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Knowledge Management Patterns Model for a Flight Test Environment

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ABSTRACT: This paper investigates how Knowledge Management patterns in a Brazilian Air Force flight test environment can be simulated using a System Dynamics approach. The research has been conducted initially by a literature review on the main Knowledge Management and System Dynamics theories. Data for this research has been collected in a previous study consisted of documental research regarding the flight test environment Knowledge Management and a questionnaire-based survey which identified both a low Knowledge Management maturity level and the flight test core competence as the capability of performing flight test campaigns. The issued problem was the tradeoff between actions focused on performing flight test campaigns *versus* Knowledge Management to transfer the core competence inside organization in order to keep it in a high level. A system dynamics quantitative model has been developed as a result of this research. Fluxes and stokes were identified within the model and the relation between them emerged by identifying systemic feedback loops that may compromise the Knowledge Management and the core competence transferring. These features enable a holistic visualization and better understanding of the problem as well as the possibilities of identifying ways of improvement.

KEYWORDS: Systems dynamics, Core competence, Knowledge transferring, Quantitative model.

INTRODUCTION

The Flight Test (FT) activity is based on knowledge attained by experience or research, and its core competence, for the Brazilian Air Force, may be expressed as "the capability of performing flight test campaigns" (Follador and Trabasso 2015) and should be kept and propagated inside the organization.

The mission of the Flight Test Organization (FTO) reads: "It is a Brazilian Air Force Organization specialized in the field of Science and Technology and its mission is to deliver specialized technological services regarding flight test, aircraft instrumentation and data telemetry to support research, development and certification of aeronautical products and to train specialized personal in flight test" (Brasil 2011, p. 7).

The FTO executes great part of the Brazilian Air Force (BAF) activities regarding flight test and offers training courses for BAF test pilots, test engineers, instrumentation engineers and flight test technical personnel. Knowledge inside the FTO environment, mainly that related to its core competence, must be preserved and the activities regarding Knowledge Management (KM) must be developed such as genesis, maturation, use, preservation and dissemination.

Follador and Trabasso (2015) presented a documental research regarding the flight test environment and also submitted a questionnaire for KM maturity level assessment, identifying a low KM maturity level inside the FTO in BAF and the flight test core competence as the capability of performing flight test campaigns. These findings, in addition to a high demanding activity in performing Flight Test Campaigns, indicated that may exist a commitment between actions focused on performing flight test campaigns *versus* KM activities regarding the transference

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of the core competence inside the organization preventing an ideal sharing of important knowledge.

The objective of this paper is to simulate and analyze the KM patterns, in a BAF FTO, in order to apprehend the relationship between the activities of performing flight test campaigns and those of KM within the organization. This problem has been addressed using a system dynamics approach, where a quantitative model is proposed to identify the main stakeholders of the FTO KM system, pointing out fluxes and stocks as well as the relationships between them.

This article is organized as follows: the second section presents the literature review and describes the contribution of this paper. The third section describes the methodology used to construct the model. The following section presents the results and discussions about FT KM model, regarding the commitment between performing flight test campaigns and KM activities necessary to maintain the core competence in the organization. The final section summarizes the contribution of this research and discusses future studies.

LITERATURE REVIEW

Sterman (2002) suggested that, in a world of accelerating complexity and change, thoughtful leaders increasingly recognize that the management tools that had been used have not only failed to solve the persistent problems encountered, but may, in fact, be causing them. Examples of organizational policy resistance are: well-intentioned efforts to solve pressing problems create unanticipated side effects. "Learning about complex systems when you also live in them is difficult. We are all passengers on an aircraft, we must not only fly but redesign in flight" (Sterman 2002, p. 4).

To understand the system a literature review was performed on the topics of KM, System Dynamics (SD) and FT.

KNOWLEDGE MANAGEMENT

KM has been researched in the last decades (Davenport and Prusak 1998; Nonaka *et al*. 2001; Nonaka and Takeuchi 2004; Grundstein 2008; Lloria 2008; Albers 2009). An organization that does not understand the importance of knowledge nor manages or improves it, based on the environment demands in which it is inserted, may be faded to a condition of capabilities loss or stagnation.

