Paper:
Giannetti, C., Ransing, M., Ransing, R., Bould, D., Gethin, D. & Sienz, J. Organisational Knowledge Management for Defect Reduction and Sustainable Development in Foundries. *International Journal of Knowledge and Systems Science, 6*(3), 18-37.

http://dx.doi.org/10.4018/ijkss.2015070102

Accepted for Publication: 10.4018/ijkss.2015070102
International Journal of Knowledge and Systems Science, 6(3), 18-37, July-September 2015

Organisational Knowledge Management for Defect Reduction and Sustainable Development in Foundries

Giannetti, C., Ransing, M., Ransing, R., Bould, D., Gethin, D. & Sienz, J.
College of Engineering, Swansea University, Swansea SA1 8EN

Abstract
Despite many advances in the field of casting technologies the foundry industry still incurs significant losses due to the cost of scrap and rework with adverse effects on profitability and the environment. Approaches such as Six Sigma, DoE, FMEA are used by foundries to address quality issues. However these approaches lack support to manage the heterogeneous knowledge created during process improvement activities. The proposed revision of ISO9001:2015 quality standard puts emphasis on retaining organisational knowledge and its continual use in process improvement (ISO, 2014). In this paper a novel framework for creation, storage and reuse of product specific process knowledge is presented. The framework is reviewed taking into consideration theoretical perspectives of organisational knowledge management as well as addressing the challenges concerning its practical implementation. A knowledge repository concept is introduced to demonstrate how organisational knowledge can be effectively stored and reused for achieving continual process improvement and sustainable development.

Keywords: ISO9001:2015, Six Sigma, 7Epsilon, Total Quality Management, Casting Process, Knowledge Representation, Knowledge Discovery, Process Improvement.

Introduction

Organisational knowledge is widely considered as a major asset of an enterprise and it is often associated with the ability to innovate and gain competitive advantage. Individual and collective knowledge, if properly managed and reused, can support organisations to fulfil diverse strategic aims such as reduction of costs, improved performances and faster time to market (Lehaney, Clarke, Coales, & Gillian, 2004; Nonaka & Takeuchi, 1995; Yew & Aspinwal, 2004). The formalisation of organisational knowledge management as an established discipline has started in the 1990s with the work of Nonaka & Takeuchi (1995) and since then knowledge management has become an active research area. Several authors have discussed the benefits of knowledge management in modern organisations (Davenport & Prusak, 2000; Lehaney, et al., 2004; Nonaka & Takeuchi, 1995; Yew & Aspinwal, 2004) and described how emerging IT technologies can support knowledge management practices (Kimmerle, Cress, & Held, 2010; Moffett, McAdam, & Parkinson, 2004; O'Dell & Hubert, 2011).

Continual process improvement is an umbrella term that refers to the ongoing effort to improve processes and consequently product and services. ISO9001 is the main quality management tool used by many organisations to achieve compliance to customer requirements and legislation and it requires industries to discover process improvement opportunities on a continual basis. Other initiatives like Six Sigma, Total Quality Management and Lean Manufacturing provide instead some practical tools and methodologies for process improvement. The role that knowledge management plays in the context of continual process improvement has been discussed in several research publications (Anand, Ward, & Tatikonda, 2010; Arendt, 2008; Giannetti et al., 2014a; Roshan, Giannetti, Ransing, & Ransing, 2014). At industrial level the importance of organisational knowledge management in process improvement has been recognised by the ISO quality standard which, in the latest draft version (ISO9001:2015), requires organisations to maintain and provide access to organisational knowledge in addition to data and information (ISO, 2014) (clause 7.1.6). There is a tight link between process improvement and knowledge management. First of all, similarly to knowledge management, continual process improvement activities are driven by a commitment to learning and the desire to avoid making the same mistakes (Arendt, 2008). Furthermore the ability to capture knowledge shared through team based activities plays an important role in the success of continual process improvement activities (Anand, et al., 2010). Last but not least continual process improvement is a source of knowledge creation (Anand, et al., 2010; Roshan, et al., 2014).

Process improvement in foundries is a challenging activity because typically the quality of the final casting is influenced by the interactions of many process variables as well as part specific quality constraint. Despite advances in casting technologies foundries worldwide still incur huge costs due to poor quality. Casting defects not only impact the bottom line but also the environment and hence are becoming an obstacle to the realisation of a more sustainable future. Typically profit margins in foundries are 5-10% with an average rejection rate 4-5%. Hence, even reduction of defects by further 1-2% contributes to its sustainability. A technological and cultural gap in the foundry industry has been identified due to the lack of process knowledge and adequate personnel trained in process control (Roshan, et al., 2014). The shortage of skilled foundry technicians has also been discussed in a recent publication with young generation of engineering workforce lacking problem solving, practical skills and experience necessary to produce quality castings (Murrell & Brown, 2014). Furthermore despite growth perspectives of the global metal casting industry several challenges need to be addressed at managerial level to create greater manufacturing efficiencies and maximise business opportunities (Spada, 2014). In foundries process knowledge is obtained by developing a sound understanding of the process, its sub-processes and the relationships between process factors and responses for a specific casting (Lewis & Ransing, 1997; R. S. Ransing, Srinivasan, & Lewis, 1995). Recently the 7Epsilon methodology has been proposed to discover and reuse process knowledge in order to stimulate a culture of innovation in foundries (Roshan, et al., 2014) (www.7epsilon.org). According to the 7Epsilon definition, product specific process knowledge is described as actionable information, in terms of the optimal tolerance limits and target values for continuous factors and optimal levels for discrete factors, in order to achieve desired process response(s) (R.S. Ransing, Giannetti, Ransing, & James, 2013). The 7Epsilon consortium distinguishes between generic and product specific foundry process knowledge. Generic process knowledge is knowledge found in textbooks or research studies and can be generically applicable, while foundry specific process knowledge is the knowledge that is specific for a certain product and foundry (Roshan, et al., 2014). This interpretation has recently been acknowledged by the ISO9001 quality standard which, in the latest proposed revision, distinguishes between external and internal knowledge sources (ISO, 2014) (clause 7.1.6). External sources include published literature, standards as well as customer and supplier knowledge (i.e. foundry generic process knowledge), while internal sources include lessons learnt, expert's knowledge and experience (i.e. product specific process knowledge). Following the dichotomy proposed by Hayes and Walsham (2003), foundry specific process knowledge can be regarded as a form of “relational” knowledge because it only exists in relation to a specific foundry and product. Typically, even if two foundries are owned by the same management, it is not possible to reproduce the same process variability. Furthermore each foundry has its own specific “recipe” for producing quality casting which often comes from experience and know-how. In order to capture and discover improvement opportunities in foundries there is the need to capture both the “art” (tacit knowledge) and the “science” (explicit knowledge) necessary to produce quality castings (Roshan, et al., 2014).

Foundry process knowledge is continuously being created in foundries as part of existing process improvement activities such as Six Sigma, DoE (Design of Experiments), FMEA and Cause and Effect Analysis. However current approaches lack adequate support for capturing and preserving process knowledge developed during these activities. Knowledge is typically stored in digital artefacts such as documents and databases and it is scattered throughout the organisation hindering the ability to retrieve and hence reuse it effectively. Information overload is typically an obstacle to knowledge reuse due to the large amounts and disorganised exchange of digital contents being held by an organisation. Appropriate management of foundry process knowledge created during process improvement activities is hence a necessary step to realise saving potentials, overcome the gap and contribute to the development of more sustainable foundries (Roshan, et al., 2014).

This paper discusses the role that knowledge management practices play to support continual process improvement and sustainable manufacturing strategies. It extends previous research by identifying the various knowledge assets created as part of 7Epsilon process improvement activities and develops a theoretical framework that supports knowledge management processes, including the creation, storage and retrieval, transfer and application of product specific process knowledge in foundries. Due to the nature of foundry process knowledge the proposed solution does not involve codification of knowledge with formal knowledge representation languages but uses ICT as a collaborative platform to support knowledge management practices during process improvement activities. These specifications are aligned with the requirements proposed in the draft version of ISO9001:2015 standard which has now included organisational knowledge as a key resource to achieve conformity of product and services (ISO, 2014). Requirements for a knowledge repository system are introduced and, by means of a prototype system, it is shown how effective management of foundry process knowledge can be achieved.

