LIMITATIONS TO THE ORGANIZATIONAL LEARNING CAPACITY ON COMPLEX ENVIRONMENTS: THE CASE OF THE AERIAL SAFETY

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ABSTRACT
The purpose of this paper is providing proposals to recover the learning capacity in complex environments where this capacity seems to decrease. To do this, the aerial safety learning model and its collateral effects will be analyzed.

During years the aerial safety has shown high pace improvement. Its learning process has based on heavy use of technological and normative development. However, it seems to have reached a plateau even though the technological and normative drivers continued to be present. Therefore, the analysis of aerial safety could help understanding the learning process and its barriers in aerial safety as well as in other environments.

Keywords: Organizational learning, complexity, knowledge management.

INTRODUCTION

Intense global competition has resulted in the emergence of increasingly complex and unpredictable business environments, where a continuous, accelerated and interdependent state of change exists. In this circumstance, organizational learning capabilities have caught great attention. Learning capabilities are the fundamental means to create new knowledge achieving competitive advantages. To Roth (1996), the capacity to learn is one of the main aspects to be developed by companies in more dynamic environments. In fact, many researchers have recognized that learning is a systematic behavior, inherent to every organization, that improves the capacity for adaptation and anticipation to the environment evolution (Duncan and Weiss, 1979; Nevis et al., 1995).

There is no doubt about the value of learning capacity for the improvement and competitiveness of any organization. The excellence of the learning capacity requires an effort materialized in what has been called “knowledge management”. Nowadays, initiatives for knowledge management are a reality in many organizations, but they are often designed to build a technological infrastructure that supports knowledge capture, transfer and use. However, this paper argues that developing learning capability only
through technological or work structured systems engenders a bias. An equally important side of knowledge management, the human aspect, should be taken into account. Specifically, we are referring to those social construction processes, which lead to plausible interpretations that can be enacted by organizational actors. Thus, we suggest that organizations must focus on initiatives based on both: (1) building up technological and structural solutions and (2) developing the human operator. Specially, we try to prove the determining importance of human factors in the success of knowledge management. So, the goal of this paper is to analyze the effects of many initiatives related to the improvement and the development of learning capacity of organizations from a techno-structural approach. Improvement in rules and procedures backfires creating problems previously unknown. Every improvement can be good to manage a planned event but, at the same time, can impede the reaction to an unplanned one.

According to this, this research begins analyzing the collateral effects to the development of the learning capacity based on a tech-structural approach. Next, we identify proposals to recover the learning capacity of the organization. Finally, all these ideas are analyzed in the aerial safety field. The air safety improved strongly through technological and normative development; nevertheless, both ways of development can have reached its top as drivers to improvement. This analysis could help to improve the learning capacity in organizational environments different to the aerial safety.

LEARNING STYLES

Organizations learn through their individual members –individual learning- (Kim, 1993). In fact, learning in organizations emerges when the interactions between the organization and the environment take individuals to identify situations or events that require applied knowledge to solve problems (Jaikumar and Bohn, 1986; Hayes et al., 1988 and Perez Lopez, 1991). By knowledge creation through problem solving, a firm refines the understanding of its environment and improves its ability to react appropriately in advance of future events.

The individual learning does not guarantee that the organization benefits from such knowledge on a larger scale. At this point, the problem faced by organizations is transferring individual learning in organization learning. For this transfer to take place, it is essential getting individual knowledge introduced and materialized in the operational systems of the organization to improve its activities. Although individual member is the means through which firms learn, the created knowledge needs to be communicated and integrated into the organizational routines in order to impact organizational effectiveness.

