Comparison of Knowledge Management and CMM/CMMI Implementation

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ABSTRACT

As software project’s deadlines have been missed, budgets grossly overspent, and resources not adequately used to its full potential, the need for a structure or model to assist in implementation have become very apparent. CMM and CMMI were developed to address these situations. In addition to structuring tasks, organizations face a daunting task of organizing and maintaining the knowledge that exists within them. Such an effort is essential for organizations to gain leverage from their knowledgebase. The process used to organize and maintain the knowledge base is aptly called Knowledge Management. In this study we highlight the symbiotic relationship between Knowledge Management and CMM/CMMI implementation in organizations.

INTRODUCTION

In a hyper competitive environment like software development industry, knowledge-based theory says that the possession of the knowledge and using it efficiently provides a sustainable competitive advantage. Innovation, the source of sustained advantage for most companies depends upon the individual and collective expertise of employees. Some of this expertise is captured and codified in software, hardware, and processes. Yet tacit knowledge also underlies many capabilities – a fact driven home to some companies in the wake of aggressive downsizing, when undervalued knowledge walked out the door! [1].

Knowledge management is an emerging discipline that promises to capitalize on organizations’ intellectual capital. The concept of taming knowledge and putting it to work is not new; phrases containing the word knowledge, such as knowledge bases and knowledge engineering, existed before KM became popularized. Software engineers have engaged in KM-related activities aimed at learning, capturing, and reusing experience, even though they were not using the phrase “knowledge management.” KM is unique because it focuses on the individual as an expert and as the bearer of important knowledge that he or she can systematically share with an organization. KM supports not only the know-how of a company, but also the know-where, know-who, know-what, know-when, and know-why.

The Capability Maturity Model (CMM) for Software and Capability Maturity Model Integrated (CMMI) describes the principles and practices underlying software process maturity and helps organization have visible ongoing processes, which have very well defined steps. In mature organizations it is possible to measure the process and product quality [1][2].

We believe that the even though knowledge management and capability maturity model studies are different approaches for the attaining sustained competitive advantage, there is a symbiotic relationship between the two implementations. Understanding the relationships between the two processes will help us implement both these processes more efficiently. In this paper, we first introduce CMM and CMMI concepts. This is followed by a discussion of Knowledge Management fundamentals. We then provide a comparison of CMM/CMMI and KM implementation. Finally, the conclusions and business implications of this study are presented.

CAPABILITY MATURITY MODEL (CMM)

The Software Engineering Institute (SEI) was established by the government in 1984 to address the Department of Defense’s (DoD) need for improved software and to define standards for software development. The government has always been a major purchaser of software and has had to deal with poor software, missed schedules, and high costs. SEI developed the Capability Maturity Model (CMM) in an effort to provide the government with a tool for gauging how well a contractor’s processes are defined. The SEI CMM is a five-level model that attempts to quantify a software organization’s capability to consistently and predictably produce high-quality software products. "The model is designed so that capabilities at lower stages provide progressively stronger foundations for higher stages. Each development stage or ‘maturity level’ distinguishes an organization’s software process capability."[3] Key process areas (KPA) are identified for each maturity level. "When an organization
collectively performs the activities defined by the KPAs, it can achieve goals considered important for enhancing process capability.\cite{7}

**How to Reach CMM Level Rating**

In order to improve its software process, an organization can initiate a software process assessment (SPA). This process involves 6 to 8 senior managers of the organization and one or two coaches from the SEI or SEI-licensed assessment vendor. The assessment generally is conducted in 6 stages: 1. **Selection Stage**- The organization is identified as an assessment candidate and the qualified assessing organization conducts executive-level briefings. 2. **Commitment Phase**- A commitment is made by the organization to participate in the full assessment process. 3. **Preparation Phase**- Assessment participants are identified and briefed. The assessment team receives training and the on-site assessment process is planned fully. It is at this time that the maturity questionnaire is completed. 4. **Assessment Phase**- The on-site assessment is completed in about 1 week and then this team meets to formulate preliminary recommendations. 5. **Report Phase**- A report, made by the assessment team, is presented to senior management. This will include the team’s findings and recommendations for action to be taken. 6. **Assessment Follow-up Phase**- With the help of the assessment organization, the organization that was assessed develops an action plan. In approximately 18 months, a reassessment is done to evaluate progress and maintain the software process improvement cycle.

