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Knowledge Management Support in the Engineering Change Process

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Abstract. Knowledge management (KM) in the engineering change management process is crucial for any manufacturing enterprise. Increasing complexity triggers an increasing demand for systematic management of information and knowledge. KM is of strategic importance to a successful management of an enterprise, especially when the key staff changes. Systematically gathered, analyzed and interpreted professional experiences can prevent unnecessary costs and unnecessary engineering changes. KM is based on the interaction between tacit and explicit knowledge. The first one refers to personal skills and the other one to written documents. However, implementation of KM is a challenge, people prefer keeping knowledge for themselves and recording of knowledge in a transparent way is always time consuming. A successful implementation of KM requires a holistic and transdisciplinary approach. The people, processes and technology should be dealt with together, not focusing on a single element. The paper presents a proposal for KM that is integrated into the engineering change process. The concept is based on recording and re-using the knowledge. Failure modes and effects analysis (FMEA) and product history files are the basic documents, used to manage the knowledge, related to a specific product. Product history files should contain good explanations for all decisions that have been made. The lessons, learned at the end of projects are additional examples of knowledge recording. Supporting activities for applying KM should include a campaign to raise the awareness and understanding of the skills for improving knowledge. The content of the acquired knowledge should be checked periodically and the analysis should be followed by corrective measures.

Keywords. Knowledge management, engineering change, tacit knowledge, product history file, lessons learned

1. Introduction

In industrial practice, variant and adaptive design level is the dominant type of design [1]. When a manufacturing company adapts a product to customer needs, this is performed by means of the engineering change (EC) management process, or variation design. Over the last decade, ECs have been studied extensively from different points of view. Several publications on ECs indicate growing interest in this area [2], [3], and [4]. ECs are costly for any development project, they consume between one-third and a half of the total engineering capacity, and represent between 20 and 50% of total tool costs [5]. ECs can be approached from a number of different perspectives [6]. Tavčar and Duhovnik presented a generalised model of the EC process, as well as specific models for different types of production [7]. Jarratt et al. [3] note that only 11% of companies are able to assess the financial impact of changes, and assess the consequences of ECs. Fricke et al. state that in their study of German manufacturing firms, only 40–60% of ECs were technically necessary [8]. Clark and Fujimoto state

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that up to two-thirds of all ECs could be prevented by better communication and discipline [9]. There are four principles for improving ECM: (i) avoid unnecessary changes; (ii) decision-makers should reduce the negative impact of an EC; (iii) decision-makers should detect ECs early; and (iv) decision-makers should speed up the EC process [10]. Changes are necessary in order for a company to stay competitive. Systems and their architectures have to offer changeability throughout their life cycle, not only within themselves, but also towards their environments. Design for changeability incorporates the following four aspects: (i) robustness; (ii) flexibility; (iii) agility; and (iv) adaptability [11]. Though internal integration is vital, it is equally important to integrate with customers and suppliers, because such network partners can provide access to information, knowledge, and unique and complementary resources that are otherwise unavailable to the firm. Since EC management (ECM) systems store minimal knowledge on EC, valuable knowledge, such as difficulties in making changes and important decision-making issues, is lost. Engineers depend mainly on their tacit knowledge based on past experience and off-line communications to solve an EC issue [12]. In order to reduce propagation due to design limitations, such as field failure, suitable controls should be developed by improving the existing tools and developing new designs. Thus, it is essential to consider this aspect in the future change propagation research, which will allow the creation of new management tools to support changes in incremental product design [13]. Further research should be performed on how ECs can be avoided by means of people-oriented measures. Such measures include improving both the quality and the frequency of communication and knowledge sharing among designers, between designers and other disciplines, and with customers and stakeholders [4]. EC propagation behaviour needs to be considered as early as the conceptual phase of product development (PD). Sub-systems can be split into three types with regard to their effect on EC propagation [14], which helps raising product designers' awareness of EC propagation. (i) 'Absorbers' can be either 'partial' or 'total'. A total absorber causes no further ECs while accommodating the requested changes. However, this is a rare situation. Much more likely is a partial absorber, which contains many ECs and passes on only a few. Absorbers lessen the complexity of the EC issue. (ii) 'Carriers' neither reduce nor add to the EC problem. They merely transfer the EC from one component to another. (iii) 'Multipliers' expand the EC problem, making the situation more complex. Such components may cause an 'avalanche' of ECs [14].

