Analysis of Engineering Knowledge Management in Latin American Military Organizations: A Case Study

by

Hernan Andres Joglar-Espinosa

B.S. Engineering, Academia Politécnica Militar, Ejército de Chile

Submitted to the System Design and Management Program in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management at the

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ABSTRACT

Many military organizations around the world face difficulty with keeping updated engineering knowledge given the high pace of technological development and increasing complexity of modern weapon systems. The problem is especially stringent in Latin American military services. These organizations are under high pressure for performance improvement as they face a number of real life threats against their countries while being highly restricted in financial resources.

This thesis investigates the issues surrounding engineering knowledge management in Latin American services by summarizing the relevant literature, developing a research framework and applying it to a case study. The case includes three different levels of analysis. At the super-system level, an organizational analysis from the strategic, political and cultural standpoints is conducted to explore influences that arise from the government and high command echelons. Insights from this analysis, along with those obtained through historic data gathering, surveys and interviews, enabled the author to further investigate influences, interactions and behaviors at the system and subsystem levels, that is, the internal engineering environment of a military organization (i.e. organizational and functional levels) and its components (i.e. project team and individual levels).

Several factors were found to affect engineering knowledge management in the studied organization. Some of them may be generalized for other services while some others are related to internal issues. These factors are summarized in a set of recommendations that are made for both Latin American military services in general and the studied organization in particular.

Thesis Supervisor: Janice Klein
Title: Senior Lecturer

Thesis Supervisor: Kent Hansen
Title: Professor of Nuclear Engineering
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1. **Objectives and Discussion**

1.1. **Introduction**

During the last few years, knowledge management has attracted the attention of many business leaders and consultants as they have come to recognize its value as the chief asset of organizations and key to sustainable advantage. Considerable excitement about the beneficial effects of knowledge initiatives has emerged in the corporate world\(^1\). Even though the specialized literature has made an effort to provide guidelines for managing knowledge, this novel discipline has no well-developed and proven theory so far. The difficulty is evident; each organizational setting has its particular characteristics and develops its own patterns of interaction. Aware of that, researchers have mainly concentrated on the industrial sector, and in particular in knowledge dependent corporations (i.e. those dealing with rapidly evolving technology), where the hastened clockspeed provides prompt feedback.

However, few investigations have covered the way knowledge is managed in the unique environment of governmental, non-for-profit organizations in the third world. Military services in Latin America are a kind of organizations that face one of the most difficult environments to make progress in this regard. As a common trait, they are very traditional organizations, with hierarchical structures, in some cases highly politicized, and having no products to ship and no bottom line to measure performance. Besides, as Latin American countries are striving to eradicate poverty, these organizations are all restricted in financial resources. However, traditional sources of conflict, political instability, environmental deterioration, population migration, drug cartels, and terrorism in the region maintain potential threats against nations. These threats, which many times become highly sophisticated, put pressure on governments and military leaders to improve their managerial schemes in order to get the most from their technical capabilities and scarce resources\(^2\).

Although commonalities among these organizations are evident, there are significant differences too. Internal culture, doctrine, discipline, size and technological means vary from one organization to the other. The history of each of these organizations is also very diverse. Some of them have participated in long internal conflicts such as Colombia, El

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Salvador and Nicaragua whilst some others, like Argentina, have fought international wars, or even others have focused on defense and stability of their countries (Brazil, Uruguay and Chile). Therefore it does not seem to be adequate to perform research about knowledge management in these organizations as a whole. The author contends that it is more productive to do a case study and then attempt to generalize only in case those factors that are found to be affecting the issue under study are applicable in other organizations. This study will do so in the Chilean Army (also termed the Army or the organization in subsequent chapters) and will propose feasible solutions to overcome the barriers that prevent leveraging knowledge in that organization. Being one of the oldest military institutions in the region, the Chilean Army presents a good example of discipline, successful history and awareness of the challenges that technological changes pose for its future performance. Most important, it serves the people and uses their tax money; hence it is always under the demanding scrutiny of their representatives and the media. The next section presents a detailed description of the factors that put pressure for managerial improvements in this organization.

1.2. The forthcoming Challenges

The landscape currently faced by the Chilean Army has forced its leaders to review a number of its managerial practices. Given the role of leadership this organization has played in every relevant transition the country has experienced and the expectations that society traditionally places on it, the Chilean Army is nowadays under great pressure to improve its capacity to adapt in a rapidly changing environment. Some of the new challenges faced are:

1.2.1. Unstable situation in neighboring countries and Latin America in general

The quick deterioration of the political and economical situation in Argentina makes it difficult to predict the status of the future bilateral relations with this country. The lack of political leadership exhibited so far in Argentina hinders any prediction of its future military policy. Besides, the social discontent towards governmental economic measures and poverty makes the Argentinean society vulnerable to infiltration by terrorist organizations and drug cartels.

Although its economic condition is not as critical, Peru has a situation that is similarly unpredictable. After a long history of governmental corruption, social agitation has soared in disapproval of the actions taken by a government that has been less than a year in power.
Bolivia, the third immediate neighbor, has traditionally sought its access to the Pacific Ocean through the Chilean northern ports, which were once claimed as Bolivian but were definitely annexed to the Chilean territory as a result of the Pacific War, held in 1879 between Peru and Bolivia together against Chile. This country is always a potential source of conflict.

The political stability in the region in general has traditionally been rather weak. In the last twelve years ten Presidents of Latin American nations have given up power in the midst of economic crisis and/or corruption scandals. Fortunately, none of them was Chilean.

1.2.2. Emerging technology
During the last decade, the always highly demanding environment of the battlefield has become more complex as weapon systems have grown more integrated with the advent of digital systems that assist gathering, interpreting and communicating information. In order to exploit the efficiency of the new systems the Chilean Army will require not just a more competent learning and thinking process but maybe a totally new approach to this activities. The speed at which information is delivered today requires that the human participation in the knowledge generation process be hastened so that it doesn‘t become the bottleneck of the system.

1.2.3. Raising efficiency requirements under scarce testing opportunities
The Chilean Army must become aware that the knowledge of today will not suffice tomorrow needs. Therefore, it needs to find the way to reach a high efficiency profile through recruiting high-quality people while attempting to train, motivate and retain them in a more effective fashion than it does today. This key element becomes a difficult task since accurate feedback is not easily obtained. As most South American military forces, the Chilean Army has quite few opportunities to test its efficiency in real life missions. Its last full-scale operation was in 1879 during the Pacific War. Afterwards, it has partially deployed its forces under stringent bilateral tension with Peru in 1974 and with Argentina in 1978. However, the most relevant action it has participated in the last fifty years is Marxist terrorist group combat during the seventies and eighties.

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3 Adapted from the History of the Chilean Army presented in the organization’s public website: http://www.ejercito.cl/historia/index.htm
1.2.4. Diminishing Budget
Intense questioning of the sources of funding of Chilean Armed Forces are currently taking place in Congress and will most probably end up restricting significantly the Army’s budget. The revision of the so called “Reserved Copper Law”, which authorizes military equipment expenses of up to 10% of revenues from government-run copper exports, is in the agenda of the political parties forming the governing coalition. Even though this funding is not likely to be nullified, its shrinkage is quite evident, considering that the governing coalition has the majority of votes in both the Senate and the House of Representatives.
The organization, then, will be forced to accomplish at least the same missions it does now but will probably be have to cut costs without harming preparedness and readiness.

1.2.5. Increasing variety of missions
Like many other military forces around the world, the Chilean Army is facing an increased variety of tasks. Besides its normal defensive and deterrent functions, this organization is participating in military task forces under the lead of international organizations (UN) and has also integrated forces deployed as part of international agreements. These missions include peacekeeping, peace-making, humanitarian assistance and disaster relief endeavors.
The above variety may be incremented in the future as it is the Government interest to show a capacity to leverage the military investment and also the Army interest to show its usefulness to society as long as it does not compromise its fundamental tasks. Emergent missions might include activities such as ecological disaster relief, drug proliferation control and suppression of terrorism.

