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KEY ISSUES IN THE TAKE-UP OF KNOWLEDGE MANAGEMENT INTERVENTIONS IN ENGINEERING DESIGN

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1. Introduction

The development of knowledge management (KM) support systems for the engineering design domain is known to face a number of challenges. Many of these will fall into the category of well documented traditional systems development issues. However, there are additional challenges to contend with: Typically, engineering design projects can be very large, spanning many years, requiring complex engineering process to develop complex products. Further, even relatively small projects involve numerous technical disciplines and multiple commercial functions. The management of globally distributed engineering teams also contributes its own set of challenges. Although these issues may be well known, the complexity of the combined issues all contribute to the potential failures of KM tools developed to support them.
The intention of this paper is to consider literature not just from the disciplines of Knowledge Management within Engineering but also from more general Information Systems development literature. The contributions of this paper are i) to distil and identify key issues in implementing KM support systems and ii) illustrate via a case study the impact of those issues upon take up of KM intervention.
In particular, this paper focuses on knowledge management systems for engineering projects. Eight key issues are identified and discussed. They are then considered with respect to a case study on a Knowledge Management intervention in a large aerospace company, which illustrates the importance of user involvement throughout the development process. It also highlights the need for analysis when designing systems using both top down (reductionism) decomposition and bottom up synthesis. An initial prioritisation and categorisation of the eight issues as a first step in developing a strategy is also undertaken. This appraisal not only serves to demonstrate their complexity, but also suggests why the failure points can be difficult to address.

1.1 Method

The paper firstly synthesises from literature, the key issues in implementing Information Technology support (solutions) for engineering projects, from a variety of domains (section 2.1). A prioritisation of these issues is drawn upon from the literature (using a matrix for illustration) predicting both the risk of occurrence of the issue and the subsequent impact to take up of any solution applied (section 2.2). A case study is then used to demonstrate how these issues are manifested in a typical KM project in a design engineering context (section 3.1). The Case Study concludes with a summary of observed successful outcomes from the intervention (section 3.2).

Subsequent discussion (section 4) of the best practice observed from the case study is used to validate the importance for KM intervention to address the key issues identified having a high risk of occurrence and potential negative impact upon the take up of any solution. The next steps to validate the framework further, using wider industrial application, is then suggested (section 4.1). A short conclusion summarises the findings of this paper (section 5).
The purpose and structure of this paper are illustrated in the process diagram Figure 1, shown below.

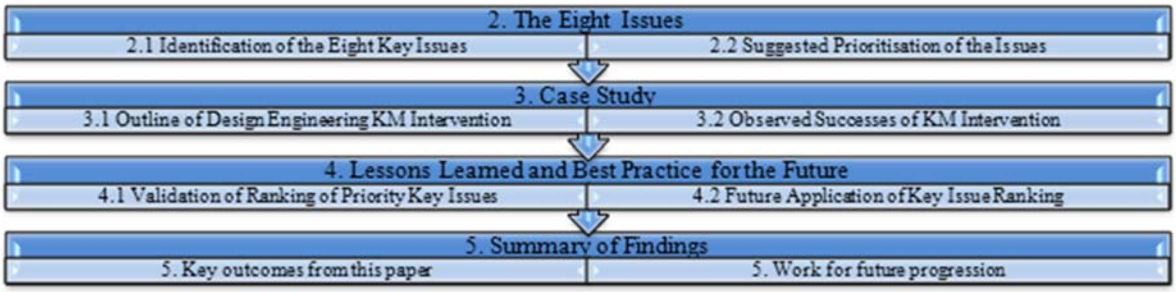

Figure 1. Analysis and synthesis process method

2. Eight key issues identified from the literature

This section first discusses eight key issues synthesised from the literature relating to KM Information Systems development for engineering (section 2.1) before ranking them against likelihood of occurrence and impact on success (section 2.2).

2.1 The eight issues

The issues listed below are evidenced from literature from the domains of, knowledge management, information systems development and engineering. Although not exhaustive, it highlights what we argue are the eight most significant and frequently occurring challenges.

Issue 1; Knowledge capture and codification

The first issue identified relates to the difficulties in capturing and codifying knowledge. Knowledge management is acknowledged as a key facilitator in distributed enterprises [McMahon et al. 2004]. It is therefore acknowledged that the processes of capturing, codifying and transferring knowledge are important tasks for large scale engineering projects as they fall into this category of distributed enterprise.

