FORESIGHT AND SYSTEM DYNAMICS IN MODELLING THE DYNAMICS OF ORGANIZATIONAL KNOWLEDGE

Paulo Edy Nakamura
Brazilian Aeronautical Command
pnakamura@gmail.com

Ricardo Matos Chaim
University of Brasilia, Brasilia, Brazil
rmchaim@gmail.com

Abstract

The loss of organizational knowledge due to the departure of skilled staff generates negative impacts on both an organization's productivity and its functional capacity to understand the key strategies and actions necessary to achieve stated goals. In order to identify, understand and model the factors likely to be involved in the causes and impacts of the loss of organizational knowledge, this article examines the dynamics of knowledge processes in a Project Management Office of the Brazilian Aeronautical Command, which is responsible for the implementation of complex aeronautical projects in Brazil. Presented here is a dynamic model based on concepts from Nonaka and Takeuchi's "Theory of Organizational Knowledge Creation", and on Michel Godet´s methodology for identifying key variables within Strategic Foresight Studies. The model enables the simulation of diverse scenarios in which are represented the consequences of changes in key variables of influence. The work concludes with a discussion of concerns and opinions that could facilitate both the formulation of policy and active intervention aimed at minimizing the unwanted impacts that result from the loss of an abstract entity known as organizational knowledge.

Keywords: System Dynamics. Scenarios. Organizational Knowledge. Knowledge Management. Dynamic Models. Complex Projects. Strategic Foresight.

1 Introduction

Organizational environments are dynamically complex by nature, and in them individual knowledge and experience, when properly valued, organized and controlled, are critical to success and survival. As such, leading organizations stand out by being well-informed and having information and knowledge that allow them to adopt the best strategies for achieving their goals (CHOO, 2006). They also have leaders, managers and decision makers who can recognize and value personal knowledge, individual experience and training as a key resource called organizational knowledge.

Organizational knowledge, whether explicit or implicit, is an abstract entity inherent to human activity which neither transfers nor can be shared with ease or spontaneity (ALVARENGA NETO, 2008). As with other types[1] of knowledge, the management of such an asset is no easy task. Unlike the administration of physical resources (such as materials, personnel and finances), which can be measured and controlled, organizational knowledge is subjective and lacks indicators that are explicit or well-defined.

A good example here is Brazilian Air Force Command (COMAER), which oversees the Coordinating Committee of the Combat Aircraft Program (COPAC), an agency responsible for coordinating activities related to the development, modernization and acquisition of aeronautical systems for use in the Brazilian Air Force (FAB). Organizational knowledge permeates the activities of these groups, most of which resides in the minds of group members and leaders, both past and present. This implicit knowledge, experience and accumulated memories are combined with explicit knowledge, policies, guidelines and manuals to achieve the goals and objectives of each organizational unit.

As these activities are carried out in projects of medium and long-term duration, that is, from 5-15 years, the organization inevitably passes through organizational and structural changes, especially with the departure of highly qualified and experienced staff. This natural process results in the loss of significant portions of acquired experiences and accumulated knowledge, important assets for the direction and continuation of administrative proceedings within COPAC.

In previous work (BONOTTO, 2005; TAVARES, 2008), it was found that the continuous turnover of qualified personnel gradually decreases accumulated experience and organizational memory. This in turn harms all processes of project management, especially during the negotiation, signing and management of contract execution.

Hence arises the need for an understanding of the factors involved in the management of accumulated knowledge, how such processes occur, and of how they are influenced by human and organizational factors, factors that can also contribute to the formation and maintenance of knowledge organizations of this nature.

2 Development

Understanding the mechanisms that enable the formation, flow and loss of organizational knowledge enables the adoption of policies and strategies that can ensure the survival and competitiveness of an organization in a turbulent environment. Thus, this study addresses the following topics:

a) Analyze the principles and concepts of Knowledge Management (KM) in an organization responsible for managing complex aeronautical projects (COPAC);
b) Identify and present a dynamic model to represent the turnover of specialized personnel and its relation to the formation of organizational knowledge; and
c) Identify and investigate the dynamics present in organizational change in terms of personnel policy and the efforts employed to create organizational knowledge.

[1] Popular, philosophical, religious or scientific (LAKATOS and MARCONI, 1986, p.20).

2.1 Knowledge Management

Different authors define Knowledge Management in different contexts and for different purposes; they conceptualize the term in different ways based on different epistemologies. This paper will therefore incorporate an interdisciplinary perspective that can capture the dynamic nature of Knowledge Management. This allows Knowledge Management to be defined as:

> "The effective learning processes associated with exploration, exploitation and sharing of human knowledge (tacit and explicit) that uses appropriate technology and cultural environments to enhance an organization's intellectual capital and performance."
>
> *Source: Jashapara, A., (2004), Knowledge Management: An Integrated Approach, Prentice Hall, Harlow, Essex: page 12.*

According to Nonaka and Takeuchi (1995) there are two types of knowledge: tacit (implicit) and explicit. Tacit knowledge consists of one's experiences, mental models, beliefs and opinions. Explicit knowledge is the kind of knowledge that can be defined and shared easily through information technology.

With these two concepts, Nonaka and Takeuchi have developed a dynamic model (Figure 1), known as SECI (Socialization, Externalization, Combination and Internalization). This framework was in turn based on studies in the Theory of Organizational Knowledge Creation (NONAKA and TAKEUCHI, 1995).

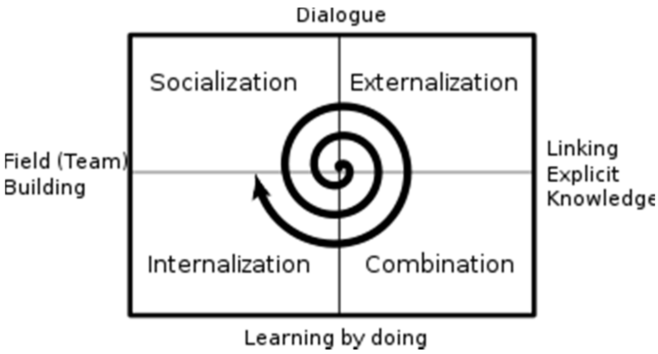

Figure 1. Nonaka and Takeuchi SECI model (1995)

These two authors argue that knowledge is initially created by individuals and becomes organizational knowledge through a process represented above (see Figure 1).

> "A spiral emerges when the interaction between tacit and explicit knowledge is elevated dynamically from a lower ontological level to higher levels"
>
> *Source: Nonaka and Takeuchi (1995), The knowledge-creating company. New York: Oxford University Press: p. 57.*

This spiral is created by the four modes of knowledge conversion through which knowledge is converted from one knowledge type to another. These modes of knowledge conversion include socialization (from tacit to tacit knowledge), externalization (from tacit to explicit knowledge), combination (from explicit to explicit knowledge), and internalization (from explicit to tacit knowledge).

The following literature review compares this theory with other schools of thought, particularly as expressed in the work of Davenport and Prusak (1998). With a more pragmatic view, these authors concentrate their studies on organizational processes that allow the generation, codification and transfer of knowledge.