Although the 7Epsilon has been developed to enhance process improvement in foundries, the framework described in this paper can also be extended to other industrial processes. From a theoretical viewpoint the paper also contributes to disseminate the importance of embedding knowledge management practices in process improvement activities offering new perspectives and helping practitioners and managers to develop sound process improvement projects that will contribute not only to realise saving potentials but also to foster innovation.

The paper is structured as follows. Following an introduction to knowledge management practices in the context of process improvement, the paper describes the role knowledge management practices play during 7Epsilon process improvement activities. Then requirements for effective storage and retrieval of process knowledge from internal and external knowledge sources are introduced and a template for a foundry knowledge repository is presented. After discussing the main findings and future work, the paper is concluded.

Organisational Knowledge Management Practices and ICT

Knowledge management concerns with the practice of creating, capturing, retrieving, and applying organisational knowledge in order to achieve strategic aims such as improved performance, cost reduction or fulfilment of legal or social constraints (Lehaney, et al., 2004). Nonaka & Takeuchi (1995) state that the success of companies depends on the ability to consistently create new knowledge, disseminate it widely throughout the organisation, and quickly embody it in new technologies and products. Furthermore knowledge management is considered an essential cornerstone to develop sustainable advantage and excellence in the enterprise field of operation (Yew & Aspinwal, 2004). Davenport & Prusak (2000) define knowledge management as: "to identify, manage, and value items that the organisation knows or could know: skills and experience of people, archives, documents, relations with clients, suppliers and other persons and materials often contained in electronic databases" (p. ix). From this definition it clearly emerges that the management of organisational knowledge is a complex task which involves continuous interaction between technologies, people and processes as well as managing different types of knowledge generated by an organisation, including intangible knowledge like know-how and people skills and explicit knowledge communicated and articulated through spoken and written words as well as knowledge stored in digital records and databases.

In the context of organisational knowledge management, knowledge is often distinguished from information and data. A common interpretation is that data can be thought as raw numbers or symbols. When data are combined for a specific use, they become information. Knowledge is instead defined as information processed in a meaningful way which can lead to action. While data and information are often associated with some physical storage medium (like a database table, a text document or a book), knowledge is more volatile. Not only it resides in documents or digital records, but also it is embedded in routines, procedures and people. As suggested by Alavi & Leidner (2001) "information becomes knowledge when it is actively processed in the mind of an individual through a process of reflection, enlightenment and learning" (p. 110). Nonaka & Takeuchi (1995) distinguish between explicit and tacit knowledge. Explicit knowledge is formal, codified and can be transmitted using natural language, a scientific formula or a computer program. In contrast, tacit knowledge is routed in actions, experience and context. It is highly personal and subjective and hence difficult to formalise and be communicated to others (Nonaka & Takeuchi, 1995). The concept of tacit knowledge includes both cognitive and technical elements. While cognitive elements are personal mental maps, beliefs and view points, technical elements consists of concrete know-how, skills and crafts that apply to a context (Alavi & Leidner, 2001). Tacit knowledge is harder to formalise and when this is done it becomes explicit knowledge. At enterprise level the tacit knowledge of individuals is a valuable asset since, when externalised, might lead to innovation (Nonaka & Takeuchi, 1995).

Although the management of knowledge does not necessary imply the use of ICT, undoubtedly ICT systems have enabled and facilitated the creation of knowledge management systems for the effective management of enterprise knowledge. Examples of knowledge management systems in an organisation include wikis, document management systems, on line directories, lessons learnt or best practice libraries, expert and decision making systems, just to mention a few. Nowadays, due to the advances in internet-based connectivity and mobile communication for sharing content and data, ICT tools are widely recognised as major facilitators for the implementation of knowledge management strategies.

However, several authors warn that an approach to knowledge management too focused on ICT can be detrimental due to disorganised information exchange that can happen through use of e-mails, Intranet and documents (Al-Ghassani, 2002) or too much emphasis on explicit knowledge at the expense of human interaction (Fahey & Prusak, 1998). A major obstacle to effective knowledge management, also known as the “Babel-tower effect", arises from interoperability problems due heterogeneity and multi-view perspective of information hold by the organisation (Panetto, Dassisti, & Tursi, 2012).

According to O'Dell & Hubert (2011) knowledge management goes beyond the implementation of a technological solution or a “knowledge repository” and must focus not only on technology but also on people interactions and knowledge processes. Moffett, McAdam, & Parkinson (2004) also suggest that the main role of ICT in knowledge management is to support knowledge transfer by managing key connections rather than focusing on some static content. According to this perspective the advent of internet based connectivity is perceived as the main enabler to develop effective knowledge management solutions. Hayes & Walsham (2003) distinguish between “content” and “relational” perspectives of knowledge management. If knowledge is perceived as a content it can be readily codified and stored, whilst “relational” knowledge can only exists in a particular context and reflects different perspectives. According to the “relational” view, knowledge management approaches should focus on the way knowledge is gained and shared rather than the knowledge itself. Hence ICT should be employed to support knowledge processes as opposed to management of knowledge itself.

Knowledge Processes

Alvi & Leinder outlined (Alavi & Leidner, 2001) important practical aspects to take into consideration when implementing a knowledge management system: a) the creation of new knowledge, b) knowledge storage and retrieval, c) knowledge transfer and d) knowledge application. These four aspects of knowledge management will be described in the context of process improvement activities. The organisational knowledge management practices are reviewed through these processes in order to propose a 7Epsilon knowledge management template for the industry with an ability to satisfy relevant ISO9001:2015 requirements.

A. Knowledge Creation

Knowledge creation practices in organisation have been described and classified by Nonaka & Takeuchi (1995) in the famous knowledge creation spiral. The model distinguishes four mechanisms for the creation of new knowledge which are characterised by the conversion between the two different types of knowledge, tacit and explicit. The four mechanisms are: externalisation (tacit to explicit), combination (explicit to explicit), socialisation (tacit to tacit) and internalisation (explicit to tacit) as shown in Figure 1.

During process improvement initiatives new knowledge is continually created by externalisation. Typically process improvement activities include a preliminary phase either in the form of informal brainstorm meetings or more formal scheduled meetings during which process characteristics are discussed among cross-functional team members considering different viewpoints. The outcome of these meetings is the codification of tacit knowledge into pictorial or written forms (Bohn, 1994; Hansen, Nohria, & Tierney, 1999). For instance, process engineers may draw cause effect diagrams, process maps, factor lists to better understand the process itself and what affects the quality of the output. Failure Mode and Effects Analysis (FMEA) is another team-based technique commonly used for process improvement to systematically identify ways in which a product or process can fail and devise corrective and preventive actions. During FMEA activities, which are often based on subjective team knowledge and experience, a vast amount of process knowledge is created by externalisation and codified in a tabular form so it becomes accessible to the whole organisation. The importance of externalisation in process improvement activities should not be underestimated because, as suggested by Alwis & Hartmann (2008), tacit knowledge is a source of success and plays a crucial role in fostering innovation. A recent empirical study, in the context of Six Sigma, has shown that knowledge creation processes, especially those that capture team-member knowledge, are key factors that contribute to the success of process improvement projects (Anand, et al., 2010). Document repositories can help to create a knowledge base to store the codified knowledge so it can be reused at a later stage.