The long lifecycles of many engineering projects also present challenges. There is a vast number of possible knowledge assets within these projects due to the high level of expertise required for the projects and the lengthy asset lifecycles (lengthy development timescales together with long product lifecycles). This results in the task of capturing, codifying and transferring knowledge being a significantly large one.

Further, it is recognised to replicate the comprehension, knowledge and experience of human experts within a system does not lead to the same quality of decision making. Computers are recognised to not yet be programmed to interpret new knowledge and experience [Boddy et al. 2002]. For a system to accurately support the processes required there needs to be a comprehensive understanding of the processes for the requirements to reflect this.

However, this understanding is often hard or impossible to elicit, summarised by [Polanyi 1967:p.4] as "*we can know more than we can tell*" That is, the many knowledge assets within knowledge-driven enterprises such as engineering are likely to be intangible and often exist as "tacit" knowledge in the minds of the project stakeholders and employees. It is often not possible to quantify the many experiences of a worker, making it an impossible task to codify that experience [Laudon and Laudon 2003]. The intangible nature of these assets can mean they are difficult to identify and quantify during analysis of the project. The 'second generation' of knowledge management is now understood to encompass more intangible aspects [McElroy 2002].

Issue 2; Undefined or evolutionary requirement set

The second issue identified relates to problems arising from the often ill-defined or evolutionary nature of the system requirements. In systems development it is possible for requirements to be categorised as functional requirements, user requirements or performance requirements. For the purposes of this discussion we will be focussing on the functional and performance requirement of a system.

For the acceptance of a system by its users, a specific set of requirements agreed at the outset of development is defined in a contract. It is well documented within systems development that the single main point of failure for a system is that it does not meet the specified requirements [Goguen 1992], [Bennett et al. 2002:p34]. Within systems development it is also widely accepted that defining the requirements of an information system is not only one of the most critical processes and remains the most difficult task to complete. [Christel 1992].

One of the key reasons for failure to elicit accurate requirements from users is that there is lack of understanding of the users of their own needs: "*Many experts cannot express their knowledge using an IF-THEN format"* [Laudon and Laudon 2003:p.335]. It is confirmed by Laudon and Laudon [2003] that the higher level tasks performed by experts such as design engineers are difficult to document as it is often difficult for a systems developer to understand their considerations and the complex or dynamic processes the user might follow.

Further, it is often the case that the system stakeholders do not always realise the potential solutions until after the requirements are defined and the system is being implemented. In the case of large systems it may be that additional requirements are identified or requested late in the developmental process. This can lead to an unmanageable evolutionary requirement set changing throughout the developmental lifecycle. [Laudon and Laudon 2003] support the evolution of requirements in particular in expert systems, stating "*Expert systems must be changed every time there is a change in the organisational environment. Each time there is a change in the rules the experts use, they must be reprogrammed.*"

Issue 3; Data format and application

This issue relates to the tasks within engineering enterprise as they are known to require a high level of expertise. The knowledge required to carry out those processes require the synthesis of large quantities of information and data. Therefore the systems designed to support these processes have the requirement that large amounts of data will need to be stored and synthesised. Speaking about an engineering system [Gopskill 2011] states "products generate huge amounts of data and information throughout their lifecycle, typically 100,000s files and records....." In the drive to improve process, support existing teams the rapid development new and bespoke tools does little to advance automation and support. Often it is the case that issues are created by the introduction of a solution for another problem.

Within engineering systems it is also a requirement that historic data [Hicks et al. 2008] will be used to aid the expert in the evolution of an appropriate solution. Therefore the requirement of storing or digitising previous data is crucial (often this data is paper based or images on microfiche and not already digitised).

For the synthesis of this data to take place it will be a requirement that retrieval of this data by users will be on a regular basis and may involve the additional repository of newer data versions (keeping historic versions to maintain the integrity of the data). This introduces an increased number and frequency of data transactions to be processed by the system. The necessity for transactions between data in incompatible formats involves the writing of bespoke scripts for these systems to interface (data exchange or communication). It must be noted that the addition of a new data set to the system will introduce the need for an additional interface to be created. These interfaces are costly and difficult to support in information systems due to the personalised nature of their development.

Issue 4; Legacy systems and lengthy data lifecycles

The previous issue is also further compounded by problems emerging from legacy systems and lengthy data lifecycles. Legacy systems have occurred as a result of the rapid evolution of systems in previous years together with the extended lifecycle of the data stored within these systems. The impact of multiple legacy systems is the complexity it introduces into the requirement specification an information system.