The intangible nature of knowledge assets prevents knowledge from being completely diffused and subsequently used in the organization, unless “mental models” are simultaneously transferred. If mental models are not shared, changes in organizational routines and decision rules will not likely take place (Kim, 1993). Thus, the extents to which these mental models are shared determine their understanding of the problem, fostering its diffusion and facilitating its materialization. In this regard, individual knowledge must be carefully codified and stored in order to it will be accessed and used easily by anyone.
Events and organizational culture

Frequency and importance of events drive the learning process in an organization. In case of organizations that do not face important events, it is possible to choose which are going to be prevented. By the other side, organizations dealing with potentially serious events do not have that option since every event has to be prevented. Actually, many organizations define their performance in terms of percentage of events handled routinely. Attending 97% of these events could be an acceptable goal in many environments. However, when consequences of an event can be serious, higher goals are expected. A catastrophic risk is usually considered acceptable if its probability is less than one in a billion.

Meeting these performance goals implies the use of specific resources to learn and to materialize the obtained knowledge. Many different criteria could be used for the selection of resources but all of them can be synthesized in only two factors: Capacity of resources and preferences established by the organizational culture.

When managers of an organization have to decide where a specific capability has to be embodied, they are theoretically free to choose among available resources: people, mechanisms, information systems, written procedures or any possible mix of them. In this selection, there are economic and physical limits impossible to overcome. It is clear that a human operator is not able to lift so heavy weight as a crane. Likewise, the human operator is not able to calculate as fast as a computer. Therefore, the real possibilities to choose are only among resources whose capabilities are alike. When different resources are alike in their potential to embody a specific ability, their selection is not predefined by the environment. In this situation, preferences established by an organizational culture acquire their relevance.

Human beings are clearly more flexible than technology, but technological progress has given to several artifacts very different capabilities making hard to compare one resource against other. That difficulty can force the decision in the direction imposed by the organizational culture. The organizational culture, applied to choose among resources, appears under the form of a dominant organizational logic (Einhorn & Hogarth, 1999) that decides which the most trustable resources are. Whereas a rigid and formalist culture prefers procedures and technology to canalize the organizational action, a humanist culture gives people the main role in the organization. Therefore, the kind of organizational culture, and its associated dominant logic, defines the organizational learning model inside the limits imposed by the potential of the different resources. Once the resources are defined, the capabilities of the organization, including the capability to learn, are given.

Organizational Learning Models

Reason (1997) identifies two basic learning models: feedback-driven and forward-driven. At the beginning, an inexperienced organization uses to have a feedback driven learning system since it does not how to face many events. Under that condition, the human operator is expected to find a valid answer to solve that problem. The operator is the key factor for the system to work. Indeed, this learning model is based on a trial-and-error and, consequently, requires that an event creates knowledge through the solving problem.

When an event has important consequences for organization, this learning model is hard to accept and a different learning model is required. In these circumstances, a forward-driven learning model is an answer to avoid catastrophic events. It is based on what we call
system armoring that try to anticipate as much as possible. The development of appliances or procedures that represent “canned solutions” with a “If…Then” format are used to prevent events. As time advances and experience increases, it is less frequent the appearance of unknown events. When this moment arrives, the forward-driven learning model starts to work and technology takes gradually the place of the human operator as the main piece of the system. The emphasis changes from the human operator to technology and, consequently, technological potential will define the organizational learning capability.

Technology is hard to outperform in tasks defined as “If…Then” since technological evolution allows storing an increasing number of this kind of instructions in an efficient way. However, not all the stored situations are crystal-clear and easy to identify because organizations start to become strictly-coupled (Perrow, 1999) and increasingly complex. The capacity to manage foreseen events has grown but, at the same time, the aptitude to manage unforeseen events has diminished since many of them are created by unforeseen interactions inside the system. Furthermore, we have to keep in mind that “breakdowns of efficient organizations are efficient too” because they use the organizational channels to get the most from low efforts. Consequently, events coming from complexity can have catastrophic outcomes, even when the starting points are trivial issues.

INFORMATION AND COMUNICATION TECHNOLOGIES AND LEARNING

Information and communication technologies deserve a very special place in the forward-driven learning model. They have been converted into an essential piece for many of the knowledge management initiatives in recent years. However, the results of these initiatives are not as clear as expected and some organizational efforts are lagging in learning terms. We have just identified this effect as a feature of an organizational learning model that develops an increasing complexity. Nevertheless, since many organizations make heavy use of information and communication technology, analyzing how these systems increase organizational complexity can be very relevant.