Nonaka and Takeuchi (2004) explore the concepts of explicit and tacit knowledge and propose 4 modes of knowledge conversion in a process called "The Spiral of Knowledge", namely: (1) Socialization; (2) Externalization; (3) Internalization; and (4) Combination.

The organizational environment must provide conditions and means for allowing knowledge to flow. Bock (1999) says that it is important to consider KM in terms of 4 integrated dimensions: content, culture, processes, and infrastructure. Content is related to the following question: what kind of knowledge is important to my organization? Prahalad and Hamel (1990) state that some knowledge, known as core competence, is the source for organizations' technological success.

"Culture sets both the limits (constraints) and the direction of movement of behavior within the organization: culture dictates the acceptance of all organization change" (McNabb 2007, p. 113). Therefore, the organization's cultural dimension is a major factor to KM success, so people and their beliefs may be responsible for the cycle of knowledge acceptance inside an organization.

Albers (2009) proposed a practical approach to implement KM based on 5 basics steps:

1. Select KM team.
2. Establish KM strategy and business case.
3. Perform knowledge assessment and audit.
4. Perform information technology (IT) assessment.
5. Develop project plan and measurement systems.

Fonseca (2011), in a study about KM in an aeronautical company, pointed out that the KM system in that environment had low effectiveness. His findings have been confirmed by institutional characteristics like lack of cultural organization and low adherence to KM initiatives. These characteristics may be also present within the FT organization, where the high workload of FT workers may contribute to reinforce the tendency of low KM effectiveness.

FLIGHT TEST KNOWLEDGE MANAGEMENT

Kimberlin (2003) states that the FT activity is dependent on efficient KM. The BAF Basic Doctrine Manual (DCA 1-1) defines the FT activity as "the action that consists in use air force resources to identify the flying qualities and the performance of aircrafts and systems" (Brasil 2012, p. 57). This statement indicates the dynamic characteristic of the FT activities, because FT deals with new systems that accompany the airspace technology continuous evolution. The correct evaluation, via flight tests, of the new systems guarantees their proper work and ensures flight safety.

Dealing with the state-of-the-art technologies available, an FT organization must have a KM concern in order to keep its operational capabilities and to be able to process the market technology push.

There are research examples relating FT and KM. Gray (2005) proposes a mathematical model to investigate and understand a FT technique called boundary-avoidance tracking, identifying the causes of dangerous flight conditions known as Pilot Induced Oscillation (PIO). Follador *et al.* (2009) analyse FT methods to evaluate aeroelastic structural vibrations using Operational Modal Analysis (OMA).

An example of KM applied to FT techniques is the aeronautical certification manuals, such as the Advisory Circulars (AC), from the Federal Aviation Administration (FAA). They suggest a great number of techniques that are recognized as a guide to conduct FT activities. The AC 25-7 — Flight Test Guide for Certification of Transport Category Airplanes (United States 2012) — indicates its purpose as: "This AC provides updated guidance for the flight test evaluation of transport category airplanes. These guidelines provide an acceptable means of demonstrating compliance with the pertinent regulations […]" (United States 2012, p. 1).

In the AC 25-7, it is worth noticing that FT knowledge is constantly evolving in line with new technology capabilities, in order to provide compliance with regulations. The evolution of the FT techniques demand constant training of Human Resources to provide them with the required ability and understanding to deal with the new techniques. Another source for FT knowledge is the reports produced after each FT campaign. It can be learned from the reports the issues regarding the whole campaign, namely, motivation, applied resources FT techniques, and final results.

Although there is a huge amount of written material regarding FT, great part of the knowledge attained during FT campaigns is related to tacit knowledge, acquired during on-the-job learning, and must be shared with the organization through the process of "externalization" (Nonaka and Takeuchi 2004). This kind of knowledge is part of the FTO core competence, identified as the capability of performing FT campaigns (Follador and Trabasso 2015).

Another important issue regarding FT reports is related to its main part, the 7-part paragraph: "There are key features likely to be required in a complete flight test report: conditions, results, analysis, role relation, conclusions, recommendations and standards compliance" (Gratton, 2010, p. 1).

