A NEW KNOWLEDGE MANAGEMENT TOOL TO FACILITATE PROCESS INNOVATION IN MANUFACTURING COMPANIES

Daniela Butan, Emma O'Brien, Mark Southern, Seamus Clifford
Enterprise Research Centre, University of Limerick, Plassey, Limerick, Ireland

Michael Pomeroy
Materials and Surface Science Institute, University of Limerick, Plassey, Limerick, Ireland

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Abstract: This paper presents a novel KM tool to allow companies to obtain sufficient knowledge about its process in order to enhance its competitiveness and to innovate. To date there is no practical multidisciplinary model that enables companies to switch from engineering chaos to a structured, robust process. This new approach creates a reliable framework which promotes innovation and it offers a sustainable model for knowledge creation in that the knowledge generated through its use can be continuously build upon to expand the body of internal knowledge within the company. The model is based on existing engineering tools and exploiting the knowledge generated through their use using the interchange between tacit and explicit knowledge thus it is presented in the context of Nonka's knowledge spiral. The model has been used successfully in a number of case studies one which is presented in this paper.

1 INTRODUCTION

It has long been recognised the role of innovation in increasing the competitiveness of a firm. Innovation provides a mechanism for a firm to respond to changes quickly and thus improve its lifecycle.

"Innovation involves the utilisation of new knowledge or a new use or combination of existing knowledge. New knowledge may either be generated by the innovating firm in the course of its innovation activities (i.e. through intramural R&D) or acquired externally through various channels (e.g. purchase of new technology). The use of new knowledge or the combination of existing knowledge requires innovative efforts that can be distinguished from standardised routines". (OECD, 2005)

The objective of this paper is to outline a method of building knowledge about a process in a company in order to facilitate process innovation. It will look at the role of Nonka's knowledge spiral in terms of knowledge creation and will describe the use of a proposed novel model (VDF) in the context of Nonka's knowledge spiral. It will outline a case study illustrating the successful use of the VDF model in building a significant amount of knowledge in a manufacturing company which allowed the company to make considerable improvements and to innovate.

2 THE KNOWLEDGE CREATION PROCESS AND THE ROLE OF VDF

The knowledge creation process as outlined by Nonka (2000) is a spiral, consisting of four phases Externalisation, Socialisation, Combination, Internalisation and Socialisation – Figure 1. It consists of a conversion process between tacit (knowledge in the minds of individuals) and explicit (documented) knowledge. As the creation process spirals through the interaction between tacit and explicit knowledge the amount of knowledge in the organisation expands.

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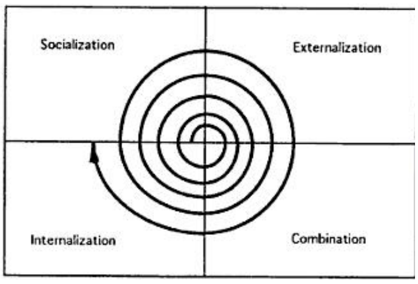

Figure 1: The knowledge spiral (Nonka 1998).

The knowledge spiral involves a number of key phases:

- Socialisation (tacit to tacit) – sharing what you have learned with other team members.
- Externalisation (tacit to explicit) – documenting in some way the knowledge you possess.
- Combination (explicit to explicit) – selecting multiple sources of explicit knowledge and combining it into some form which the individual understands.
- Internalisation (explicit to tacit) – using existing information automatically in your daily work.

The knowledge spiral offers a method that provides companies with a guide of what phases are required to increase the amount of knowledge in the organisation however it does not offer practical tools to allow the company to create, build that knowledge and to promote innovation. The VDF model offers a suite of practical tools to allow companies to build the knowledge they require for process innovation.

3 USING THE VDF MODEL IN THE CONTEXT OF THE KNOWLEDGE SPIRAL

The VDF model combines a number of existing tools in order to complete the phases in the knowledge spiral to maximise the effect of increasing the body of knowledge in the organisation. The engineering tools used in the VDF model are:

- **V**ariation Mode and Effect Analysis (VMEA)
- **D**esign of Experiment (DOE)
- **F**inite Element Analysis (FEA)

3.1 The VDF Model - Description

The new VDF model represents a powerful KM practical tool which is capable of using the existing tacit knowledge, converts it into an explicit knowledge package and uses that in the most efficient way to solve problems, optimize and innovate in companies. Unlike process improvement the current method creates a multidisciplinary framework which promotes innovation into the organization

The first component of the VDF model, the VMEA uses a brain storming- like technique in order to elicit the tacit knowledge in the minds of the team involved in the process and transforms it into explicit knowledge. The team of experts brainstorm the factors which they think are causing process problems, they rank these and assign them weights using VMEA tables. Then using dedicated ranking algorithms, the VMEA finds and prioritizes the process characteristics for which the unwanted variation is detrimental. This results in a list of factors with different priority numbers those with the highest priority numbers are the factors which have the most impact on the process or product.