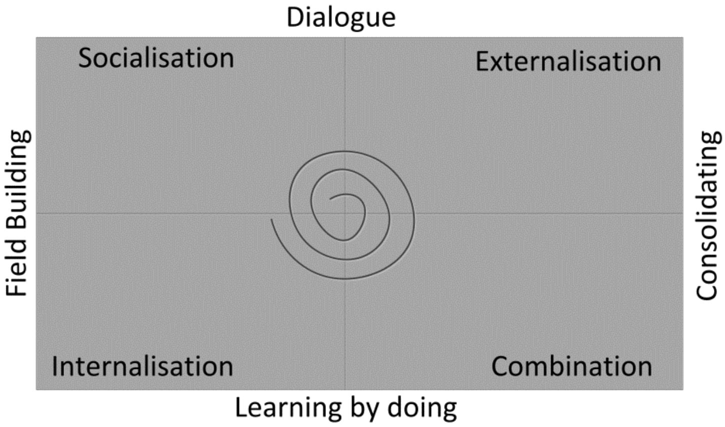

Figure 1 –The Knowledge Creation Spiral (Nonaka & Takeuchi, 1995) includes different mechanism for knowledge creation: externalisation, combination, internalisation and socialisation (Adapted from Nonaka & Takeuchi (1995)).

An alternative way of creating knowledge is by combination which is achieved by combining existing explicit knowledge. (Nonaka & Takeuchi, 1995). Humans are often good at interpreting and combining existing pieces of information to create new knowledge. However, within an enterprise, this ability is hindered by the fact that too much information is available which is too complex to be analysed and being processed by the human brain. In this case the use of statistical techniques can help to create new knowledge by combining existing explicit knowledge. Statistical Process Control and Design of Experiments (DOE) are examples of techniques widely used in process improvement to create new knowledge by combination.

Another important aspect of knowledge creation is socialisation. For instance knowledge can be transferred from an individual to another by observing a person doing a specific task or discussing a topic. In process improvement, knowledge creation through socialisation is achieved by forming cross functional teams (Anand, et al., 2010). The advantage of socialisation is that knowledge transfer happens without the need of codifying the knowledge in an explicit form, but it might be time consuming and communication needs to be encouraged and facilitated. For instance communication barriers may arise from the lack of a common vocabulary and shared understanding. Recently, social software platforms like Wikis, blogs and social bookmarking, the so called Web 2.0 technologies, have provided scope for the development of collaborative environments where individual and collective knowledge creation through socialisation can be supported and enhanced. Although interaction through social media may not be regarded as rich as face-to-face interaction, it is particularly helpful when co-workers are located at remote sites (Panahi, Watson, & Partridge, 2012).

Finally internalisation, which also requires individual commitment, is another aspect of knowledge creation. Internalisation occurs when the explicit knowledge available in an organisation is again transformed into tacit knowledge of individuals. The availability of knowledge management systems to store knowledge acquired during previous process improvement initiatives can contribute to internalisation of knowledge and enable knowledge transfer within an organisation.

B. Knowledge Storage and Retrieval

The ability to efficiently store and retrieve organisational knowledge is one of the key aspects of knowledge management. The choice of appropriate storage and retrieval methods highly depends on the kind of knowledge that needs to be stored. A relational database can be useful to store some kind of declarative knowledge, while Artificial Intelligence techniques are better suited to store procedural or causal knowledge. Since the ultimate aim of knowledge management is the use of knowledge to fulfil specific business objectives, knowledge storage should focus on a selected body of knowledge (Davenport & Prusak, 2000). Also knowledge should be codified in a way that it retains its meaning and purpose. For instance once knowledge is recorded in a database system the meaning is lost as it becomes raw data (Davenport & Prusak, 2000). Ontology based approaches try to address this problem by providing alternative knowledge codification methods where the meaning is retained. In the context of knowledge management ontologies can be used as documents metadata to enhance search capabilities and hence improving the ability of retrieving knowledge embedded and codified in documents or web pages. They can also be used for the purpose of representing and querying a body of knowledge, database integration and applications related to natural language processing.

The term ontology is quite broad and ontologies may be developed with different degrees of formalisation using different languages. They can range from being just vocabularies or taxonomical definition of terms (lightweight ontologies) to being complex representations of some domain knowledge including rules and axioms and hence providing the capability to generate logical inference and reasoning (heavyweight ontologies) (Borst, 1997). Depending on the type of knowledge to be modelled, different levels of formalism and languages may be required (Gomez-Perez, O. Corcho, & Fernandez-Lopez, 2004). In industry ontologies are used to solve conflicts due to the heterogeneity of information among different business and operational layers of an enterprise or a network of enterprises, the so called "Babel-tower effect". For instance, in a scenario of an extended enterprise comprising of several interconnected partners, an ontology can be used to agree on a well-defined terminology of the domain of interest (Choudhary, Harding, & Khilwani, 2009).

C. Knowledge Transfer

Knowledge transfer is an essential process to ensure knowledge is effectively shared for the benefit of an organisation. Alongside with knowledge application, knowledge transfer is one of the major driving forces for the development of knowledge management strategies. Knowledge transfer is a broad term and includes mechanisms to move knowledge between two individuals, between an individual and an explicit source, an individual and a group or among groups of individuals (Alavi & Leidner, 2001). A number of initiatives can support knowledge transfer at different levels involving different transfer channels. Holtham & Courtney (1998) distinguish between formal, informal, personal and impersonal channels. Examples of knowledge channels are given in Figure 2. Informal knowledge channels, like unscheduled meetings and occasional conversations, rely on socialisation. Their major drawback is that the extent to which knowledge is passed depends on the willingness or ability of the recipient to assimilate the message. Training programmes are instead an example of formal channels. They are more structured and usually tailored specifically for a certain audience; hence the knowledge can be passed more efficiently and more broadly. Personal transfer channels include apprenticeship, tutorials or other forms of close collaboration or observations. They are typically face-to-face and involve close interaction and trust among actors. Personal knowledge transfer is particularly suitable to transfer tacit knowledge since there is no need to transform tacit knowledge into explicit knowledge saving time and resources (Fahey & Prusak, 1998). The main disadvantage is that it requires close proximity between the source and the recipient. Impersonal knowledge, which is usually achieved by codifying and storing knowledge, is instead appropriate to enable knowledge transfers between actors to overcome geographic and temporal barriers. Impersonal knowledge transfer mechanisms require some form of codification of knowledge as well as storage medium infrastructure to support the transfer of knowledge. In order to facilitate knowledge transfer it is important that, during process improvement activities, an emphasis is given to all knowledge creating activities as well as re-using existing knowledge.

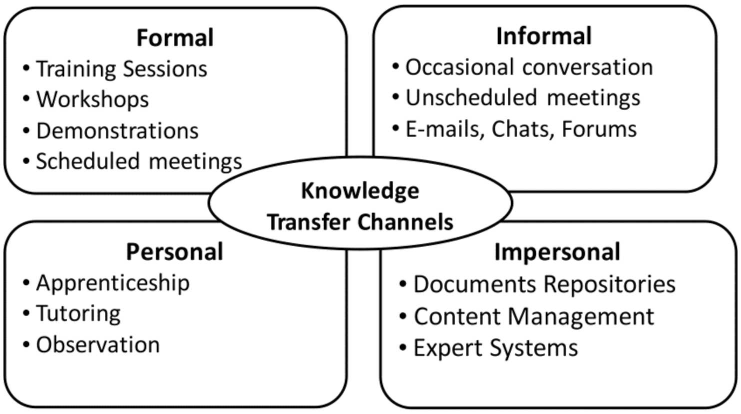

Figure 2 – Categorisation of Knowledge Transfer Channels by Holtham & Courtney (1998). Knowledge transfer channels mechanisms are classified as: Formal, Informal, Personal and Impersonal.

D. Knowledge Application

Knowledge application refers to the use of knowledge assets for the fulfilment of a specific aim or action. Appropriate application of enterprise knowledge can enhance decision making capabilities, increase efficiency and lead to innovation. Alavi et al. (2001) state that the source of competitive advantage is the application of knowledge rather than the knowledge itself. Knowledge application mechanisms include organisational directives and routines (like procedures, standards and interaction protocols) aimed at increasing efficiency in day to day business operations as well as task oriented activities where individuals gather together to solve particular problems (Grant, 1996). Documentation overload can be an obstacle to achieve effective knowledge application. In fact although knowledge can be stored in a persistent storage medium it might become too large and difficult to access it timely and appropriately to support decision making.