For this research, the SECI model was chosen because it views the social as dynamic by nature (NONAKA and KONNO, 2000). Humans play an important role and organizational networks generate knowledge through social processes of sharing, exploring and creating tacit knowledge (stories, experiences and concepts) and explicit knowledge (raw data, bank and organized data reports).

Analysis of works by Tavares (2008) and Bonotto (2005), which describe the vulnerabilities of knowledge production and project management in COPAC, reveals similarities between the SECI model and the processes in which knowledge is transferred through this organization.

Through these works, an important issue was identified: the loss of organizational knowledge due to the departure of skilled staff. Here could be seen a physical resource (humans) influencing an intangible entity (knowledge), and this is a common problem for many knowledge-based organizations.

Peter Massingham (2008) also explores this issue in a case study within the Australian Ministry of Defense. In this work, the author simulates the consequences of the departure of key personnel and discusses the results of this research in the context of existing literature. He concludes by presenting a preliminary conceptual model able to identify and isolate the causes and nature of the risks involved.

Following suit, the dynamic model here was developed to understand the factors driving the management of accumulated Organizational Knowledge, and how they are influenced by human and organizational activity.

2.2 The System Dynamic Approach

Due to the dynamic nature of the SECI model, with the presence of cause and effect relationships and feedback loops, a system dynamics approach was chosen to model such behavior.

System dynamics is an aspect of systems theory, used for understanding the dynamics of complex systems. It is also a computer-aided approach which can be applied to dynamic problems arising in complex social, managerial, economic and ecological systems.

The basis of the method is the recognition that the structure of any system — the many circular, interlocking, sometimes time-delayed relationships among its components — is often just as important in determining its behavior as the individual components themselves (http://www.systemdynamics.org).

The approach begins with defining problems dynamically, proceeds through mapping and modeling stages, then arrives at steps for building confidence in the model and its policy implications.

Relevant here is the work of Sterman (2000), who defines a sequence of steps that allow the dynamic modeling of the proposed problem. This methodology can be applied in different areas of knowledge (STERMAN, 2000), especially those in which it is difficult to predict the behavior of key variables, and where the system is relatively complex.

The necessary steps may be laid out as:

1 Problem Articulation;

2 Formulation of Dynamics Hypotesis;

3 Structure of the simulation;

4 Tests;

5 Project and evaluation of policies.

Articulating the problem is the first and the most important step in modeling (STERMAN, 2000), and it and the model was accordingly designed to explore policies that could mitigate the loss of organizational knowledge in a Project Management Office due to the departure of skilled staff .

Within this first step, it is also necessary to characterize the problem dynamically, that is, as a pattern of behavior unfolding over time, which shows how the problem arose and how it might evolve in the future. So, a reference mode, literally a set of graphs and other descriptive data showing the development of the problem over time, should be developed (STERMAN, 2000).

In this stage, several project managers from COPAC were involved to identify the time horizon, define those variables and concepts considered important for understanding the problem and designing policies to address it. A Casual Loop Diagram (CLD) was built to represent both hypothetical causes of a system's dynamics and the mental models of individuals and teams.

2.3 The MICMAC method

To build a first Causal Loop Diagram, it is necessary to select a range of elements that the modeler considers relevant (STERMAN, 2000). This selection process, which identifies key variables over less important ones, involves qualitative data collection.

In 1997, James Ritchie-Dunham demonstrated a method to summarize the findings from multiple Casual Loop Diagrams as analytical tools, and to check their rigor. Part of this methodology integrates the MICMAC approach (in the French acronym: Matrix of Crossed Impact Multiplications Applied to a Classification) (GODET, 2006).

The MICMAC method is proposed by Michel Godet within “Strategic Foresight”. In effect, MICMAC does allow participants to see the influence that one variable exercises on another through a third, a fourth, even a fifth. Highlighted are the determining factors (or 'main determinants’) of the situation under investigation. The input variables and results or output variables help participants understand the organization and structuring of the system under the microscope (GODET, 2001).

Godet proposes the use of a matrix to evaluate and ranks the key factors agents in a system. This involves a method consisting of three basic steps:

1 Defining relevant variables;

2 Specifying relationships between variables;

3 Identifying key variables in the group.

The cross-impact matrix, called Matrix of Direct Influences (MDI) (Figure 2), can be constructed as a table, where each entry in the matrix is a variable, each variable in row *i*, on trade-in, moves to the variable in column *j*. Direct influence I(*i*,*j*) can be rated as follows: No influence (0), Weak influence (1), Moderate influence (2) and Strong influence (3). Once the grading is done for all entries, it is possible to observe the sum of each row, which will indicate the influence level. The sum of the columns, meanwhile, shows the level of dependency.

To facilitate the process, the software MICMAC version 6.1.2 - 2003/2004, developed by the French Computer Innovation Institute 3IE, was used. This program can also perform the matrix multiplication applied to graded direct impacts many times. This process produces a Matrix of Indirect Influences (MII) which allows the study of the diffusion of impacts along the chain of influence and also feedback. We can therefore rank the variables according to their influence on the system as a whole.

	Variable 1	Variable 2	Variable 3	Variable 4	Variable j	Influence
Variable 1	I (1,1)	I (1,2)	I (1,3)	I (1,4)	I (1,j)	$\sum_{j=1}^{n} I\,(1,j)$
Variable 2	I (2,1)	I (2,2)	I (2,3)	I (2,4)	I (2,j)	$\sum_{j=1}^{n} I\,(2,j)$
Variable 3	I (3,1)	I (3,2)	I (3,3)	I (3,4)	I (3,j)	$\sum_{j=1}^{n} I\,(3,j)$
Variable 4	I (4,1)	I (4,2)	I (4,3)	I (4,4)	I (4,j)	$\sum_{j=1}^{n} I\,(4,j)$
Variable *i*	I (n,1)	I (n,2)	I (n,3)	I (n,4)	I (n,*n*)	$\sum_{j=1}^{n} I\,(n,j)$
Dependence	$\sum_{i=1}^{n} I\,(i,1)$	$\sum_{i=1}^{n} I\,(i,2)$	$\sum_{i=1}^{n} I\,(i,3)$	$\sum_{i=1}^{n} I\,(i,4)$	$\sum_{i=1}^{n} I\,(i,n)$	

Figure 2. Cross impact matrix - Matrix of Direct Influences (MDI).

As the method suggests, the first goal of such an analysis is to stimulate group thinking and to initiate reflection on 'counter-intuitive' aspects of system behavior. It should be remembered that there is not simply one "official" reading of Micmac results. Numerous meetings were necessary to obtain both an homogeneous list of variables and also a common understanding of respective meanings. Unstructured and non-directed interviews were conducted with members and former members of COPAC, and these aimed to identify and understand the factors that influence the flow and knowledge management in the organization.

At this point, a limitation of the method became clear. This concerns the subjective character of the list; even after extensive discussions, differences in terms of the relations between variables have remained.

In our illustrative COPAC case, a first set of relevant variables were identified through interviews and relevant literature, but these were always attached to both the SECI model and to the problem, 18 variables were identified (Table 1).

The MDI (ANNEX I - MDI) were analyzed through MICMAC software and both direct and indirect influences can be represented in a map (Figure 3). This is divided into four quadrants representing four types of variables: 1. Buffer Variables; 2. Dependent Variables; 3. Relay Variables and 4. Influent Variables. The results can be observed in figures 4 and 5.