Even though the challenges above are based on certain assumptions about the future, they are very likely to affect the Chilean Army. Summarizing, I would argue that three factors will always be part of the future environment: technological challenge, uncertainty in several fields and a constant need to improve at an accelerated rate. These factors call for a permanent process of innovation and adaptation in order to keep leadership and to face different threats and the critical observation of the public.
The situation described above clearly resembles that of the leading industrial organizations that work under great pressure and constantly strive to build sustainable sources of innovation and efficiency. They need to accomplish that objective in order to maintain market leadership and as a survival means. One of the most important
competitive advantages companies have utilized is their knowledge stock. Each time their position is threatened by a competitor through matching its product quality, price or functionality, knowledge-rich organizations have the ability to move onto a new level of quality, creativity and efficiency.

From the analog situation faced by industrial organizations and the Chilean Army stems the idea that improved knowledge management actions would help the Army to deal with the changing and demanding environment it will confront in the future. Other Armies have implemented interesting solutions to these issues with great results. By examining those examples as well as those of companies, the author will select his approach for this case.

It is the author’s opinion that the rapid pace of technological improvements poses one of the most significant challenges for which the organization may prepare in advance. In order to utilize available technological advancements in the military fields, the organization needs solid financial support and an adequate amount of relevant knowledge, i.e. engineering knowledge. The former depends on many factors over which the organization has varying levels of influence, which change over time and are different for almost each circumstance. The latter, in turn, resides within the organization, thus it should be a much more manageable variable. It is recognized however that engineering knowledge, though being regarded as a stepping stone to progress, has been very difficult to crystallize into significant design and manufacturing improvement.

1.3. Problem Statement

As many military organizations around the world, the Chilean Army faces difficulties with keeping updated engineering knowledge given the high pace of technological development and increasing complexity of modern weapon systems. The organization invests in its engineer’s education and provides them with some opportunities to apply the theories they have learned. These opportunities are limited, however, by the financial means and available infrastructure.

The outcomes of the technical efforts within the organization are perceived to be less than optimal by both the Army command and the technical staff. Besides, the organization’s capacity to assess complex equipment acquisitions demonstrates shortage of technical knowledge when materiel modernization is undertaken through purchase of finished products. As a result, acquisitions are delayed while the relevant knowledge is captured

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or, if the situation demands rapid solutions, the risk of making sub-optimal decisions is
incremented.

The author contends that the above situation may be improved with the application of
well-selected and achievable policies and tools that may be implemented immediately or
may be scheduled for future application.

1.4. Literature Search

Although aware of the problem since long ago, organizations have only started taking
actions to better manage their knowledge during the last decade or so. Undoubtedly, one
of the most important cornerstones that brought awareness of the importance of
organizational knowledge was the advent of the theory of the learning organization,
which has gained increasing recognition since 1990. After a series of publications
advocating the importance of knowledge as a competitive advantage, Peter Senge planted
the first wide-impact seed on the topic with his book "The Fifth Discipline". The book
provides the basic theory that justifies the need for learning at the organizational level
and explains what are the key disciplines that must be developed in order to accomplish
such purpose. Learning organizations, as Senge defines them, are:

"Organizations where people continually expand their capacity to create the results
they truly desire, where new and expansive patterns of thinking are nurtured, where
collective aspiration is set free, and where people are continually learning how to
learn together".

Senge argues that, in order to improve in an environment of growing ambiguity,
economic and political instability, and increasing interdependence of global markets and
global enterprises, radical changes are necessary. Those changes, he argues, not only
include organizational redesign but also transformations in the way we think and how we
interact within and among organizations. The new interaction style should enable
organizations to work towards a shared vision, with shared understanding, using mental
models adaptation, fostering team learning, and, most important, developing systems
thinking. The latter is a conceptual framework, a body of knowledge that has been
developed during the last fifty years, whose value stems from the fact that it enables us to
see how organizational behavior patterns develop over time, to understand the way
structure affects interactions, and to visualize the effects of decisions made today in

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future behavior within settings of high complexity. Systems thinking helps decision makers to foresee the consequences of the most critical decisions made in organizations, which have systemwide effects stretching over years and decades, a timeframe that makes learning from experience impossible.

Many scholars, corporate leaders and consultants have recognized the value of Senge’s ideas and have published studies to complement them or to propose alternatives to them. They all have contributed at different levels of abstraction to shape a theory that is still under development, and which generates significant attraction in the managerial world. Knowledge has been recognized as the most important asset in modern organizations. It has gone from being a complementary element of capital and muscle power to being their very essence. The battle for controlling knowledge and the means of communication is becoming fierce around the world. Knowledge is nowadays regarded as the eventual substitute of all other resources (Toffler, 1990) and perhaps the only meaningful one (Drucker 1993). The advent of the information age has induced radical changes in contemporary society, which distinguishes itself for the dominant role it attributes to knowledge over other assets. In today’s society the “knowledge worker” is the most important resource. Included in the definition of knowledge worker is the knowledgeable executive who is capable of allocating knowledge to productive objectives, the same way capitalists knew how to assign capital to productive uses (Drucker 1991). This skill is rapidly becoming the critical executive expertise of this era (James Bryan Quinn 1992) and the competitive advantage resides in those who possess it and are also capable to utilize it in identifying and solving new problems (Reich 1991).

At this point it is relevant to clarify the definition of knowledge and those of the concepts that are most related to it in order to avoid confusion and understand what we are talking about when we refer to knowledge. In this regard, it is important to emphasize that data, information and knowledge are not interchangeable concepts. Data is a set of discrete,
objective facts about events (Davenport and Prusak 1998)\textsuperscript{11}. In an organizational context data is most usefully described as structured record of transactions, tests, trial or assessments. Quantitatively, companies evaluate data in terms of costs, time, capacity, functionality, market share, etc. Data does not differ too much in an army, however there are some distinctive measurements, such as unit mobility, weapon system range and stealth capability and deterrence power, among others.

Information is data that shapes the opinion of those who receive it in a message, letter or report. It is data that makes a difference in the way the receiver perceives something (Davenport and Prusak 1998)\textsuperscript{11}. Unlike data, information has relevance and meaning, it is organized and presented for a specific purpose. Data becomes information when it is contextualized, categorized, analyzed, freed of errors and organized for a given objective.

Knowledge, on the other hand, must be understood as being primarily tacit, that is, something not easily visible and expressible. The part of knowledge that may be expressed in words and numbers — structured or codified knowledge— is just the tip of the iceberg. Tacit knowledge, is highly personal and hard to formalize, making it difficult to communicate or to share with others. In the category of tacit knowledge, subjective insights, intuition and hunches are included. Besides, tacit knowledge is deeply rooted in an individual’s action and experience, as well as in the ideas, values, or emotions he or she embraces (Nonaka and Takeuchi 1995)\textsuperscript{12}. Hence knowledge exists within people, it is part and parcel of human complexity and unpredictability. For information to become knowledge human intervention is required. This transformation takes place through comparison between pieces of information, understanding of its consequences, insight of its relationships with other information and the interaction among people that captures different opinions (Davenport and Prusak 1998)\textsuperscript{11}. Hence, one can obtain data from records, information from messages and knowledge form individuals or groups of individuals. Most important, in most cases it is necessary that human interactions take place for knowledge to emerge.

Japanese companies, especially in the auto and electronics industries, have provided significant lessons regarding the mechanisms and processes through which knowledge is generated within firms. The success of these companies in keeping up with their high


pace of innovation is attributable to their high concern for knowledge and its long-term impact (Nonaka and Takeuchi 1995). Tacit Knowledge, as seen by Nonaka and Takeuchi, is segmented into two categories. The first one is the technical dimension, which includes the informal and hard-to-pin-down skills of what we call “know-how”. An illustration of this dimension would be the wealth of expertise developed by a craftsman after years of practice, the technical or scientific principles behind which he is not able to explain. The second one is the cognitive dimension of tacit knowledge. This category, which is very aligned with Senge’s insight, sees knowledge as composed by schemata, mental models, beliefs and perceptions so ingrained in organizational culture that people take them for granted. It reflects our internal image of reality (what is) and our vision of the future (what ought to be). While these models cannot be articulated easily, they determine the way we perceive the world around us.