The assessment process is completely voluntary and confidential. However, the software capability evaluation (SCE) is generally performed by an outside organization such as the government or a software contractor. The organization that is trying to acquire a contractor to produce their software will use this evaluation to help them get a better understanding of the engineering practices of the bidder. The bidding organization must first complete a maturity questionnaire. An evaluation team then uses the questionnaire to help select representative practices for detailed examination \cite{4}.

**CAPABILITY MATURITY MODEL INTEGRATED (CMMI)**

CMMI was sponsored by the Under Secretary of Defense for Acquisition, Technology, and Logistics. CMMI was developed due to the fact that many process improvement models had been developed to address different disciplines. Organizations that wanted to use process improvement models had difficulty in determining which one to use to meet their needs or, more likely, one model was not capable of addressing all their needs. Organizations also found that implementing numerous models was not cost or time efficient. As this was a common problem many organizations came up against the need for a more integrated model became apparent. CMMI was developed to address these problems. \cite{12}

CMMI is being called the CMMI Product Suite because it is not limited to one discipline or area in which it can be implemented. Areas of implementation include project management, software engineering, systems engineering, integrated product and process development to name a few. \cite{14} There are several considerations to be made when deciding whether to upgrade your organization to the CMMI. Such factors include where your organization is at in the current CMM levels. If you are in the process of moving up to a higher level, it is suggested that may not be the best time for the change over.

**Comparison of CMM and CMMI**

CMMI was developed to build on the “best practices” of CMM. It has been felt by some that CMMI will be successful where CMM could not because most organizations that implemented CMM used it while “still entrenched in a default waterfall model mentality”\cite{15}. There have been some modifications to the Process Areas, which include some additions, and some areas have been combined. What is considered a “generic goal” has also been added to each maturity level. \cite{15}

In CMMI changes have been made to CMM’s maturity Levels 2 through 5. The Key Process Areas added the CMM levels in CMMI are: Level 2: Measurement and Analysis, Level 3: Risk Management, Validation, Technical Solution, Requirements Development, Product Integration and Decision Analysis and Resolution. In Maturity Levels 4 & 5 there are no new KPAs added. However, some of the KPAs have been combined. In Level 4, the Quantitative Process Management and Software Quality Management KPA have now become Quantitative Project Management and Organizational Process Performance. In Level 5, Technology Change Management and Process Change Management KPAs have been replaced by a new KPA called Organizational Innovation and Deployment. In this restructuring Causal Analysis and Resolution replaced Defect Prevention as a KPA\cite{14}.
Benefits of CMMI and CMM

According to the Carnegie Mellon Software Engineering Institute, some of the benefits of implementing CMMI that companies are reporting are as follows: While business objectives have been the concern of management, there is now more cohesion between both management and engineering to attain these business objectives using CMMI. Organizations are better able to see if their project is on target with customer expectations. Also reported were more "robust high-maturity practices." Carnegie Mellon does concede that because CMMI is relatively new there is limited empirical data that shows the quantifiable benefits.[14]

Hughes Aircraft and Raytheon both implemented CMMI and found it beneficial. Hughes Aircraft Software Engineering Division had a two year program to raise itself from a level 2 to a level 3 organization. They invested 78 man-months and $400,000 from 1987-1990. Hughes standardized uniform data definitions across projects, which were then used to track cost estimates, actual costs, errors, and schedule performance.[4] Hughes also places a priority on training its employees, making it mandatory rather than a launch pad for promotion. Raytheon’s improvement program focused on policy and procedures, training, tools and methods, and a process database. Their process improvement model involves a 3-phase process-stabilization, process-control and process-change process.

