et al., 2010); thus, the knowledge management system needs to be used to fulfil such functional requirement.
Presently, the function of knowledge management can be achieved by some Product Lifecycle Management (PLM) software packages, such as Windchill (PTC), Team Centre (UGS) and CATIA (Dassault System). These software packages can support information exchange between developers adequately, especially in the later phases of the engineering lifecycle which are characterized by more deterministic and well-known processes (Brandt et al., 2008). However, these packages lack essential capabilities for the management and reuse of design knowledge (Bilgic and Rock, 1997; Gao et al, 2003). Besides, a significant weakness of the existing PLM systems is that they are lack of adequate information models for product representation, as these models are needed to effectively capture, exchange, retrieve, and reuse design knowledge (Brandt et al., 2008).
Knowledge model is always used as the core of knowledge management system and it has a significant influence to its performance. A few models have been proposed for knowledge management, which focus on identifying the data, information and knowledge, presentation of knowledge, or providing ways to deal with explicit and tacit knowledge in a project (Alavi and Leider, 2001). Funtion-Behavious-Structure (Gero and Kannengiesser, 2007), Ontology-based approach in design process (Brandt et al., 2008), and Design Rationale (Bracewell et al., 2009) are some existing models which are proved to be beneficial for the knowledge management systems. Moreover, some current research has also focused on combining product, process and organization knowledge into an integrated model (Baxter et al., 2007; Wang et al., 2012), while they are still in the early stage and seeking the method in dealing with the relationships between different elements within information and knowledge, and they are not specific for the automotive engineering design.
The study of information requirements and information-seeking behaviours is also an important research area in the field of knowledge management for engineering design. It considers what kinds of information and knowledge may be beneficial for designers during the engineering design process. One of the main challenges in this area is that many novice designers do not use design strategy and often they do not know how to find required information in a proper way (Ahmed and Wallace, 2004). This also implies that designers might not use the well organized database system efficiently. Moreover, the information stored in the database basically has the form of drawings, reports, and standards etc. It is always difficult for the designers to access what they actually need from the database. Therefore, an information system is necessary to be developed to overcome the problems mentioned above and fulfil the function of knowledge management.
The current research has showed that the knowledge management has a significant effect for engineering design as it can improve the design efficiency by supplying the information and knowledge the designers required effectively. Several knowledge management systems have been developed to assist the knowledge management for engineering design. However, the complexity of information requirement makes it is difficult to meet the requirements for effective information storage and retrieval during an engineering design process. Thus, a knowledge model should be developed and used to identify the different characteristics of information and meet various information requirements; and this model will be acted as the base of the knowledge management systems. Besides, the existing knowledge models are not specific for automotive engineering design. Therefore, an integrated knowledge model for the knowledge management system supporting automotive engineering design is desired.

3 THE FORMULA STUDENT DESIGN PROJECT

3.1 Project Background

Formula Student (FS) is Europe's most established educational motorsport competition, run by Institution of Mechanical Engineers (IMechE). The competition aims to inspire and develop enterprising and innovative young engineers. It challenges universities from all over the world to design and build a single-seat racing car for competing in static and dynamic events, which demonstrate their understanding and test the performance of the vehicle. According to the aim of the competition, official specifications and regulations are established to guild the design and manufacture of the vehicle. One significant rule is that the chassis of the vehicle must be a new design every year. For other parts, there is no restriction for their reuse.

The authors have been undertaking the research work on effective design information and knowledge reuse for the Formula Student project at the University of Portsmouth. The FS project team is composed of 30 to 40 university students who major in mechanical, electrical and manufacturing engineering. The students involved in the project normally are in their second or third year in the university, being leaded by one final year student or one senior student. Basically, a small portion of the team members are from previous year's project, and as such these students are treated as experienced designers, while the students who have just joined the team are regarded as novice designers. Although, the project is being undertaken at the university level, the project involves a complete vehicle design process which includes demand & specification analysis, conceptual design, embodiment design, detail design, manufacture, testing and competition. Thus, it covers all the major aspects in a real car design project in the automotive industry.