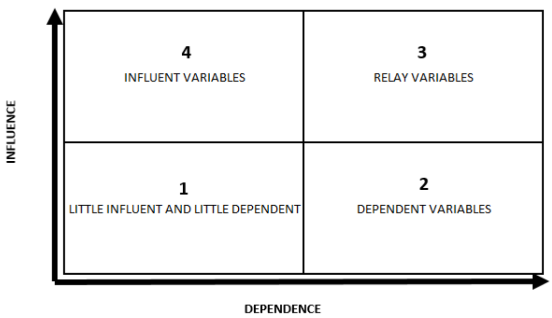

Figure 3. The influence x dependence chart

Table 1. Relevant Variables

N°	**Long label**	**Short label**
1	Shared Knowledge	Shrd_Knw
2	Individual nowledge	Ind_Knw
3	Non-shared Knowledge	N_Shrd_Knw
4	Organizational Knowledge	Org_Knw
5	Staff Training by externals	Ext_Trng
6	Staff Training by internals	Int_Stf_Tr
7	New PMP (Project Managent Professional)	New_PMP
8	New Rookie	New_Rk
9	Interpersonal Interactions	IPers_Int
10	Research and Development	Rsr_&_Dev
11	Organizational Policy	Org_Pol
12	Human Resources Quality	HR_Qual
13	Rookie Quit	Rk_Quit
14	PMP (Project Manager Professional) Quit	PMP_Quit
15	Information Tecnology	IT
16	Best Practices Exchange	Best_Prct
17	Sharing Capacity	Shr_Cap
18	Time to be Promoted	Time_Prom

As an option, MICMAC software can generate a direct (from MDI) or indirect (from MII) relations graph. A direct graph (Figure 6) helped the modelers to establish a first reference for a Casual Loop Diagram (CLD) construction. Of course, this was a generalization needing further analysis.

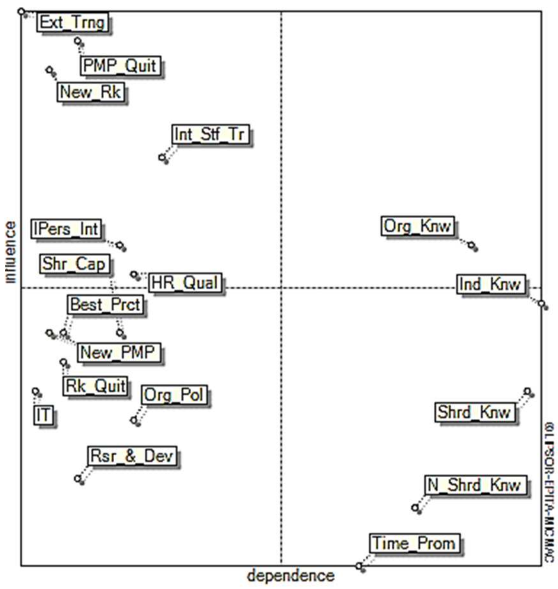

Figure 4.Direct influence/dependence map

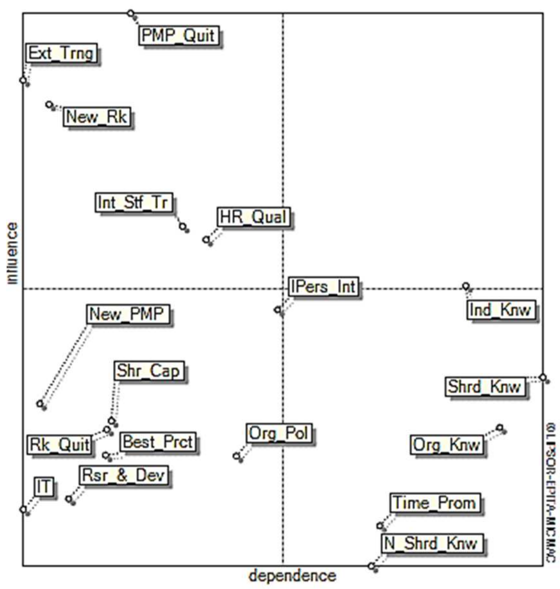

Figure 5. Indirect influence/dependence map

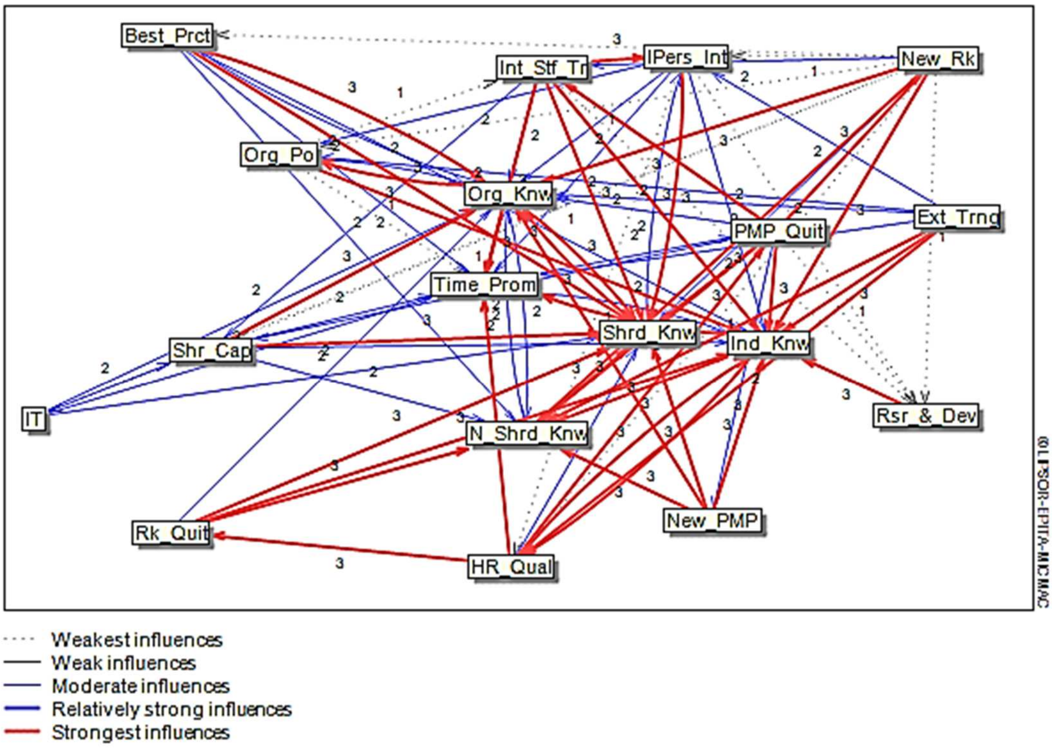

Figure 6. Direct influence graph

In a strict formalistic application, this method is heavily reliant on participant choices. The results can be strongly biased by dominating competencies within the group. Therefore, it is necessary to set up as multidisciplinary a team as possible to constantly check the understanding and meaning of the variables.

Obtaining a consensus does not mean no errors. However, collective, participatory method greatly limits the risks of incoherence and, at the same time, offers the opportunity to build up together a common experience, a common knowledge (GODET, 2006).