After the VMEA, a statistical DOE analysis will be performed to determine the effect of altering the parameters on the process and the most suitable combination of these parameters which will ensure maximum efficiency of the process.

After the VMEA and DOE were performed, the FEA analysis comes into play, underpinning the process. Using specialised modelling packages and dedicated engineering principles, FEA simulates and predicts process behaviour and finds out factors that went undetected by the VMEA and DOE methods.

The three components of the VDF model act as feeds to one another and their complementary approaches produce the most efficient analysis of the process, creating a structured and sustainable platform for robust process and innovation into the company with minimum cost involved – Figure 2.

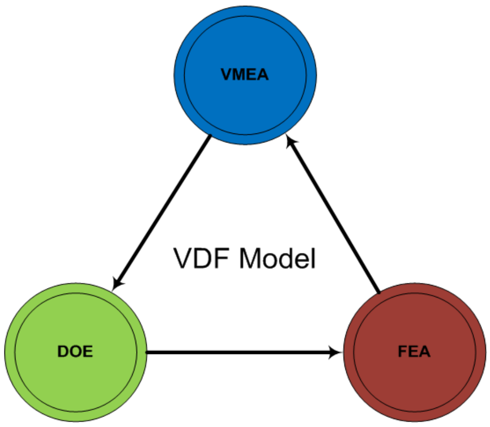

Figure 2: VDF model – Component elements.

3.2 VDF Model and the Knowledge Spiral

The VDF model can be used as a tool in process innovation to increase the body of knowledge in the organisation in line with the steps outlined in the knowledge spiral:

- Socialisation (Tacit to Tacit) – VMEA allows employees from several departments to disseminate their knowledge to the others using brainstorming sessions
- Externalisation (Tacit to Explicit) – The VMEA then documents this knowledge into a form which can be used. The VMEA uses a structured method to calculate the greatest causes of problems in a process and this is documented and fed into the DOE and FEA.
- Combination (Explicit to Explicit) – In the VDF process knowledge is combined from a variety of explicit processes. The DOE uses the results of the VMEA to concentrate on the factors that are the greatest cause of process problems and to determine the effect on the process of altering these factors at different levels. The FEA uses the knowledge obtained from the VMEA and DOE to fine tune the process and to produce process behaviour predictions. The FEA results will be compared and evaluated against the results of the experimental DOE and the predictions will be validated. Process factors that were undetected by the DOE will be found through the FEA analysis, a complete body of knowledge of the process will be produced.
- Internalisation (explicit to tacit) – The results from the DOE and FEA are disseminated to the original brainstorming group in a final VMEA using the findings of the experiments and analysis and through discussion. This internalises the knowledge within the minds of the individuals so they can use it in their work

3.3 The VDF Model in Operation – Case Study

The engineering company in this case study is a medical company which presented itself with a product failure due to the unknown causes during the fabrication process.

Due to confidentiality issues, the company cannot be named, as well as their product and fabrication process. The names will be kept confidential but the procedure will be explained in detail. To investigate the process and the root cause of the product's failure the proposed approach was the VDF model.

The investigation started off with a VMEA brainstorming session which allowed employees from several departments (technicians, design engineers, managerial team, quality department etc) to disseminate their knowledge to one another, approach that encompasses the tacit- to- tacit aspect of the 'Knowledge Spiral' model.

Then the knowledge in the minds of the team involved in the process was transformed into explicit knowledge through the VMEA document which outlines the tacit to explicit feature of the Knowledge Spiral model.

Using the VMEA structured method and the ranking algorithms proposed by Johansson et al. (2006), the greatest causes of variation in the process that affected the failure of the product were identified and documented as shown in Table 1 below. A Variation Risk Priority Number (VRPN) was calculated which computed the effect of each process factor on the failure of the product and identified the process factor that needed to be investigated further. The highest the total VRPN number - the greater the influence of that factor on the product failure.

Initially it was thought that Factor 1 was the greatest cause of variation on the product but from Table 1 it can be seen that the calculated highest VRPN total number (1730396) corresponded to the Sub-KPC Factor 7. It was concluded that the Factor 7 process characteristic, by its variation, had the greatest influence on the product failure.

However the method above only provides an indication of the factors with the greatest effect on process variation that could ultimately affect the product failure but it cannot show how these factors actually impact on the process itself. Therefore more in depth explicit analyses are needed.

