The MKN Project: Knowledge Retention and Recovery in Chemical Manufacturing R&D

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Abstract

Chemical manufacturing companies are being challenged to retain and replace expertise during the "crew change" or industry-wide, generational turnover of professionals. The impacts of lost expertise are magnified in R&D groups that rely on experience and lessons learned to maintain a safe work environment when developing and testing new processes and products. Training, mentoring, and online information sharing sites are a partial solution for transferring information and experience, but novel approaches are being developed that accelerate and improve the retention, sharing, and recovery of both explicit, implicit and tacit expert knowledge, effectively reducing the time to competency for less experienced employees.

This presentation will introduce the Manufacturing Knowledge Network (MKN) method for improving safety by enabling expert knowledge sharing using an online, process-oriented, visual method. Real-world scenarios will be presented in order to highlight how expertise impacts safety in chemical manufacturing R&D; and how safety incidents can be prevented by improving knowledge sharing and the transfer of lessons learned. Domain visualization examples will show how understanding and communication are improved by visual representations that provide contextual information and functional relationships between domain elements.

For recovering and accessing external expertise, the presentation will include how to access knowledge sources outside of the subject department or organization; so that retired or relocated experts, vendors, consultants, and academic institutions can contribute relevant knowledge to a given domain. The business value of this approach will be discussed.

Keywords: Knowledge retention, knowledge recovery, human capital, mental model, visualization, knowledge network, process safety

Knowledge and Experience Matters

In "Too Big to Know", David Weinberger[1] presents the case that business, science and the government are learning how to use networked knowledge, the internet and crowdsourcing as sources to understand and manage growing complexity and make smarter decisions than they could when relying on individual experts. This is a growing concern in the years ahead as Boomers retire, taking decades of knowledge and experience when they leave; and Millennials, making up 50% of the workforce by 2020[2], enter with gaps in STEM knowledge, problem-solving, teamwork and critical thinking skills.

Weinberger is right: the smartest person in the room no longer has sufficient experience to handle increasingly complex cognitive tasks. We have to rely on the room itself – the collected expertise of practitioners who have acquired a wide range of experience over their years of work. A Manufacturing Knowledge Network is one example of this type of collaborative structure that facilitates knowledge-sharing, learning and development of new ideas.

Strategic consequences of knowledge loss and poor collaboration for chemical manufacturing R&D organizations are especially large on both safety and employee effectiveness in chemical manufacturing R&D. Several literature surveys[2-4] show that safety incidents occur 10-20 times more often in industrial pilot plant or laboratory settings than in full-scale, commercial plants. R&D employee effectiveness is especially sensitive to expertise losses in experimental work requiring specialized instrumentation or analytical methods.

Shared process or product insights and incorporation of past lessons learned can result in significant time and cost savings. This knowledge flow can be realized by linking retiree, vendor and academic resources to a network available to a less-experienced researcher. Senior management investment and promotion of this type of approach can be a critical success factor in establishing a robust safety culture in chemical manufacturing R&D.

Effect of Retirement and Millennial Crew Change on Human Capital

Major shifts in workforce demographics are underway. With economic recovery, Boomers are beginning to think seriously about retirement or job change. Meanwhile, the Millennial (Gen Y) generation will swell to 50% of the workforce by 2020[5]. What affect will these changes have on an organization's human capital?

Two predictive factors for human capital are work experience and job tenure[6]. Work experience measured as the total number of years of work is a fairly obvious component. Over a long career, individuals will gain a wide range of skills and experience. Additionally, a long work history develops knowledge about general business and specific industry practices, and useful experience with how "work gets done" in an organization. This improves the ability for making good decisions.

Job tenure is a measure of how long a person works for a specific company or in a specific role or function. Studies[7] have compared typical job tenure of Boomers, Gen X and Gen Y. Millennials have a very short tenure, tending to work 2-3 year "gigs" for one company before moving on to new opportunities. Boomers have greater longevity in a specific position, averaging about seven years. In addition to longer average job tenure, many Boomers have spent much of their career (10-20 years or more) becoming experts or thought leaders in a specific discipline. Millennials do not seem to be following this pattern. As organizations trend towards a contractor-based workforce, this tenure factor will become even more significant.