In this work, this method proposed by Godet, despite not following a strict formalistic application, proved to be useful in the identification and organization of variables to be considered. Moreover, it allowed the initial draft of the model to be realized.

3 Dynamic Model

To build the model, a framework to capture the dynamics of staff turnover was required. This had to reflect both possible improvements and deteriorations in organizational knowledge. The framework, known as a "coflow", is used to keep track of the attributes of various items as they travel through the stock and flow structure of a system (STERMAN, 2000).

A mental model (Figure 7) was created to represent the COPAC coflow. In this structure each NEW ROOKIE flowing into the PMP TOTAL adds the marginal attribute (knowledge) to the KNOWLEDGE TOTAL. Similarly, for each outflow from PMP TOTAL there is a corresponding drain from the KNOWLEDGE TOTAL.

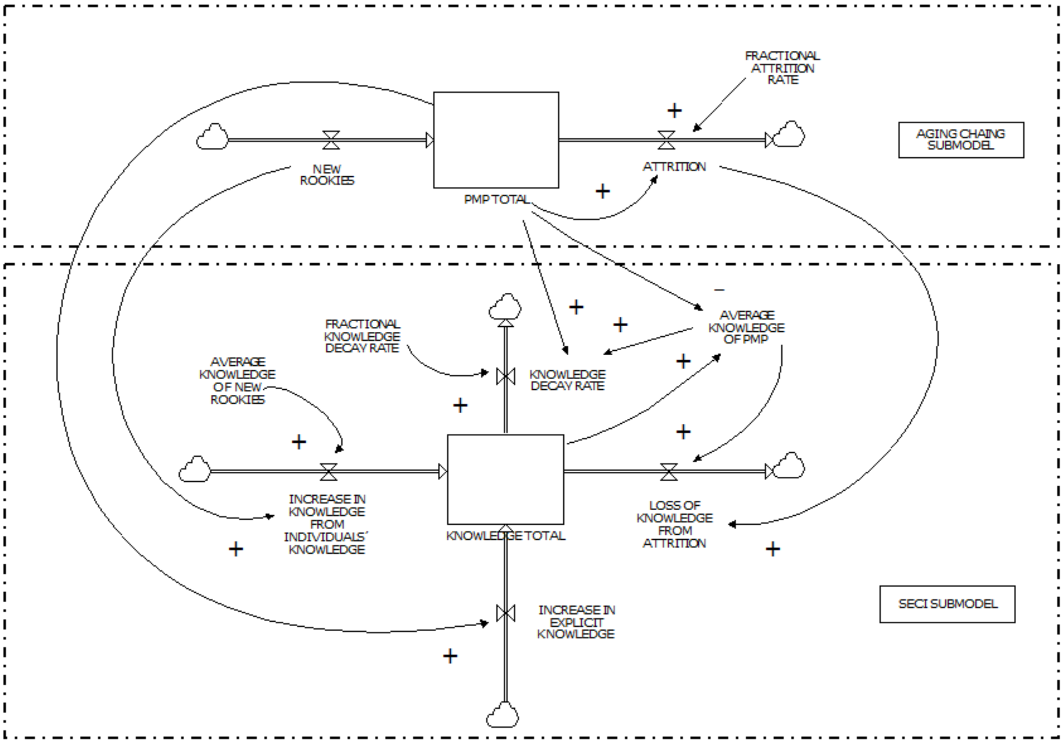

Figure 7. COPAC´s Knowledge coflow structure. Adapted from STERMAN, 2000.

Individual knowledge increases with training and declines as professionals forget or as changes in the process make existing experience obsolete. The KNOWLEDGE TOTAL associated with a PMP is not conserved and the coflow structure should include additional flows into or out of the KNOWLEDGE TOTAL stock. This is a “nonconserved coflow” (STERMAN, 2000).

The COPAC model (ANNEX I) can be divided into two distinct connected sub models, as observed in figure 7, the first (AGING CHAIN SUBMODEL) reflects staff turnover, while the second (SECI SUBMODEL) simulates the relationships that determine the formation of organizational knowledge. The model was created in Powersim Studio 10 Professional (10.00.5486.6) software.

3.1 The Aging Chain sub model

The turnover model uses a structure called "Chain of Aging" (STERMAN, 2000) (Figure 8) and it assumes a staff policy based on the inputs and outputs rates of ROOKIE, staff with low level business knowledge, and Project Manager Professionals (PMP). The Project Management Professional (PMP)® is an industry-recognized certification from the Project Management Institute (PMI) for project managers. The PMP® demonstrates that you have the experience, education and competency to lead and direct projects (www.pmi.org).

In COPAC is not necessary to have a PMP certificate to be considered an experienced manager, but the requirements to get this certificate were used to define the transition from a rookie to an experienced manager. So, the variable “time to be promoted” was defined: 2 years as a default period for promotion in the COPAC model. This variable also depends on other factors (Figure 10) which have a negative

(Balancing) loop, for example, increasing staff training by externals will accelerate the prospects of promotion.

In this model, a COPAC policy of turnover control was established. The “rookie acquisition rate” depends on the “PMP quit rate” (assumed to be exogenous) by a fraction of 40%, defined as the “increase margin factor”. This is enough to guarantee a total staff increase rate of 5% per year to support future incoming projects.

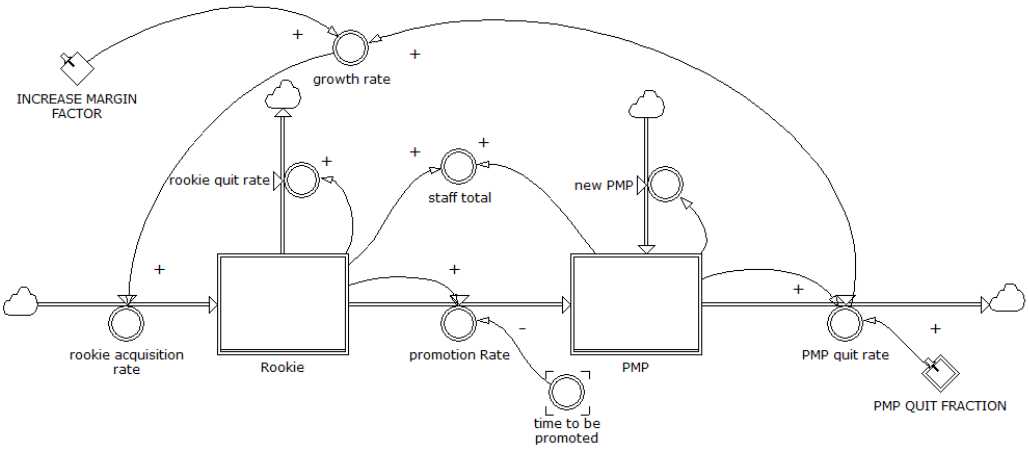

Figure 8. Model "Chain of aging". Adapted from STERMAN, 2000.

This is a two-level promotion chain, adapted from Sterman (2000), for rookie and PMP, which provides a way to model the learning curve for new staff members. It should be embedded in a full model of the organization so as to also characterize the dynamic nature of knowledge flow.

