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Application of a visual method to determine the abilities of engineers reveals new and useful insights.

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MAPPING *competencies*

Success at a job requires a level of competence. Few, we assume, would disagree with that. But defining what makes people competent is another matter. Certainly, if a job requires only a few simple tasks, competency can be easy to determine. But what about the complexities that engineers face in the management of technology? How many competencies does an engineer need? And how can they be identified?

When the management of petrochemical and refining operations at one of South America's largest energy enterprises, Ecopetrol, S.A., decided three years ago that it wanted to

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improve the overall performance of its engineers, it was taking on a big job. Before it could work any change, the Colombian energy company needed to have a clear understanding of the competencies that its engineers had to master.

This kind of fundamental understanding is growing increasingly important today, not only for constant improvement but also to assure continuity. As the professional workforce ages, technology companies of all kinds need to understand the competencies of their engineers. A clear grasp of the knowledge needed by engineers will help companies see that critical capabilities do not retire from the workplace along with older professionals.

Ecopetrol's initial efforts at identifying engineering competencies proved that it wasn't an easy task. It developed or acquired lists of competencies that were not viewed as credible by many engineers and their managers.

Ecopetrol eventually enlisted the aid of a consultant, RWD LLC. Working together with Ecopetrol's subject matter experts, the RWD team began applying a new method and tools for identifying the necessary technical competencies of engineers. As a result, the company has learned a great deal about what its various engineers need to know.

Ecopetrol had embarked on a process known as competency mapping. The term is often applied to identifying the soft skills or behaviors that make employees effective in their roles and distinguish some as candidates for leadership positions. In Ecopetrol's case, the competencies to be mapped were the objective skills that engineers require to deal successfully with the daily operations of a refinery.

Lists and Grids

Many competency mapping methods use lists. But there are problems with that. Lists do not make it easy to detect an underlying pattern. One never knows if a list is complete.

RWD has devised an approach that uses a grid format to reduce uncertainty. The method is derived from a simple premise: An engineer is a problem solver.

Once we recognize that engineers create value for the enterprise by solving problems, we can reduce our problem of competency mapping to two questions: "What needs to be solved?" and "How can it be solved?"

RWD uses those two questions as a basis to create two-dimensional maps of competencies.

There are two maps to be created. The first we call the Outcome/Experience map.

This map decomposes each task that needs to be done

SECTIONS OF THE O/E MAPS FOR FIXED AND ROTATING EQUIPMENT ENGINEERS

In the Outcome/Experience map, a company sees the objectives that need to be met for each class of equipment. "P1," "P2," "P3," and "P4" refer to job levels. P4 is a junior engineer. P1 is equivalent to a principal engineer.

FIXED EQUIPMENT ENGINEER	Safety (relief, bursting disc, pressure, and vacuum)	P3	P3	P3	P3		P2	P2	P1	P1
	Other valves (gate, needle, etc.)	P3	P3	P3	P3		P2	P2	P1	P1
	VALVES									
	Above ground (ambient)	P3	P3	P3	P3		P2	P2	P1	P1
	Above ground (hot)	P3	P3	P3	P3		P2	P2	P1	P1
	Underground	P3	P3	P3	P3		P2	P2	P1	P1
	STORAGE TANKS									
ROTATING EQUIPMENT ENGINEER	Electrical	P4	P4	P3	P3	P3	P3	P2	P2	P2
	Internal combustion	P4	P4	P3	P3	P3	P2	P2	P2	P2
	MOTORS									
	Reciprocating	P4	P4	P4	P3	P3	P3	P3	P3	P3
	Rotary	P4	P4	P4	P3	P3	P3	P3	P3	P3
	Positive displacement									
	Centrifugal	P4	P4	P4	P3	P3	P3	P3	P3	P3
	PUMPS									
	STATE OF EQUIPMENT →	NORMAL OPERATIONS (STEADY STATE)						TRANSITION		
	ACTION →	MONITOR			TROUBLESHOOT	PRESERVE	OPTIMIZE	DEBOTTLENECK	ASSESS FLEXIBILITY	SUPPORT STARTUP AND SHUTDOWN

into an action and an object of the action. For example, if the task is "Troubleshoot compressors," "Troubleshoot" goes on the *x*-axis and "compressors" the *y*-axis. An engineer is responsible for other actions to be taken with the compressor: "inspect and document" would be another and so would "perform vibration analysis." Those and all other identifiable actions would be added to the *x*-axis. The different types of compressors in the plant—reciprocal, axial, centrifugal, etc.—would be added to the *y*-axis.

The same exercise would be carried out for all the equipment that the engineer is responsible for overseeing, and for all the actions the engineer must take with each object.

The list of tasks associated with each engineering discipline is generated in two steps. First we identify an activity cycle that best fits the discipline or function under consideration, and then we list tasks associated with each phase of that cycle. This strategy ensures that the tasks on the list are distinct and that the list is exhaustive.