3.2 The Engineering Design Process

The aim for this Formula Student project is to design and manufacture a racing vehicle for competition purpose. Thus, the major task is to generate a new car through the engineering design process. Based on the official specifications and rules, the FS project has been divided into several small sub-sections: chassis, powertrain, drivetrain, suspension system, braking system, electronic system and bodywork etc. For the chassis, as required by the organiser, it needs to be a new design for each year's competition. Hence, the producing of this sub-section is a whole engineering design process from needs & specification analysis to conceptual design, embodiment design and detail design, and then to the manufacture and testing. Although the chassis should be a new design, it is permitted that the design can be based on the experience of the previous design and makes some improvements. The present chassis design aims to build on the basis of the one completed in the previous year and optimize the structure and reduce the weight. As the chassis is the foundation of the vehicle, other sections are developed based on it. Thus, the designs for different sub-sections have some connections with each other. For instance, the suspension system needs to be fit with the chassis, which requires its adjustment to accommodate the chassis. In this case, the data and information storage and sharing during the design process become significant. For some parts such as engine, as it is permitted by the competition organizers to use the one from previous car, the new powertrain is the improved system from previous vehicle. From the analysis of the previous powertrain, a problem has been indentified on the oil sump. Then the design of the present powertrain is aimed at solving this problem and improving the property. Hence, the major work of this kind of sub-section is to analyse the previous problem and implement an improved scheme. In this situation, the previous data and information are also required and important. Besides, there are also some small parts such as nuts and bolts, rods and electronic elements should be purchased. The previous choices on these components are a good guidance in terms of both the technical and economic aspects.

Every sub-section has a student from the previous project as the section leader; he/she will guide and supervise the development process of the specific sub-section. When undertaking new designs, the students will firstly refer back to the design of last year through searching for relevant data and information. They will also ask experienced team members for advices, as well as search information and standards from the internet. Normally, each sub-section will hold formal and informal section meeting to discuss the progress and the problems needed to be solved, and regular meeting will be held weekly for the whole project team. When the designs are finished, every sub-section will be manufactured and assembled together, and then several tests will be undertaken before the competition.

3.3 Information Flow

During the engineering design process, there are mainly two kinds of information flow. One is the information coming from the outside of the present project, such as the design specifications and regulations of the competition, the standards required to undertake the design, and the data and information from the previous projects. Another is the information generated during the present design project, e.g. the sketches, engineering drawings, testing data etc. Besides, there is also information flow between any connected two stages during the whole process, as shown in Table 1.

The Formula Student project aims to produce a racing car for the competition, which is similar to the commercial car design in the automotive industry, while the customer of the car can be treated as the competition organizer. Thus, the requirements are obtained from the competition organizers, expressed in the form of design specification and competition regulations. These requirements are the important

information intake by the project team in the university and used as the guidance for the project. Also, similar to the other kind of design projects, the relevant national/international standards are important to the project and should be followed throughout the project. The agreements with sponsors and supporters are also significant information flowed into the project, which influence the progress of the project through determining the budget and boundary of the project. This information is always kept as contracts and stored in documents. Besides, the cost information about parts, materials purchase and manufacture outsourcing is flowed into the project as well. This part of information is the key for making quick and right decisions during the design process, thus should be efficiently stored and readily available when needed.

When the design project is proceeding, the information in the form of sketches, drawings, calculations and testing data will be generated, which is regarded as the output information flow of the project. The amount of this kind of information normally depends on the complexity of the project. The Formula Student project is a complete vehicle design project, and a large amount of data and information is generated throughout the design process. This information has continuity and connection with each other, thus it is helpful and valuable for the processes in the following stages, as well as beneficial for similar future projects. Hence, the management of the data and information is significant and they should be stored in a well organized way for future reuse. When the project finished, formal reports such as design report and cost report will be generated and organized into several documents, then sent to the competition organizer for project evaluation. These documents will be stored both in paper documents in the project team office and in electronic files in the network drive of the university for future reuse.

Table 1. The information flow throughout the engineering design process

	Information Flow In	Information Flow Out
Market/Customer Needs Analysis	Questionnaire, Survey	Requirement analysis report
Specification	Official specification, Rules	Product design specification
Design Process	Product design specification, requirement analysis report	Sketches, analysis, calculations, drawings, layouts
Manufacture and Testing	Completed drawings, layouts	Test results, instructions
Selling/Competition & Service	Instructions	User feedbacks

4 PROJECT-PROCESS-PRODUCT KNOWLEDGE MODEL

As mentioned above, there are two kinds of information flow throughout the engineering design process of the vehicle. The effective management of the information flow will certainly improve the efficiency of the project as the large amount of the information flow will be generated. Therefore, a Project-Process-Product knowledge model has been proposed to underpin the management of the data and information required and generated during the project, as well as to lay the foundation for the development of a knowledge management system for the project. The proposed model incorporates issues from the perspectives of the whole project management, the engineering design process and the product development. The model can also be used to identify the relationships between these issues, and to explore the way for their integration. Firstly, the Project Model describes the whole project in terms of Project Management and Design Management. Then, the Process Model presents the exact way of undertaking the project using a model based on Total Design (Pugh, 1991), covering stages from market and customer needs, product design specification to design and manufacture process, and then to the sale or competition. Finally, the Product Model identifies the product itself (e.g. the racing car in this case study) in a detailed ring structure, describing the sub-sections of a product. All of these will be demonstrated in the following sections.