Organisational Knowledge Management Practices: A Foundry Case Study

A classification of knowledge creation practices in the context of foundry process improvement is proposed in Figure 3. This classification is important to identify potential knowledge assets that can support process improvement activities. Process engineer can gain process knowledge through internalisation by accessing literature and research studies. Alternatively new process knowledge can be discovered by studying patterns in process data. Social activities such as brainstorming meetings and informal e-mails and conversations can also contribute to the creation of new process knowledge.

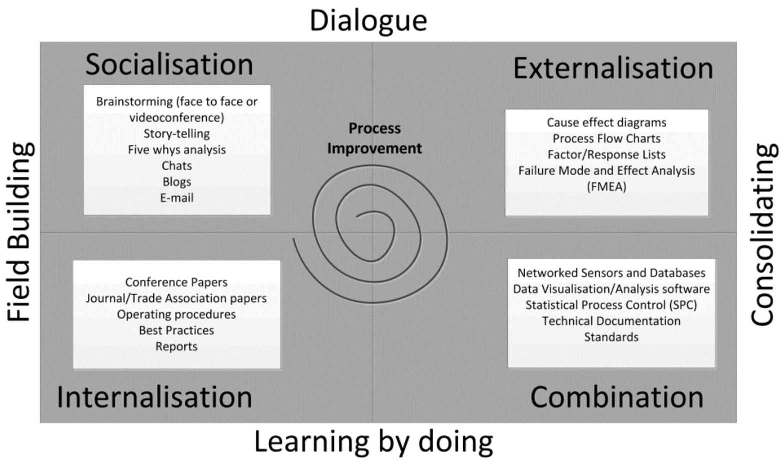

Figure 3 - Revised knowledge creation spiral in the context of foundries process improvement.

Current process improvement methodologies like Six Sigma focus too much on knowledge creation by combination and they lack of adequate methods to reuse and apply knowledge that is created in various formats as part of process improvement activities. This knowledge is often codified and stored in the form of electronic documents but it is not reused because typically there is not a single entry point for knowledge retrieval. The 7Epsilon methodology, described in the next section, has been proposed to overcome limitations of current process improvement approaches in the foundry industry. It facilitates the management of organisational knowledge by providing support to integrate, in a single framework, the knowledge processes described in the previous session, namely knowledge creation, storage and retrieval, transfer and application. It also introduces the concept of a knowledge repository to preserve and manage knowledge created during process improvement projects. The knowledge repository is a single entry point for the storage of knowledge codified in various formats like documents, videos, pictures and formal and informal conversation threads such as meeting minutes or e-mails. In the next section the 7Espilon steps are presented and it is shown how, through the 7Epsilon steps, knowledge is discovered, reused and retained as part of ISO9001:2015 requirements.

The 7 Epsilon Methodology

The 7Epsilon methodology is an extension of Six Sigma approach and consists of 7 steps to ERADICATE defects. The steps has been recently presented, by means of an illustrative but real foundry scenario, at the recent 71st World Foundry Congress and they are described in (Roshan, et al., 2014) . In this paper the 7Epsilon steps are reviewed in the context of knowledge management practices and theoretical framework discussed in earlier sections. A summary of the steps is also shown in Figure 4.

Step 1: Establish Process Knowledge

A 7Epsilon project starts with a preliminary phase where a cross-functional team is gathered and process knowledge is obtained by accessing the knowledge repository as well as other internal and external knowledge sources. Internal sources include both explicit knowledge codified in documents as well as tacit knowledge, including technical knowledge and know-how of team member. The outcome of this phase is the creation of new process knowledge that is codified in the form of Process Maps, SIPOC Diagrams and Cause and Effect Diagrams or FMEA documents. Furthermore knowledge can also be created through less formal activities such 5 Whys or Story Telling. Often knowledge created during informal brainstorming meetings tends to be lost because of the lack of appropriate codification of knowledge. 7Epsilon recommends capturing this knowledge in the form of videos, images or pictures taken via smart phones or computer screenshots or files. This gives rise to a body of knowledge stored as heterogeneous digital contents in different format such as PDF, Word, JPEG, MPEG, TIF, mp3 or avi files and so on. The importance of this phase should not be underestimated because formal and informal meetings are sources of knowledge creation. In this phase knowledge is not only created and transferred through externalisation but also through socialisation, i.e. by direct interaction between individuals. The foundry knowledge taxonomy developed as part of the 7Epsilon approach can help process engineers to overcome communication barriers due to use of different terminology and synonyms. Also, in case of geographically distributed process improvement teams, knowledge creation through socialisation is facilitated by social media technologies such chats, blogs and video streaming. In order to retain knowledge created during this phase in its various forms, it is recommended that the digital content is stored and indexed in the knowledge repository for future reuse.

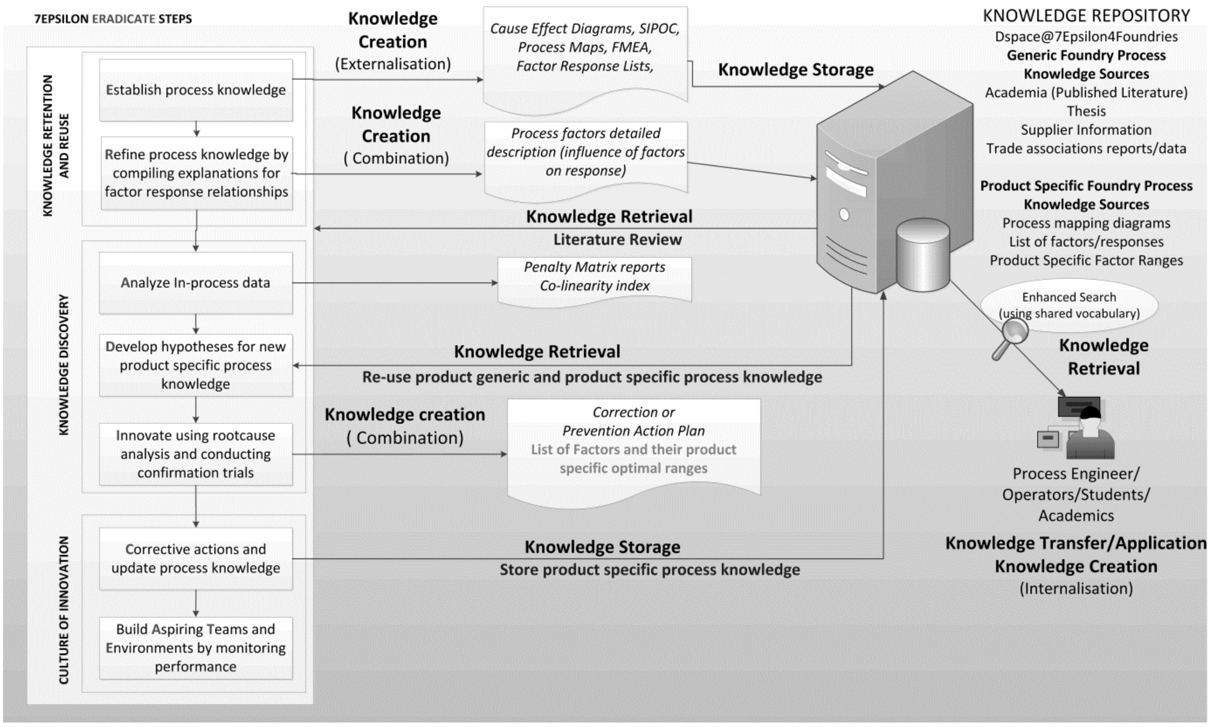

Figure 4 – The 7Epsilon approach improves traditional approaches to zero defect manufacturing by focusing on innovation through knowledge sharing and reuse (Roshan, et al., 2014). (Adapted from (Roshan, et al., 2014)).