In contrast with Senge’s insight, which is mostly intellectual, Japanese organizations consider both of the above categories as relevant for the way they generate knowledge. In this process they use mind and body, theory and experience, feelings and practice. This observation is clearly reflected in Toyota’s sourcing and strategy choices (Fine 1998). This company is very conscious of the kind of dependency its sourcing decisions generate and the long-term impact of them. Toyota avoids becoming dependent for knowledge, that is, lacking the knowledge to produce an item they need and consequently looking for an expert supplier to fill the gap. By contrast, the company is quite open to become dependent for capacity. In this case the firm could make the item in question and may indeed already do so, but due to scarcity of time, money, space or management attention, it chooses to extend its capacity by means of a supplier. Thus, Toyota outsources the portion of its work that is not likely to harm neither its technical nor its cognitive knowledge. For its transmission subsystems, for instance, Toyota designs all the products, but outsources the manufacture of 70 percent of the volume keeping production of the most complex items in-house. Toyota also makes its own

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design software and most of its manufacturing equipment, the most sophisticated elements used in car production (Fine and Whitney 1996)\textsuperscript{15}.

At a more pragmatic level, some studies have determined what are the generic categories for organizational activities that enable knowledge generation and its transformation in core capabilities that may be utilized for production outcomes. All of these classifications include internal development and imports of knowledge. One widely accepted of these classifications (Leonard-Barton. 1995)\textsuperscript{16} describes four key activities that create flows of knowledge and direct them into core capabilities. These activities, if well managed, may enable an organization to generate and leverage its knowledge consistently and continuously. Knowledge flow is regulated and renewed through such new-product and new-process development-related activities as: (1) integrated problem solving across different cognitive and functional barriers, (2) implementation of new methodologies and process tools (to enhance internal operations), (3) formal and informal experimentation and (4) importing know-how from outside technological and market sources. As the reader may have noticed, these activities embody the Japanese approach of learning through the intellect and through the body (learning by doing). At the same time they also follow Senge’s insight by facing knowledge management as a systemic as well as an individual problem. Hence, this activity classification takes the aforementioned theoretical approaches and puts them in a more practical level, which enables its implementation.

The above activities are key enablers but they must not be understood as being the only ones that are necessary for a meaningful generation and utilization of knowledge, and its transformation in core capability. Managers at all company levels and in all functions must become gatekeepers for the flow of information and knowledge. In order to grow, organizations, like individuals, need the stimulus of challenge and innovation. Therefore, managing knowledge requires designing an environment that fosters creative performance of the four activities in question. In other words, it is the management of these activities that distinguishes organizations that are capable to learn from those that are not.

Given the fact that this thesis analyzes the knowledge management situation in an organization with limited resources to do in-house development, the author looked deeper into the factors affecting organizational knowledge imports. In this regard, the ability of

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an organization to recognize the value of external knowledge, assimilate it, and apply it for its own purposes, is critical for its technical capabilities. This ability is termed absorptive capacity and is largely a function of the organization’s level of prior related knowledge (Cohen and Levinthal 1990)\textsuperscript{17}. It is the prior possession of relevant knowledge and skills what gives rise to the sort of associations and linkages that are needed to transform information into knowledge. The underlying rationale is almost intuitive. From our experience we all know that learning is a cumulative process, and that its performance is greatest when the object of learning is related to what is already known. Learning, then, is more difficult in novel domains and, in a more general sense, organizational as well as individual expertise evolves only incrementally. Therefore, absorptive capacity and its effects on recognition of valuable information suggest a dynamic of path dependency that prevent an organization from exploiting new information regardless of the value it may have for accomplishing its high level objectives. This happens because if it does not invest in absorptive capacity in some early stage, its beliefs about the potential opportunities in a given technological field will remain still over time and, when new opportunities emerge, the organization does not appreciate them. This effect combined with the fact that previous knowledge facilitates the subsequent development of absorptive capacity, results in increasing difficulty to update knowledge and diminishing attractiveness of investing in subsequent periods, even if usefulness of a given technology becomes evident.

One of the most relevant sources of absorptive capacity is Internal R&D. Research shows that companies that conduct their own R&D are more capable to utilize external information. Hence absorptive capacity may be generated as a byproduct of an organization’s investments in R&D (Cohen and Levinthal, 1990)\textsuperscript{17}. This idea is very aligned with the above description and example of the Japanese concern for external dependency and also with Leonard-Barton’s need of experimentation activities in knowledge generation.

Another crucial factor that generates organizational absorptive capacity is “connectedness” to external sources of public and private knowledge (Cockburn and Henderson 1998; Lim, 2000)\textsuperscript{18,19}. Among these sources we may count: consultants,


customers, national labs, vendors, universities, other companies (non-competitors), and other companies (competitors). The types of relationships though which connectedness is implemented in practice, ordered by increasing efficiency, are: observation, non-exclusive licensing, R&D contracts, equity acquisitions, co development, exclusive licensing, joint ventures, and acquisition or mergers (Leonard-Barton. 1995)\(^2\).

Although crucial, the interactions with the external environment are not the only factor that affects an organization’s connectedness. It also depends on the way knowledge is shared within and across organizations. In this regard, an especially interesting study is that by Nancy Dixon, which she describes in her book *Common Knowledge*\(^2\). Dixon focuses only in the kind of knowledge that is generated by teams in work experiences, which she calls “Common Knowledge”. This kind of knowledge can be successfully transferred from team to team and from one location to another. However, sharing is successful only when the transfer system is appropriately selected, which in turn is a function of the kind of intended receiver, the nature of the tasks the knowledge refers to and the type of knowledge being transferred. There are at least five identifiable types of knowledge transfer, each being appropriate for different combinations of the three variables above. The design used in each type of transfer include different levels of interaction such as moving teams, moving individuals, team meetings featuring different characteristics, distant synchronous and asynchronous communications, etc. In this respect, many organizations have succumbed under the temptation of implementing knowledge systems based only on information technology. The results have shown that this approach has been often overemphasized. The reason for the poor results is that many organizations have not understood that information technology is only the transportation means and the storage repository for knowledge exchange. It does not generate knowledge and neither does it stimulate knowledge sharing by itself if a cultural component does not support it (Davenport and Prusak, 1998)\(^3\).

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Dixon's work has the great merit of being current and practical. It suggests solutions that in many cases would be possible to implement immediately in any company equipped with the average means any well established American company has. However, as she recognizes, there is no principle of general application for knowledge transfer, therefore the analysis of what is the appropriate transfer method must be done on a case-by-case basis.

Another interesting piece of work, also along the lines of knowledge sharing is that presented by Paul Carlile in his series of working papers\textsuperscript{23,24}. Carlile describes organizational knowledge as localized, embedded and invested within functions and explains how when working across functions, consequences often arise that generate problematic knowledge boundaries. To resolve the consequences of problematic boundaries, Carlile examines the use of boundary objects as a means of representing, learning about and transforming knowledge. He also analyzes boundaries themselves and proposes a framework of three increasingly complex types of knowledge boundaries—which he terms syntactic, semantic and pragmatic boundaries. Then, he describes the attributes of each boundary and explores the appropriate transfer mode, infrastructure required, and limitations and challenges for each case.

Carlile's work is theoretically strong and provides useful insights for dealing with the complexity that arises in many situations in knowledge management. His case studies and illustrations demonstrate that his theory is valid in real life and also that it is complementary to what other authors have stated at a more generic level of analysis of knowledge management.