A definition of a computer that can provide some understanding comes from Varela (1988). A computer should be a device that manages symbols but only handles its physical shape and not its sense. This characteristic represents a lack of capacity to manage unforeseen events and, therefore, those events should require human operators to manage “remaining uncertainties” in terms of Luhmann (1996). Consequently, human operators are supposed to be the last barrier since they are able to go beyond the design of the system. Hofstadter (1987) mentioned the “double-loop” as the main and non-imitable feature of the human being since this seems to be a logical flaw. Human operators should be able to be a part of the system and, at the same time, to analyze the whole system from outside.

Actually, things do not work exactly like that. Operators who learn in complex environments of technology and normative use the system but the complexity of its design can impede them know the principles of its functioning. When that happens, it is not possible the “double-loop” phenomenon since operators do not know much about the underpinning functional model to diagnose it and fix it.

Technology designers and, especially, information technology designers, have introduced more capabilities in their developments in order to avoid human errors and, thus, traded
meaning for legibility. They have paid special attention to get visual representations, easy to understand for operators but, at the same time, have hidden the functional model to the operators’ eyes. This kind of solution, instead of providing capabilities to manage unforeseen events, increases the complexity of the system that turn into a source of new unforeseen events. Human operators are familiar with inputs and outputs designed as an added feature of the system and, when this feature fails, the operator’s capability to fix the problem is bare minimum since the functional model is unknown for this operator.

Any user familiar with PCs knows this phenomenon through the difference between the old DOS systems and the newer WINDOWS systems. Last ones are more legible but, unlike the old ones, when something fails the user is confronted with a blue screen, without any key about what happened and without a better solution that re-starting the computer.

The situation just described shows the negative side of something that Winograd and Flores (1986) consider a real progress. They point out that the opacity of implementation is one of the key intellectual contributions of computer science. Every level of design can become independent from the one below keeping its own logic. That does not happen in the construction of a mechanical system because every level of design has to be justified by the one below. This fact makes mechanical systems more complicated to design than information systems. The good part of the interdependence among design levels in a mechanical system design is that a problem can be traced until its origin and be solved by the human operators. By the other side, in an information system the opacity of implementation breaks the logical chain among its different levels of design. The hardware designer, the software designer and the operator live apart and they can become experts in their fields having no idea about the others’ fields since they have become functionally independent.

“SRK” model and the role of meaning in the learning process

When everything happens as planned, this blind-to-meaning model does not present any problem. However, in opposite situations where unplanned contingencies appear, the feasibility of dealing with them is decreased compared to the old mechanical systems. Reason (1997) explains this fact under his “SRK” model where “S” stands for Skills, “R” for Rules and “K” for Knowledge. Each character represents a level. The Skills Level is the basic and the Knowledge Level is the top in this model. An opaque system only allows its operators to reach the Rules Level since the opacity of its design makes it impossible for the operators to get the Knowledge Level.

In the field of Knowledge Management, Choo and Bontis (2002) introduced the concepts of meaning and sense making as important issues for the improvement and learning in organizations. The loss of meaning makes the human operator to act under the Skill Level and Rules Level instead of using the Knowledge Level (Reason, 1997). Every new added feature could reinforce this process. Thus, the real improvement -from a whole system scope- will be lower than expected since increases in technical capacity go together with decreases in human capacity. The technical model of development not only adds capacity to the system but also extracts capacity from one of its components transferring it to the other one. As result, the system increases its performance in situations where technology can provide improvements and decreases its performance where human operators is required.
In summary, since information technologies do not have access to the meaning but to symbols (Varela, 1988), those activities requiring access to meaning –those events representing exceptions to the general rule and not included in the system design- could have serious limitations to be performed. By the other side, actions than can be included in the system design can be performed efficiently, decreasing the number of errors.