4.1 The Project Model

The Project Model considers the project in the terms of Project Management. Thus, the model includes several important aspects in the engineering design project, as shown in Figure 1.

Figure 1. The Project Model

The model begins with the analysis of the market and customer needs that will be transformed into specific requirements of a product & design. Then, the product design specification provides the guidance for the whole project by outlining various requirements and explanations. Moreover, the information regarding to sponsorships, contacts and other legislation documents are also included in the model as it offers the context of the project undertaking. Based on these, the project plan will be generated and work breakdown structure should be made according to the project plan. When the project is being undertaken, the budget & cost management, purchase & warehouse management, and risk & reliability management should be ongoing at the same time. Furthermore, the sustainability and re-manufacturing issues are also significant and should be considered all through the project.

This model emphasises the importance of considering the various issues relevant to Project Management. Also, the model provides a clear structure for organizing the relevant supporting data and information generated during the whole project. Although the supporting information is not used directly for the product design or manufacture, it indicates the scope and limitation of the project. Hence, it will be an important section in the knowledge management system to be developed.

4.2 The Process Model

The Process Model describes the process of the design project based on the Total Design Model (Pugh, 1991), as shown in Figure 2. Thus, the process of the project starts from the market and customer needs analysis and then generates a product design specification. Following is the design process which includes conceptual design, embodiment design and detailed design. Then, the process moves to manufacture and texting stage. The final step is the product sale or entering competition (e.g. the Formula Student project).

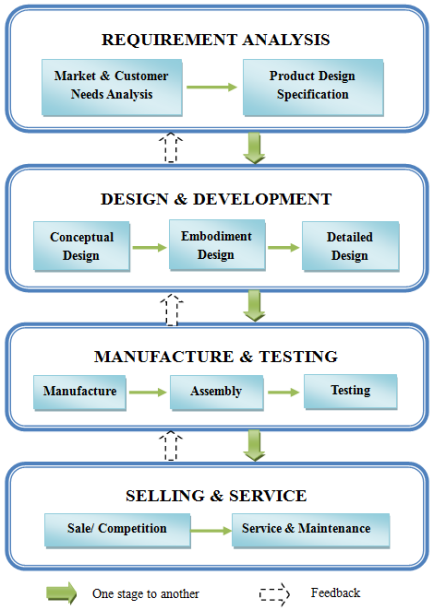

Figure 2. The Process Model

The key function of this model is to clarify and streamline the whole process of the design project. The method proposed by the model is focused on organizing the data and information relevant to the product during the engineering design process, at the same time, capturing the Design Rationale (Bracewell et al., 2009) throughout the process, and structuring them into the knowledge management system to be built for the project. In this case, the people who will take part in the project in the future can easily understand the whole process and find out the valuable information for decision making. Besides, the data and information flow from one stage to the next, at the same time, they can be used in previous stage when necessary for correction or improvement.

4.3 The Product Model

The Product Model explores the structure of a product in details, as shown in Figure 3. In the automotive industry, the product is a vehicle which consists of chassis, powertrain, drivetrain, suspension system, braking system, safety system, electronic system and bodywork. Within each section, there are various parts, such as engine, oil tank, exhaust etc. in the powertrain. These sections integrate into a whole vehicle, whilst having tight connections with each other. For instance, chassis is the backbone of a vehicle, and thus other sections are built based on it accordingly. Powertrain, drivetrain, suspension system and braking system are also connected and they have functional dependencies upon each other in several ways. Other sorts of connections between two different sections include: the electronic system provides control to some of other sections; the bodywork provides an outer shell for all the other sections; and the safety system considers the safety and reliability of the whole sections. Within the Product Model, these sections comprise the central product (i.e. the racing car), whilst these sections also interact with each other. This indicates that the knowledge management system to be developed should embrace the connections between related sections, which would improve the efficiency of the data & information organization and reuse. The outer circle of the Product Model identifies the main procedures of developing each section, as they are universal to every section and runs into a one way cycle. Importantly, the data and information generated during these procedures should be captured for future reuse.