In general, organizations have reported improvements in their software development process. And the ROI has been quite spectacular. Basically, an increase in productivity and a decrease in cost are benefits afforded to those contractors who implement CMMI/CMMI practices. "Published studies of software engineering improvements measured by the CMM indicate significant cost savings or profit return. This implies that software testing and maintenance costs were reduced, since the software better met verification and validation requirements..."[7]. Organizations, as a general rule, saw an increase in the quality of the software product they were developing. This was accomplished through the company’s efforts to build a maintainable product, and through their efforts to seek improved quality as well as stabilization of their schedules, meeting commitments, and working to meet or exceed deadline [3]. Those organizations that are continuing to improve themselves through CMMI/CMMI efforts give themselves a competitive edge over other organizations due to the fact that CMMI/CMMI has become so widely accepted and respected. Software contractors that do not use CMM or the CMMI Product Suite are more likely to have their projects come in over budget, missed deadlines, and their products may be inferior to those who use CMM.

Hughes Aircraft: Hughes published predictability improvement data indicating the Cost Performance Index (CPI) went from .94 to .97 when implementing CMMI maturity improvements.[10] This is based on a 50% reduction of its cost-performance index.[4]. Raytheon has reported their organization can now estimate budget and time to within +/- 3% with CMM, reducing overrun by as much as 40%.[9] Raytheon initially invested almost $1 million annually on process improvement and in return received a 7.7:1 ROI. This translates to a $4.48 million return on $.58 million. [4] Raytheon also experienced savings (1995-1998) from less rework because of better inspection procedures. It is estimated that Raytheon reduced the cost of rework by $9.2 million. Raytheon estimates that its organization achieved a 144% productivity increase over this same period. Raytheon also so that the use of CMM improved their competitive position, there was higher employee morale, and lower absenteeism and attrition were secondary benefits of using CMMI [10]. While studying the disadvantages of CMMI/CMMI implementation we find that companies are now subjected to what some may call an intrusion into their “private” environment during the SCE process. There is also concern that the SCE that are being used are not the ones that were published and that no two speakers on the topic of SCE described its methods in the same way. [4] Companies listed 5 common concerns with the SCE process, which included the use of different SCE methods. They took into question the training and subsequent qualifications of those conducting the SCE’s. It was felt by companies that the SCE teams were intimidating personnel and did not provide feedback in a timely manner. The companies also cited ambiguous compliance criteria as a concern and also the discrepancies between SPA and SCE results. [4]

KNOWLEDGE MANAGEMENT

Knowledge Management (KM) is an organizations ability to gather, organize, share, and analyze the knowledge of individuals and groups across the organization in ways that directly impact performance. It is about helping people communicate and share information. As a matter of fact, it is about getting the right information, to the right person, at the right time. Knowledge is commonly distinguished from data and information. Data represent observations or facts out of context, and therefore not directly meaningful. Information results from placing data within some meaningful context, often in the form of a message. Knowledge is that which we come to believe and value based on the meaningfully organized collection of information (messages) through experience and
communication. Knowledge can be viewed both as a thing to be stored and manipulated and as a process of simultaneously knowing and acting - that is, applying expertise. As a practical matter, organizations need to manage knowledge both as object and process. Knowledge can be classified as explicit or tacit knowledge [16]. Explicit knowledge would include such things as patents, customer data, and trademarks. Tacit knowledge is described as not being as easy to identify. It is the knowledge that people carry around in the minds that need to be laid out and managed [16]. A company’s greatest assets may not lie in the products they make but the knowledge of the people who produce those products. Therein lies the importance of having a method of collecting, managing, and maintaining that knowledge. Again, in order for an organization to be able to handle their data there must be a process for collection. This is where KM also struggles with implementation as did CMM and CMMI. There has to be buy-in from others and your organization will be faced with the innovators, the adopters, the early majority, late majority and the laggards. One way a company can get a level of buy-in from their employees is to offer an incentive program. However, Santosus and Sarmacz [16] point out that the buy-in may only be for the incentives and therefore, less concern for the quality of the knowledge collected or how it is managed.

Davenport [17] points out that “Knowledge Management is expensive, but so is stupidity.” According to him, there are several KM activities required in order to build and maintain a good knowledge database. They include; collection of data, editing of that data, categorization of the data, developing infrastructures and applications for the distribution of the data and, training and education employees on the collection and use of the data.