We define "human capital factor" (HCF) as the product of work experience and job tenure. The longer a person works, and the longer that work is in a specific area, the greater will be the person's expertise and impact on business results. The shorter work history and job tenure of Gen Y suggests that their human capital contribution will be less than that of the inexperienced staff. Over the next 10 years, HCF will drop significantly (20%) in the U.S. workforce (Table 1)

	2014 Workforce (%)	2020 Workforce (%)	2024 Workforce (%)
Boomer	30	19	10
Gen X	35	34	31
Gen Y	35	47	59
Human Capital	**1750**	**1590**	**1400**

Table 1. Predicted U. S. Workforce Human Capital Due to Generational Crew Change

The impact of the crew change is more severe in established industry sectors such as energy, manufacturing and healthcare. Figure 1 illustrates a ten year forecast of demographic changes due to hiring and attrition for a large manufacturing company. The age distribution over time shows a significant shift in Millennial and Boomer employee population.

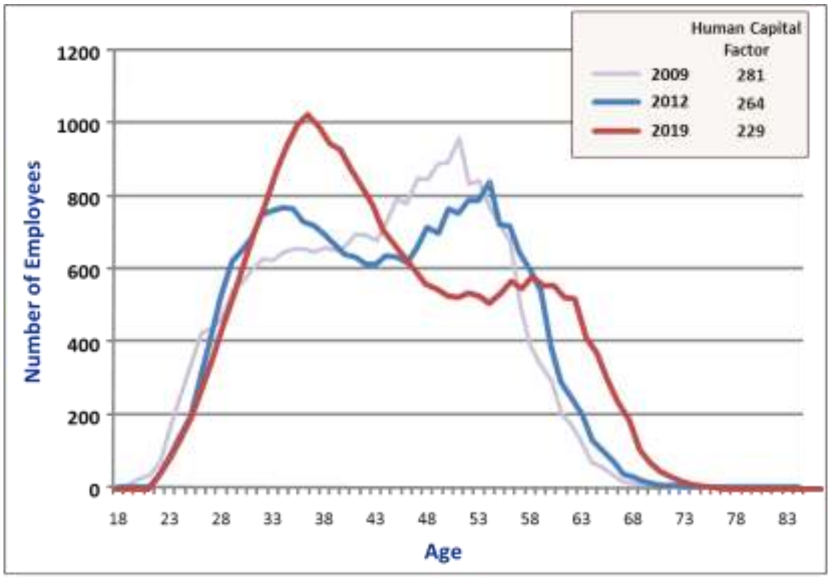

Figure 1. Predicted Demographic Changes in a Large Manufacturing Company

The loss of human capital ("corporate IQ") is significant while the safety risks and work complexity are increasing.

Accelerating Competency and Retaining/Recovering Expertise

In 2006, Schlumberger's Business Consulting group began a series of studies[8] on the development time of petro-technical professionals (e.g., geologists, petro-physicists, drilling and reservoir engineers). Since these disciplines were in short supply. Schlumberger was looking for effective ways to accelerate competency. They targeted the "point of autonomy", the time it takes for a new practitioner to be trusted to handle complex work independently and able to make non-standard technical decisions.

They found that they could distinguish two learning philosophies: conventional and innovative. Smaller companies tended to focus on traditional learning methods. The innovative companies invested more on blended learning such as providing early on-the-job experience, job rotation, and engagement strategies. They also used KM methods in a big way such as rehiring retirees as mentors, coaches and experts and participation in knowledge-sharing networks.

As shown in Figure 2, the innovative approaches were able to reduce the time to autonomy by six years compared to the conventional 10-12 year development period[9]. Better training and the use of knowledge transfer methods had a tremendous acceleration effect. As part of the early career experience, companies focused on developing relationships between new cohorts and more experienced professionals (one of the outcomes of participating in networks). These relationships resulted in longer job tenure. Innovative companies also showed higher growth.