With regard to organizations that have successfully implemented knowledge management systems, authors cite several organizations as examples to illustrate the points they attempt to highlight. Among those organizations, perhaps the most interesting case for the purpose of this study is that of the US Army. This is the most commonly cited example in the literature and one that has attracted the attention of many researchers, given the successful adaptation this organization has experienced during the post Viet-Nam and post Cold-War periods.

The effectiveness of the knowledge leveraging practices at the US Army is based on the discipline of its members and the fact that these initiatives enjoy the permanent support of Army leaders. Long ago, they recognized their organization needed to learn how to adapt


to new situations faster and also to generate knowledge related to the new situations it was facing. The scheme implemented has evolved for about 20 years, after the organization started using After Action Reviews (AAR)\(^{25}\). AARs were first adopted at the US Army’s training centers. They consist of meetings developed by team members after a combat engagement is over and before starting the planning phase of the following action. An AAR as conducted at the Army’s training centers normally\(^ {23}\):

- Reviews first what the unit intended to accomplish (the overall mission and the commander’s intent).
- Establishes the “ground truth” of what actually happened by means of a moment-by-moment replay of critical battlefield events.
- Investigates what might have caused the results, concentrating on key issues.
- Provides the team an opportunity to consider what it should learn from this review, based on what they did well and want to replicate in the future and on what they believe they need to improve.
- Ends with a preview of the next mission and the issues the unit might face during the next action.

AARs are unique in that they analyze both past and future events and also because teams learn from their own experience not from recommendations by other teams. In this respect it is important to point out that AARs are different from the typical retrospective critique in two aspects. First, they take place throughout the training process instead of when it is over. And second, they have an impact on the planning of the next action the team participates. Most important, no attempt to pass on experience from one team to another is made during the AAR stage. Therefore, behavioral changes are easier to accomplish since learning has taken place through personal experience.

Interestingly, AARs were initially implemented at the Army’s National Training Center (NTC) to gain as much learning as possible from the training event. However, they proved so beneficial to a team’s effectiveness that gradually started to be utilized in non-training situations as well. Nowadays, they are commonly used throughout the Army, not because it has been made mandatory by the leaders of the organization, but rather because they are useful in getting the job done\(^ {26}\). Engineering initiatives are included among the activities that use the method. As Darling and Parry\(^ {25}\) assert, several AAR


meetings are scheduled in advance to take place during the life of a project, rather than by the end of it (retrospective critique style), when people are about to disperse. AARs were so successful that US Army leaders felt the knowledge that was being generated through these practices should be disseminated to enable organizational learning based on team experience. The solution was found in the rebirth of the Army’s lessons learned process, which had already been adopted during the World War II but had been discontinued after the conflict. In 1985 a formal Center for the Army Lessons Learned (CALL) was established at Fort Leavenworth, Kansas. Its purpose was to capture the learning taking place at the training centers and circulate it throughout the entire organization. After its foundation, CALL has expanded its charter to include lessons from actual operations. Besides, due to the enhanced capabilities provided by information technology to report and diffuse through on-line databases, experience can be disseminated almost as rapidly as it is collected.²⁷

1.5. **Research Framework**

Many military organizations in developing countries face the difficult task of maintaining their capabilities while keeping expenditures within a budget always scarce for their needs. Latin American military services are also affected by this phenomenon. These organizations are permanently struggling to obtain the most from its modest budget in the capital-intensive environment of defense systems.

The need to make correct decisions in the defense field is evident: they imply costly investments and are, for the most part, irreversible. This type of organization does not seek to lead a market or to come up with breakthrough products, they rather want to be able to make appropriate decisions in order to get the most from the funding they spend, which has highly valuable alternative uses. Therefore, it is reasonable to think that the main purpose of knowledge management in these organizations is to maintain an absorptive capacity that enables them to understand current and new emergent technologies being used in weapon systems.

The role of technical knowledge starts at the point a shortage of equipment or infrastructure is detected. They arise as the useful life of equipment expires and is to be replaced, and also as the capabilities of units are found insufficient due to lack or malfunction of equipment or infrastructure. At this early stage the iterative process of product development begins with its first phase, usually called front-end process (Ulric and Eppinger)\(^\text{28}\) or upstream process (Edward Crawley)\(^\text{29}\), see Figure 1. At this point the need must be determined. The role of engineers in this moment is to verify that the need has been articulated appropriately since many times the end-user is not able to do so or they believe they need something different from what they really need.

Then, target specifications are established and potential solution concepts generated. The participation of engineers in this stage is essential as it is the only way to make sure that the end-user needs are translated into adequate technical terms. Besides, it is necessary to verify that the full solution space, given the state of technology, has been explored, when selecting the concept that addresses the need or set of needs.

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By the time the concept is selected, a decision must be made on whether the equipment will be obtained through in-house development, conjoint project, outsourced development (very rare) or it will be acquired as a finished product. This decision also needs participation of technically knowledgeable people, as an evaluation must be

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30 Unless noted, all figures are original work developed by the author.
performed on internal capabilities, availability of potential partners or contractors, and market offer.

After a decision has been made, the product development process continues if the development is made in-house or in a conjoint effort. Otherwise, an acquisition or contract process is initiated.

The abovementioned decision is the landmark that indicates whether design and development will take place or only acquisition will be executed. The difference among these options is the impact on engineering knowledge and the kind of opportunity to learn that they provide. In-house development situations provide richer “learning-by-doing” opportunities. There is much more problem solving, experimentation and prototyping. Errors are made and learning is obtained from them. Besides, engineers that have to solve new technical problems seek knowledge within and outside the organization, which increments diffusion and fosters connectedness with the outer world. Hence absorptive capacity is enhanced or at least maintained in the specific field of engineering where development takes place.

Acquisitions, on the other hand, provide less learning-by-doing but they offer an opportunity to do technology comparison, which increases internal research. They also provide new connections with vendors through which a flow of knowledge may be generated. The major advantage in this case is the potential increment in connectedness. Usually the vendor is the army of a developed country that has operated and maintained the equipment for a decade or so. Therefore, their technical people know the very details of their functioning and maintenance. If well leveraged, this opportunity to learn is very valuable. It may increase absorptive capacity in engineering fields more advanced than those in which the organization is performing its development projects.

In between both of the above options are conjoint projects. They provide the learning opportunities of both options but in a milder fashion. Here, again, chances have to be well managed in order to leverage opportunities. Figure 2 shows the mapping of learning opportunities this kind of organizations face, given the type of activities they develop. These activities range from pure internal lab research at one end to research outsourcing at the opposite end. Both extremes are very rare but the types of projects in between are seen quite often, especially acquisition endeavors.
The type of project developed is influenced by many factors, some of them are internal and some others arise from forces created outside the organization. Among the internal factors are: the perception of urgency to satisfy the need, internal technical capabilities (knowledge stock), internal politics, etc. The external factors, on the other hand, are mainly based on the role of government, congress, international organizations and providers. All these parties bring different interests into play, which they work to satisfy; therefore many lobbying and negotiations take place around these decisions.

Though important, decisions at the front-end stage are not the only elements affecting engineering knowledge. At the execution stage there are many other important factors affecting engineering knowledge too, especially in the internal environment. Within this set of factors we will find decision making rules at the executive level, the way technical people are motivated and all the elements that influence their morale; the internal patterns of communication and diffusion styles, among others.

All the aforementioned factors and sources of influence act simultaneously and affect one another in a complex network of interactions within a social system. In order to understand such interactions a careful analysis is necessary and effort must be made to
disentangle, categorize and assess the influences driven by each factor and its impact in the outcome.