In the researcher's judgment, the core part of the 7-part paragraph is the role relation or Mission Impact. This part deals with the impact of the tested system characteristics on the mission it is supposed to perform. The test team must joint the operational knowledge with the FT information obtained and predict if the mission is still possible to be accomplished or how it will be affected by the issues revealed by the FT. A lack on this operational knowledge may lead to a misinterpretation and a false FT result that may produce serious problems in the future system FT or even in the aircraft operational performance.

Follador and Trabasso (2015) also identified the following characteristics in the KM environment analyzed in their study:

- Lack of infrastructure dedicated to KM.
- Lack of KM specialist.
- High turnover of trained staff.
- Flying Test Course (CEV) and library are the main stocks of registered knowledge.
- CEV and library not linked.
- High workload of the FT teams, impairing them to conduct knowledge sharing.
- Frequent occurrence of rework.

These findings, especially the 6th characteristic, emphasize that the operational knowledge may be lost because of the FTO high workload on performing FT campaigns; consequently, there is little or no time to maintain the FT pilots updated with the evolution of operational missions.

SYSTEMS DYNAMICS

SD is a methodology largely used for analyzing systemic behavior in organizational or social systems, by means of representing causal relations between its elements and by analyzing its evolution in time (Forrester 1971, 1994, 1997; Sterman 2002; Villela 2005; Morecroft 2007; Figueiredo 2009; Ford 1999; Amaral 2012). The awareness for SD is growing because of its unique capacity for representing the real world. It deals with complexity, non-linearity and feedback structures, inherent to social and physical systems. It is a methodology that provides better understanding of complex systems evolution (Forrester 1994; Sterman 2002; Meadows and Wright 2008).

SD response is usually represented by particular behavior and pattern like exponential growth and oscillations and by its direct relation with feedback loops characterized as reinforced, balanced, delayed balanced and their combination (Ford 1999; Gonçalves 2009).

Sterman (2002) proposes the iterative approach for SD modeling. Results of any step can yield insights that lead to revisions of the previous step, as depicted in Fig. 1. The first step of the SD modeling process is to understand the problem (Ford 1999; Sterman 2002; Morecroft 2007).

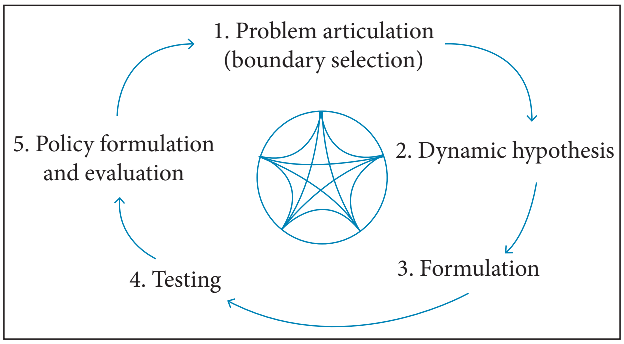

Figure 1. Iterative SD modeling process (Sterman 2002).

Ford (1999) proposes 8 steps for SD modeling, namely:

1. Get acquainted with the system.
2. Be specific about the dynamic problem.
3. Construct the stock and flow diagram.
4. Draw the Causal Loop Diagram (CLD).
5. Estimate the parameters values.
6. Run the model to get the reference mode.
7. Conduct sensitivity analysis.
8. Test the impact of policies.

Several authors studied the relation between qualitative and quantitative approaches to SD modeling (Ford 1999; Wolstenholme 1999; Coyle 2000). These 2 approaches are complementary as seen in the 8-step method proposed by Ford (1999): the first 4 can be classified as qualitative whereas the remained 4 steps belong to quantitative approach to SD modeling.

One important aspect of Step 5 — Estimate the parameters values — is to choose the correct time horizon. Sterman (2002) says that it should extend far enough in history to show how the problem emerges and describes its symptoms. A common mistake at this step is to estimate a time horizon too short that does not allow for correctly estimating the length of delays in the system. "[…] A good rule of thumb is to set the time horizon several times as long as the longest time delays in the system…" (Sterman 2002, p. 119).

The Step 8 — Test the impact of policies — may be applied both in qualitative and quantitative SD modeling (Coyle 1996). This may result in new policies to be applied to the model in order to achieve improvements in the system performance and to minimize the problem addressed (Morecroft 2007).