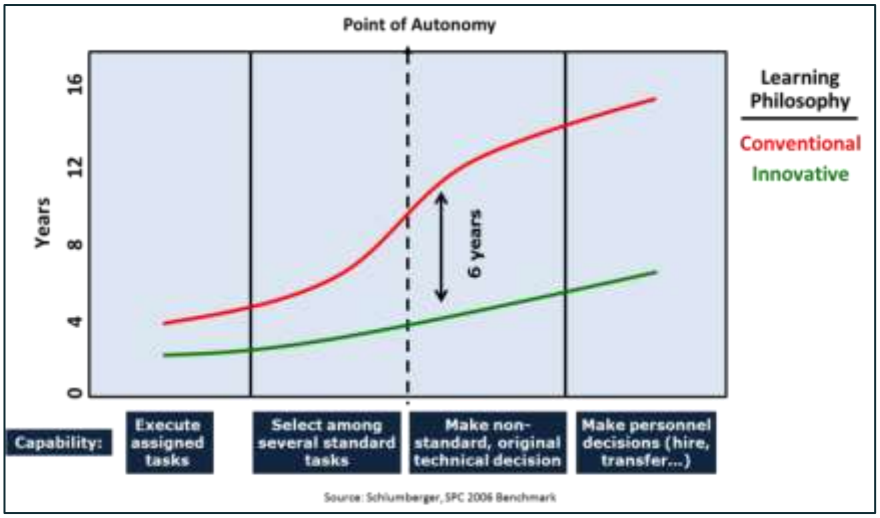

Figure 2. Innovative Learning and KM Methods Can Accelerate Competency

These innovative practices align very closely to what Millennials are looking for from their organizations. They expect quick career growth and opportunities for development, and consider these more important than compensation. These are exactly the kinds of practices that will increase retention.

Creating Business Value with Knowledge Networks

A Knowledge Network enables collaboration among people who are interested in a similar topic (e.g., discipline, process, practice) to share what they know, learn from each other, improve the way they work and deliver value to members and their organization. The group is often supported by technology that permits them to ask and answer questions, find others with specific expertise, share practices and lessons learned and contribute experience and insights that help all members increase performance.

Example business value from knowledge networks in several large energy and manufacturing companies include: operating cost reduction ($2 billion annually); energy savings ($1 billion); global refining operations ($100 million); exploration and production operations ($50-250 million); manufacturing best practices ($1 billion); drilling process improvement (reduce drilling time by >50%); and world-class safety performance.

Developing MKN – Smarter Networks

An effective, "smarter" network provides a number of valuable assets to its members (see Figure 3). For a chemical manufacturing process, the assets can include operating best practices and lessons learned, typical operating parameters and process functional knowledge. Smarter networks also provide an effective question and answer process so that those experiencing a problem or unusual condition can quickly solicit feedback from colleagues who have had similar experiences. Sometimes an answer is needed immediately, so a directory of expertise can be used to locate a resource for quick help. All of this operational know-how is online and available for problem solving. It can also be quickly extended when a member adds new experience.