Technology, trust and opacity as related factors
Improvements in the technology capacity have increased its presence in organizations with important advantages. As an example, a robot can reach a precision level in some manufacturing processes beyond the capacity or resistance of any expert operator. Therefore, different kinds of artifacts have become increasingly trustable partners (Choo & Bontis, 2002) displacing often its human counterparts. Furthermore, technology can allow certain degree of flexibility adding more and more complex “If...Then” instructions in its design.

When technology starts to be the most trusted resource in an organization, the behavior of this organization starts to be defined by the features of this resource, including the non-desired ones. One of these features is the splitting between the operating and functional organizational models. Rasmussen (1986) identified the requirements for operators to run cognitively a program and pointed out that they are hardly met. Instead, the possibility of information systems to give to every level its own and independent logic has been widely used (Winograd and Flores, 1986). Thus, the operating model follows a logic that does not come from a description at a higher level of the functional model. Instead, this is something fully different.

According to the above, efficiency is improved because operators do not require to know the functional model reducing time and costs linked to training. By the other side, organizations become opaque for their operators. If operators do not know the functional model, they cannot act beyond their own model –the operating one- and the diagnosis of an intervention when an unplanned event arises can be hard to achieve. That opacity of the system, and its consequences, when unanticipated events arise is increased when the organizational learning process is aimed to armor the system against every foreseeable event.

As commented, technology implies feasibility to store many “If...Then” instructions; however, the anticipated events are not always independent but there are possible interactions among them. Thus, the attempt to anticipate a larger number of possible interactions produces a bigger organizational complexity. Luhmann (1996) links concepts of complexity and trust pointing out that trust in human operators is not a gift but a resource used to reduce complexity since this way it is unnecessary to build controls over operators if they are reliable. In that way, all the complexity linked to design of controls is avoided through removing the controls themselves. However, the evolution followed a different path displacing trust from people to technology, aimed to gain instrumental supremacy.

Briefly, the increasing potential of technology has supported the objective of getting instrumental supremacy but, at the same time, the added complexity produces unanticipated events and, as commented, builds opaque organizations.
Next, these phenomenons, together with their effects on organizational learning and alternative proposals are analyzed in the aerial safety environment.

**AERIAL SAFETY CASE: AN ORGANIZATIONAL LEARNING MODEL**

Aerial safety has been considered as an exemplary activity regarding its organizational learning capacity. At this regard, Perrow (1999) had identified several features that qualified aerial safety as a model to imitate. First of all, improvement record was especially brilliant. Furthermore, improvement was produced in a very complex organizational and technological environment. Additionally, there was a strong pressure to improve due the potential consequences of an aerial accident.

These characteristics produced a learning model that, being basically shared with many organizations, was enforced to improve faster. This fact is particularly relevant since the aerial safety development path can be useful to foresee what could happen in organizations sharing its development path but enjoying a lighter pressure to improve.

The Boeing study (2002) indicates that until 1975 the accident rate decreases sharply, showing a high learning capacity. However, since that moment, figure 1 show that the improvement rate was stopped. At a first glance, it could be asserted that there is nothing special since this is a usual learning curve. However, there are two factors that invite to analyze more carefully this learning curve.

First of all, an important increase of aerial traffic is expected. In this situation, Boeing foresees that keeping the present safety levels and meeting the traffic expectations, an important aerial accident will take place every week in 2015. Therefore, pressure to improve is still present and quantified in five times the present rate (White House Commission on Aviation Safety and Security, 1997). Additionally, however the learning pace was almost stopped 25 years ago, technology and operating procedures kept evolving. Many important improvements have been made but they are not reflected by a decrease in the accident rate. If pressure to improve is present and resources for improvement have increased their capacity, we can conclude that the problem is beyond the capacity of resources. The learning model itself has to be analyzed.