Step 2: Refine process knowledge by compiling explanations for factor response relationships

Process knowledge is the ability to understand how process factors affect the process outcomes. In this phase process engineers systematically research about process factors and responses to find out how variability of factors affects responses. The knowledge repository plays an important role as it provides access to knowledge sources from existing research studies, published papers and process improvement case studies. The outcome of this phase is the creation of a list of factors and descriptions on how process factors may affect a given response. The list is then stored in tabular form in the knowledge repository. The purpose of this phase is to gain further understanding of the process which will help to develop and validate hypotheses in subsequent steps. An example of explanation of factor response relationship is given in Figure 5. The list was compiled as a part of a case study on reduction of conchoidal fracture and presented in a recent publication (Roshan, et al., 2014).

Step 3: Analyse in-process data

In the third step, product specific process knowledge is discovered by analysing in-process data that are being collected as part of ISO9001 requirements. This is the typical knowledge creation process by externalisation similar to Six Sigma projects. During this phase hypotheses about potential root causes of defects are generated by using data driven approaches such as the penalty matrix algorithm (R.S. Ransing, et al., 2013) and the co-linearity index methodology (Giannetti et al., 2014b; R.S. Ransing, et al., 2013). Creation of knowledge by combination is not straightforward because issues such as noisy and missing data and the presence of outliers may affect the outcome of the analysis. These can be overcome by using techniques for noise reduction such as the co-linearity index which discovers correlations in a reduced dimensional space where noise has been removed (Giannetti, et al., 2014b).

Factor (X)	Description
Carbon drop	In the basic melting practice of steel, charge carbon is so adjusted that during the Oxygen blow there is a minimum carbon drop of 30 points. During the Oxygen blow the extra carbon is oxidized and the resulting CO bubbles essentially remove N and H from the melt.
Tap Temperature	Higher tap temperatures have been found to result in the retention of harmful gases in the liquid metal.
Pouring Temperature	Higher pouring temperature than the optimum also have been found to be undesirable in the production of sound castings.
Argon Stir Time	Argon stirring is found be very useful in removing the harmful gases N and H through the bubbling action and also maintain uniformity in temperature in the ladle.
% Carbon	Higher C than the optimum is found to have undesirable effect in increasing the propensity of defects resulting from quenching.
% Mn	Optimum range of Mn is necessary to minimize the harmful effects of S in the melt and to produce sound castings.
% Titanium	Ti in steel castings is added as a deoxidizer to enable having low percentages of Al thus preventing the formation of Aluminum Nitride. Titanium is a more powerful deoxidizer compared to Aluminum and will tie up Nitrogen more effectively. However percentage of Ti should be carefully controlled to prevent the formation of excessive titanium carbonitrides. Titanium also acts as a grain refiner in steel castings.

Figure 5 - Example of explanations for factor response relationship. This list is compiled by accessing sources from published literature as well as previous case studies (Roshan, et al., 2014).

Step 4: Develop hypotheses for new product specific process knowledge

The discovery of correlations can help process engineers to identify root causes of defects and develop an understanding on how process factors might relate to process responses. This is not enough for the creation of product specific process knowledge because these findings need to be verified and tested. In order to create new knowledge, the 7Epsilon methodology does not only rely on knowledge created as a result of data analysis but also on both generic and foundry specific process knowledge that has been accumulated in previous process improvement activities or studies. In this step new hypotheses are developed if correlations found in the previous step are confirmed with findings and knowledge created during the "Refine process knowledge" step. New tolerance limits are proposed and a corrective action plan is outlined or a decision is taken to collect either more in-process data or conduct one or more design of experiments. The knowledge repository helps to retrieve the appropriate knowledge sources which can support confirmation of hypotheses.

Step 5: Innovate using root cause analysis and conducting confirmation trials

Based on the results from the previous phase, the 7Epsion methodology requires that hypotheses about root causes are validated with confirmation trials. During confirmation trials new tolerance limits are tested. This step is important because foundries need to investigate the effects of the proposed changes on all the relevant process outputs to avoid adverse effects on other process responses.

Step 6: C**orrective actions and update process knowledge**

Upon successful completion of confirmation trials the new product specific process knowledge is created and codified in a tabular form. The new knowledge (i.e. the new set of tolerance limits) is specific for a given part and process. An example of product specific process knowledge created during a 7Epsilon project to reduce occurrence of conchoidal fractured surface area during steel casting is depicted in Figure 6. The knowledge is stored and indexed in the 7Epsilon repository.

Process Variable (CTQ)	Specification Range
Carbon Drop (X1)	13 - 47
% Sulfur (X7)	0.007-0.009
% Phosphorus (X8)	0.009-0.013
%Titanium (X15)	0.011-0.016
Mn/S Ratio (X16)	104-134
%Ca/%Al Ratiox1000 (X19)	6.67-57.5

Figure 6 - Product specific process knowledge created following a study on reduction of conchoidal fractured surface area during melting process of steel (Roshan, et al., 2014).

Step 7: Building Aspiring Teams and Environments by monitoring performance

In order to meet requirements of ISO9001:2015, foundries must continually monitor performances and find new improvement opportunities. The 7Epsilon repository provides documented evidence of commitment to continual process improvement required to comply with the requirements. The knowledge repository can also be used to support new process improvement projects as well as to train operators and process engineers.

7Epsilon Template for a Foundry Knowledge Repository

The new tolerance limits, stored in tabular form and discovered through the 7Epsilon approach, represent a valuable source of knowledge necessary to achieve product conformity. Continual process improvement requires that past knowledge gained during process improvement activities is made available to process engineers. In foundries such knowledge (both in tacit and explicit form) is highly heterogeneous and lies untapped in the organisation because it is either difficult to externalise it (as in the case of product specific process knowledge) or knowledge retrieval in hindered by information overload. The 7Epsilon approach introduces the concept of a knowledge repository to store and reuse product specific process knowledge. The notion of process knowledge described in this paper is close to the one adopted by ISO9001:2015 standard which defines knowledge as a “collection of information being a justified belief and having a high certainty to be true” (ISO, 2014, p. 22).

A knowledge repository often seems to entail the notion of knowledge as “content”. In order for tacit knowledge to become content it needs to be externalised and codified in some digital form. In the past there has been a lot of emphasis on expert systems and artificial intelligence techniques to mimic human decision making capabilities for instance by codifying knowledge using rule based systems or description logic. Although these approaches have found successful industrial applications, they have not been adopted in foundries or complex manufacturing processes. Product specific process knowledge is discovered when new robust ranges for process parameter are found. Rule based systems are not an optimal knowledge representation technique for foundry process knowledge because it would be very complex and cumbersome to characterise the many interactions among all combinations of process parameters. In particular the knowledge elicitation bottleneck is a major issue since the codification of knowledge in rigid schema and languages would be too time consuming. Furthermore foundry specific process knowledge exists and has its validity within the specific context of each foundry project. It would require a commitment of each foundry to devote time and resources to develop and maintain such a system every time there is a new product specification or new process. In order to be effective, knowledge management strategies in foundries need to take into account the heterogeneous and highly dynamic nature of generic and product specific process knowledge.

The foundry knowledge repository is a single entry point for preservation and management of knowledge assets created during process improvement where the knowledge is stored in the format it has been created. The knowledge repository does not commit to a rigid knowledge representation schema but it facilitates the storage and access to a valuable collection of information and data. These assets can then become knowledge when used consistently as part of continual process improvement activities. Several requirements have been identified for the development of a knowledge repository in foundries and they are summarised in Table 1.

Table 1 –High level requirements for the implementation of the 7Epsilon Knowledge Repository to store foundry process knowledge.

	Requirements
1	Single entry point for storage and retrieval of foundry knowledge
2	Support for heterogeneous documents (different file formats)
3	Minimum amount of knowledge codification (pictorial or natural language representation)
4	Full text search by keywords and metadata
5	User-defined metadata
6	Search by knowledge source (foundry/product specific) and generic knowledge
7	Ability to manage user permissions for read/write access and submission

Based on these requirements a template for a foundry knowledge repository has been developed. This is built by using DSpace (http://www.dspace.org/), an open source and customisable digital repository software widely adopted by academia and many organisations (Smith et al., 2003). DSpace was chosen because it satisfies the high level requirements identified in Table 1. It can store and organise a wide range of digital contents, including pictures, documents and data files. It embeds advanced search capabilities such as full text and metadata based search. This means respectively that the user can search specific terms either in the corpus of the document or in special fields, called “metadata” (e.g. author, title, subject, abstract etc.). Furthermore in order to overcome problems due to ambiguity of terms or incorrect use of keywords, standard DSpace search capabilities have been enhanced by using the Controlled Vocabulary adds-on that allows specifying user defined keywords from a fixed taxonomy (Ferreira & Baptista, 2005).