3.2 The SECI sub model

To represent the SECI sub model (Figure 1) and, after that, link it to the Aging Chain model (Figure 8) it was necessary to consider knowledge, both tacit and explicit, as resources (stocks), where they accumulate and either decay or get utilized.

The knowledge, generally speaking, passes through all steps of the SECI model (Socialization, Externalization, Combination and Internalization) as a knowledge sharing process. This process by which knowledge held by an individual is converted into a form that can be useful by other individuals. It is also important because it provides a link between the individual and the organization by moving knowledge that resides within individuals to the organizational level, where it is converted into economic and competitive value (HENDRIKS, 1999).

This capacity to share knowledge is also a necessary condition for the creation of new knowledge (NONAKA and TAKEUCHI, 1995). As knowledge sharing refers to the sharing of not just codified knowledge but also beliefs, experiences, and contextualized practices (DAVENPORT and PRUSAK, 1998), it is only through such sharing that a base of jointly held knowledge, necessary for mutual understanding, can be created (NONAKA and TAKEUCHI, 1995).

So, the model (figure 9) basically has three stocks: Rookie Non-Shared Knowledge, PMP Non-Shared Knowledge and Shared Knowledge.

New Rookies bring a certain amount of experience (knowledge) with them, but the model treats only part of this as useful for project management. The knowledge, at this stage, is individual and non-shared with others because there haven’t been any kinds of interaction yet. The same occurs for new PMP entering the organization.

For example:

<u>new rookie individual knowledge</u> = 'growth rate'*'rookie factor'

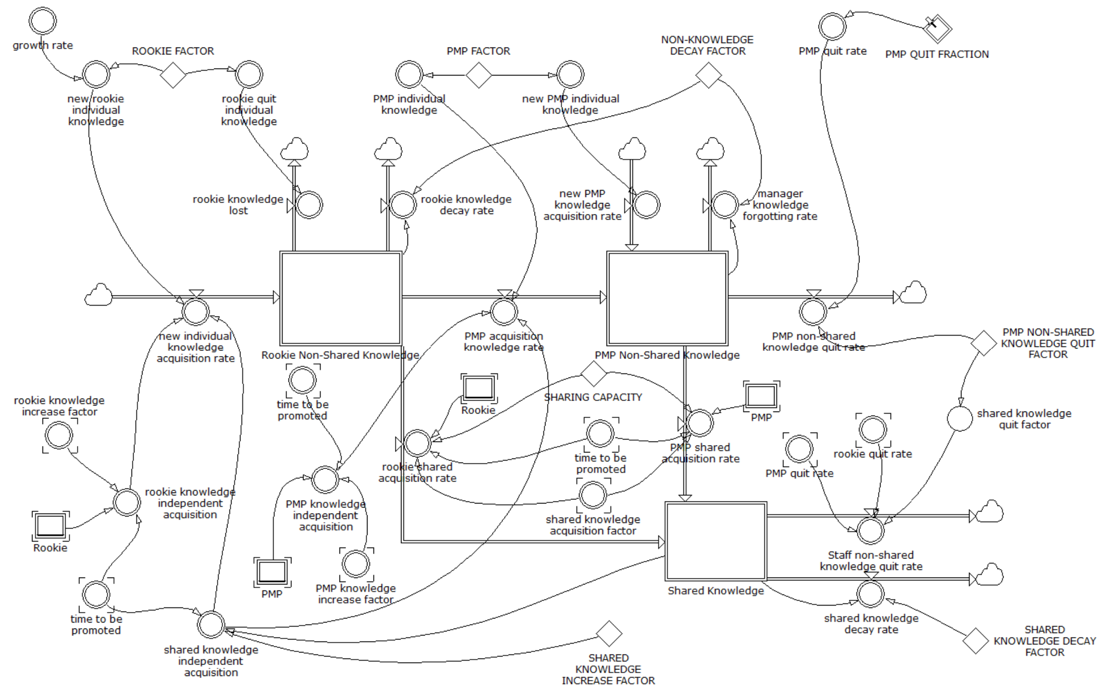

Figure 9. Model for knowledge sharing in a SECI process.

All the SECI modes (Socialization, Externalization, Combination and Internalization) were modeled through rates that increase the shared and non-shared stocks: new individual knowledge acquisition rate, PMP acquisition knowledge rate, rookie shared acquisition rate and PMP shared acquisition rate.

Socialization (implicit-to-implicit) consists of sharing knowledge through social interactions (tacit to tacit) or better, sharing experience, know-how and secrets directly at work through a tutor and apprentice liaison.

The process of externalization (tacit-to-explicit) gives a visible form of tacit knowledge and converts it to explicit knowledge. Tacit knowledge may take the form of metaphors, analogies, concepts, hypotheses, or models" (NONAKA and TAKEUCHI, 1995). In externalization, individuals are able to articulate their knowledge and know-how and, in some cases, the know-why and the care-why.

Combination (explicit-to-explicit) is the process of recombining discrete pieces of explicit knowledge into a new form. No new knowledge is created at this step. It is rather to improve what we have gathered so far, to make a summary or review report, a brief analysis or a new database. The content has been organized logically to extract more sense.

The last conversion process, internalization, occurs through diffusing and embedding newly acquired, consolidated knowledge. In some way, internalization is strongly linked to "learning by doing" (NONAKA and TAKEUCHI, 1995), it converts or integrates shared and/or individual experiences and knowledge into individual mental models.

Once internalized, new knowledge is then used by members who broaden it, extend it, and reframe it within their own existing tacit knowledge.

The rates that increase the shared and non-shared stocks depend on factors and variables (figure 10) identified during the MICMAC process (and subsequent discussions). This helped the modelers to define the weights or coefficients (**X1, X2, …, Xn**) by which they multiply the variable. In such cases case, the sum of the coefficients should be 1.0 (**X1 + X2 + …+ Xn = 1.0)**

For example:

> ‘rookie knowledge increase factor’ = α *(1+(X1 *'STAFF TRAINING BY INTERNALS'+ X2 *'STAFF TRAINING BY EXTERNALS'+X3 *'RESEARCH AND DEVELOPMENT'+ X4 *'INFORMATION TECHNOLOGY'))

In this example, α is the initial value of this parameter (α=0.5)**.** It is an individual factor that will raise (or decrease) a Rookie's knowledge stock, depending on the impact of each variable.

At this point, note that the model runs in reference mode, i.e., an initial condition is assumed (the zero referential) and all the variables (under study) are considered as variations around the zero. For example, if there are 10 (ten) external training sessions per year and they increase to 12 (twelve) per year, this represents an effort 20% above the initial condition. The coefficient **X2** should thus be equal to 0.2.

One limitation of this approach is that the reference condition or level for measures of intangible resources may alter over time (WARREN, 2008).