Ruggles [18] has developed a few essential component of KM. The first listed is the development of new knowledge. Second is accessing outside sources, third is using the knowledge that has been attained when decision-making. The next component listed is entrenching that knowledge in the products and services of the organization. The fifth essential component listed having that knowledge in documents, databases, and software. The next component listed goes along with the first. Not only do you want new knowledge generated, it may be that your organization will need to help assist that growth process by providing incentives. Once the knowledge is collected (which is always an ongoing process), it needs to be shared with other parts of the organization for them to experience growth. Finally, you should be able to measure, to some degree, the benefit of Knowledge Management on your organization. Measurement can be difficult due to the intangible nature of some of the benefits that will befall your organization.[18]

RELATIONSHIP BETWEEN KMM AND CMMI/CMMI

There are four omnipotent pillars for KM: people, processes, technology and leadership [21]. Several KM practitioners include other important dimensions such as strategy, infrastructure and KM Practices. This is different from the scope of CMM which only focus on the software process and based on technology solutions. There are two distinct knowledge strategies: personalization and codification. Personalization focuses on linking people who know with people who want to know. Codification creates explicit knowledge objects (in the form of documents etc) and makes them available to those in need of such knowledge. The business space in which either of these strategies can be deployed is very different. As we mentioned above, these strategies are very useful if applied in CMM levels.

In this section, we will provide a few examples that illustrate the relationship between the CMMI/CMMI and KM implementations. See Table 1, for complete analysis of this relationship. In Table 1, we show how CMMI/CMMI and KM affect each other. In Level 2 of the CMMI the new KPA is Measurement and Analysis. The purpose of this KPA is to “develop and sustain a measurement capability that is used to support management informational needs.” [17]. This KPA in itself supports the need for knowledge management. It shows the need for a measurement procedure to be developed and recorded for future use. Something has to be established in order for it to be measured against in the future.

In Level 3 of the CMMI the new or combined KPAs are Risk Management, Validation, Technical Solution, Requirements Development, Product Integration, and Decision Analysis and Resolution. In the KPA of Risk Management the most obvious use of KM is learning from previous mistakes. You want to catch potential risks before they occur. If KM is being used, the mistakes of products past should be well documented as a “what not to do” for future use. If not, your organization may fail to making mistakes that could have been avoided. For validation purposes, there will also be a benefit to knowledge of previous projects and what worked for them. For validation, there too needs to be a measurement to validate against.
The Level 3 KPA of Technical Solutions is to design, develop, and implement solutions to requirements. As with CMM, CMMI requires a lot of documentation. Since the documentation is already being done it makes sense to use that documentation through Knowledge Management.[20] In doing this, you will have available to you several approaches that can be taken and your organization can choose which approach would be most appropriate to take.

The KPA of Requirements Development is to be used for the production of an analysis of customer, product, and product-component requirements. It is during this time that it is determined what the customer's needs are and how to go about best meeting those needs. It is important to understand exactly what the customer is wanting.[18] One way in which KM can be used is if a product such as what your customer wants has already been designed, you may tap into your knowledge base and have an idea of whether your customer's desires are feasible. This will save a lot of time due to not going forth with requirements that you later find out are not possible to meet. Same goes for product and product-component reuse. The purpose of KPA Product Integration is "to assemble the product from the product components, ensure that the product, when integrated, functions properly, and delivers the product," according to Zubrow. As product-components become more and more complex as products, seamless integration and delivery can be difficult. With the help of KM and the iterative process rather than a one time integration, the process can become more flawless. But this comes with practice and the use of prior knowledge. As with most anything in life, the more a task is attempted and completed, the quicker and more efficiently we can do it the next time around. The final KPA for CMMI Level 3 is Decision Analysis and Resolution. "The purpose of Decision Analysis and Resolution is to analyze possible decision using a formal evaluation process that evaluates identified alternatives against established criteria," [20]. The actions that take place during the formal evaluation process include:

- Criteria need to be established for alternative evaluation.
- The identification of other options.
- Deciding which methods will be used in the evaluation of the alternatives.
- Using the established criteria to evaluate the options.
- The selection of the most appropriate solution to use.[20]

In being able to perform the last three actions, a knowledge repository would likely have to have been established. Your organization's knowledge repository could be most helpful to you in this KPA if it has been set up through an organized collection and editing method such as that with Knowledge Management.