DSpace organises documents through a hierarchy composed of communities, sub-communities, collections and items. Communities are at the top of the hierarchy and can contain several collections. A collection is a group of related contents, while an item is the basic archived component. An item can be composed by one or more bitstreams (or files) and is typically indexed using metadata. In the knowledge repository generic and foundry specific process knowledge are stored in different sub-communities. Generic process knowledge includes general literature and other learning resources such as conference and trade association journal papers, best practices, reports and theses. Foundry specific process knowledge includes documents and any other material created during process improvement activities. It also includes results of 7Epsilon studies and a tabulated list of process factors with their tolerance limits discovered as part of the 7Epsilon steps as shown in Figure 6. A general hierarchy of structured content proposed for the knowledge repository is shown in Figure 7. This hierarchy may need further customisation to satisfy specific foundries requirements. Process improvement case studies are stored as items in different collections and indexed using metadata. Among the metadata, the subject keyword is chosen from a fixed taxonomy to increase the likelihood of retrieving the relevant content. An example of item structure and its associated files for a 7Epsilon case study is included in Figure 8. Digital content created during other process improvement initiatives can be archived in a similar way.

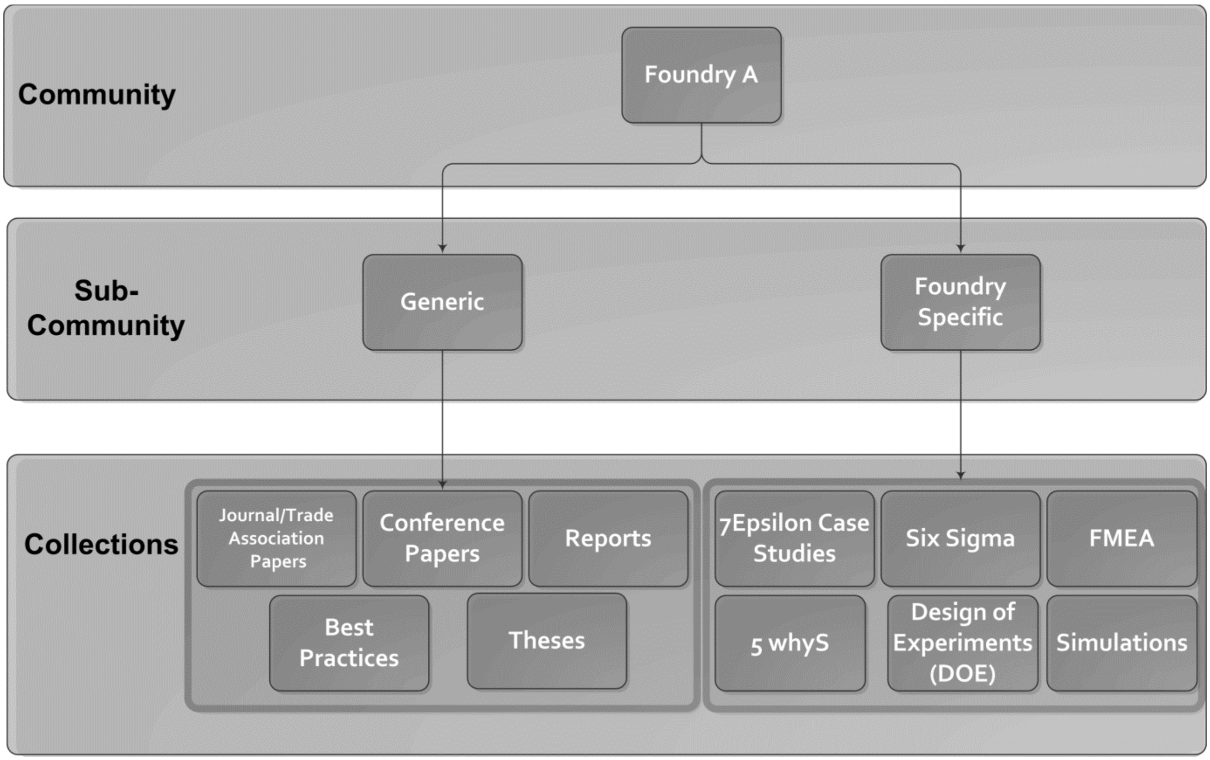

Figure 7 - Proposed hierarchical structure of content for the foundry repository prototype.

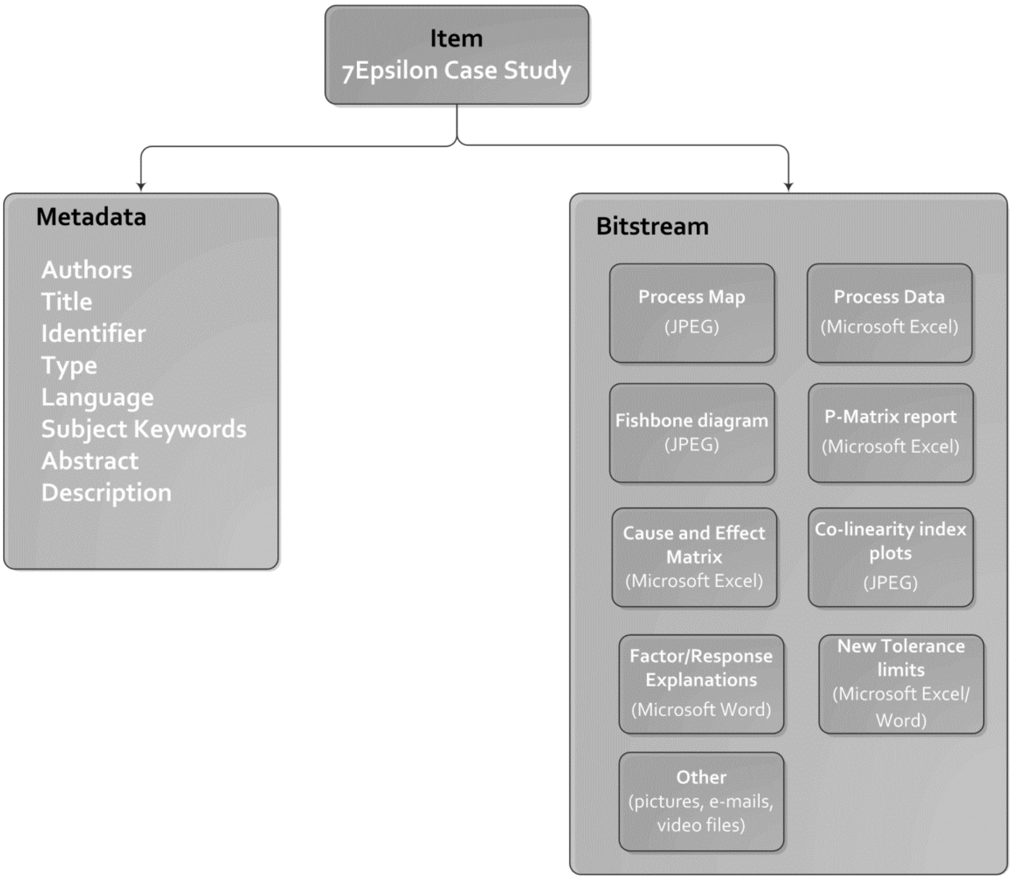

Figure 8 - A process improvement study is stored as an item and includes all the digital contents generated during the process improvement activities. Each item is associated with metadata for enhancing retrieval capabilities.