Technology improvement has helped to decrease the cabin crew members from 3 to 2. Some plane models have seen their indicators cut in two thirds (900 in first version of Boeing 747 and about 300 in the last one). Reliability has invited to decrease the number of engines making twin transoceanic planes familiar. Hydraulic controls have been changed into electronic controls where the pilot gives instructions to an information system. Required periods to train crew for a specific plane have also been reduced (Airbus, 2002); navigational aides have increased their precision inviting to reduce the distance among flying planes; zero visibility landings are possible in many planes and airports…and so on. In a word, technological improvement has played an important role in every aviation area. However, accidents happen and, the most important issue, many accidents are produced by unexpected interactions inside the system or by mistakes of human operators non familiar with the functional model of the system. This kind of accidents that derives from the technological evolution did not exist in former learning phases.
Next, we briefly describe accidents that were caused by unexpected interactions, which combinations were not foreseeable and produced disastrous consequence. Under that condition, operators become unable to get a solution or, even worse, their confusion was the final required piece that caused the accident. The reason for these accidents can be found in the displacement of trust from people to technology and in the increasing of opacity and complexity that it produces (Baberg, 2001; Campos, 2001; Mauriño, 2000).

- Air Inter (Ministère de l’Équipement, des Transports et du Logement, Inspection Générale de l’Aviation Civil et de la météorologie, France, 1992): The same indicator could be used to select rate of descent (4 means 4 degrees below the horizontal line) or to select regime of descent (4 means 4,000 feet by minute). Confusion between both modes produced an accident in the Alps.
- American Airlines 191 (NTSB, 1986): An engine separated from the plane during take-off had the effect of retracting flaps and slats that required the hydraulic energy from the missed engine. The pilot reacted as prescribed for an engine-stop putting the plane below the stall speed and crashing the plane.
- Concorde (Ministère de l’Equipement, des Transports et du Logement, BEA, France, 2002): As a consequence of a blow tire, a fuel tank is damaged throwing out part of its content. This plane uses after-burners for take-off and the after-burners inflamed the lost fuel provoking a fire.
- Learjet of Payne Mitchell: A problem in the cabin pressure gets all the occupants of the plane unconscious. The automatic pilot keeps the programmed altitude at a level without breathable air bringing to death to the occupants.
- American Airlines 965 (Simmon, 1998): Two nearly radio-stations share the same radio-frequency. Pilots were offered a direct approach and, after accepting it, they
had to plan a new approaching course. Unconscious of the shared frequency, they tuned the wrong station crashing the plane against a mountain.

- United 232 DC-10 (NTSB, 1990): The plane had three hydraulic systems. The malfunction of all of them had been calculated in less than one in a billion. However, the explosion of the tail-engine affected the pipes of the three systems producing a full loss of conventional control at 37,000 feet.

DISCUSSION
The emphasis in new technological and organizational developments (Wells, 2001) does not solve the opacity and complexity problems affecting many different kinds of organizations. Increased complexity of functional models and operators who only know operating models prevent those operators from acquiring knowledge different to the purely operating one. Technology introduces a strict separation between design and operation of a system and, doing that, makes hard extracting new learning from the daily activity of operators. Operators, having only the specific knowledge to operate the system, are not expert and lack diagnosis capacity. Their role is reduced to the privileged witness whose testimony has to be interpreted by designers to make it useful.

The revitalization of the learning pace requires the recovery of the links between functional and operating models. The present separation between the two models increases the designers’ freedom and decreases the training costs but the human operator capability, as an alternative resource, is lost. There are not remaining resources to manage unanticipated events since operators are not those resources anymore. Going back to a situation where a link exists between both models implies the access of operators to the functional model.

At the present moment, this objective does not seem easy to reach. Differences between functional and operating models might not be perceived until an unplanned event makes clear the existence of different models. E.g. there are pilots of fly-by-wire planes who enjoy piloting “manually” however a simple description of the system shows that this is not possible. By the other side, system designers speak about “transparency to the user” meaning that, under an easy and attractive interface, there is a hard and complex program running.

A design of systems really transparent to their operators might be the challenge for next years. That might lead the development of new and more intuitive languages easy to understand for people non-familiar with technology. If so, that will occur at the cost of efficiency. However, in the past information technology has been able to overcome situations where efficiency of systems was traded by efficiency of operators – e.g. the development of high level programming languages. Currently we do not find any special cause to suspect that it would not be possible trading again efficiency by meaning.

REFERENCES