Meadows and Wright (2008) identify 12 leverage points, as places to intervene in a system with new policies, in order to change the structure of systems to produce more of what is needed and less of that which is undesirable. Examples of the leverage points are:

- Numbers: constants and parameters such as subsidies, taxes, and standards.
- Buffers: the sizes of stabilizing stocks relative to their flows.
- Delays: the lengths of time relative to the rates of system changes.

The literature presents several studies using SD as a tool for modeling subjects as: technology innovation (Swinerd and McNaught 2014), improvement of anemia control (McCarthy *et al.* 2014), adult obesity trends (Fallah-Fini *et al.* 2014), infection screening among young women (Teng *et al.* 2015), information sharing, psychological safety performance effects (Bendoly 2014), and diffusion of technological innovation (Swinerd and McNaught 2014).

Regarding specifically researches on KM, the following topics are found: KM performance (Chen and Fong 2015), KM process in airlines (Zaim *et al.* 2013), organizational IT investment strategy and market performance (Liao *et al.* 2015), analysis of technology districts' evolution in a knowledge-based perspective (Dangelico *et al.* 2010), and capacity planning (Špicar 2014).

Gonçalves (2011) analyzed the balance between the provision of relief and recovery and the capacity building in humanitarian operations. This is carried out by modeling the performance of 2 polar resources allocation strategies: one focusing in relief and recovery efforts and the other on capacity building. The author reports a counterintuitive behavior from relief/recovery and capacity tradeoff that is characterized as capability trap.

Repenning and Sterman (2002) define capability trap as the phenomenon that arises when people's efforts to achieve performance targets come at the expense of maintenance and learning, thereby eroding the health of the system. The SD model developed by Gonçalves (2011) is presented in Fig. 2, where a causal loop diagram depicting the feedback processes for an organization allocating resources between providing aid and building capacity can build on the capability trap phenomenon.

A similar condition reported by Gonçalves (2011) was identified in the KM system for the FT environment addressed in the present paper. Follador and Trabasso (2015) also report the high workload as an obstacle for knowledge sharing between flight test teams, which may be characterized as a capability trap.

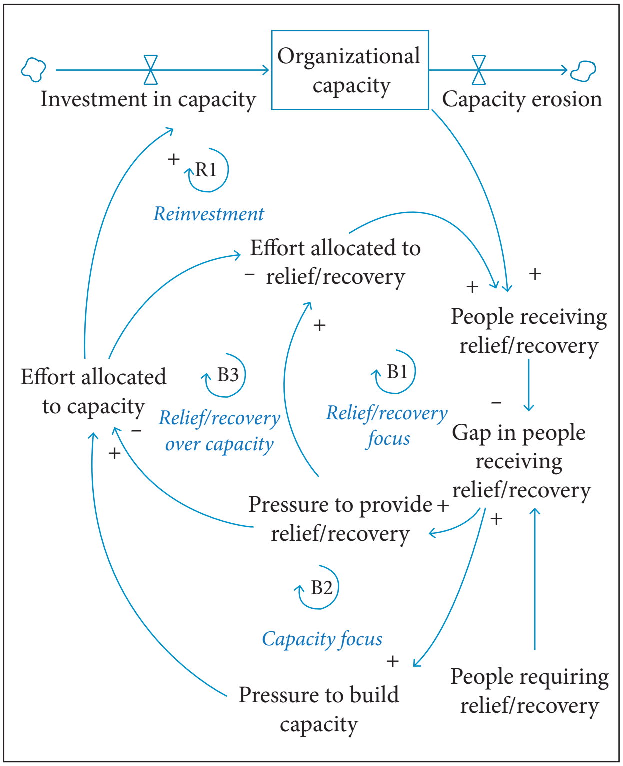

Figure 2. Counterintuitive behavior from relief/recovery and capacity tradeoff (Gonçalves 2011).

The searched literature showed the increased relevance of SD in the modeling of complex systems, but it did not address specifically the KM regarding the knowledge transferring problem in an FT environment. Thus the present study aims to identify a counterintuitive relation between the dedication of performing FT campaigns and the risk of losing the organization core competence using a SD modeling process. Then a course of actions is proposed as means to mitigate the risk of losing the FT core competence.