The legacy system could be paper based or be a previous application version. This causes issues such as the incompatibility of data types and the need for interfaces required to conduct transactions between them [Ambler 2010]. It is in some cases possible to transfer data into more useful formats, often however the integrity of the data is lost in this process. For example the scanning of paper based files does not address the issue of what data is useful for a process or the quality of the information. It does not also mean that a PDF file can be understood by the information system without considerable addition of interfaces [Ambler 2010]. Therefore, in reality organisations often face a decision between what transactions may be plausible to automate and those that cannot be shown to have a significant cost benefit.

Issue 5; Multiple stakeholder objectives, aims and processes

Effectively stakeholder management is also widely recognised as a fundamental aspect of effective project management [Nokes and Kelly 2003:p.265]. In the engineering design domain [McAlpine et al. 2010] illustrates clearly that there are many stakeholders, comprising both technical specialists from various disciplines and also specialists across disciplines. Each of the stakeholders has their own personal and different aim, objectives and industrial process.

The integration of the needs of different stakeholders therefore raises information system challenges. It increases the risk of lack of understanding of the requirements due to the number of stakeholders and increases the possibility of conflicting views, personalities and needs of each stakeholder. If managing communication is an issue it can result in an important stakeholder not being involved in the analysis process and their requirements then not considered fully. It also lends to suggestion that the main academic challenge is that these professionals do not understand their own requirements well enough to translate that to the systems developer. The facilitation of communication between parties in a distributed team is a management issue however the impact of these difficulties is high for a systems developer and remains for the duration of the project lifecycle [Nokes and Kelly 2003].

Issue 6; Consequences of automation

Related to the previous discussion on the importance of stakeholders, the wider consequences of the intervention on its users must also be considered, especially when the intervention seeks to automate aspects of the process. The need for a system to understand and mimic the actions of those users is also identified in the literature as critical to its success and the motivation for a user to "use" a system is a critical to its success [Boddy et al. 2002]. If a user refuses to "use" a system then it would be deemed to a failure.

If an experienced worker fears the risk of redundancy as a result of the automation of processes they are unlikely to be motivated to support the developmental process. Information systems should aid a worker and aim to complement their skill set not aim to replace them. Workers then are less reluctant to feel pushed out or in fear of automation [Laudon and Laudon 2003].

A further aspect is that the automation of all tasks is not yet possible as it is recognised that systems are limited to their functional requirement (Wang, 2004). It is also possible that process automation may not be as effective as human input. Innovation for the success of engineering projects is one process that is recognised cannot be automated. It is the facilitation of a user to use their knowledge base that results in the innovation [Boddy et al. 2002]. [Laudon and Laudon 2003] is in agreement, that experience is the critical means for the creation of new knowledge for future use.

Finally, [Boddy et al. 2002] states, "*It is very hard to comprehend all the knowledge and experience of human experts and to reach the same quality of decision making. Computer based systems are not as good as people at interpreting new knowledge and experience.*" Hence most information systems are designed to support the laborious tasks the experts undertake to improve their productivity. The aim of the system should not be to replace them.

Issue 7; Usability

It is recognised that an important part of the design process for any product is the consideration of the needs of a user [Nielson 1993]. This may be for an item to be intuitive to use aiding user interaction, to make the item aesthetically appealing encouraging its up take or improvement of an items accessibility (meeting specialist needs), or as a means to confirm user acceptance of a product [Dillon 2001]. The

elicitation of requirements is aided by the close involvement of the users for a system, while trust and confidence in a system is built by developing a relationship with your users. The involvement of the user from the outset of development also reduces the need for education about the system upon implementation, the increased awareness increases up take.
There are a number of methodologies and techniques introduced to systems development to improve the usability of systems and the scientific metrics for analysis, thus reducing the failure risk. These include User Centred Design principles [Rubin 1984], the heuristic analysis of user interfaces (Neilson 1994), Scenario Based Design of Human Computer Interactions [Carroll 2000] and Schneidermans' Eight Golden Rules for Interface Design [Schneiderman 1999]. In practice, an integrated approach would be more effective, adapting the approach to the system being tested. These approaches require the involvement of users throughout the entire lifecycle an information system.
However, often it is still the case that the actual systems users are not involved enough in the development process. It is possible in large projects that not all of the stakeholders are available to be involved in the user testing process, or the need for their involvement may not be clearly understood by management (leading to lack of education for the user). Ultimately this will contribute to the intervention failure. It is the employees of a company that should be involved in the testing as they are one of the key stakeholders in an information system [Boddy et al. 2002].