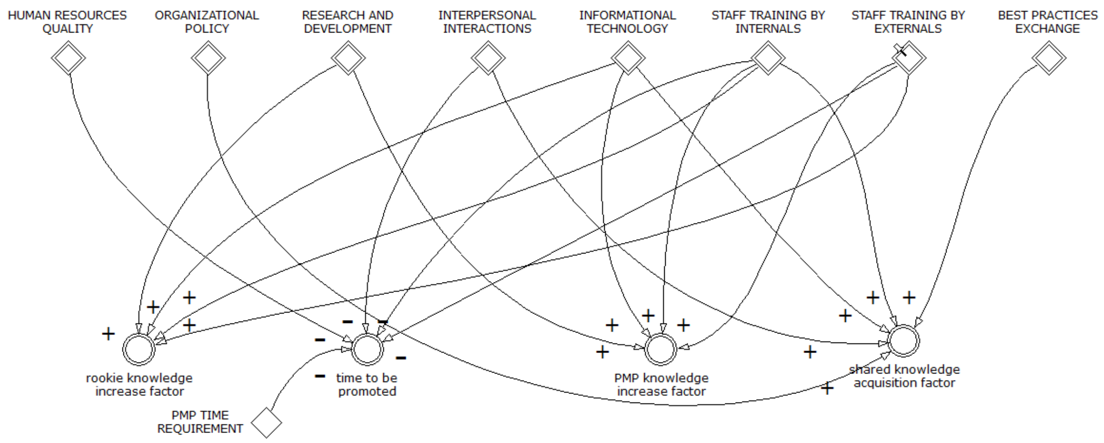

Figure 10. Factors affecting shared and non-shared knowledge acquisition rates.

The loss of organizational knowledge is also proportional to the obsolescence of knowledge. In this sense, the model assumes a lifespan for useful knowledge (shared and non-shared), represented as the ‘SHARED KNOWLEDGE DECAY FACTOR’ and the ‘NON-SHARED KNOWLEDGE DECAY FACTOR’ respectively. These factors have a negative polarity, i.e., the longer the factor is (i.e knowledge with a longer 'life'), the slower is the decay rate.

We can also observe that non-shared knowledge depends directly on individual knowledge; it declines over time and is forgotten as members no longer use it in the everyday ways that normally reinforce it. By contrast, shared knowledge is collective and so takes more time to be forgotten. So the SHARED

KNOWLEDGE DECAY FACTOR is generally greater than the NON-SHARED KNOWLEDGE DECAY FACTOR.

The dynamic behavior of organizational knowledge is directly influenced by the gains and losses of shared and non-shared knowledge. So, the model represents Organizational Knowledge as a sum of shared and non-shared knowledge (Figure 11).

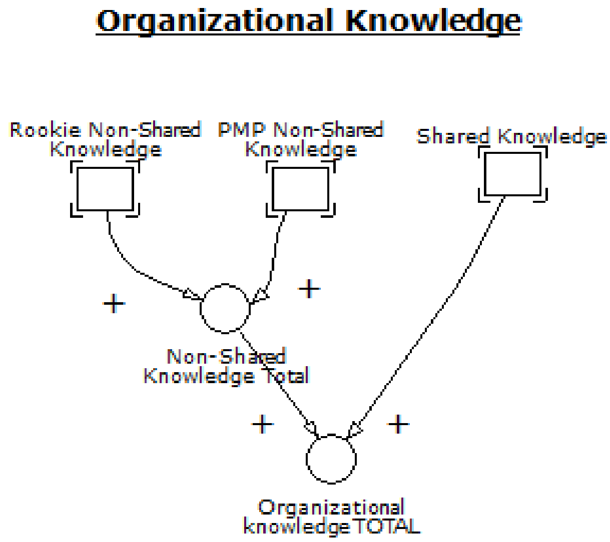

Figure 11. Organizational Knowledge as a sum of shared and non-shared knowledge.

In order to integrate the two sub models (the Aging Chain and SECI), the work of Kim Warren (2008) provides useful leads and insights. He has developed strategy dynamics frameworks and discusses key issues, such as integrating intangibles into the strategic architecture, and resources "attributes" – the qualities that change as resources are won or lost.

The resulting model can be observed in Annex I.

4 Scenarios

The understanding of how certain variables influence a complex system can be achieved through the study of a set of future occurrences likely to result from existing conditions. As time passes, it can be observed how these variables give rise to future situations.

Various definitions of such scenarios can be identified in the literature, especially that of Michel Godet (2001), who claims that scenarios are "a description of a future situation and the course of events that allows us to move from the original situation to the future situation". This theme is explored in several publications by Godet, under the theme "Strategic Foresight", which refers to an effective methodology for understanding the future and defining directions and organizational strategies (Godet, 2001, 2000).

Two types of scenarios are distinguished:

- Exploratory: setting off from past and present trends, and leading to a credible future;

- Normative, or anticipatory: constructed from alternative images of the future, these can be unwanted or even feared; they are also conceived retrospectively.

Scenarios and comparisons between present and possible future situations inform the model. The term "scenario" was used to describe states or changes in key variables and future changes in organizational environment from these variations.

In this study, exploratory research scenarios were simulated in the dynamic model. They encompass the intervention of various key events or circumstances that occur between the original situation and a possible future. This allowed the model to be effectively evaluated.

The following scenarios were established:

Scenario 1: Variations of 20%, 30%, 40% and 50% occurred among departing PMP (managers), which kept within the policy of acquiring new members (Rookies) with an “increase margin factor” by 40%;

Scenario 2: Variations of 20%, 30% and 40% increases in “staff training by externals”, while keeping constant a PMP departure rate (35%).

The first scenario represents a policy that guarantees an increase in staff of 5% per year. But, the question to be answered here is: What is the effect on organizational knowledge of the loss of PMP managers with experience?

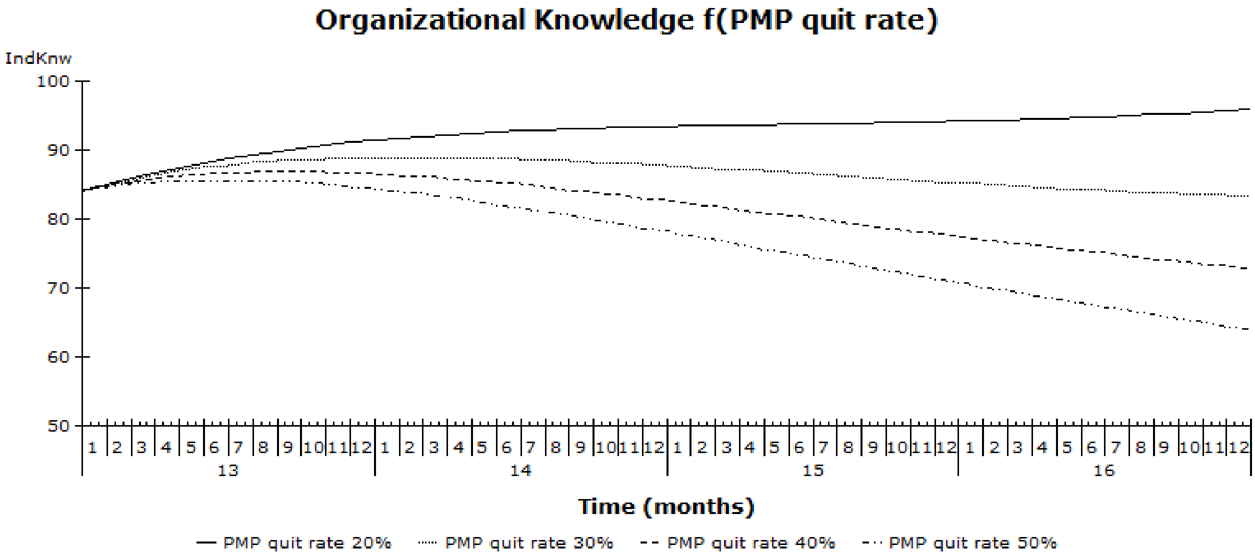

Figure 12. Graph resulting from POWERSIM software on variations in organizational knowledge related to the ratio of output managers.