MODEL DESCRIPTION

The SD modeling process used is based on that proposed by Sterman (2002) and Morecroft (2007). For this development it was chosen the methodology proposed by Sterman (2002), following the 2nd path proposed by Morecroft (2007):

- Identification of the problem under study.
- Identification of the dynamic response.
- Conception of a map of the main sectors involved.
- Model the system checking for flows and stocks.

The acquaintance with the KM system was achieved based on the results presented by Follador and Trabasso (2015) and Fonseca (2011) about KM systems. The KM acquaintance in a flight test environment provided enough information to formulate the dynamic problem: there is a poor knowledge transferring inside FT knowledge management environment. This, in turn, implies rework and the loss of important FT knowledge achieved mostly during FT campaigns.

It was understood that a KM system may have a good initial knowledge transferring, because, to became an FT pilot or engineer, one must go through a capacitating course where the basic knowledge is provided. After this initial stage, the knowledge transferring opportunities tend to stabilize at a lower level along the time. This assumption of dynamic response is presented in Fig. 3. This curve corresponds to one of the fundamental modes of dynamic behavior, corresponding to a reinforced loop followed by a balanced loop plus another reinforced loop (Sterman 2002).

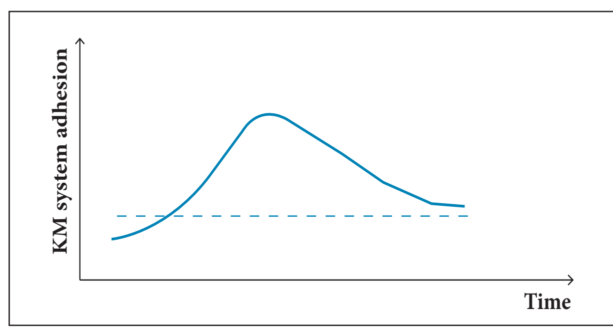

Figure 3. Dynamic response of knowledge transferring in a KM system.

The dynamic mode reflects the behavior of a crescent adhesion in the initial moments of a KM system responding to a reinforced positive loop, due to the value it may have inside the organization. Then, a temporal progression occurs and the adhesion behavior reaches the maximum value, influenced by a balanced loop. Finally, the dynamic mode directs the KM system behavior to a lower level, represented by the dashed line, caused by a reinforced negative loop, due to systemic issues in the FT organization that correspond to the problem addressed in this paper.

After the KM dynamic response identification, a map of the main sectors involved in the system was conceived based on the research on KM maturity level performed by Follador and Trabasso (2015). This map involves 3 main areas that affect

KM: culture/people, processes and technology/infrastructure, as it is presented in Fig. 4.

For example, the CLD for process sector was constructed based on the research performed by Follador and Trabasso (2015) and Fonseca (2011). The CLD of KM process sector is presented in Fig. 5.

Once the CLDs for all KM sectors are constructed, they are grouped to construct the stock and flow diagram for the KM system model, depicted in Fig. 6.

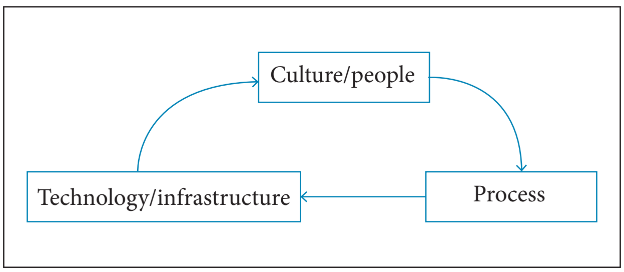

Figure 4. Map of the main sectors involved in the KM system.

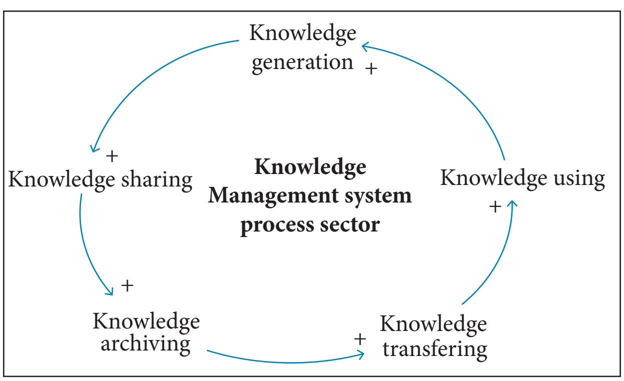

Figure 5. CLD of the KM process sector.