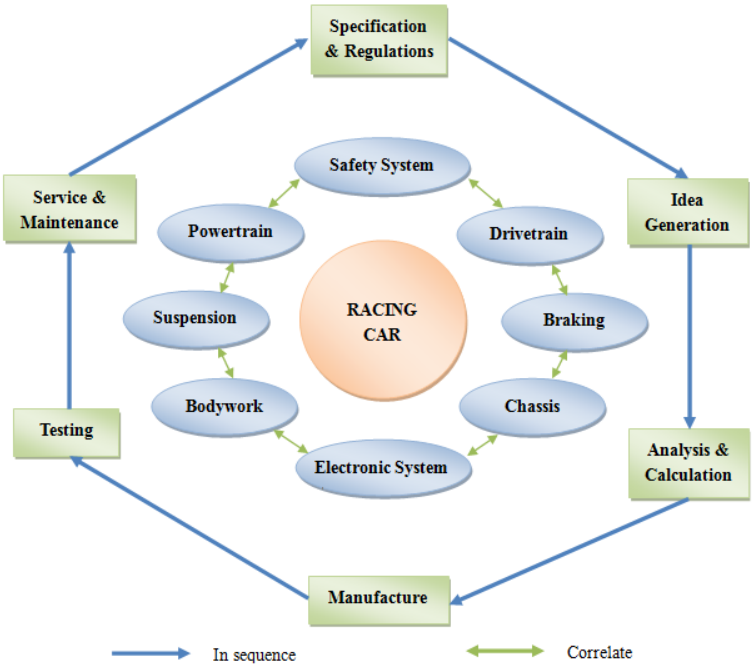

Figure 3. The Product Model

4.4 Integration of the P3 Model

As discussed above, the Project Model provides an overview and the guidance for the design project and it describes issues in terms of project management; the Process Model explains how the project can be undertaken; while the Product Model describes the result of the project in details. These three models have interrelation with each other and these models can be integrated together to form the P3 Model, as shown in Figure 4.

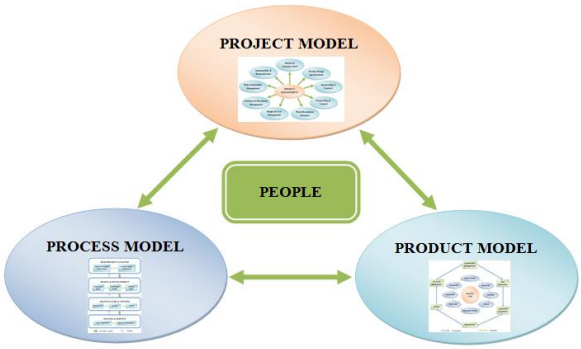

Figure 4. P3 Knowledge Model for Automotive Engineering Design

The P3 Model offers a clear way for analysing a design project in the automotive industry and it indicates what kinds of data & information will be generated during a project and how to organize and manage these different kinds of data and information for future reuse. Therefore, this model forms the basis of the Knowledge Management System to be developed in the author's future work.

5 APPLICATION & DISCUSSION

5.1 Application

The P3 Model specifically consists of the Project, Process and Product Models, thus when using the model, it should be used by first identifying the elements of these three sub-models before integrating them based on their relationships. When considering a whole project, the Project Model is helpful for identifying the major tasks involved. Whilst, the Process Model provides the ideas of how to undertake the project step by step; and the Product Model indicates every detail needed to be considered when producing the product. As mentioned previously, the way to integrate them is based on the relationships between each part. Hence, the P3 model can be divided into several modules which can be connected with others to achieve various functions, such as storing relevant data and information, organizing design rationale and making automatic suggestions. For instance, the Project Plan & Control, Work Breakdown Structure, and Budget and Cost Management are three modules of the Project Model. In the Formula Student project, the Product Model can be regards as core and the Chassis is one module of it, including engineering drawings, material selections and cost etc. When the design of the chassis is proceeding, it will follow the procedure in the Design & Development module of the Process Model as well as using the Work Breakdown Structure module to undertake the works in detail, as shown in Figure 5.

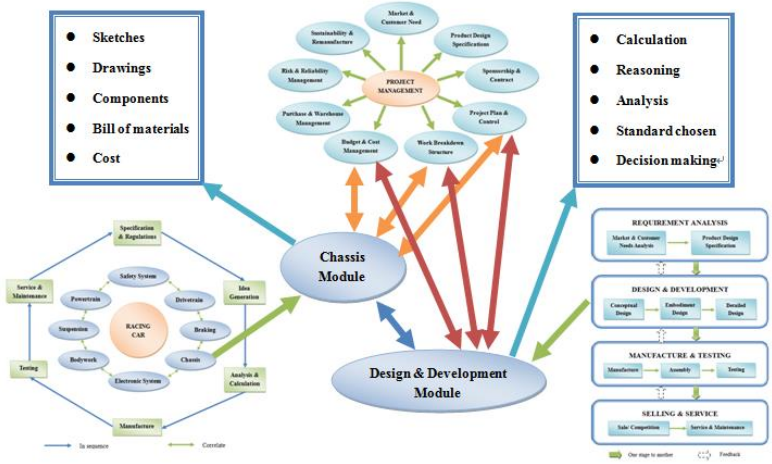

Figure 5. Connections between the modules in the P3 Model

At the same time, Project Plan module is used for the time management, while the Budget and Cost Management module is used on decision making (e.g. materials selections) during the design process. These modules have connections with each other, which determine how to integrate these three sub-models into the P3 Model. At the same time, the modules provide a method to organize the data and information as well as the relationships between them. Thus, the benefit of using the P3 Model in