Knowledge management (KM) has been recognised as an important enabler for reducing the number of ECs [15]. A comprehensive research on ECM has been conducted within eight automotive component and system suppliers of different sizes. ECM starts during product development. A systematic collection of knowledge, and the use of this knowledge during the conceptual product design phase can provide significant improvements. A weak point of medium-sized suppliers is KM and the formal transfer of knowledge over different products and from one product generation to the next. KM mainly depends on people, which has its limitations [15]. This paper is an extension of the research and conclusions presented by Tavčar et al. [15]. Implementation of KM should consider the specifics of the production programme, organisation culture and the structure of a company. It has been recognised that KM is a transdisciplinary problem that needs to consider technology, organisation and socio-emotional relations between personnel. Efficient recording of knowledge and its integration into the ECM process in a user-friendly way is the research topic of this paper.

2. Knowledge management – advantages and definition

The introduction of a KM software solution requires a detailed analysis of what the enterprise needs. In large systems it is fairly easy to justify an investment in information systems and better KM. Such an investment brings a competitive advantage [16]. Small and medium-sized enterprises are often faced with the dilemma of investing into information solutions that do not yield the same benefit, compared to large systems. KM tools have a broad scope of functionalities. Miklosik and Zak have shown positive correlation between KM and innovations in processes, innovations in products, and continuity of innovations. They define KM as a source of competitive advantage, together with optimizing business processes and social responsibility [17]. Other benefits of knowledge management system (KMS), recorded in the literature, include: (i) Quicker and improved decision-making within the enterprise, (ii) Promotion of good practice between employees, (iii) Reduced effect of losing experienced staff, (iv) Reduced time, required for developing a product, (v) Learning from mistakes and ongoing improvement of the process, (vi) Earlier detection and faster processing of EC.

Thierauf defines three components of knowledge: (i) data is the lowest point, an unstructured collection of facts and figures; (ii) information is the next level, and it is regarded as structured data; (iii) finally knowledge is defined as information about information. Relationships between the three components of knowledge are shown in Figure 1 [18].

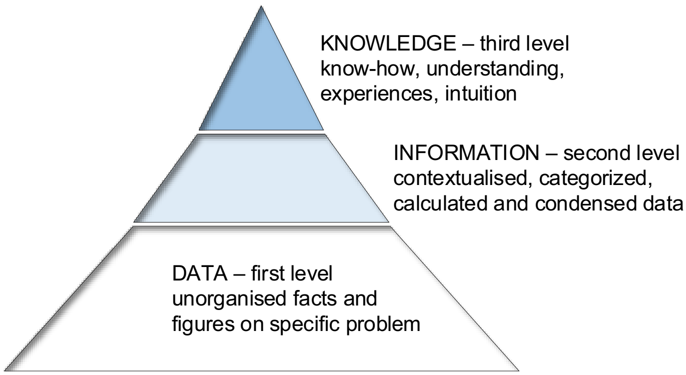

Figure 1. Three components of knowledge [18].

One of the first KM theorists is the Japanese Ikujiro Nonaka. He introduced the notions of tacit and explicit knowledge [19], [20]. The first one refers to personal skills and the other one to written documents. KM is based on the interaction between both types of knowledge. This concept was developed in the 1990's and remains the core of this discipline. In practice, knowledge is a matter of a combination of both tacit and explicit knowledge, rather than a single one. Knowledge management (KM) is a term that refers to the techniques of systematic collection, transfer, security and management of information of an organisation. KM is defined as a process of capturing an organisation's collective knowledge from various sources and using this knowledge base to the benefit of the organisation. The objective of KM is to increase the added value of the knowledge created within the organisation. This added value is reflected in improved functioning of the enterprise in all areas: business functioning, customer service, discovering new market opportunities, improved internal processes etc [19], [21].