The VDF model then adds a combination of two engineering methods - DOE and FEA, which enhances the company's knowledge and through its explicit to explicit approach outlined in the knowledge spiral in Section 2 of this paper the model creates efficient practical paths to innovation. The engineering knowledge captured through the VMEA brain storming session and the data provided by the VMEA table above acted as feeds for the remaining two explicit elements of the VDF model: the DOE and the FEA.

The DOE was performed on the process stage named Factor 7 to determine the process optimum running parameters and the most suitable

Table 1: VMEA Table – tacit to explicit document.

Process:	Process ABC					**Revision level:**	1.0
KPC	Sub-KPC	KPC sens to sub KPC	NF	Sub KPC sens to NF	NF Variation size	VRPN (NF)	VRPN (Sub KPC)
The Lack of Performance due to Product Failure before its prescribed time outlined in the Specifications	Factor 1	6	Factor 1.1	6	6	46656	90040
		5	Factor 1.2	5	6	22500	
		4	Factor 1.3	6	6	20736	
		3	Factor 1.4	2	2	144	
		2	Factor 1.5	1	1	4	
	Factor 2	8	Factor 2.1	3	3	5184	5184
	Factor 3	8	Factor 3.1	3	3	5184	6482
		4	Factor 3.2	3	3	1296	
		1	Factor 3.3	1	1	1	
		1	Factor 3.4	1	1	1	
	Factor 4	1	Factor 4.1	1	1	1	1
	Factor 5	10	Factor 5.1	4	2	6400	19776
		8	Factor 5.2	4	2	4096	
		8	Factor 5.3	4	2	4096	
		8	Factor 5.4	4	2	4096	
		8	Factor 5.5	2	2	1024	
		2	Factor 5.6	2	2	64	
	Factor 6	5	Factor 6.1	2	2	400	400
	Factor 7	9	Factor 7.1	8	7	254016	1730396
		9	Factor 7.2	8	7	254016	
		10	Factor 7.3	8	6	230400	
		9	Factor 7.4	8	6	186624	
		7	Factor 7.5	8	7	153664	
		8	Factor 7.6	8	6	147456	
		8	Factor 7.7	8	6	147456	
		8	Factor 7.8	5	8	102400	
		9	Factor 7.9	7	5	99225	
		6	Factor 7.10	5	8	57600	
		5	Factor 7.11	5	8	40000	
		9	Factor 7.12	4	3	11664	
		9	Factor 7.13	4	3	11664	
		9	Factor 7.14	6	2	11664	
		9	Factor 7.15	3	3	6561	
		9	Factor 7.16	3	3	6561	
		9	Factor 7.17	3	3	6561	
		9	Factor 7.18	2	2	1296	
		9	Factor 7.19	2	2	1296	
		3	Factor 7.20	2	2	144	
		2	Factor 7.21	2	2	64	
		2	Factor 7.22	2	2	64	

combination of these parameters which will ensure the product meeting the life outlined in the specifications. As there were too many factors in this process stage which would make the DOE experiment very expensive, the most significant measurable factors had to be taken into consideration. Out of the 22 factors having an influence on the variation of the Factor 7 process stage, only 7 factors were identified as being significant and measurable and they formed the main elements of the DOE design – Table 2. The process was run 14 times with these factors at different combinations of high and low settings, the effect of these settings on factor 7 for each run was recorded.

Using the statistical package Wisdom the R^2 values were computed. The R^2 value indicates how much of the variation was attributed to that factor.

Good R^2 values, over 80%, were obtained for all of the factors from the DOE experiment. Therefore, almost all experiments found at least 80% of the causes of variation.

An optimum process set up was found by the

Table 2: Extract DOE design table, explicit to explicit approach.

Plackett - Burman Design

Factors: 7 Replicates: 1
Base runs: 14 Total runs: 14
Base blocks: 1 Total blocks: 1

Center points: 2

Factor 7.4	Factor 7.12	Factor 7.13	Factor 7.15	Factor 7.14	Factor 7.3
1.45	7.7	2.7	8	50	26.2
1.45	6.3	2.7	8	40	23.2
1.45	7.7	3.3	8.3	50	23.2
1.45	7.7	3.3	8.3	40	23.2
1.45	6.3	2.7	8.3	50	26.2
1.45	6.3	3.3	8	40	26.2
2	7	3	8.15	45	24.7
2	7	3	8.15	45	24.7
2.55	7.7	2.7	8	40	23.2
2.55	6.3	2.7	8.3	50	23.2
2.55	7.7	2.7	8.3	40	26.2
2.55	6.3	3.3	8	50	23.2
2.55	6.3	3.3	8.3	40	26.2
2.55	7.7	3.3	8	50	26.2

The DOE analysis also showed that the product exhibited a non-uniform microstructure after fabrication and that was considered a possible cause for the product failure.