Analyzing the behavior of Organizational Knowledge variable in the COPAC model, in which the number of trained managers increases by 5% per year, it suggests that the policy initially adopted (scenario 1 – figure 12) will lead to a gradual loss of organizational knowledge.

The second scenario takes one variable (STAFF TRAINING BY EXTERNALS) which can be manipulated and which should impact most on the whole system. It was chosen with the aid of MICMAC, especially through the analysis of the Matrix sum of Direct Influences (MDI) (Table 2). This sum ranks variables according to their influence or dependence. The objective here is to analyze the impacts caused by the increase of one variable on the system, but a combination of several factors could also be analyzed.

Table 2. Directly influences/dependencies rating of variables according to the MICMAC method

N°	VARIABLE	INFLUENCE FACTOR	DEPENDENCE FACTOR
1	Shared Knowledge	11	37
2	Individual Knowledge	16	38
3	Non-shared Knowledge	6	29
4	Organizational Knowledge	12	34
5	Staff Training by externals	23	1
6	Staff Training by internals	18	11
7	New PMP	12	3
8	New Rookie	21	3
9	Interpersonal Interactions	15	11
10	Research and Development	7	5
11	Organizational Policy	9	9
12	Human Resources Quality	14	9
13	Rookie Quit	11	4
14	PMP Quit	22	5
15	Information Tecnology	8	2
16	Best Practices Exchange	10	4
17	Sharing Capacity	12	8
18	Time to be Promoted	4	18
	Totals	231	231

This influence, of the "STAFF TRAINING BY EXTERNALS", can be seen in Figure 13:

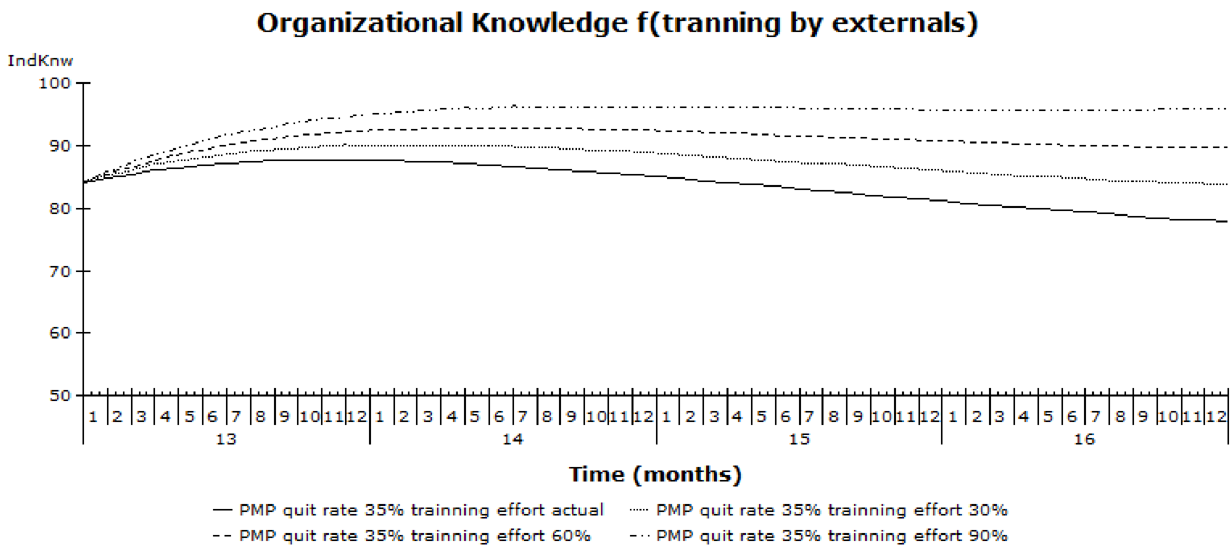

Figure 13. Graph resulting from POWERSIM software on variation in organizational knowledge resulting from increased training efforts.

In this scenario, increased training can reverse organizational knowledge loss. For example, an initial condition of 10 (ten) external training sessions per year, could be increased to 13 (thirteen) per year, this represents an effort 30% above the initial training condition and can increase the organizational knowledge level, but not enough to reverse the overall tendency of loss. So, training sessions could be raised to 60% and 90% to reverse this trend.

Of course, there could be an operational limit to increase the training efforts and combined scenarios could then be used to reverse the organizational knowledge loss, for example: increasing efforts in both STAFF TRAINING BY EXTERNALS and INTERPERSONAL INTERACTIONS.

5 Conclusions

The COPAC knowledge model represents the turnover of specialized personnel and its relation to the formation of organizational knowledge and can be divided into two distinct connected sub models, as observed in figure 7, the first (AGING CHAIN SUBMODEL) reflects staff turnover, while the second (SECI SUBMODEL) simulates the relationships that determine the formation of organizational knowledge.

The modeling process was facilitated with the use of concepts from Godet´s Strategic Foresight, especially by the use of the MICMAC method, which provided an initial approach for the COPAC members to understand and determine the relative importance of each variable in the system being modeled.

After performing the simulations, the results suggest that the increased PMP quit rate (after 20%) will lead to a gradual loss of organizational knowledge (Figure 12).

The organizational factors related to key variables, as suggested by MICMAC analysis and COPAC members, such as increased STAFF TRAINING BY EXTERNALS have a strong influence on the system (scenario 2). This factor can compensate variations in organizational knowledge caused by personnel policies (scenario 1).

A combination of changes in the influence variables, for example: INTERPERSONAL INTERACTIONS and ORGANIZATION POLICY, can be simulated and may also be alternative solutions to reverse the loss of organizational knowledge. Testing these before final implementation can help reveal the capabilities and the complex combinations of factors that are involved in various feedback relationships or in complex feedback.

The architecture of this model is generic by nature, and can be applied to other organizations by replacing initial values of factors affecting shared and non-shared knowledge acquisition rates.

The model is easy to expand and modify in both structure and parameter values, as new data becomes available. This can then be rerun, the results analyzed and improvements made as necessary.

In sum, the understanding of key factors of influence in Knowledge Management through a dynamic model can provide clear guidelines for the adoption of policies that encourage all staff to share important knowledge and experience leading to organizational success in complex projects of this nature.

Finally, our main proposal for future work is the creation and analysis of dynamic models able to evaluate the impacts of knowledge loss on productivity within complex organizational structures.

6 References

[1] ALVARENGA NETO, R.C.D. *Gestão do conhecimento em organizações: proposta de mapeamento conceitual integrativo*. São Paulo: Saraiva, 2008.

[2] BONOTTO, M. B. *Gerenciamento de projetos no âmbito do subdepartamento de Desenvolvimento e Programas – Possíveis Vulnerabilidades*. Monografia – Escola de Comando e Estado-Maior da Aeronáutica, Rio de Janeiro: Universidade da Força Aérea, 2005.