Within the processes taking place inside an enterprise the vital ones should be identified. In order to capture the processes, taking place in an organisation from the KM viewpoint over a longer period, the notion of KM life-cycle is introduced. This concept is based on the interaction between three components: (i) People: It refers to the staff, their interpersonal relations, their attitude to work, sharing the knowledge, teamwork, motivation, organisation of the enterprise, etc. (ii) Knowledge: Anything that helps the design department do its job better. (iii) Process: The process of knowledge transfer from technical infrastructure to the user [20]. Knowledge and its sources should be in the right place at the right time. Knowledge sharing can be referred to as "push and pull". The pull mechanism takes place when and employee actively searches for sources of knowledge (archives, professional assistance, colleagues), while the push takes place when knowledge is pushed against the user (design guidelines, instructions, scripts).

3. Knowledge management in EC process

A generalised EC process presented in Fig. 2 is an extension of the process, presented in [7] and [15]. The points for knowledge recording and its reuse have been added. New is also shifting radical changes into a new generation, when it comes to safety critical products. There are different triggers for proposing a new change. EC assessment includes systemic analyses of the proposed EC, as well as its consequences. The approval process needs to be supported by access to all bits of information necessary for decision-making. When EC affects a product function, detailed process and product validation is needed. Several process changes often require fine tuning of tolerances and process parameters. Thus, the level of re-validation, required in the new EC is a challenging decision. In most cases, product EC validation includes time consuming testing. Any bigger change needs to be shifted to the next product generation to avoid validation costs and unpredictable consequences, which is a common practice in the automotive supply chain (Fig. 2).

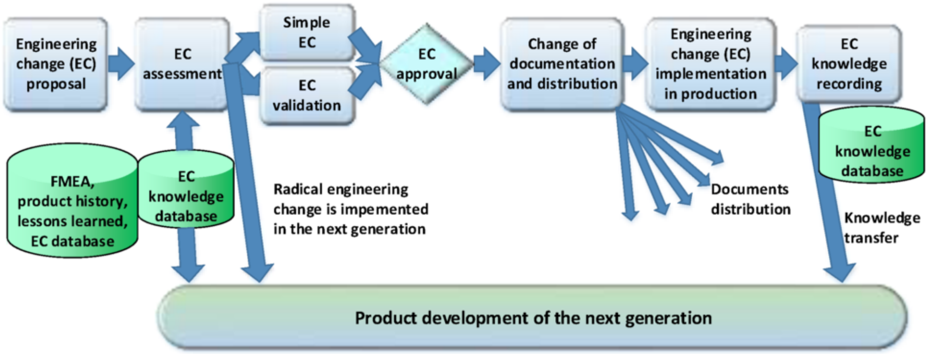

Figure 2. Generalised EC process with points for knowledge recording and its reuse.

In general, the ECM processes in the companies concerned are well defined and documented. The employees are aware of the importance to ensure traceability within each EC. This was a conclusion of the survey in the automotive supply chain, conducted by the authors of this paper [15]. Product history records and prescribed procedures for the EC process in daily practice comply with the requests. However, a weak point of medium-sized companies is KM and the formal transfer of knowledge over different products and from one product generation to the next. KM mainly depends on people, which has its limitations. This approach works well if the enterprise complexity is within certain limits (number of employees and product complexity). The information provider needs to be motivated to make the information available to others, and to capture this information as early as possible. KM has potential for improvement. Therefore, guidelines are specified in the next section.

4. Proposal for KM support in the EC process

Integrating KM into ECM and not burdening engineers with recording information is an open issue. We believe that this should be done in several steps as a long-term company strategy. The proposed steps for KM implementation are presented in Fig. 3. A detailed description follows in the text bellow.