To construct the KM model it was used the software Vensim® version 6.3 provided by Ventana Systems in an academic version. This software is an integrated framework for conceptualizing, building, simulating, analyzing, optimizing, and deploying models of complex dynamic systems.

The model was constructed by the identification of "stocks" (or levels) as {*Organizational Knowledge*} and "flows" (or rates), like [*Knowledge use*] and [*Knowledge erase*]. Influence variables where also identified and added to the model, such as <*researching*>, <*contracting*>, <*capacitating*>, and <*on the job training*>.

Considering the interactions among flows, stocks, and variables, it was possible to identify reinforced and balanced feedback loops represented by the symbols such as (R) and (B), respectively. These loops provide the possibility of studying the causal relations in the KM system that are traduced into equations and into curves of behavior over time. Once the main stock-and-flow structures (or levels and rates of change) and feedback processes characterizing the system are captured, it is possible to translate them into a mathematical simulation model (Gonçalves 2009).

RESULTS AND DISCUSSION

In Fig. 6, the stock {*Organizational Knowledge*} participates in one loop involving [*Knowledge transferring*], [*Knowledge use*], and [*Knowledge generation*]. This loop deals with the knowledge generation effort of the organization. Several variables are relevant in this loop, such as <*researching*>, <*contracting*>,

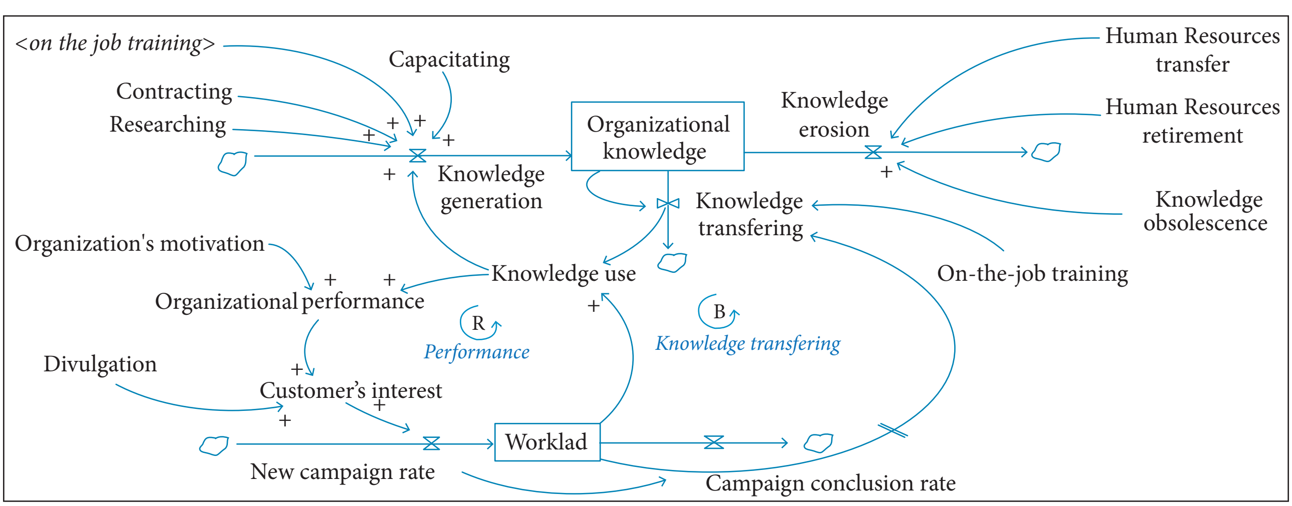

Figure 6. Proposed stock and flow diagram for the KM system model.

<*capacitating*>, and <*on the job training*>. In terms of FT, the variable <*on the job training*> bears singular importance, as it carries the experience exchanged during execution of FT campaigns or flight tests. Even the operational knowledge, as a basis to understand the mission impact, is transferred from pilot to pilot during flights or participates in operational campaigns.