1.6. **Objective of the Research**
This research seeks to discover the set of policies, decision rules, beliefs and other environmental factors that influence generation and transfer of engineering knowledge within the organization and its correlation to the actual performance. Applying the “right” set of policies and utilizing the adequate tools is critical to technical performance and ultimately to the organization’s success. It is the belief of the author that the right balance and focus of the factors affecting knowledge management enhances the organizational ability to maintain a level of technical knowledge suited to its need. This thesis will focus primarily on those factors that are internal to the organization and which the Chilean Army authorities may manage to better the current situation. External factors such as government decisions, political pressure in congress, foreign policy, etc., will be described in the next section but not analyzed in detail given the scarce power of the organization to modify them. As a result, this thesis will provide a set of recommendations deemed necessary to improve the situation on the matter. It will also offer a set of general guidelines that may be applied in other Latin American military organizations, which will complement the general framework above.
2. Research Design

2.1. Introduction

Being aware that the topic under study is embedded in a highly complex system, the author devised a research process that provided him with an incremental understanding of the issues affecting knowledge management. The approach consisted of performing a review of the organization first, in order to keep awareness of the system level issues, and then drilling down into the more specific aspects affecting the problem. The method prevented the author from falling into the trap of linear thinking while enabling him to understand cause and effect relations that were separated in time and organizational levels. This process also provided a good grasp of the structural relationships among the factors influencing the outcomes and their evolution over time.

The first research effort the author made was to improve his understanding of the environment the system under study was operating. This starting point is framed by two concepts: Edward Crawley’s “Upstream Process”\textsuperscript{31} and by Charles Boppe’s\textsuperscript{32} “System of Systems”. Both of them tend to focus a system engineer on the high level issues surrounding the subsystem under study. This effort was conducted through non-structured interviews and conversations with people with more experience in the organization than the author in terms of time and diversity of activities. The results of this first effort were utilized in the organizational analysis discussed on Chapter 3.

Then, further information was gathered in order to gain insight of the problem itself in a more formal fashion. The details of this process are described in this chapter.

The first step consisted of building a list of factors that were believed to affect knowledge management in an a priori judgment, which oriented the initial search. Then, existing official historic data was gathered in order to obtain a first approximation to the present state of the issue. Next, information was collected in an attempt to capture what the current situation is perceived to be by individuals within the system. Subsequently, further insight was gained firstly by comparing and combining those perceptions and secondly by discussing them with key people in the system. By the time the above steps were finished, the author felt he had gained a clear perception of what the factors affecting knowledge management were and how they interacted to influence each other. The research effort was then centered on building the structures of relationships that resembled the real situation as understood by the author after going through the above-


mentioned process. The thought process necessary to build such structures required additional interactions with persons in the system, thus further insight was gained at this step. Such understanding was then enhanced by modeling the structural relationships and simulating its dynamic behavior through the Systems Dynamics Modeling technique. To get to this point, qualitative and quantitative data were required. The former enabled the process of building, refining and gaining confidence in the model while the latter provided data to calibrate it. Qualitative data gathering was key in obtaining the perceptions of people with long working experience in the system. Their opinions provided the kind of information that is difficult or impossible to quantify. In this category are facts such as most of the interactions between variables, their variation over time and their influence over other variables. This data became the information that enabled the author to develop a representation of a highly complex reality. Dynamic complexity stems from the fact that systems are tightly coupled, governed by feedbacks, exhibit nonlinear behavior, and are history-dependent, adaptive, counterintuitive, policy resistant and characterized by trade-offs. Quantitative data, on the other hand, was utilized to evaluate how accurately the model describes historic behavior of the system and to classify the impact of each variable on the problem under study.

2.2. Data Collection
The first source of data that was explored was the Chilean Army itself. The available data were provided, however its amount and topics covered were rather meager. Many of the variables believed to affect knowledge management were not easily quantifiable; therefore the data needed were found to be more qualitative than quantitative. Besides, the organization object of this study is a governmental entity in a developing country and, as such, its communications and data storage means are limited compared to any organization of its size in the US. Even so, some of the quantitative historical data needed were available at the organization, whilst some others were collected by the author through direct or asynchronous interaction with people in the organization, using e-mail, phone, fax, and also through literature research (internal documentation). Further, quantitative research was conducted by means of a survey and qualitative data was collected by performing live interviews in which the survey was also utilized. By using both tools combined respondents were forced to think about the topic a longer time and to

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elaborate on his/her answers to justify them. The objectives, structure and application style of both of these instruments are described below.

2.3. A Priori Variable Identification

In order to select the relevant data, the main variables affecting engineering knowledge management in the aforementioned organization were recognized. This process was initiated by identifying the most relevant factors affecting the issue under study according to the literature\textsuperscript{34,35,36,37} and the actual environment of the organization. Then, a list of all the variables believed to have some effect on the problem was built. This array was developed based on information gathered through informal interviews, through the experience of the author and conversations with fellow students at the SDM program who provided their opinions based on their personal experience in a variety of organizations. As a result, 23 variables were identified:

1. Time pressure
2. Number of experienced engineers
3. Funding
4. Contacts with engineering consultants
5. Finished equipment acquisitions
6. Interactions with provider’s engineers
7. Communication patterns
8. Number of conjoint projects
9. Desire to seek knowledge
10. Interactions with universities and labs
11. Fraction of in-house developments
12. Army incentives for engineers
13. Number of Acquisition projects
14. Private sector incentives for engineers
15. Number of in-house development projects
16. Effect of professional development opportunities on morale
17. Engineers Morale
18. Effect of word-of-mouth on morale
19. Advanced maintenance activities
20. Effect of morale on quality of engineers’ work
21. Number of technical management activities
22. Effect of morale on engineers’ productivity
23. Communication tools


\textsuperscript{37} Cohen , Wesley and Levinthal, Daniel (1990), “Absorptive Capacity: A New Perspective on Learning and Innovation”. Administrative Science Quarterly..
2.4. Quantitative Research

2.4.1. Historic Data

Historic data available at the organization was collected and organized to show some tendencies that were useful for the purpose of this study. In the figures below are the relevant charts and tables.

The first table (Figure 3) presents data regarding engineers’ population. These figures refer to the following:

- Total number of engineers: number of engineers in the payroll of the organization.
- Highly capacitated engineers: number of engineers that had an MS or PhD and worked more than 5 years in the area of his studies.
- Number of engineers graduated: refers to the number of engineers that joined the workforce each year. They obtain their undergraduate engineering degree from an Army-run academy.
- Engineer depletion: is the number of engineers that left the organization each year. The major components of this rate are migration to the private sector and retirement.

The same data are showed in charts in Figure 4 thru Figure 7.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Total # of Engineers</th>
<th>Highly Capacitated Engineers</th>
<th># Of Engineers Graduated</th>
<th>Engineer Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0</td>
<td>180</td>
<td>32</td>
<td>34</td>
<td>36</td>
</tr>
<tr>
<td>1993</td>
<td>12</td>
<td>178</td>
<td>29</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>1994</td>
<td>24</td>
<td>172</td>
<td>31</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>1995</td>
<td>36</td>
<td>173</td>
<td>30</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>1996</td>
<td>48</td>
<td>173</td>
<td>31</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>1997</td>
<td>60</td>
<td>168</td>
<td>28</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>1998</td>
<td>72</td>
<td>166</td>
<td>29</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>1999</td>
<td>84</td>
<td>168</td>
<td>24</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>2000</td>
<td>96</td>
<td>165</td>
<td>24</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>2001</td>
<td>108</td>
<td>164</td>
<td>25</td>
<td>28</td>
<td>29</td>
</tr>
</tbody>
</table>

Figure 3: Historical data of number of engineers in the organization
Figure 4: Number of engineers in the organization, historical data

Figure 5: Number of highly capacitated engineers, historical data
The next table (Figure 8) presents data about engineering projects carried out at the organization. These figures have been cleansed so that they present only the projects and acquisitions that were found relevant for this study\(^{38}\). The same data are showed as a function of time in the charts in Figure 9, Figure 10, and Figure 11.