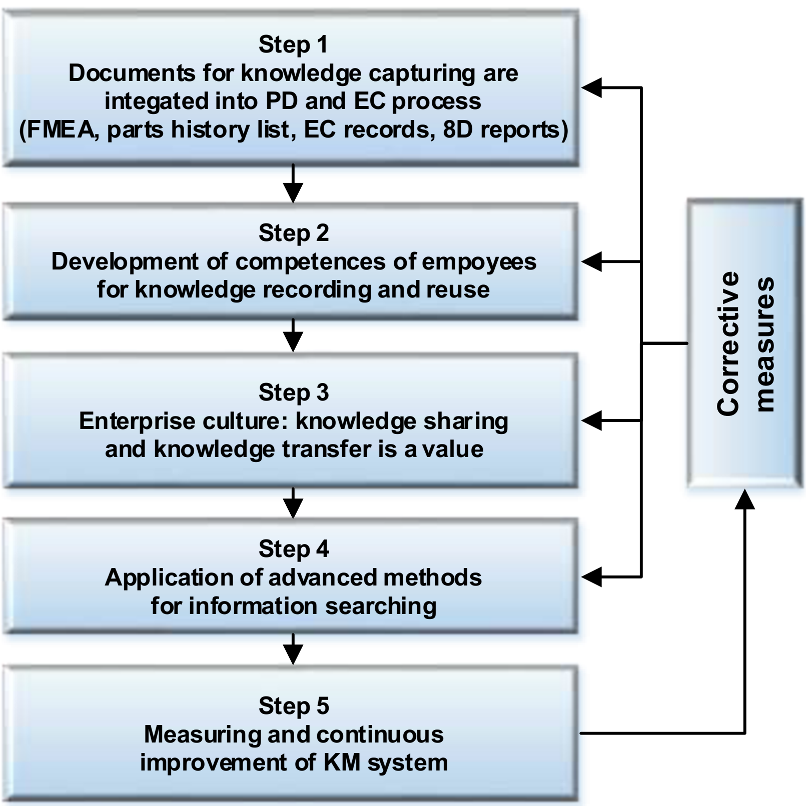

Figure 3. Steps for application of KM into the ECM process.

4.1. Step 1: Introduction of formal documents that capture knowledge

Proper recording of information should be a part of regular work and not a matter of the engineers' good will at the end of a project. It means that each project, each EC should include the documents, such as design and process FMEA, product history file, 8D reports with important information. Companies in the automotive supply chain are forced to use the said documents, due to rules in the automotive industry (IATF 16949). Similar practice with strict information recording is requested also in the quality systems for medical devices (ISO 13485). The introduction of such documents into the ECM process allows searching for the recorded information and its reuse in the next phase. However, the existence of documents that have a potential for storing valuable information is not yet a guarantee for a better reuse of knowledge. In step 1 the acquired knowledge is more or less at the level of partly structured data (level 1 in Fig. 1).

4.2. Step 2: Competences of employees for systematic work and structured recording of information

The structure of FMEA or 8D report guide engineers to work systematically (Fig. 4). However, the competences of employees determine how efficiently the methods are used. Employees need to understand that time, dedicated to FMEA workshops, is a good investment. Well-recorded decisions, explanation of important details, structured and self-explained presentation of data allow searching and reusing information also for engineers in other teams. Competences of employees need to be systematically developed, workshops should be moderated by trained people, all documents need to go through strict approval process with a focus on how well knowledge is recorded [22]. Documents should be available in a central database such as PLM (Product Lifecycle Management) and accessible through a user-friendly classification and searching tool. Human-based KM is an acceptable solution for smaller companies with minimal personnel fluctuations. In complex systems, a systematic recording of knowledge is of utmost importance. Implementation of Step 2 means that knowledge is stored in a structured method (level 2 in Fig. 1); it is a prerequisite for searching.

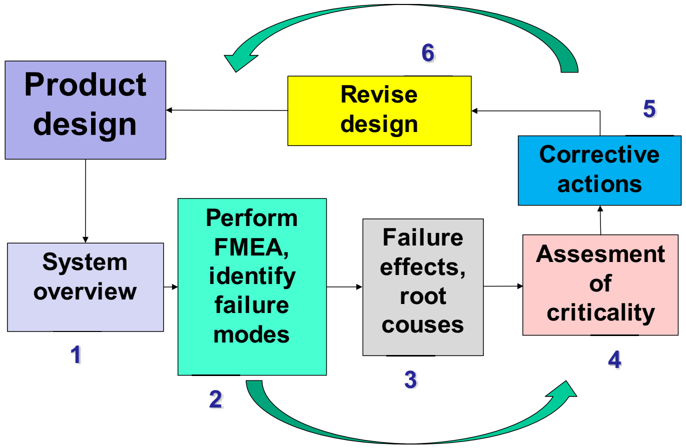

Figure 4. Structured method of work at FMEA workshops generate well-recorded decisions - knowledge.