Another important variable in the model is <*knowledge use*>. It participates in 3 feedback loops, namely, Knowledge generation (reinforced loop), Performance (reinforced loop), and Knowledge transferring (balanced loop).

These 3 loops interact among themselves and are influenced by a high Human Resources attrition rate, denoting 2 conflicting concerns to the FTO: (1) performing FT campaigns; and (2) transferring knowledge among the teams involved in FT campaigns execution. This conflict shows that, with a low number of FT teams in this organization and the stress to perform flight test campaigns continually required by the main customer (BAF), the KM activity and the organization knowledge may be jeopardized. This can be seen from Figs. 7 and 8, where the simulations response for <*organizational knowledge*> and <*knowledge transferring*> are presented.

The results represent a counterintuitive observation: the greater the effort to maintain the FT organization totally focused

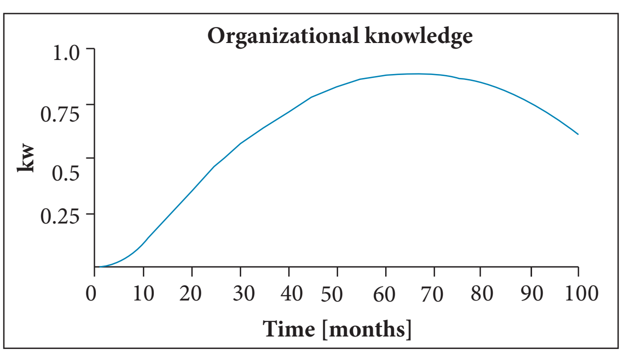

Figure 7. <*organizational knowledge*> response simulation.

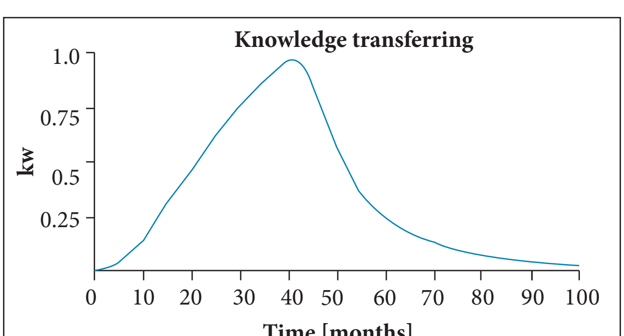

Figure 8. <*knowledge transferring*> response simulation.

on performing FT campaigns, the greater the risk of losing its core competence and ability to continue fulfilling the customer's needs in the future. Despite the effort to generate and transfer knowledge by the FTO, the additional workload influences the system and it may be prevalent over the other activities. Furthermore, in a medium to long term, it may threaten the knowledge transferring, characterizing a capability trap that may prevent the organization from sharing and continuously learning its core competence.

It is important to notice the great similarity with the curve presented and the dynamic hypothesis for knowledge transferring inside the FTO. This finding is important because it brings awareness of the importance to look for leverage points in the model to introduce new policies for providing a more stable knowledge transferring and a preservation of the organizational knowledge while attending the requirements of FT campaigns.

CONCLUSION

This paper has shown that it is feasible to construct the SD model to represent a KM system inside an FT environment, providing means for observing the existing feedback loops in the KM system and identifying a simulated response for knowledge transferring very similar to the dynamic hypothesis formulated.

The SD model has provided means to understand the main variables in the FT environment regarding KM and to observe how they influence the KM system. Also, it was possible to understand a counterintuitive aspect, regarding the necessity of performing FT campaigns and to preserve FT knowledge, where efforts to maintain the FT organization focused on performing FT campaigns may offer a risk of losing its core competence and the ability to continue fulfilling the customer's needs in the future. This pattern characterizes the existence of a capability trap within the FT organization.

Further research will be addressed to improve the model where new policies will be proposed in order to change the structure of systems, looking for a way to provide a more stable knowledge transferring and a preservation of the organizational knowledge. Parameters of the SD model will be adjusted in order to run a sensitivity analysis and to test the impact of policies to change the system into a more appropriate behavior of knowledge transferring. The aim of this procedure is to ensure that the FT organization maintains its core competence without affecting its ultimate goals of providing FT campaigns according to the customer's needs.

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