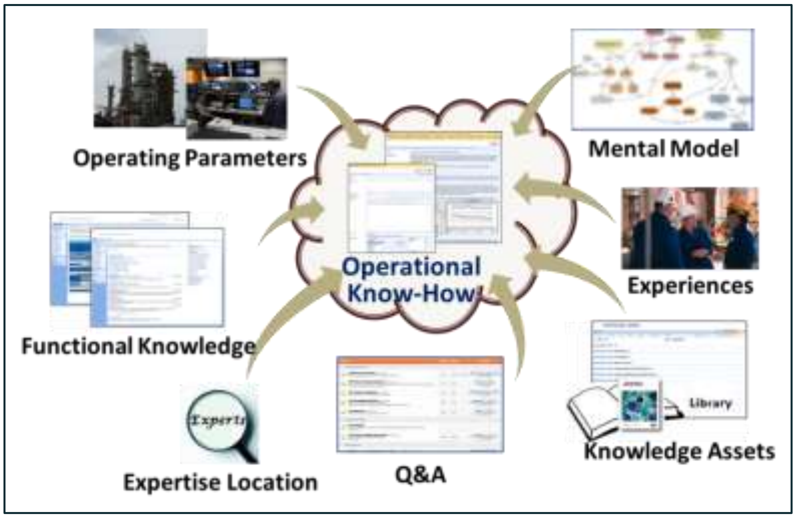

Figure 3. Key Assets in a MKN Smarter Network

Mental Models and Visualization

Mentally cataloging experience in frameworks or schema is a continuous, and individual, human process that was described for business contexts by Harris[10]. He referred to the process as sensemaking, which is a form of continuous learning where individuals process and organize information they perceive in their business environment. Significantly, many individuals are able to adopt and share the same generalized framework, but the details of their individual experience remain unique. The complexity of transferring detailed experience is very high, making it impractical, unless you can organize the transfer process around a framework.

A hierarchical framework is a common way to organize and display explicit information, but how accessible is this approach to individuals in their work? Information that is textual in nature, even when organized hierarchically, has limited accessibility. In order to provide context, and to allow individuals to relate the information to their existing mental models, they have to see the big picture, and the interrelationships between basic elements in a work domain. A spatial, framework representation enables individuals to immediately process the entire domain and relate their experience to the elements represented there[11]. If that spatial representation reflects an expert's thinking, a connection is immediately established to the experts' experience.

Using visualizations of work domains, the MKN smarter network is able to teach newer practitioners how to think like an expert. An expert seems able to observe a situation, quickly recognize relevant characteristics and almost immediately recall solutions that have worked in the past or even suggest a new approach by synthesizing results from several past experiences. Ericsson[9] describes this performance as an ability to efficiently encode the knowledge of events and solutions using the most important domain-related concepts learned over years of practice. Rapid retrieval of solutions follows as much of the situation's information can be filtered out. Less experienced practitioners take much longer to determine what really matters. These key concepts form the expert's mental model.

Experts performing cognitive tasks such as design, analysis and problem-solving are often unable to clearly articulate these key characteristics. We have found that an expert interviewer can facilitate expert knowledge elicitation. This is often done by asking the expert to describe patterns of characteristics they have observed in both good and abnormal situations. The knowledge can be efficiently visualized and taught to less experienced practitioners, significantly reducing the customary years of trial and error trying to figure out what is important. The learner still needs to do actual work to gain experience, but the experience is gained more efficiently. An example mental model for a gas-to-liquids process is shown in Figure 4.