4.3. Step 3: Enterprise culture: Knowledge sharing, recording and reuse is a company value and supported by top management

An enterprise should foster and promote a culture of knowledge sharing, permanent recording of knowledge and its reuse. Good practice has to be shared and reused between different projects (i.e. product families) and between product generations. Right decisions need to be taken during the PD phase to avoid unnecessary changes after the beginning of serial production. Senior engineers should dedicate time to documents and decisions reviews. Knowledge from past projects and new technologies needs to be systemically collected and made available during PD and EC. A requirement for checking the applicability of the collected knowledge should be built into processes. Optimum configuration of the KM system depends on the size of the company and product complexity.

Besides the explicit knowledge, stored in documents, there is tacit knowledge. It is an open issue how to transfer tacit knowledge from experienced senior engineers to beginners. It is a long-term process that needs to be implemented with several supporting activities, such as mixed project teams of senior and new engineers. The company policy should encourage mentoring beginners over longer periods of time. By means of better circulation and sharing of knowledge across the organization, a higher proportion of tacit knowledge will be kept and reused (level 3 in Fig. 1).

4.4. Step 4: Application of advanced methods for information searching

Step 2 allows storing of explicit knowledge in documents and retrieving it by searching in most cases in PLM systems. Searching is successful if documents are well-classified and described with key words. Proper classification can be time consuming and there are always important knowledge details that are not accessible through the classification system. An alternative solution is full-text indexing that enables fast and user-friendly search through the whole document contents. Well-written documents with structured information are a prerequisite for KM; indexing is of no use if step 1 and step 2 are not well implemented. The necessary steps for full-text indexing search:

1. Identification of documents that contain useful information (FMEA, parts history list, lessons learned, 8D report, research reports)
2. Enabled access of the search engine to the identified documents and prompt indexing
3. User-friendly interface of the search engine and document retrieving
4. Integration of search tools into the processes and employee training

Full-text indexing is a universal software application that can be applied on top of existing documentation system, without any significant changes in the document processing. Other methods are based on more structured organisation of data. The case-based reasoning method has the following additional advantages when retrieving EC cases. First, diverse factors pertaining to ECs can be considered in order to find similar cases of past ECs. Components, processes, problems, products, and solutions are reflected as the attributes of ECs [12]. A method that supports ECM is the change prediction method (CPM). The function–behaviour–structure (FBS) linkage method enhances the CPM, and allows for more detailed modelling and analyses of ECs [4]. There are also additional proposals for more advanced KM. A requirement–function–behaviour–structure–evolution (RFBSE) knowledge representation model is capturing designers' tacit knowledge and integrates the knowledge on design objects with knowledge on the design activities [23], [24]. The key of the knowledge-based environment is to maximise the learning. Dynamical capture and reuse of knowledge enables more robust decision-making [25], [26]. Knowledge capturing by using data mining methods in the field of series production is another option [27], [28]. The Kanban knowledge system is an effective tool to facilitate an efficient knowledge flow, and transmits the right knowledge to the right people at the right time [29].

4.5. Step 5: Measuring and continuous improving of KM system

Functioning of KM is based on permanent learning and continuous improving of a system. Upon completion of each project and EC, the captured data are analysed and the findings – that include new knowledge – are recorded. New findings complement the knowledge base. The captured knowledge should be checked periodically and the analysis should be followed by corrective measures (Fig. 5). The measures can refer to the system of capturing knowledge or, for example, training the staff due to recurrent faults, and dissemination of good practice guidelines. The culture of knowledge sharing needs to be permanently fostered and promoted at the organisation level. We believe that an analysis of the KM system should be conducted at least once per year.

For the purpose of analysing KM, the indicators for assessing the suitability of the functioning of the system can provide some additional assistance. The first indicator assesses the intensity of using KMs. If a system is not used regularly, there are no KMs benefits. The indicator measures the number of search requests per user. The second indicator is the number of executed EC per product and EC time overrun. The third indicator measures the user's experience – simplicity of the use. Although it is subjective, it can contribute to the improvement of the efficiency of KMs when a trend is detected. The fourth indicator is the users' assessment how useful the retrieved information is. It is closely related to how precisely knowledge is recorded in documents.