Foundry Process Taxonomy

In ontological engineering, a taxonomy is a hierarchical classification of terms related to a certain domain that can be used for document classification and description (Ferreira & Baptista, 2005). The Foundry Process Taxonomy is a classification of terms related to foundry processes. Its main purpose is to structure and organise process knowledge stored in digital artefacts with the final aim to overcome documentation overload issues and improve search precision. In addition, the taxonomy serves the purpose to promote a common understanding of process improvement terminology among team members during 7Epsilon process improvement activities. The Foundry Process Taxonomy has been developed by using a number of published literature, books and expert knowledge. An excerpt from the Foundry Knowledge Taxonomy is shown in Figure 9 . In the current implementation of DSpace repository the taxonomy is added as a user-defined vocabulary to the Controlled Vocabulary DSpace adds-on (Ferreira & Baptista, 2005). During submission of items the taxonomy (displayed as a tree structure) allows users to select a fixed set of subject keywords, hence avoiding ambiguity of terms or spelling mistakes. At retrieval time, users can also browse the tree structure and select keywords to be included in the search.

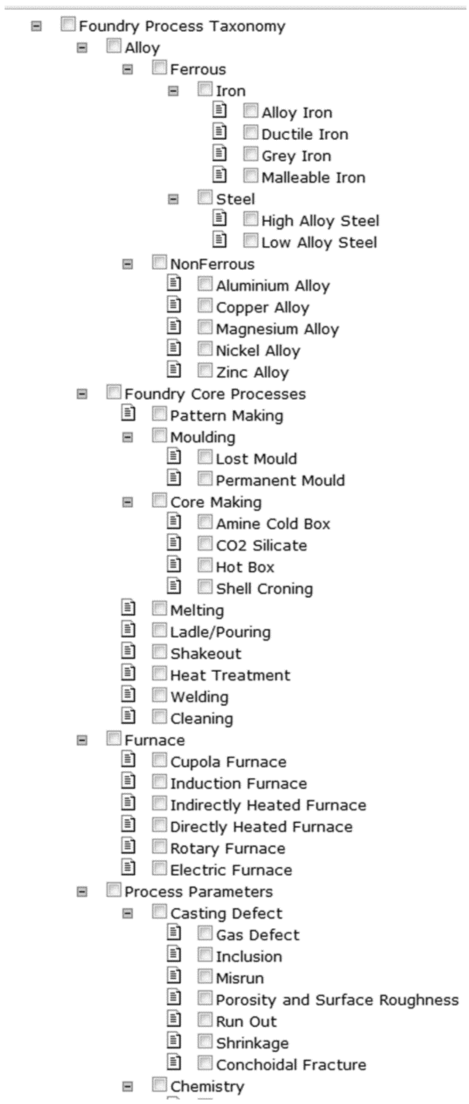

Figure 9 – The Foundry Process Taxonomy has been developed to improve search capabilities of DSpace standard installation. It might require some customization to address specific foundry needs.

The use of the taxonomy both during document submission and retrieval significantly improves the precision of the search because only the relevant documents are retrieved hence providing a more efficient access to foundry process knowledge. An example of DSpace guided search is shown in Figure 10. The foundry taxonomy that drives the knowledge repository has been developed in XML (Extensible Markup Language). Although taxonomies do not have full expressive power, they offer a good trade-off between enhanced retrieval and easiness of implementation and maintenance. Future research will address the impact of adopting more complex ontologies as backbone of the knowledge repository. The availability of heavyweight ontologies will allow the implementation of more complex queries by embedding reasoning capabilities.

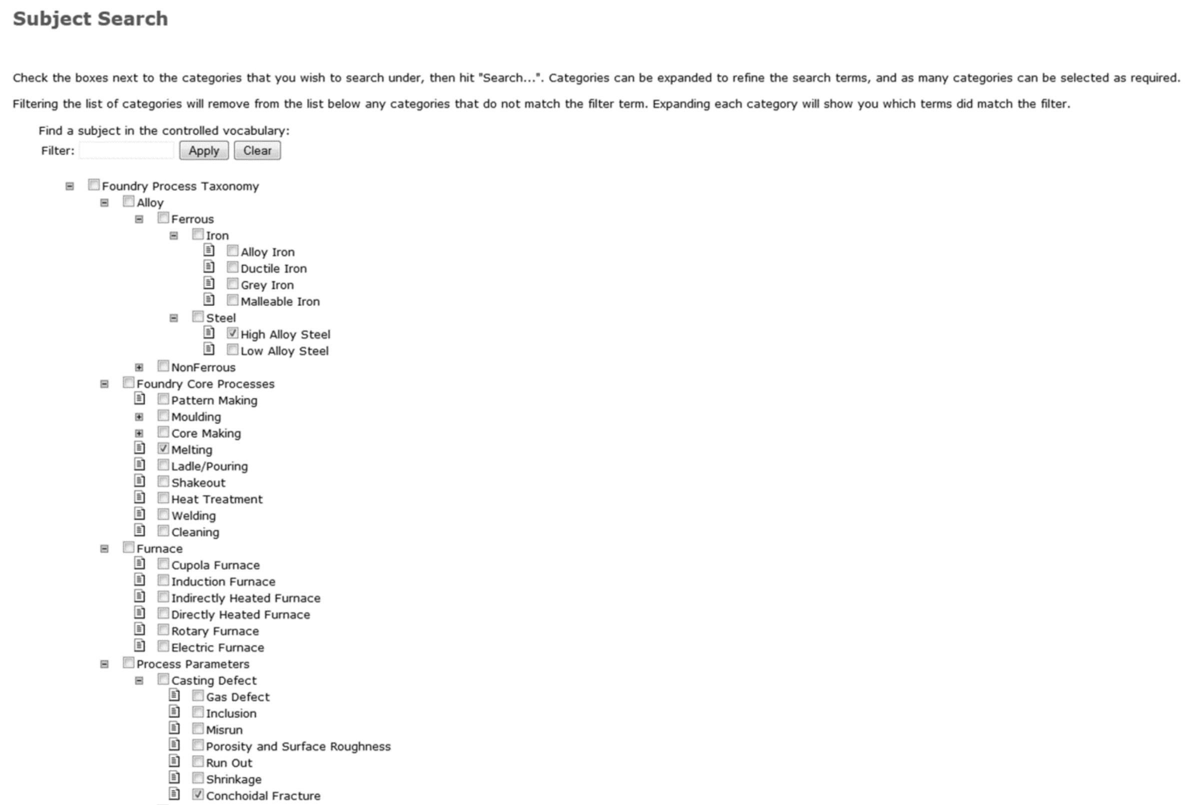

Figure 10 – The subject search of DSpace allows user to retrieve items that are relevant to a specific foundry process, alloy and casting defect.

Discussion and Future Work

An understanding of the interplay between knowledge management and process improvement is necessary to leverage the benefits of process improvement activities which ultimately can lead to cost saving and efficiency gains. The 7Epsilon methodology recognises the importance of embedding knowledge management practices in day to day process improvement activities and promotes the use of ICT to store organisational knowledge as well as to facilitate its creation, transfer and application. Process knowledge is viewed as an asset and the heterogeneous knowledge that is created as part of process improvement projects is stored and indexed in a knowledge repository to preserve it and retrieve it for later uses. Storing process knowledge in foundries poses many challenges because knowledge assets are made not only of results of simulations and data analysis that can be collected in tables and graphs but also of skills and know- how of people. The externalisation and codification of such knowledge is difficult to achieve and it would be difficult and complex to develop an expert system to encompass all the different aspects of such knowledge. In order to reduce the burden of knowledge codification, knowledge is stored in the format it is created and indexed using the Foundry Process Taxonomy. This enables users to add knowledge content easily and overcome the knowledge elicitation bottleneck which usually happens due to the lack of time or unwillingness of experts to contribute to the knowledge base. Also knowledge reuse is facilitated because process engineers can narrow down the search by choosing a combination of keywords they are familiar with, including processes, alloys, defects and furnace types.