\(^{38}\) Data cleansing criterion was to dismiss projects staffed with less than one engineer full time for one month.
Each column refers to the following:
- Number of engineering projects: average number of projects being carried out during each year.
- Average engineers per project: average number of engineers assigned to each engineering project.
- Acquisition projects: average number of acquisition projects being executed at any time during these years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th># of Engineering Projects</th>
<th>Average Engineers per Project</th>
<th>Acquisition Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0</td>
<td>14</td>
<td>5.14</td>
<td>6</td>
</tr>
<tr>
<td>1993</td>
<td>12</td>
<td>12</td>
<td>5.92</td>
<td>7</td>
</tr>
<tr>
<td>1994</td>
<td>24</td>
<td>12</td>
<td>5.33</td>
<td>8</td>
</tr>
<tr>
<td>1995</td>
<td>36</td>
<td>11</td>
<td>4.80</td>
<td>8</td>
</tr>
<tr>
<td>1996</td>
<td>48</td>
<td>13</td>
<td>4.77</td>
<td>7</td>
</tr>
<tr>
<td>1997</td>
<td>60</td>
<td>10</td>
<td>5.20</td>
<td>9</td>
</tr>
<tr>
<td>1998</td>
<td>72</td>
<td>10</td>
<td>4.70</td>
<td>8</td>
</tr>
<tr>
<td>1999</td>
<td>84</td>
<td>8</td>
<td>5.10</td>
<td>9</td>
</tr>
<tr>
<td>2000</td>
<td>96</td>
<td>10</td>
<td>4.50</td>
<td>8</td>
</tr>
<tr>
<td>2001</td>
<td>108</td>
<td>8</td>
<td>4.70</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 8: Historical data about projects executed at the organization

Figure 9: Number of engineering projects
2.4.2. Survey Development

Quantitative data was also collected through a survey. The first step was to identify the general purpose of this survey and its objectives. The main purpose of the survey was to gather the necessary data to build a Systems Dynamic model of the organizational
behavior affecting engineering knowledge. Accordingly, the following objectives were identified:

1) Verify if the problem of engineering knowledge management actually exists.
2) Confirm if there is agreement on the principal variables believed to affect engineering knowledge.
3) Determine the relative influence of each variable.
4) Investigate if there were any other relevant factors affecting engineering knowledge management that were not previously considered.

Survey was selected as a research tool because it presents several advantages regarding data validity. First, questions are answered objectively, that is, if questions are clear enough the answers should be free of biases. Second, it reflects differences among groups located at different levels of the organization. And third, it provides numerical values that enable ranking and comparison among variables.

It is recognized though that the method also presents some weaknesses that had to be taken care of:

- The number of participants must be representative enough. In this case, 21 participants responded the survey out of 35 surveys sent out. The former figure represents roughly 10% of the total population of engineers working in the organization.
- Participants must have enough experience to provide a relevant opinion on the factors under study. Significance of the answers was assured in this instance by sending the survey only to experienced engineers (12 years of experience average).
- Limited representation of specific groups within the target population. This factor did affect somehow the data collection as just few respondents from the executive level (high command) were reached. The effect of this issue was mitigated by performing interviews with people at this organizational level.

In order to improve the survey response and data quality, the document went through a careful development cycle:

- The document was prepared by the author and exposed to critique of fellow students and some adjustments were made based on comments.
- Review by experienced surveyors and further adjustments.
- Finally, it was applied to a couple of non-survey participants in order to test it and surface potential flaws.
In order to achieve a high response, the survey was intended to take no longer than 20 minutes to fill out. The document was translated into Spanish using the vocabulary that is normally used in the engineering environment within the organization so that the questions would be easy to understand and time to respond minimized. Some marketing survey best practices, such as assigning the same rating scale for each variable, were adopted from Churchill. A copy of the survey can be found in Appendix B. It was applied through e-mail and participation was voluntary. Although unit commanders and senior managers supported this study, no order to respond it was imposed.

2.4.3. Data Collected through the Survey

a. Demographics

Survey demographics are depicted in Figure 12. The survey was conducted within the various organizations of the Chilean Army that develop engineering projects, equipment acquisition projects and major maintenance activities. These organizations have a total population of roughly 190 engineers. The survey was sent out to 35 experienced engineers; 21 responded. The group of respondents included 6 senior engineers with long experience at both the decision level and the execution level. For each type of organization 1-2 senior engineers and 4-5 less experienced engineers responded. All of the respondents have more than 15 years of working experience in the Army. 52% of them have more than 9 years of engineering experience and 19% more than 12 years in the same activity.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of Experience at Army</td>
<td>18.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Years of Engineering Experience</td>
<td>10.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Number of Survey Participants</td>
<td>7.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

*Figure 12: Survey Demographics*

b. Most Relevant Findings

The survey successfully accomplished its objectives described above. The most important data obtained, which provide answers to the inquiries implied in those objectives are:

Objective 1)

All the respondents (100%) agreed that engineering knowledge management is a problem that must be tackled as soon as possible in this organization.

Objective 2)

Most of the variables considered initially were found to affect knowledge management, however a few of them were not considered relevant. The rejected variables were:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Prevalent Comment Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time pressure</td>
<td>Time slippages are common. We are more concerned about performance, safety and reliability</td>
</tr>
<tr>
<td>Management of technical activities</td>
<td>Prevents engineers from acquiring technical knowledge but we all need to do some of these activities to keep things going.</td>
</tr>
<tr>
<td>Contacts with engineering consultants</td>
<td>We hardly ever hire engineering consultants</td>
</tr>
</tbody>
</table>

Objective 3)

Respondents rated the relative impact of each variable on knowledge management as follows (in a 1= Irrelevant thru 6= Crucial scale)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of in-house development projects</td>
<td>5.43</td>
<td>0.73</td>
</tr>
<tr>
<td>Number of Acquisition projects</td>
<td>5.19</td>
<td>0.66</td>
</tr>
<tr>
<td>Fraction of in-house developments</td>
<td>5.15</td>
<td>0.76</td>
</tr>
<tr>
<td>Finished equipment acquisitions</td>
<td>5.08</td>
<td>1.21</td>
</tr>
<tr>
<td>Engineers Morale</td>
<td>5.00</td>
<td>0.94</td>
</tr>
<tr>
<td>Interactions with provider’s engineers</td>
<td>4.86</td>
<td>0.77</td>
</tr>
<tr>
<td>Desire to seek knowledge</td>
<td>4.71</td>
<td>0.93</td>
</tr>
<tr>
<td>Communication patterns</td>
<td>4.67</td>
<td>0.64</td>
</tr>
<tr>
<td>Communication tools</td>
<td>4.62</td>
<td>1.05</td>
</tr>
<tr>
<td>Interactions with universities and labs</td>
<td>4.52</td>
<td>0.91</td>
</tr>
<tr>
<td>Funding</td>
<td>4.52</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Drivers and effect of engineers’ morale were rated in the following order:

- Morale drivers

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Army incentives for engineers compared to private sector incentives for engineers</td>
<td>5.19</td>
<td>0.66</td>
</tr>
<tr>
<td>Effect of professional development opportunities on morale</td>
<td>4.38</td>
<td>1.21</td>
</tr>
<tr>
<td>Effect of word-of-mouth on morale</td>
<td>3.00</td>
<td>0.87</td>
</tr>
</tbody>
</table>

- Effects of morale on variables that affect knowledge management

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of morale on quality of engineers’ work</td>
<td>5.00</td>
<td>0.82</td>
</tr>
<tr>
<td>Effect of morale on engineers’ productivity</td>
<td>4.57</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Objective 4)
Respondents proposed a number of new variables in the comments section of the survey. Those variables and the arguments supporting the need to consider them are shown in the table below:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Arguments supporting its consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of engineers</td>
<td>Knowledge is embedded in people, therefore we need to prevent our engineers from leaving the organization</td>
</tr>
<tr>
<td>Graduation rate</td>
<td></td>
</tr>
<tr>
<td>Engineer attrition rate</td>
<td></td>
</tr>
<tr>
<td>Time for knowledge to become obsolete</td>
<td>Knowledge is relevant only for a period. As technology evolves knowledge becomes outdated.</td>
</tr>
<tr>
<td>Effect of knowledge diffusion on morale</td>
<td>Although not the most important factor, we appreciate learning opportunities</td>
</tr>
<tr>
<td>Workload</td>
<td>Our morale is seriously affected when we are made responsible for more than we can handle.</td>
</tr>
<tr>
<td>Time to forget unused knowledge</td>
<td>Once we stop using knowledge our capacity to recall it and utilize it degrades.</td>
</tr>
<tr>
<td>Effect of morale on migration</td>
<td>When morale decays one starts looking for somewhere else to work where one can feel more comfortable. Then, one compares salaries and benefits to make a decision.</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Number of engineers working on engineering projects</td>
<td>It is within engineering projects that we are able to study, experiment, manipulate and test unknown technologies. This opportunities become our means for acquiring new competencies</td>
</tr>
</tbody>
</table>

2.5. Qualitative Research

Qualitative information was gathered through interviews conducted in combination with the aforementioned survey as described below.