The software organization in CMM level 4 should have a firm foundation for introducing measurements and statistical management. Management should now pay more attention to quantitative planning and process control. One of the best ways to evaluate a software organization is to examine the quality of its products. Product quality is thus a key measure of the software process. It provides a clear record of development progress, a basis for setting objectives and a framework for current action. KM emphasizes on 1. elicitation and documentation of the tacit knowledge of experts (knowledge acquisition), 2. creation of electronic repositories, such as knowledge bases or organizational memories, and 3. use of tools for electronic collaboration, data searching, warehousing, mining, and discovery. All three features of KM will help in coming up with a quantitative measure that level 4 in CMMI/CMMI demands. On the other hand, organizations that are already at level 4 of CMM will have the data for KM in place to organize. Organizations at CMM level 5 have already obtained pretty mature software processes and much "knowledge" developed in the previous levels. How to integrate the knowledge from different levels and different situations as well as using it efficiently is crucial for organizations to continuously improve processes. The three Key Process Areas of level five are Defect Prevention, Technology Change Management, Process Change Management. We will evaluate the activities in each KPA in terms of the application of Knowledge Management.

We think that KM technique is pretty important in Defect Prevention KPA because the data transfer is between projects and is from knowledge practitioner to users. If the knowledge can be efficiently used by this mature organization, not only defects can be defined and traced easily, the defect trends can also be systematically analyzed and predicted. KM should also apply to the Integrations of the software management and software product engineering key process areas in order to efficiently define the root cause and the future activities. Due to the knowledge in this KPA is based on the understanding of the project's defined software process and how it's implemented, both the project and the organization can obtain enormous benefits currently and in the future if KM is well used.

The goal achievement of Technology Change Management KPA should be also deeply involved with KM technology. The reason is that the purpose of Technology Change Management is to identify new technologies and transition them into the organization in an orderly manner, and this is one of the identified functions of KM technology. The manage group
need to exchange their understanding of the existing technologies and introduce and evaluate the risks and the feasibilities of new technologies. The step both require completed maintenance history and knowledge transferring in terms of software-related technology innovations, evaluating and experimenting. Particularly the selections, changes and the way to incorporate the new technologies into the current project and to fit the organization’s standard software process need high-quality knowledge exchanging and management technology.

The continuous process improvement is planned in the activities of Process Change Management KPA, and the participation is organization-wide. Therefore, knowledge exchanging should achieve the peak of the organization history. And efficient KM technology use is especially valuable in this step. It concerned with the training and the establishment of incentive programs to enable and encourage every member in the organization to join the process improvement. To join the knowledge and powers of each individual can form a tremendous strength to drive improvements in both the process and the organization. A well-defined KM technology for this organization can help to achieve this goal under the organization culture and need. Efficient knowledge exchanging and transferring not only shorten the time consuming of the process improvement, but also break the barriers inside the organization and decrease the cycle time of the product development. The potential benefits are countless.

In this Optimizing level, Continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies. Predictability, effectiveness, and control of an organization’s software processes are believed to improve as the organization moves up these five levels. While not rigorous, the empirical evidence to date supports this belief.

In the above discussion, we are starting to see a pattern here. Documentation is required at every level and at every Key Process Area. However, in order to move up in CMMI, there has to be shown a proven record of being able to do the same type of project and get predictable results. This can, and likely should, be done through the use of Knowledge Management.

CONCLUSION

CMMI focus on software process, which can affect people’s effectiveness and effective technology adoption. These will help the organization attain its business objective. On the other hand, to apply KM technology in CMMI levels can bring enormous tangible and intangible benefits. These two area studies have dramatically different scope but similar methodologies such as maturity models and the evolution through the processes. Interestingly, in the recent studies, one has taken effects on the other. We can see CMMI levels and models applied to some KM models, and KM techniques applied to CMMI activities. No matter how they affect each other, we believe that the debates and learning from each other should modify the studies to reach a more mature “model!”. Further, to learn from both the two studies can obtain the knowledge and clear concept of the operation of the organization as well as problem solving capability. The CMMI provides a conceptual structure for improving the management and development of software products in a disciplined and consistent way, while KM provides a broader view of knowledge use and its power. When Knowledge Management is used with the Capability Maturity Model or Capability Maturity Model Integrated, the organization become more efficient and effective in the development of the projects they are used on. The organization is able to maintain better documentation and management of this information for use whenever needed. KM can save an organization hundreds of hours due to its ability to collect and organize knowledge resources and making these resources accessible with relative ease and speed.