Issue 8; Other system and organisational constraints

Related to the discussion in 2.2 that requirements that cannot be fulfilled due to constraints outside the control of the project, this section looks in more detail at other general systems and organisational constraints. There are also more fundamental theoretical constraints such as the limitations of software to procedural function [Wang 2004] or the capabilities of artificial intelligence thus far (hybrid systems for evolutionary computing).
Business strategy for both the engineering organisation and the systems developer will influence many areas of the developmental process. The business strategy may place constraints upon developmental budget or the technologies available for development. The business strategy will influence the balancing act between developmental costs and organisational productivity. It is therefore key for an intervention to address the business strategy by adding value and remaining within the organisational constraints [Bocij et al. 2003].

2.2 Proposed ranking matrix

It is important to note that this mapping suggested below is a prioritisation for the issues identified within KM intervention for Design engineering information systems. The identification of and prioritisation of issues may differ somewhat depending upon the literature and domain studied. Clearly the issues identified are not mutually exclusive and overlaps exist, for example between user process codifications, into specified system requirements. It is also not the only way of categorising the issues, but we believe it is a useful one for this domain.
The matrix shown below is a suggested mapping to demonstrate the prioritisation of the key issues identified, drawn upon from the literature. The prioritisation is illustrated highlighting the risk of an issues occurrence together with the potential impact to user take up of any KM intervention or information system development.

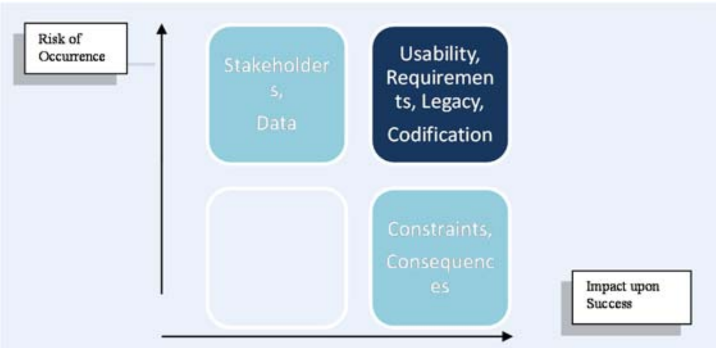

Figure 2. Prioritisation of key issues identified

It is interesting that the take up issues are very diverse and wide ranging, hence the focus of this paper. It appears that, prevalent within KM systems for design engineering, are complex or legacy data sets and large scale information flow processes, existing together with knowledgeable or experienced users, hence the specialist requirement. Designing systems to replicate all of these facets is challenging.

3. The Intervention case study

The following case study is an example of a Knowledge Management intervention in the in-service department of a large transnational aerospace company, who have to design solutions for a wide variety of repair situations. Although the work load of the department is expected to increase significantly, the same number of personnel will be expected to continue to provide a high level of customer service and achieve similar KPI's (key performance indicators) in the future. The intention of the project was to automate parts of the design engineering process to support engineers to reduce turnaround times. The system was largely developed as an incremental development upon the current tools used in the in-service team. Following a description of the background to the intervention and what was actually implemented, section 5, reflects on the lessons learned from this intervention with respect to the eight issues previously identified.

3.1 In-Service design team

The In-Service team use historic information to support the repairs designed for new cases. Some of this information is paper based due to age of the historic files. A large percentage of the original paper files have already been migrated to a new digitised repository. Team members refer to the paper based or digitised files as part of the process to support the design of a new repair case. The main requirement for the resulting development was to produce a tool that looked and felt like the "Google" search application, to reduce the time an engineer spent looking for a suitable historic file. Due to the organisational constraints a decision was made to modify the use of existing tools to improve the current information system.

The existing, very extensive and widely used, system uses a standard spreadsheet approach to record summarised information regarding the digitised historic data files together with a redirection link to retrieve the historic file stored in ".pdf" format. Filters are then manipulated within these files to text search for related case information, leading to the retrieval of a similar case. Paper files would have to be searched manually using the engineers recall to locate related files. This process was a source of much frustration due to the laborious task of searching and the length of time taken to find a matching case.