Still more research had to be done to capture all of the process factors that have an impact on the product behaviour.

In the meantime, a FEA analysis was performed to simulate the product behaviour in order to get an understanding of the product parameters that were most likely to be influenced by the variation into the fabrication process and which could contribute to the failure.

The FEA Ansys multiphysics package was used to simulate the product behaviour – a thin metallic plate vibrating at a very high frequency. Different vibration mode shapes were found for different values of the Plate Natural Frequency - NF

The results (Figure 3 – middle), were compared with the literature models (Figure 3 - top) and experimental readings (Figure 3 - bottom). Good correlation was found, therefore the FEA model was declared valid. A series of important predictions of product behaviour related to the material properties and geometrical characteristics were made, results that could not be identified by the VMEA and the DOE analysis described earlier.

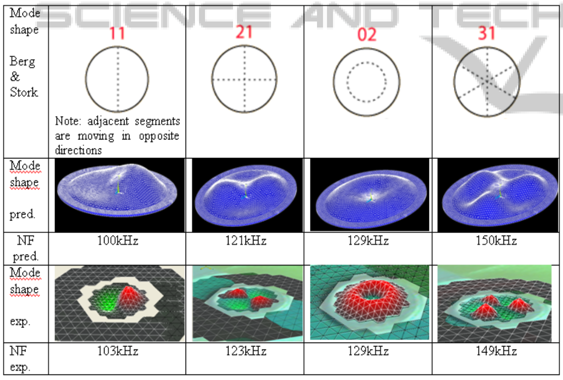

Figure 3: FEA simulation, explicit to explicit approach.

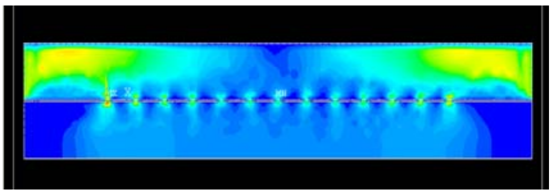

Figure 4: FEA simulation, process behaviour, explicit to explicit approach.

After the product behaviour was modelled, the same FEA package simulated the process behaviour using the Ansys multiphysics Fluid option and the optimum setting parameters found through the DOE analysis.

A lot of variation during the fabrication process was predicted due to the flow behaviour - Figure 4, factor that was not possible to be identified by the VMEA and the DOE analysis and that could contribute to the premature failure of the product and to low yield.

Based on the FEA results above, a new feature of the fabrication process was designed to ensure a more uniform flow distribution – Figure 5. A more consistent product's microstructure and higher yield were expected.

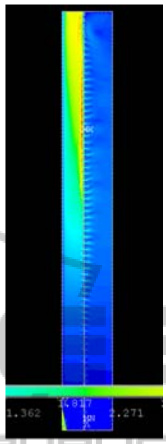

Figure 5: FEA simulation, new process design feature.

The new process design feature along with the knowledge captured by modelling the product behaviour and the DOE analysis were implemented into the process.

A better product's microstructure uniformity was achieved, the product met the life expectancy outlined in the Specifications, the process became fully controllable and an increase in yield by 80% was recorded.

In the final stage of the VDF approach, the results from the DOE and FEA were disseminated to the original brainstorming group in a final VMEA using the findings of the experiments and analysis and through discussion, allowing the knowledge to come back full circle to the employees in a similar explicit to tacit manner as in the knowledge spiral model.

This final step internalises the knowledge within the minds of the individuals so they can use it in their work.

4 CONCLUSIONS

The VDF multidisciplinary approach proved its efficiency and validity through the successful case study results described in the Section 4 above. The VDF model can be used as a tool in process innovation to increase the body of knowledge in the organisation in line with the steps outlined in the knowledge spiral. Unlike process improvement the current method creates a multidisciplinary framework which promotes innovation into the organization

The model can be iteratively used to expand the engineering knowledge in the organisation. The knowledge developed in the model and recorded in the FEA can be used to determine the impact of other alterations on the process if they are required as a result of market changes (such as a change in technology, raw material) or customer requirements. These can be used as a basis to expand the knowledge about the process by conducting a VMEA on the factors which may cause problems in the new process and conducting DOEs on these factors to obtain in depth information. Thus the VDF model offers a sustainable process for the creation of engineering knowledge which can be continuously built upon and enhance the competitiveness of the firm.

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