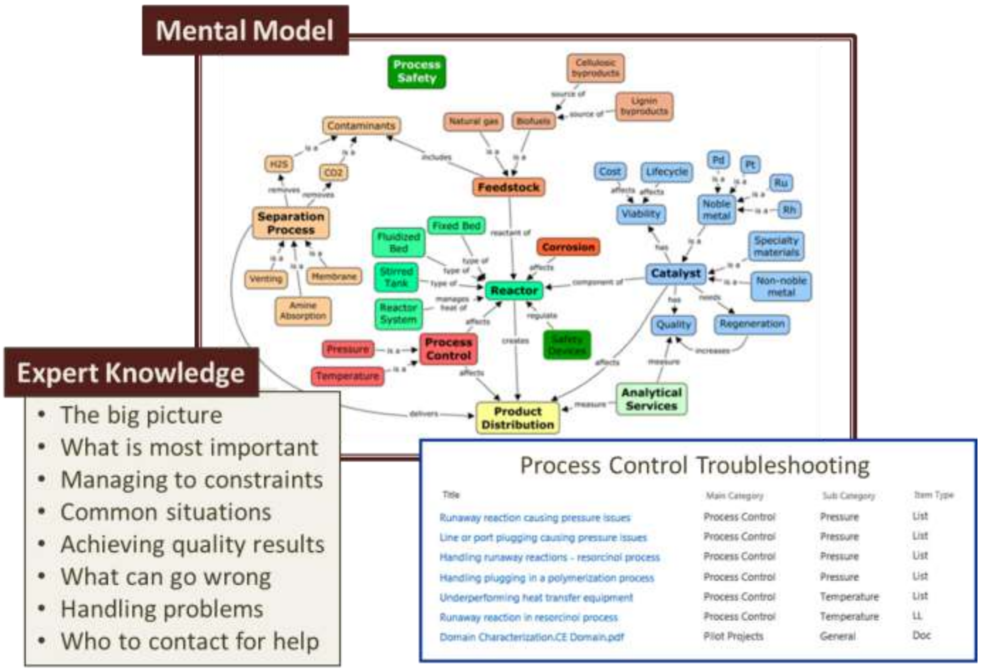

Figure 4. Chemical Process Mental Model and Visual Indexing

The expert mental model becomes a useful framework, a visual index for a filing cabinet for the types of knowledge illustrated above. Navigating through the model when searching for or posting new knowledge helps reinforce the relationships between key components. In a way, physically cataloging experience in the network mimics development of their personal knowledgebase of problems and solutions. Figure 4 shows a list of process control solutions that result from clicking relevant objects on the mental model. A new practitioner can see how the equipment is linked to process operations and product quality. The "Expert Knowledge" box describes important perspectives targeted during the expert's interview process. Being able to understand and apply this operational know-how is critical to safe and reliable performance.

Domain comprehension and communication are improved by visual representations that provide contextual information and functional relationships between domain elements. Consider the common alternative organizing scheme for repositories: nested text-based taxonomies. Which approach would help you understand the big picture?

Extending the Network Boundary

Most knowledge networks consist only of members of the organization. If the network's supporting technology is set up with secure extranet accessibility, there is no reason why other trusted people can't be included. The first group to consider is retirees. Often they are eager to stay current in their discipline and connected to their former work colleagues. They are a great source of expertise on tough problems. Their collaborative contributions may even lead to consulting engagements (a good motivator). Adding other thought-leaders including external consultants, academic and vendor partners helps to tap into a wider level of expertise.

Process Safety Examples

Example 1: R&D Safety

The following examples drawn from our chemical manufacturing R&D experience show how potentially disastrous safety incidents were completely avoided by knowledge-based designs, equipment selection and operating procedures.

The first example is taken from an experimental program to demonstrate a safe and effective sprayed-liquid-potassium-catalyzed olefin dimerization process. The objectives were to find reaction conditions giving high conversion and selectivity for the desired product and safe and efficient recovery and re-use of the liquid potassium catalyst, all in continuous, round-the-clock pilot-scale operation. The primary explicit knowledge elements included the well-known, exothermic reactions of liquid or solid potassium on contact with air or water and the well-known injury or burn potential in human contact with liquid or solid potassium. We also had the explicit knowledge of small set of experimental results obtained in bench-scale, batch preliminary work disclosed to us by our client.

Crucial implicit knowledge possessed by consultants consisted of hands-on experience designing and building barricaded pilot systems, familiarity with specialized pump and spray nozzle vendors and equipment and extensive experience with hazardous, toxic components at elevated temperatures.

These elements of explicit and implicit knowledge were shared verbally and in written form in numerous, one-on-one or small group conversations with all the operators/technicians who would participate in the experimental program. As Figure 5 shows, this knowledge sharing allowed a successful demonstration of the process with no safety incidents, good product yields and several re-uses of the liquid potassium catalyst.

Figure 5. Bowtie Diagram – Pilot Plant Testing of Olefin Dimerization Process Safety

The second example is the development and subsequent long-term use of a synthesis process with acetylene as one reactant. A key part of explicit knowledge here is the well-known hazard of acetylene vapor detonating spontaneously at pressures greater than 30 psia. The desired ton quantities of the synthesis product meant that a round-the-clock, continuous-flow process was needed to achieve economic product pricing.

Implicit knowledge supplied by the consultant was familiarity, experience with and frequent use of outside vendor and literature resources in selecting solvents capable of keeping all the acetylene in the liquid phase at required reaction temperature and pressure. Selecting a solvent required substantial experimental VLE measurements and computer modeling work.