The tool developed is based on the work reported in [Xie et al. 2011] and extended the functionality of a visual basic script, embedded within a macro in the excel spreadsheet, in a manner that relates to the issues discussed above. The matching cases were linked by a similar redirection link to directly retrieve the digitised file. A simple XML-based taxonomy is implemented to support the provision of a library of semantic terms when entering text to the search tool bar. This enabled the automation of searching for similar terms, shortening the length of time to find a suitable case. The critical thing here is that although the developer remains to support the application and its use, key functions such as the update of terms to the semantic library have been successfully passed to an in-service team member.

It should also be noted that due to the reduction in the time required for research using the application, the team involved now use the tool consistently as part of their search process. The migration of the system to another team in America has successfully taken place and deployment is now planned to further teams in Germany and France.

3.2 Observations on the impact of the tool

Evidence that the case studied system (in section 3) is now used frequently and consistently by the expected users is acknowledgement of its usability and functional success (issues 2 and 7). The migration of the tool by management into further departments and applications suggests the tool must contribute to successfully reduce the processing time for each repair case as requested, thus improving departmental KPI's (issue 2 and 5). The simplicity and accuracy of requirements elicited and system design (scope of project) limiting the number of system interfaces (affecting performance), all contribute to the achievements of the system (issues 2 and 3). The inclusion of the semantic library to the application increased the functionality further, to aid both the capture of knowledge from the experienced administrator and to support the transfer of knowledge to less experienced users (issue 1 and 7). Rule 2 from Schneidermans' Eight Golden Rules of interface design [Schneiderman 1999], infers that an interface should support both the experienced or naïve user. The semantic prompt function, provided by the system, in the case study is consistent with this rule, thus improving ease of use for all.

Case Study Learning	Issue Addressed	Literature Reference
Legacy data integration into useful digitised form increases data accessibility and integration into current process, feeding forward to develop new "best practice" within the department.	• Legacy Data	[Ambler 2010]
Semantic tool integration reduces need for experience to understand search terms, improving search efficiency. This aids expert knowledge transfer coding experience in a meaningful manner.	• Codification	[McMahon et al. 2004]
The use of excel macro's to take copies of text for local processing keep the transaction overhead to a minimum (reducing network traffic overhead and increasing system reliability).	• Usability • Data and Application	[Ambler 2010]
User engagement throughout entire developmental lifecycle improved awareness of the intervention and education of the benefits to users. In the moment and continuous feedback from users has been integrated into the development ensuring stakeholder buy in.	• Usability	[Nielson 1998]
Provision of continued user support into the future increases user trust in the development and post implementation changes ensure a system "fit for purpose".	• Usability	[Schneiderman 1999], [Rubin 1984]
Super User retention of administration rights for the system remains within the department thus passing ownership of the tool any updates to the users. This enables the further development of the tool to capture process or practice updates and keeps the application and use of the system up to date with departmental need.and	• Usability • Requirements • Consequences of Automation	[Laudon and Laudon 2003]
The simple viewing/search interface and the retention of existing functionality (retrieval of historic .pdf documents) adheres to usability principles for design. Facilitating "ease of use", for both experienced and inexperienced users.	• Usability	[Schneiderman 1999]
Regular communication in person with all system stakeholders (users, management and knowledge management teams) about the development and an extended transitional support period for users has increased confidence, awareness and system utilisation.	• Stakeholders • Usability • Requirements	[Nokes and Kelly 2003], [Bocij et al. 2003]
The developer has observed the team process and practices in person and over an extended period of time increasing the time taken for requirements elicitation, thus increasing the accuracy of the requirements and adding experience to the codification process.	• Codification • Requirements	[Boddy et al. 2002], [Laudon and Laudon 2003]
The legacy data needs only to be read not written, the integrity therefore remains as the Search function uses text copies compatible with current data format. Also reducing network overhead considerations.	• Legacy Data • Data and Application	[Ambler 2010]
The reuse of the existing information infrastructure and toolset to extend its functionality means the system remains compliant with current company IT strategy and constraints. This eases system mobility internally as the toolset used remains compatible with internal systems removing the need for additional legacy system interface requirements, thus increasing possibility of migration to wider teams.	• Legacy Data • Wider Constraints	[Bocij et al. 2003]
The departmental Key Process Indicator for turning around daily queries has remained achievable (>97% of daily queries). This is a significant achievement given the number of aircraft in service (therefore daily queries) has increased and the number of experienced staff has decreased. This is due to a reduction in the time overhead for searching for information (historic data) to design a repair.	• Requirements • Consequence of Automation	[Laudon and Laudon 2003], [Boddy et al. 2002], [Dillon 2001]