A template for the 7Epsilon knowledge repository is described to demonstrate the feasibility of the proposed solution using existing technologies. Although a full evaluation of the populated template on real industrial settings has not been carried out yet, this paper has identified the high level requirements for the development of a knowledge repository in the foundry industry. Furthermore it proposes a possible practical implementation of a knowledge management system that satisfies clause 7.1.6 of the latest proposed ISO9001 standard.

The extent of success of the knowledge repository will depend on the ease of use and the ability to retrieve generic and foundry specific process knowledge with minimal effort. If users perceive that the knowledge repository is useful to them they will also be more willing to contribute. Future research effort will be focused in populating and evaluating the effectiveness of the knowledge repository. Furthermore more research is needed to assess the impact of adopting more complex ontologies as backbone of the 7Epsilon repository to provide the ability to perform more advanced and intelligent queries and hence retrieve knowledge more accurately.

Conclusion

In this paper a novel methodology for process improvement in foundries is presented in the context of the latest requirements of the ISO9001:2015 quality standard. The methodology, called 7Epsilon, is systematically reviewed taking into account theoretical perspectives of knowledge management. This work has contributed to the characterisation of different types of knowledge assets and knowledge management practices that occur during process improvement activities. A knowledge repository concept to store generic and product specific process knowledge in foundries is introduced along with the definition of high level requirements and architecture. By means of a knowledge repository prototype it is also demonstrated how existing ICT tools can contribute to leverage process improvement activities by adding support for knowledge creation and reuse.

The 7Epsilon methodology and repository can help foundries worldwide to streamline current process improvement initiatives to reduce defects and contribute to a more sustainable future by minimising adverse effects on environment. The Foundry industry relies on years of experience of its experts in solving problems. It is known for not documenting its knowledge, rediscovering the ‘knowledge wheel’ many times and risk losing the experience once its experienced staff leaves or retires. The proposed formulation not only helps foundries to satisfy ISO9001:2015 requirements but also ensures sustainability of knowledge transfer across its staff. Although the current work has been developed in the context of foundries, extension of this methodology can be generalised to other industrial sectors.

Acknowledgements

The first author would like to thank the financial support from the ASTUTE (http://www.astutewales.com/) project that is funded via the European Regional Development Fund through the Welsh Government.

References

Al-Ghassani, A. M. (2002). *Literature review on KM tools. Technical Report, July 2002*. Loughborough University, UK: Department of Civil and Building Engineering.

Alavi, M., & Leidner, D. E. (2001). Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Quarterly, 25*(1), 107-136.
Alwis, R. S., & Hartmann, E. (2008). The use of tacit knowledge within innovative companies: knowledge management in innovative enterprises. *Journal of Knowledge Management, 12*(1), 133-147.
Anand, G., Ward, P. T., & Tatikonda, M. V. (2010). Role of explicit and tacit knowledge in Six Sigma projects: An empirical examination of differential project success. *Journal of Operations Management, 28*(4), 303-315.
Arendt, M. (2008). Six sigma and knowledge management. *Economics and Organization of Future Enterprise, 2*(2), 14-20.
Bohn, R. E. (1994). Measuring and managing technological knowledge. *Sloan Management Review, 36*(1), 61-73.
Borst, W. N. (1997). *Construction of Engineering Ontologies for Knowledge Sharing and Reuse.* Unpublished Thesis.
Choudhary, A. K., Harding, J. A., & Khilwani, N. (2009). Semantic web in manufacturing. *Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture, 223*(7), 905-924.
Davenport, T. H., & Prusak, L. (2000). *Working knowledge: how organizations manage what they know*: Harvard Business School Press.
Fahey, L., & Prusak, L. (1998). The eleven deadliest sins of knowledge management. *California management review, 40*(3), 265.
Ferreira, M., & Baptista, A. (2005). *The use of taxonomies as a way to achieve interoperability and improved resource discovery in DSpace-based repositories*.
Giannetti, C., Ransing, R. S., Ransing, M. R., Bould, D. C., Gethin, D. T., & Sienz, J. (2014a, 28th-30th April 2014). *Knowledge management and knowledge discovery for process improvement and sustainable manufacturing: a foundry case study.* Paper presented at the Sustainable Design and Manufacturing 2014, Cardiff, UK.
Giannetti, C., Ransing, R. S., Ransing, M. R., Bould, D. C., Gethin, D. T., & Sienz, J. (2014b). A novel variable selection approach based on co-linearity index to discover optimal process settings by analysing mixed data. *Computers & Industrial Engineering, 72*(217-229).
Gomez-Perez, A., O. Corcho, O., & Fernandez-Lopez, M. (2004). *Ontological Engineering: with examples from the areas of Knowledge Management, e-Commerce and the Semantic Web*: London: Springer.
Grant, R. (1996). Toward a knowledge-based theory of the firm. *Strategic Management Journal, 17*(Winter Special Issue), 109-122.
Hansen, M. T., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge? *Harvard Business Review, 77*(2), 106-116.
Hayes, N., & Walsham, G. (2003). Knowledge sharing and ICTs: a relational perspective *Handbook of organizational learning and knowledge management* (pp. 54-57).
Holtham, C., & Courtney, N. (1998). The executive learning ladder: A knowledge creation process grounded in the strategic information systems domain. *AMCIS 1998 Proceedings*.
ISO. (2014). Draft BS EN ISO 9001 Quality Management Systems - Requirements: Geneva, ISO.
Kimmerle, J., Cress, U., & Held, C. (2010). The interplay between individual and collective knowledge: technologies for organisational learning and knowledge building. *Knowledge Management Research & Practice, 8*(1), 33-44.

Lehaney, B., Clarke, S., Coales, E., & Gillian, E. (2004). *Beyond Knowledge Management*: London: Idea Group Publishing.

Lewis, R. W., & Ransing, R. S. (1997). A semantically constrained Bayesian network for manufacturing diagnosis. *International Journal of Production Research, 35*(8), 2171-2178.

Moffett, S., McAdam, R., & Parkinson, S. (2004). Technological utilization for knowledge management. *Knowledge and process management, 11*(3), 175-184.

Murrell, P. A., & Brown, R. S. A. (2014). *Developing the Future Workforce: The UK Perspective. The need for technicians* Paper presented at the 71st World Foundry Congress, Bilbao, Spain.

Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-Creating Company*: New York: Oxford University Press.

O'Dell, C., & Hubert, C. (2011). *The new edge in knowledge: How knowledge management is changing the way we do business*: John Wiley & Sons.

Panahi, S., Watson, J., & Partridge, H. (2012). Social media and tacit knowledge sharing: developing a conceptual model. *World academy of science, engineering and technology*(64), 1095-1102.

Panetto, H., Dassisti, M., & Tursi, A. (2012). ONTO-PDM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment. *Advanced Engineering Informatics, 26*(2), 334-348.

Ransing, R. S., Giannetti, C., Ransing, M. R., & James, M. W. (2013). A coupled penalty matrix approach and principal component based co-linearity index technique to discover product specific foundry process knowledge from in-process data in order to reduce defects. *Computers in Industry, 64*(5), 514-523.

Ransing, R. S., Srinivasan, M. N., & Lewis, R. W. (1995). ICADA: Intelligent computer aided defect analysis for castings. *Journal of Intelligent Manufacturing, 6*(1), 29-40.

Roshan, H. M., Giannetti, C., Ransing, M. R., & Ransing, R. S. (2014). *"If only my foundry knew what it knows ...": A 7Epsilon perspective on root cause analysis and corrective action plans for ISO9001:2008*. Paper presented at the 71st World Foundry Congress, Bilbao, Spain

Smith, M., Barton, M., Bass, M., Branschofsky, M., McClellan, G., Stuve, D., et al. (2003). DSpace: An open source dynamic digital repository.

Spada, A. T. (2014, 19th-21st May 2014). *Global Metalcasting: Assessing Our Strengths and Weaknesses & Developing Inputs for a Sustainable Future* Paper presented at the 71st World Foundy Congress, Bilbao.

Yew, K. W., & Aspinwal, L. E. (2004). Characterizing knowledge management in the small business environment. *Journal of Knowledge Management, 8*(3), 44-66.