After solvent selection, explicit and implicit knowledge elements were then shared with operators in one-on-one or small group conversations and demonstration experiments. As shown in Figure 6, the process was successfully developed and operated for over 10 years with no safety incidents.

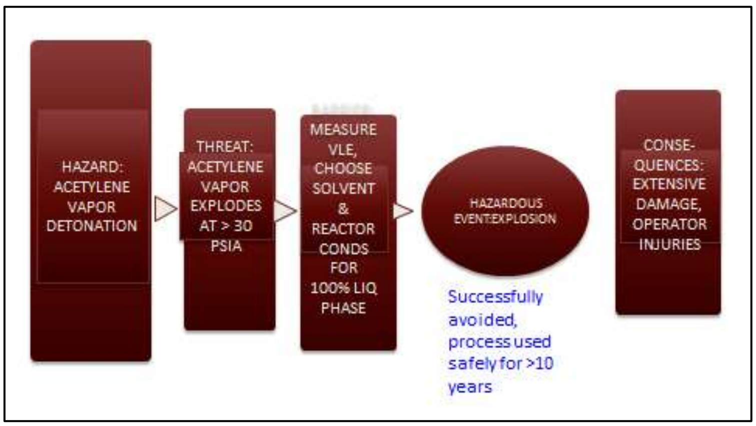

Figure 6. Bowtie Diagram – Acetylene Process Safety

Figure 7 describes a process development safety challenge overcome mostly by implicit rather than explicit knowledge. The goal was to develop and demonstrate a new resorcinol process using hydrogen peroxide in one of the reaction steps. This reaction was significantly exothermic. Its rate and heat generation were dependent on hydrogen peroxide concentration.

Figure 7. Bowtie Diagram – Hydrogen Peroxide Process Safety

Hydrogen peroxide concentration was a potentially important economic parameter, which called for pilot experiments at increasing hydrogen peroxide concentrations. Effect on reaction rate was an unknown to be determined. Our lessons learned with liquid phase exothermic reactions called for precautions including design of a water deluge system to be triggered automatically by temperature and pressure increases. As anticipated, a runaway reaction occurred which was safely stopped by the water deluge with no damages or injuries. The continuous process was demonstrated successfully with reduced hydrogen peroxide concentration. Our experience-based hazards anticipation and safety equipment was crucial to the successful process development.

Example 2: Operations

After a merger, a large oil and gas company more than doubled the size of its refining system. Prior to the merger, the U.S. refineries received technical help from a small team of experienced process engineers. This support was not sustainable for the new organization. We linked all of the refineries into a large, technology-supported knowledge network.

Over 2,000 operators and engineers, who are globally distributed across 16 sites, are able to ask for advice and share successful practices regarding day-to-day manufacturing operations. Supported by an email-enabled collaboration tool (Figure 8), they get answers in hours instead of weeks. These solutions and ideas add to a continually expanding, searchable knowledge base that can be tapped in future situations. It also helps technical experts pinpoint multiple instances of events that can trigger evaluation and development of effective practices to improve operations.

Figure 8. Refining Knowledge Network

Example 3: Drilling Team Knowledge Transfer

It is not unusual for an organization to have multiple teams performing similar tasks. Some examples include setting up commercial outlets (e.g. gasoline food marts), environmental remediation and manufacturing operations across multiple factories. Significant value can be created when these teams share successful practices and lessons learned.

Drilling for oil is a very expensive process. Costs for drilling rigs range from $100-400K per day. Multiple wells are drilled in a single field over a period of time, but the original drilling team has probably moved on to other assignments. By following a standard process and carefully documenting each step in the work (e.g., type of rock encountered at various depths, type of drill bit that cuts best through a rock layer), the team leaves an important legacy for their successors.