2.5.1. Interview Objective

Given the intangible character of most of the information needed to model the interactions affecting knowledge management, interviews were the means that provided the greatest opportunity to get a deeper insight of what the generalized view of the problem was within the organization. With that idea in mind, the following objectives for the interviews were established:

- To experience direct interaction with those that are providing the information on which this study will be based.
- To understand the way interviewees think and see the problem under investigation, in order to assess the value of his/her answers to the survey.
- To gather firsthand information with a thorough explanation on the variables affecting engineering knowledge in the organization and the relative influence these variables have on the issue compared to one another.
- To gain insight with regard to the mutual influences among variables and their evolution over time.
- To sketch SD model causal loops and collect data for its structural design.

2.5.2. Pre-interview discussion

A previous interaction with interviewees was conducted through email, explaining the intent of this thesis and the methodology applied. The purpose was to introduce the topic and to allow some time for the interviewees to think about it and recall some of the most salient experiences they have lived with regard to the topic. Besides, the survey discussed above was sent to each interviewee the day before the interview took place, hence when the interview was conducted the conversation could flow smoothly without need to get into further explanation about the study being conducted.
2.5.3. Boundary Objects

The boundary object theory by Paul Carlile \(^{40}\) was very useful for this situation in which the interaction is conducted remotely. Objects illustrated ideas and created a shared syntax for improved interactions. The ideas conveyed by boundary objects sounded familiar to the majority of the interviewees; consequently they stimulated openness and fluid interaction.

The first boundary object applied was the abovementioned survey, which was already answered by interviewees when the conversation took place. Using the responded survey, a quick review of the answers was conducted so that the interviewer could ask for justification of the answers. Through this procedure the interviewer got an idea of the level of understanding and profundness of the analysis the interviewee made while answering the survey. This part of the dialog was targeted to evaluate the quality of the answers obtained in the survey.

The second boundary object was the shortened version of the problem statement included in Section 1.3, as presented in the following paragraph:

"I believe that engineering knowledge is not well managed in the Chilean Army. The outcomes of our technical endeavors are poor and our technical capabilities to evaluate acquisitions of finished equipment or infrastructure are in shortage compare to our needs. Why does this happen? What can we do to improve?"

The problem statement was reinforced by reading the following paragraph of an article published in a renowned Chilean business and politics magazine on September 17, 2000, two days before the last anniversary of the Army in the last century:

"Do the Chilean Military Services have an acceptable technological level? The expert in defense matters, Daniel Prieto, argues that while our Navy and Air Force are working with cutting edge equipment, the Army is dealing with thirty-year-old technologies. We cannot forget that the 206 Leopard tanks [purchased by the Army 2 years ago] were designed in the sixties" \(^{41}\)


\(^{41}\) Araneda, Daniela and Cordoba, Maria Luisa. "El Poder de las Armas". Que Pasa magazine, issued September 17, 2000.
This objects along with the survey answers framed the discussion on whether the interviewee agreed or not that the problem exists and what his/her view of the situation was.

The paragraph of the article was intended to show that it is not the author’s idea that the technical knowledge is somehow disregarded in this organization. Rather, this is a generalized opinion that goes beyond the boundaries of the Army. Que Pasa magazine is one of the best in its category within the Chilean media spheres.

2.5.4. Further dialogue

The next part of the interview was devoted to obtain some information on the impact of the variables affecting knowledge management over time and the way they affect each other:

Of all the variables affecting knowledge management that have been mentioned in this interview, please consider the two most relevant ones. How do you think they have behaved over time during the last five years? Give me the directions so I can draw a chart of their values qualitatively.

- What parameters do you think affect the behavior of these variables? Why? Why?
  Why?
- What other factors do you think will be affected by the behavior of these variables as time goes on? Why? Why? Why?
- Why do you think these parameters behave like they do?
- How do you think these parameters will develop in the future? Why?
- From your experience, are there any variables affecting knowledge management that you would like to add to my list? Why? Why? Why?

Afterwards, the interviewer tried to make the interviewees elaborate on the feasible approaches to find a good solution to the above-mentioned problem:

- Please enumerate the variables that may be combined in order to accomplish a system-wide solution.
- Describe how these variables may impact on the problem. Why? Why? Why?
- What is the right amount you would increase/decrease each of these variables in order to reach the best outcome? Why? Why? Why?

Finally, interviewees were invited to revisit their ideas after the interview was over, to give them some more thoughts, to think whether their approach was sustainable and
realistic or not. They were then asked to send an email within the two following days if they had any new ideas they believed useful for the purpose of this study. Interviews lasted for 50 minutes in some cases and in some others for more than an hour. Approximately half of the interviewees kept contact with the interviewer through email after the interview in order to clarify ideas, especially on the impact of those variables that were found to be more important as the investigation continued.

2.5.5. Insight gained through interviews

Interviews provided the most important portion of the information the author used to build the System Dynamic Model described in the next sections. Again, interviewees confirmed that engineering knowledge management was recognized as a problem that needs to be taken care of in the short term. Through the interviews, the list of variables affecting engineering knowledge was completed as the questions above were answered. Also, the manner in which these variables affect engineering knowledge management was analyzed during the dialog. Several variable drivers were added as a result of the “Why?” questions and a number of effects of different variables on knowledge were discussed.

In addition the interactions among variables were discussed and causal loops sketched as conversations went on. Finally, the effect of each variable was evaluated and the ranking obtained from the survey was validated.

As mentioned above intense dialog was maintained with a number of the interviewees after interviews took place as further information and discussion was deemed necessary. The list of variables in Section 2.3 became a new list that included 43 variables. Some of the original variables were dismissed, while some others were complemented with its corresponding drivers and effects.

The new variables are presented in the following list in no specific order:

1. Total number of engineers
2. Army incentives for engineers
3. Hiring rate for engineers
4. Private sector incentives for engineers
5. Migration rate for engineers
6. Contact rate with external sources
7. Retiring rate for engineers
8. Number of external sources contacted
9. Fraction of engineers working in engineering projects
10. Effectiveness of contacts with external sources
11. Number of engineering projects
12. Time for knowledge to become obsolete
13. Average engineers per project
14. Time to forget unused knowledge
15. Effect of career development opportunities on engineers morale
16. Amount of knowledge acquired through engineering projects per time unit
17. Number of engineers seeking knowledge
18. Amount of knowledge acquired through
The results obtained from interviews with regard to interactions, relationships between variables and impact of each variable provided the basic relationships in the structure of the System Dynamic Model.

The causal relationship diagram in Figure 13 illustrates how the research participants perceive the dynamic structures affecting engineering knowledge management within the organization. The arrows specify the direction of influence. The “+” sign indicates that an increase in the cause variable at the beginning of the arrow generates an increase of the effect variable at the end of the arrow, whilst a “-“ sign indicates that an increase in the cause variable creates a decrease in the effect variable. This structure is a representation of the way experienced people in the organization believe interactions take place.
Figure 13 Dynamic causal relationship structure
3. Organizational Analysis

3.1. Introduction
Despite the extended experience of the author in the organization object of this study, the theory indicates that our informal diagnoses is based on bits and pieces of our experiences and are, therefore, partly right but somewhat incomplete and misguided. Consequently, a formal organizational analysis, considering the three classic lenses on organizations, was performed. These lenses include the strategic design, the political and the cultural lenses as described by Ancona et al\textsuperscript{42}.