Since we use a visual map, it is easy to spot if there is an overlap between verbs. For example, if the action is "Monitor," does "Monitor" include "Diagnose"? In our approach the two verbs will appear in separate cells making it clear that "Monitor" and "Diagnose" are distinct from one another.

The best representative cycle for all supporting functions in a refinery is the plant's life cycle. A typical refinery life cycle consists of the following states: business justification, conceptual design, detailed design, procurement, pre-commissioning, commissioning, normal operation, transition mode, abnormal operation, revamp, turnaround, and expansion.

To ensure that each task occupies a unique location on the map, items on the *y*-axis are organized in an ascending order of complexity from the bottom to the top. Simple components are at the bottom. One moves to functional equipment items and eventually to systems as one moves up the *y*-axis. Similarly, on the *x*-axis, the actions are arranged in an ascending order of difficulty.

> "First we identify an activity cycle that best fits the discipline, and then we list tasks associated with each phase of that cycle."

This map is called the Outcome/Experience, or O/E, map because it focuses on the outcome and not on the "how." This map type, with cells left blank, can be used by engineers to document their experience.

The second grid is the Knowledge-Capability, or K-C, map, which we derive by reverse engineering each task on the O/E map. The second map provides answers to two questions: What items could be used as resources to prepare an engineer to do a task? At what cognitive level, skill level, or assessed performance level (if it is a procedure) does an engineer have to process the resource items to qualify to do that task?

The resources are arranged by degree of utility from top to bottom on the *y*-axis, and the *x*-axis is divided into three or four cognitive levels of complexity derived from Bloom's taxonomy. Benjamin Bloom, a professor of education at the University of Chicago, identified six levels of cognitive processes and arranged them in increasing level of complexity. Bloom's work has been used worldwide for developing assessments and for defining educational objectives. Bloom's original work was updated in 2001 by his research partner, David Krathwohl, and his student Lorin Anderson.

Each cell in the map contains a competency statement that matches a specific resource item with a specific level on the *x*-axis.

What Can You Do?

The Knowledge-Capability map's main use is to determine what a person is capable of doing. A completed K-C map can be used to create a curriculum map. In the curriculum map, the competency statements become the objectives of training.

Ecopetrol and RWD decided to take an incremental-iterative approach to competency mapping for engineers at Ecopetrol's refineries. The idea was to start with one discipline, build a training plan for it, and then apply the project lessons learned to other engineering disciplines. Process engineering was picked as the first discipline.

Competency mapping and training plan development was completed for that discipline in September 2008. The work with the mechanical engineering departments began in October 2008. Mechanical engineers play many different roles in the refinery. The two roles (or job designations) picked for this project were fixed equipment engineers and rotating equipment engineers.

Two separate teams of subject-matter experts were formed—one for fixed equipment engineering and the other for rotating equipment engineering. Arranging the equipment on the *y*-axis and the actions on the *x*-axis took some time.

Once the Outcome/Experience maps were complete, the teams began work creating the Knowledge-Capability maps. Writing the competency statements in the K-C maps was the most resource-intensive step. The team members met several times to fine tune the contents of the two maps.

The Outcome/Experience and Knowledge-Capability maps developed for each engineering discipline are used to complete a four-step process.

The first step is to create the "to be" maps. The managers and subject-matter experts in a discipline match each task on the Outcome/Experience map with an

SECTIONS OF THE K-C MAPS FOR FIXED AND ROTATING EQUIPMENT ENGINEERS

The Knowledge-Capability map describes the learning and the ability to perform tasks needed for competency at each job level.

	Knowledge Object	Remember, retrieve, recognize, explain, etc.	Implement, use, illustrate, calculate, perform, etc.
FIXED EQUIPMENT ENGINEER	ASME B31 Code for Piping	Explain the scope, purpose, and types of routes covered by the Code.	Identify types of fuel lines covered by ASME Standard B31 and select the applicable section depending on the type of fuel. Use the guidelines and procedures for inspection of pipes.
	API 570 Piping Inspection Code	Summarize the scope, purpose, and types of analysis covered in the Standard API RP 570.	Identify the types of damage discussed in the Standard API RP 570. Conduct the FFS Level II data analysis to assess suitability of design service.
ROTATING EQUIPMENT ENGINEER	ANSI/ASME B73.1 – 2001 specs of centrifugal pumps of horizontal suction end for the chemicals process	Explain the requirements centrifugal pumps should fulfill with discharge piping designs aligned to the center (of a horizontal stage).	Use the standard to solve operational, maintenance, and installation problems of the pumps according to this standard and generate recommendations.
	API 682 – Systems of axle sealing for centrifugal and rotating pumps	Summarize the scope, purpose, and types of analysis covered in the Standard API 682.	Solve performance problems in the sealing systems in the assigned equipment. Generate recommendations. Select mechanical seals according to the application.

appropriate job level. For each job level, they also mark up the corresponding required competence levels for all resource items in the Knowledge-Capability map. At the end of this step there are two completed "to be" maps for each job level.

The next step is to map the current competency of engineers. Each engineer is given a blank O/E map and K-C map. Each engineer highlights the tasks he or she has actually done on the O/E map and also marks his or her competence level for all resources on the K-C map. These maps completed by each engineer are called the "as is" maps.