[3] CHOO,C.W. *A Organização do conhecimento: como as organizações usam a informação para criar*

significado, construir conhecimento e tomar decisões. 2 ed. São Paulo: SENAC, 2006.
[4] COYLE, R.G. *System Dynamics Modeling: a Practical Approach*. London: Chapman and Hall, 1996.
[5] DAVEMPORT, T. H.; PRUSAK, L. *Conhecimento empresarial: como as empresas gerenciam o seu capital intelectual*. 4. ed. Rio de Janeiro: Campus, 1998.
[6] DURANCE, P.; GODET, M. *Scenario building: Uses and abuses*, Disponível em http://en.laprospective.fr/dyn/anglais/articles/scenario-building-tfsc-2010.pdf ,Acesso em 20 mar 2013.
[7] FORRESTER, J.W. *Industrial Dynamics*. MIT Press, Cambridge, MA : 1961.
[8] FORRESTER, J.W., LUX, N., STUNTZ, L. *Road Maps: a Guide to Learning System Dynamics*. MIT Sloan School of Management, MIT Press, Cambridge, MA: 1994.
[9] GODET, M. et al. *A "Caixa de ferrramentas da Prospectiva Estratégica"*, Caderno CEPES, 2000.
[10] GODET, M., *Creating futures – Scenario Planning as a Strategic Management Tool*, Paris:Economica, 2001.
[11] GODET, M. *"L'art et la méthode" Tome II – Editions Dunod ("The art and the method"*, Volume II, Dunod Edition), 2001.
[12] HENDRICKS, P. *Why share knowledge? The influence of ICT on the motivation of knowledge sharing*. Knowledge and Process Management, 1999. HISLOP, D. *Knowledge Management in Organizations: A Critical Introduction. New York: Oxford University Press, 2005.*
[13] JASHAPARA, A. *Knowledge management: An Integrated Approach*. Essex: Ashford Colour Press, 2004.
[14] LAKATOS, E.M.; MARCONI, M. *A. Metodologia Científica*.São Paulo: Atlas, 1986.
[15] LESSER, E.; PRUSAK, L. *Communities of practice, social capital and organizational knowledge*.Whitepaper, IBM Institute for Knowledge Management, Cambridge, 1999.
[16] MARCONI, M. A.; LAKATOS, E. M. *Técnicas de pesquisa:planejamento e execução de pesquisas, amostragens e técnicas de pesquisa, elaboração, análise e interpretação de dados*. 7. ed. São Paulo: Atlas, 2008.
[17] MASSINGHAM, P. *Measuring the impact of knowledge loss: More than ripples on a pond ?*. Sage Publications: 2008.
[18] NONAKA, I ; KONNO, N. *The Concept of "Ba": Building a Foundation for Knowledge Creation*. California Management Review 40: 4054, 1998.
[19] NONAKA, I. ;TAKEUCHI, H. *The knowledge-creating company*. New York: Oxford University Press 1995.
[20] PARDUE, J. H. ;CLARK, T.D. ;WINCH, G.W. *Modeling short-and long-term dynamics in the commercialization of technical advances in IT producing industries*, System Dynamics Review Vol.15, 1999.
[21] PIDD, Michael. *Modelagem empresarial: ferramentas para tomada de decisão*. Bookman: Porto Alegre, 1998.
[22] SILVA, A. *A Viabilidade de implantação de um projeto piloto de gestão do conhecimento no Subdepartamento de Desenvolvimento e Programas da Aeronáutica*. Brasília: UNB, 2004.
[23] STERMAN, J. *Business dynamics: systems thinking and modeling for a complex world.* USA: Irwin McGraw-Hill, 2000.
[24] STERMAN, J. *System Dynamics Modeling for Project Management.* Sloan School of Management,Massachusetts Institute of Technology. Cambridge, 1992.
[25] RITCHIE-DUNHAM, J. *Initiating management dialog using a summary presentation that integrates the findings from multiple SD analytical tools*. Proceedings of the 15th International System Dynamics Conference, Istanbul, Turkey. August 1997.
[26] SVEIBY, K.; LINARD, K.; DVORSKY, L.*Building a Knowledge-Based Strategy: A System Dynamics Model for Allocating Value Adding Capacity.* Artigo disponível em: http://www.sveiby.com/articles/sdmodelkstrategy.pdf . Acesso em 12 fevereiro de 2013.
[27] TAVARES, J.C.C. *Produção de conhecimento no âmbito dos projetos da Subdiretoria de Desenvolvimento e Programas*. Monografia – Escola de Comando e Estado- Maior da Aeronáutica, Rio de Janeiro: Universidade da Força Aérea, 2008.
[28] UNB. Curso de Modelagem de Sistemas Dinâmicos Complexos. apostilas de textos.Universidade de Brasília, Brasília: 2012.
[29] WALTZ, E. *Knowledge management in the intelligence enterprise*. Boston: Artech House, 2003.
[30] WARREN, K. *Strategic Management Dynamics*, Wiley: New York,2008.
[31] WENGER, E.; MCDERMOTT, R.; SNYDER, W. M. *Cultivating communities of practice:A Guide to Managing Knowledge*. Harvard: Harvard BusinessSchool Press, 2002.

ANNEX I

COPAC´s Matrix of Direct Influences (MDI)

	1 : Shrd_Knw	2 : Ind_Knw	3 : N_Shrd_Knw	4 : Org_Knw	5 : Ext_Trng	6 : Int_Stf_Tr	7 : New_PMP	8 : New_Rk	9 : IPers_Int	10 : Rsr_&_Dev	11 : Org_Pol	12 : HR_Qual	13 : Rk_Quit	14 : PMP_Quit	15 : IT	16 : Best_Prct	17 : Shr_Cap	18 : Time_Prom
1 : Shared Knowledge	0	1	0	3	0	1	0	0	3	0	1	1	0	0	0	0	0	1
2 : Individual Knowledge	1	0	3	2	0	1	0	0	2	0	0	3	1	0	0	0	0	3
3 : Non-shared Knowledge	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4 : Organizational Knowledge	3	1	2	0	0	0	0	0	0	0	3	0	0	0	0	2	1	0
5 : Staff Training by externals	1	3	3	2	0	1	1	0	2	1	2	3	0	0	1	1	0	2
6 : Staff Training by internals	3	3	1	2	0	0	0	0	3	1	0	0	0	0	0	0	2	3
7 : New PMP	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 : New Rookie	2	3	3	3	1	2	0	0	1	1	1	1	0	0	1	1	1	0
9 : Interpersonal Interactions	3	2	1	2	0	1	0	0	0	1	2	1	0	0	0	0	0	2
10 : Research and Development	1	3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
11 : Organizational Policy	1	3	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1
12 : Human Resources Quality	2	3	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	3
13 : Rookie Quit	3	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 : PMP Quit	3	3	3	2	0	3	2	3	0	1	0	0	0	0	0	0	2	0
15 : Information Technology	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0
16 : Best Practices Exchange	3	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 : Sharing Capacity	3	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2
18 : Time to be Promoted	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0

COPAC Organizational Knowledge Model