REFERENCES


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TABLE 1. Relationship between CMM/CMMI and KM

<table>
<thead>
<tr>
<th>CMM/CMMI Levels</th>
<th>CMM/CMMI’s effect on KM</th>
<th>KM’s effect on CMM/CMMI</th>
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<tbody>
<tr>
<td>Level 2:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Requirements Mgt</td>
<td>• This is still a learning process for the organization and is likely there is no established routine or process for the collection of information at this time.</td>
<td>• Still no systematic way to approach KM</td>
</tr>
<tr>
<td>• Software Project Planning</td>
<td>• Justification of expenditures on KM initiates.</td>
<td>• Avoid over-evaluation of new ideas</td>
</tr>
<tr>
<td>• SW Project Tracking &amp; Oversight</td>
<td>• The structure of the organization can greatly impede the use of KM in that there is no buy-in from upper mgmt.</td>
<td>• An organization attempting to incorporate CMM is still in the learning phase and may feel overwhelmed trying to integrate KM also.</td>
</tr>
<tr>
<td>• SW Subcontract Mgt</td>
<td>• Organizational culture not likely set up for information sharing.</td>
<td></td>
</tr>
<tr>
<td>• SW Quality Assurance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Software Configuration Mgt.</td>
<td>• KM could be enhanced by CMM at this level due to the documentation that is required by CMM. That knowledge should be collected anyway. KM that knowledge would then be organized for later use.</td>
<td></td>
</tr>
<tr>
<td>• Measurement &amp; Analysis</td>
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| Level 3          |                          |                         |
| • Organization Process Focus | • The Organization is to provide the resources and long-term commitment for CMM. It still may not be clear to the decision makers the importance of KM and therefore, the budget may not include the resources necessary for implementation. | • Avoid over-evaluation of new ideas. |
| • Org. Process Definition | • The skills and knowledge of the people are still in the development phase. | • Over documentation. As more documentation is required, it may become tiresome for employees and less likely to be done. |
| • Training Program |                          |                         |
| • Integrated SW Mgt. |                          |                         |
| • SW Product Engineering |                          |                         |
| • Intergrup Coordination |                          |                         |
| • Peer Reviews |                          |                         |
| • Risk Mgt |                          |                         |
| • Validation |                          |                         |
| • Technical Solution |                          |                         |
| • Requirements Dev. |                          |                         |
| • Product Integration |                          |                         |
| • Decision Analysis & Resolution |                          |                         |

| Level 4          |                          |                         |
| • Quantitative Process Mgt. | • At this level also, CMM requires meticulous documentation. The collection and distribution of knowledge at this level by KM would greatly enhance the CMM effort. This is considered the DEFINED level in CMMI. | • KM Impeded by KM |
| • SW Quality Mgt. | • An activity in Integrated SW Mgt is using the organization’s historical data. This information could already be available if used in conjunction with KM. | • Avoid over-evaluation of new ideas. |
| • Quantitative Process Mgt. & Org. Process Performance | • The only obvious impediments at this point would be not allowing resources for the KM initiative or still not identifying the intangible benefits. | • KM Impeded by KM |

| Level 5          |                          |                         |
| • Defect Prevention | • The organization should be collecting process performance data at this level. This is a good time for the use of KM to organize the information for further use. | • KM Impeded by KM |
| • Technology Change Mgt. |                          |                         |
| • Organizational Innovation and Deployment |                          |                         |
| • Process Change Mgt. |                          |                         |
| • Organizational Innovation and Deployment |                          |                         |

CMM/CMMI Impeded by KM

- The only obvious impediments at this point would be not allowing resources for the KM initiative or still not identifying the intangible benefits.

KM Enhanced by CMM

- A tool used by KM is Communities of Practice. It is at this stage in CMM/CMMI established relationships with community resources could be a boon for the use of KM.
- Another tool used by KM is that of Knowledge Centers. This should be well established in a level 5 organization and could therefore transfer on to KM. This includes connection people with each other as well with information in documents and databases.
- Common causes of defects are identified and documented. Well-organized information harvested through KM will have this knowledge readily available.