Step three is to compare and analyze the "to be" maps and the "as is" maps to reveal the competency gaps for each engineer. The data provided by the engineers can also be used to estimate the cumulative competence gaps by each job level. If there are no gaps, an engineer is well trained and qualifies for the job.

The final step is to recommend an action plan for engineers who show competency gaps. Two types of gaps are possible: An engineer's competence levels in one or more tasks may be lower than that required by his or her job level, or higher. If competence is lower than expected for some tasks, the curriculum map is used to match the best training interventions (e.g., courses, projects guided by mentors, shadowing, simulator training, etc.) to fill those gaps. If an engineer's competence averaged over all the tasks linked to a job level exceeds requirements, he or she may be ready to be considered for a promotion.

The Next Steps

As of this writing the RWD team with the help from Ecopetrol's subject-matter experts has completed gap analysis and curriculum map development for all engineering disciplines, and the RWD team is in the process of developing a one-page design document for each recommended training intervention.

The project also gave the company other insights into the skills of its engineers. A side-by-side comparison of the Knowledge-Capability maps for different engineering disciplines revealed that almost 30 competencies were common among the various engineering disciplines. These competencies included information technology skills such as ability to use Microsoft Office and tools for capturing real time data; technical foundational competencies such as working knowledge of probability and statistical analysis, ability to use various company documents, and business competencies such as knowing Ecopetrol's key performance indicators.

Not all engineering disciplines are equal. A side-by-side comparison of the K-C maps revealed that a greater number of knowledge-objects or resources appears on the *y*-axis of maps for fixed and rotating equipment engineers than on the map for process engineers. The equipment engineers' maps had over 125 items each. The process engineers' map had 80 items.

The project team concluded that the main reason for the difference was that fixed and rotating equipment engineering disciplines are more regimented with regulations and standards than process engineering. Working knowledge of these practices and standards is critical to the success of refinery mechanical engineers.

Another finding was that at Ecopetrol (and this applies to most refineries) for equipment engineers the words "expertise" and "specialization" are synonymous. Several areas of specialization were identified including specific equipment types such as compressors and specific inspection techniques.

A New Urgency

Competency mapping has taken on a new urgency in today's professional world.

The increasing median age of engineering professionals worldwide threatens a skills shortage as attrition and early retirements take veteran engineers and their accumulated knowledge out of the workplace. The aging of the workforce has created a need to find fast and reliable methods and tools for mapping competencies of professionals to identify missing knowledge and to take steps to replace it.

> "Competency mapping has taken on a new urgency as the increasing age of engineering professionals threatens a skills shortage."

Traditional industry wisdom can become outdated. The conventional wisdom has been that the focus of training programs should be exclusively on the new hires because that is where one would find the most competency gaps. The results at Ecopetrol, which are likely to be true in many other companies, showed that competency gaps existed at all job levels in the company. This implies that there is also a need and an opportunity to develop faster, cheaper, and better training interventions for complex and highly specialized competencies.

In many cases, however, competency mapping initiatives have either progressed very slowly or the projects have failed completely. Common problems are incomplete lists of competencies, too many competencies, the top-down nature of programs, lack of sense of ownership among workers, lack of fit between generic competency maps and specific company environments, and short shelf-life of maps due to rapid organizational changes.

Competency mapping takes time and requires unwavering support of company executives. This new method and the tools developed by RWD can give managers insights to address many of these issues.

The simplicity and the visual and intuitive nature of the method and the tools are factors that broke down many initial barriers to adoption at Ecopetrol. Engineers, who naturally prefer visual-spatial thinking modes, are likely to support an initiative if they can see the big picture.

Ecopetrol has completed its training intervention plans for mechanical engineers and has decided to use this same approach for mapping competencies of other professionals.

Another factor that helped with the method's adoption was the cross-functional applicability of the method and the tools. From a human resource management viewpoint, a common method and set of tools lowers the cost of training and maintenance.

For engineering students exploring careers in the manufacturing sector being knowledgeable about software tools they will need will give them a competitive advantage. For new fixed or rotating equipment engineers it is important to select an area of specialization as early as feasible. This will help them later in their careers. ■

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To Learn More

F.D. Le Deist and J. Winterton, "What Is Competence?" *Human Resource Development International* 8, no.1 (2005). The authors have done extensive research on various competency models used in many different countries. In this article they integrate the models based on knowledge, skills, and assessed performance into a useful typology.

B. Bloom, et al., *Taxonomy of Educational Objectives: Handbook I, The cognitive domain* (New York, David McKay & Co., 1956). Bloom's work has been used worldwide for developing assessments and for defining educational objectives.

L.W. Anderson and D.R. Krathwohl, *A Taxonomy for Learning, Teaching and Assessing: A Revision* (New York: Addison Wesley Longman Inc., 2001). Bloom's research partner, David Krathwohl, and his student Lorin Anderson propose four types of knowledge objects: facts, procedures, concepts, and meta-cognition.