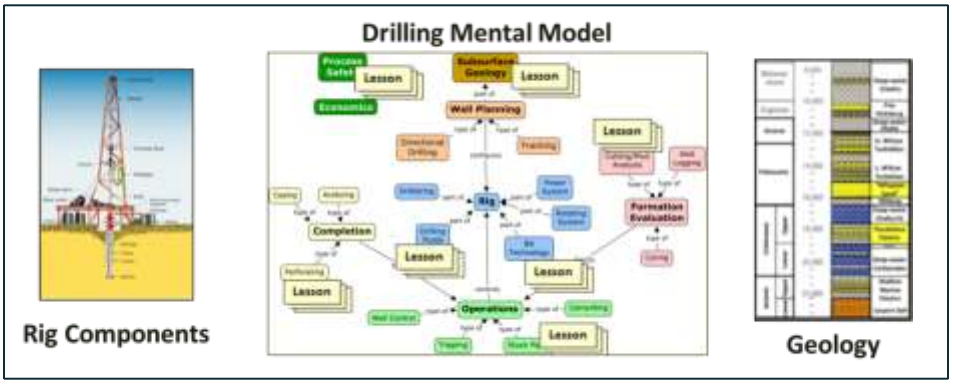

Figure 9. Drilling Operations Knowledge Network

Figure 9 illustrates a knowledge model for drilling teams. This can be used for both a specific reservoir and as a team-to-team vehicle for sharing practices and lessons. Each drilling operation needs detailed information about the underground geology and drilling rig components. Such a system can be used to record actual experience such as rock structure penetrated, bits and fluids that work effectively. In Figure 9, these lessons are captured in a drilling log and "tagged" to corresponding components of the drilling mental model for quick reference.

This team-to-team knowledge transfer dramatically reduces drilling time and saves a lot of money on subsequent wells. Figure 10 documents several learning scenarios as a reservoir is drilled many times over multiple years with different crews.

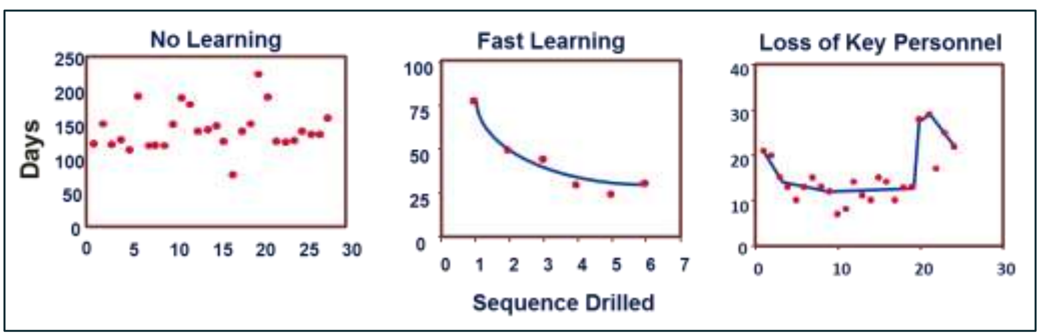

Figure 10. Impact of Learning in a Drilling Project

When nothing is transferred to future teams you see "no learning", an almost random amount of time to drill the well based on the skills and experience of the current team. When experiences are carefully documented and available to subsequent teams, it is possible to achieve a tremendous time savings. In this "fast learning" example, the time to drill is cut in half. At $250K per day, this can save $10 million for the well. The final scenario shows that the documentation isn't the whole solution. When experienced engineers are no longer available to translate the past experience to daily operations, the drilling time can revert to "no learning".

Achieving a Sustainable Change in Workforce Performance

An effective knowledge and know-how transfer system should not be considered a one-time reaction to the impending Boomer retirements; the need is universal and never-ending. The strategy presented here provides managers with proven ways to achieve significant, sustainable value by accelerating competency, raising performance, maintaining business continuity and developing the next generation of thought leaders. Implementation by a multi-disciplinary MKN pilot team will provide the right mix of processes, tools and skills to incorporate knowledge transfer into your existing operations. The business benefits will align with your company's business strategy and metrics, and the resulting knowledge-sharing behaviors will help your company remain competitive in the years ahead.

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