modules is to clarify the project structure, identify specific procedures, and increase the efficiency of the design process.

5.2 Discussion

This paper presents the very early stage of authors' research project on developing a knowledge management system for automotive design projects. In particular, a novel knowledge model is developed on the basis of an investigation of an ongoing design project, i.e. the Formula Student project at the University of Portsmouth. Although the Formula Student project is relative small in terms of scale compared to the design project in the automotive industry, it is a complete design project with activities ranging from needs & specification analysis, to design, manufacture, testing and competition. Thus, the research is useful for the automotive engineering design process and the model proposed can be expanded further to other design projects in the automotive industry. In this preliminary work, the authors have demonstrated the model to the designers involved and have got positive feedbacks in terms of both usefulness and feasibility of the proposed model and the planned system.

The P3 knowledge model illustrated in this paper forms the basis of this research and it will be used for developing knowledge management systems. Hence, this model tries to identify answers about what are included in the design project, how to deliver the project successfully and why doing these in this way. Besides, the model describes what and when the data and information will be generated and the clear structure to organize them. The model also identifies the relationships of each sub-section within a project, and indicates that it is important to use these relationships for planning and developing an effective and efficient knowledge management system. Moreover, the P3 model has a feature that it helps novice designers to understand the project, process and product quicker than the situation where no structured information is offered, which is significant for handing over from experienced designers to novices. As the novices do not always know how to find the information, this model can provide guidance and suggestions for them. Also, the model suggests what kinds of data and information should be kept for the further reuse, together with its storage and retrieval.

During the research of the Formula Student project, the authors found that the documents of the previous projects are lack of good arrangement, which makes the designers difficult to find relevant data and information from the previous projects. This raises the need for generating a good way to organize the data and information stored in the documents, drawings and other files in various forms. In this case, the P3 model gives a promising solution to solve these problems, according to which the previous data and information can be reorganized in a clear way. Moreover, the P3 model considers project, process and product, in a holistic way and emphasises and integrated knowledge space. Apart from its three aspects, people, i.e. designers, are also very important though it is not created separately as a part of the model. In the authors' research, the model is actually generated as a tool for the people, meaning people are actively involved in the creation of models and the models in return help people throughout design project. Thus, the users are also an important part of the P3 model although this is not explicitly stated in its name. For the three sub-models, the Project Model considers the whole project in the perspective of project management, which identifies every aspect of delivering a successful design project and reminds the designers to consider the project completely. The Process Model analyses how the design and project are undertaking, which will indicate what kind of information are knowledge are required. Through the process, the design rationale behind the decision making plays an important role and it should be captured as part of the Process Model. The Product Model demonstrates the details of the product, which breaks down a product into smaller sections, whilst utilising the relationships between these sections for effective information storage and retrieval.

6 CONCLUSION & FUTURE WORK

In the competitive automotive industry, increasing the efficiency of the design process and shortening the time to market of a product are becoming the key factors for a company's success. It has been identified that effective and efficient management of design knowledge has significant impact on the success of a product. This paper proposes a Project-Process-Product Model to clarify the major elements, activities and issues in a design project and indicates the way for structuring them and streamlining the design process. The model also illustrates the relationship between project, process and product as well as the subsections inside the holistic structure. Moreover, this P3 model aims to assist novice designers to understand the design project easily and quickly by providing a clear

structure of the whole project, which is also beneficial for them to understand what information is useful for their designs as well as why it is useful. The preliminary study from the Formula Student racing car project indicated that the information system based on this P3 knowledge model can increase the efficiency of the automotive engineering design.

The model is also the basis of the information system for automotive engineering design. This model identifies the inner connection of the information flow of a design project, as well as the connection between them. Besides, it captures the information and knowledge based on design rationale. Thus, it truly provides what the designers need during the engineering design process in order to improve the efficiency of the design process. The future work will be focused on developing the system architecture and enabling technologies of the information system, and followed by several evaluations on both the knowledge model and information system.

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