Figure 3. Case study learning

The working with users closely for a significant length of time increased their trust (issue 3 and 6) developing confidence that the system was being designed support their process (issue 6 and 7), automating the laborious tasks [Laudon and Laudon 2003]. The simplicity of the tool interface and similarity of the application to a "Google" search bar make the human interface appear familiar and intuitive for use [Neilson 1998] (issue 7). The continued engagement of the users from an early stage in the development increased their awareness of the tool's existence and purpose (issue 7). The extension of a currently used application also reduced the need for users to require education about the application (issue 7 and 8). Both of these factors increase the usability of the tool. Management have clearly used the implementation of the application for usability and functionality testing, before deploying the system further (issue 5).
The observations below in Figure 3 are synthesised in an industrial context working closely with the developer and being embedded in the team post intervention implementation for a period of approximately two months. The observations have been made through questioning and observing both the end users, administrators, senior management and the developer.

4. Discussion of lessons learned

It has been demonstrated that within the engineering domain the projects are typically very large scale, combined with individual complex process [McMahon et al. 2004]. These add to the performance constraints, the involvement of limited key user groups and difficulties eliciting and defining the requirements for the system. However, it is important when developing an information system that there are clearly defined metrics against which the success of a system can be measured [Dillon 2001]. The priority of key issues found in the ranking in Figure 2, suggests that the issues predicted to be most frequently occurring and influential to take-up are i) Usability considerations, ii) accuracy of Requirements elicited and meeting these Requirements, iii) Codification of current process and iv) practices and Legacy Data integration. The influence of these factors in the successful development of a KM intervention can be seen within the observations made from the case study (Figure 3). The frequency of the issue being addressed by the case study (Figure 3) is demonstrated in Figure 4, where the most addressed issues correlate to those ranked as most risky and most influential (Figure. 2).

	Usability	Requirements	Legacy Data	Codification	Data and Application	Automation Consequences	Stakeholders	Constraints
Frequency of Occurrence (from fig.3)	6	4	3	2	2	2	1	1
Matrix Rank (from fig.2)								

Figure 4. Frequency and ranking of key issue addressed by case study

The success of the case study and the predicted priority of key issues suggest that for a successful uptake of KM intervention, the development process should be driven by identifying and addressing those factors having the highest impact upon acceptance criteria and the highest risk of occurrence. However, for all eight issues identified none are categorised as low risk and low impact, thus it must recognised that they all influence the development of a system and its success, to some degree.

4.1 Next steps

Future research will look at the validation of a means to prioritise issues considered as highest risk and most influential upon the take-up of KM interventions. This should include the possibility of defining 'core' requirements for design engineering systems (such as legacy data integration). This will be a key to the success of implementing systems that are fit for purpose and therefore consistently taken-up. Key areas to direct future work include i) integrating the areas of Knowledge management and systems analysis, ii) taking a holistic approach to analysing engineering systems, iii) developing open standards to integrate with future generations and iv) integrating this with end user involvement in development.

5. Conclusions

We began by identifying from the literature eight key issues in the take up of knowledge management intervention for engineers: *constraints, consequences, requirements, codification, stakeholders, usability, legacy and data.*

We have then defined these areas in more detail and suggested a prioritisation relevant to KM interventions within design engineering, as supported by the literature. The case study that followed was documented to demonstrate the best practices we can learn from experience to the impact of these issues in industrial application. In the discussion we have highlighted the impact and priority these issues may have upon the success of knowledge management intervention. The suggested prioritisation of the issues from the literature has been partially validated by the case study observations, thus validating the consideration of their importance in KM intervention for the future.

By using the industrial lessons learned and existing literature, accurate predictions can be made to prioritise issues thus driving the focus of a particular intervention to improve its successful take up in the work place. It has been shown that although all of the take-up factors influence the success of a project, there are four main factors impacting upon the success of the intervention presented in section 3. These are i) usability factor, ii) codification for accurate requirements definition, iii) meeting those requirements for user acceptance and iv) support for integration of legacy systems and data. It is expected that the eight issues will be further developed and refined in the next implementation and development of the system in other parts of the case studied organisation.

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