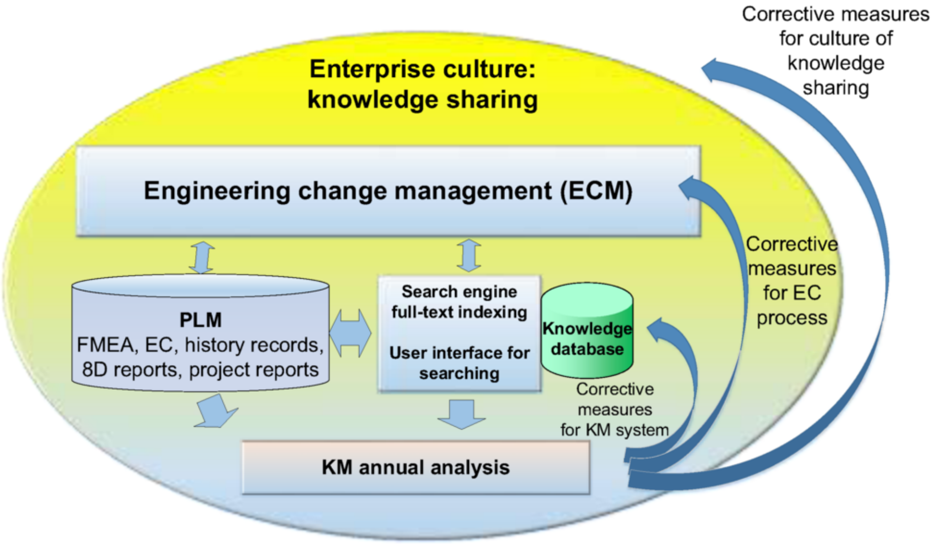

Figure 5: Periodic assessment of KMS and corrective measures in a continuous improvement loop.

5. Conclusion

A successful implementation of a KM system requires a comprehensive approach, it is a typical transdisciplinary issue. Although a tool has been installed within a manufacturing enterprise, its proper use and positive results are not guaranteed. The people, processes and technology should be dealt with together, not focusing on a single element only. All these components should develop simultaneously in order to create an integrated system for data capturing and management [30]. Besides technical issues, a KM system should include a campaign to increase awareness, build the skills for improving knowledge recording and its reuse, developing a reward scheme, and resources for measuring the performance [31]. Once the system has been installed in an enterprise, the key responsibility is with the management, who is responsible for motivating the staff to use it. This paper presents a proposal for integrating KM into the EC process. The implementation model consists of five steps as a long-term company strategy. Its implementation is partly based on explicit knowledge, stored in documents, and partly on the stimulation of sharing tacit knowledge among employees. Knowledge recording and its reuse should be part of regular work and not overly time consuming for the engineers. Parts history files and FMEAs are the key documents, used to store information on a specific product. A parts history file includes all ECs and designs, and the FMEA process contains assessment of all modifications. Proper handling of the documents that have some ability to store knowledge is already the entry level of KM. Product history files should contain good explanations for all the decisions that have been made. In addition, the key knowledge-containing documents should be stored in a database that allows searching across different product families and criteria. A model was set up on the basis of the conducted research of ECM maturity assessment in the automotive supply chain [15]. Larger suppliers in the automotive supply chain have in general already implemented steps 1, 2 and 3 of KMS, according to the model presented in Fig. 3. There is room for improvement especially in smaller companies, where knowledge recording does not follow strict formal procedures. The key enabler of tacit knowledge reuse is the knowledge-sharing culture that should be systematically developed in companies. The application of advanced methods for information search (step 4), and continuous improvement (step 5) are very rarely used in practice. A classification system and full-text indexing can significantly improve searching. The proposed system has been already implemented as a pilot project in a small company, operating as a supplier of automotive components. In the near future, the model will be upgraded according to the gained experiences. At the same time, there is a plan to introduce KM in some other companies.

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