3.2. Strategic Lens
The following analysis shows what the strategic goal of the Chilean Army is, how this organization has been designed in order to achieve such goal and what are the most salient misalignments between its design and its basic organizational systems. It also highlights the most relevant strategic aspects that affect engineering knowledge as a means to visualize how technical matters are inserted in the whole.

3.2.1. Strategic Intent
The Chilean Constitution institutes:

\textit{"... the Army is one of the fundamental organizations that conform the Armed Forces. These forces exist for the national defense, are essential for national security and must guarantee the institutional order within the republic. They are professional, armed, obedient and non-deliberative corps with their own hierarchy and discipline."}

Based on the constitutional mandate, the mission of the Chilean Army has been established by the Chilean Government as follows\textsuperscript{43}:

The permanent mission of the Army is to guarantee the country's territorial integrity and sovereignty by means of an efficient preparedness and correct use of its manpower and material potential.

In addition, its mission is to participate in preserving the security of land borders against any action waged from the exterior. According to the law and with the purpose of


\textsuperscript{43} Extracted from "The Book of the National Defense of Chile" issued each five years by the Chilean Ministry of Defense. It is aimed to describe and set the objectives and instruments of the Defense Policy to all Chilean citizens. See www.defensa.cl
fulfilling certain tasks aimed at maintaining public order during states of exception\textsuperscript{44}, the Army provides internal stability, maintains the normal civic functions of its citizens and provides for the free exercise of the country's basic institutions.

\textbf{3.2.2. General Tasks}

The following are the Army permanent tasks, which must take place nationwide:

- To develop review and adjust the strategic planning that is necessary to accomplish its mission.
- To organize and maintain in high preparedness and readiness the force required for accomplishing what the strategic planning prescribes.
- To cooperate and coordinate with the other Armed Forces to develop the defense capability of the Chilean people through reserve recruiting and training.
- To permanently monitor the potential threats to the territorial integrity and national security and functioning, being them inside or outside of the country.
- To guard, reinforce and renew the national history and identity.
- To strengthen the citizen's compromise with the country defense.
- To participate in international task forces for peacekeeping or peace-making operations.

According to the task classification made by [Ancona et al\textsuperscript{45}] these are reciprocal tasks, that is, they are carried on in dense interaction with each other. However, except for tasks a) and g), which are high level endeavors, they mostly take place in the same geographic location. There are a number of places where most of these tasks must be fulfilled and where the required interactions may occur locally.

Engineering knowledge is needed in this organization at both the nationwide level and the local level. At the higher level it is required for Army procurement and strategic technical advise (tasks a) and g)), while at the local level for maintenance activities and operational technical advice (tasks b) and d)).

\textsuperscript{44} States of exception are legal instances activated under very special circumstances specified in the Constitution. This states provide the President increased autonomy to act and restrict certain rights of the citizens that are guaranteed by the same document when this states are not in force.

3.2.3. **Strategic Grouping**

The Chilean Army designs and organizes its forces geographically (See Figure 14)\(^\text{46}\) according to its doctrine and to the mandates of the Defense Planning for Ground Forces (DPGF). The DPGF is the master plan for the Army deployment and is derived from the Integrated National Defense Plan issued by the Ministry of Defense. These documents contain the best feasible reaction the country may generate in case any of the perceived potential threats are activated. They are prepared based on the best knowledge these organizations have access to at a given time and are revisited periodically. The DPGF assigns missions to the major combat units of the Army under a variety of scenarios in different locations and during specified periods of time.

According to its doctrine, the Chilean Army units are designed to perform campaigns, operations and actions as the DPGF mandates. Each campaign comprises several operations, which in turn are composed by two or more actions. The difference between these tasks is given by the type of mission, that is, magnitude and characteristics of the enemy unit, time span, geography of the area, etc. Hence, bigger units with broader tasks are composed by smaller units that may perform more limited tasks. This gives the army a modular design of its forces that provides it with the capacity to adapt itself to potential threat changes.

Consequently, the Army units are located close to their deployment zone and are organized and designed according to their missions and to doctrine. This way, the organization is able to pursue its main purpose of the defense of the country at any given time while keeping certain flexibility.

Along with the combat units, the organization below includes those organs that support the decision making process of the Army Commander in Chief, those are the Army Chief of Staff and his subordinate directorates, the Advisory Staff and the General Inspectorate. It also includes the Logistic, Administrative and Technical Support Commands, which support the combat units when their needs exceed the planned levels and their autonomy must be increased.

From the very general description of the structure of the Army above it is evident that the grouping has been well selected. It follows the strategic intent of the organization and is adequate for performing its general tasks. It provides the combat units with the organizational constituents that ensure their independence while maintaining a high-level support infrastructure capable of increasing the autonomy of such units, which justifies the geographic organization.

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\(^{46}\) Based on the organizational representation the Chilean Army shows in its public website: [www.ejercito.cl](http://www.ejercito.cl) and on the author’s working experience in the organization.
Figure 14: Organization of the Chilean Army and units locations (peacetime)
Regarding engineering knowledge grouping, this is represented in small groups (1 to 3 engineers) in each of the major combat unit locations; in larger groups in the Logistics Directorate (Army procurement) and in the Technical Support Commands (communications and engineers corps); and also in the Army-run factories that are to satisfy the organization combat needs. These factories are shown in Figure 14 linked to the Army Commander in Chief through a dotted line since they are, in theory, independent from the Army. In practice, though, this is not totally truth as the Army provides them with management and engineering personnel. These staff members are assigned for periods usually not longer than four years, after which they are reassigned in the Army. This grouping pattern derives from the Army needs of procurement, design and development, maintenance and technical advise. However, from the engineering knowledge generation and diffusion standpoint, the geographical and organizational dispersion of the scarce available resources is a factor that poses additional difficulties.

3.2.4. Strategic Linking

The Chilean Army uses a combination of different linking mechanisms to perform internal communications. Formal hierarchical reporting structures, informal structures, temporary cross-unit groups and liaison roles are some of the mechanisms applied. The predominant one, however, is hierarchical formal reporting structure. A squad commander reports to the platoon commander, who reports to the company commander that in turn reports to the battalion commander, and so on. Depending on the level they take place, this interactions are usually supported by some sort of communication and information technology.

The tendency to use this linking style stems from military doctrine. Firstly, in real combat situations hierarchy is vital. Each echelon must profoundly trust that what it is being ordered to do is the best action possible and that it plays an important role in the context of a greater a unit. Secondly, it is the mechanism of breaking down information as it flows down the chain of command so that each unit gets only the pieces it needs to accomplish its mission. Horizontal coordination is commanded, not assumed to be necessary. And lastly, communications are usually restricted to the minimum. There is no time for unnecessary contacts and radio-frequency emissions are considered a type of vulnerability since they reveal the position of a command post. This aspect is obviously intended to affect only the patterns of communications in combat situations; however, it also affects peacetime communications to a certain extent as it is part of the doctrine. This topic will also be touched in the cultural lens analysis.
Finally, the information technology support deserves its own comment. This powerful tool that plays a prominent role in facilitating interaction is still in its developmental stage. The Chilean Army’s internal networks are able to transmit codified voice but have limited capabilities to transmit data. Most of the important documents are transferred only in hard copies and soft versions are used only for storage purposes at the facility where they were originated.

The aforementioned linking mechanism represents additional obstacles for engineering knowledge management. Scarce communications tend to isolate those engineers working in combat units and also hinders interactions between engineering teams in the Army and those in the Army-run factories. The lack of an IT network limits interactions to hard documents and voice communications.

3.2.5. Strategic Alignment

In this section I will analyze the suitability of the strategic grouping and linking with respect to the rest of the organization’s structures and processes.

3.2.5.1. Organizational performance measurement system

The Army leaders utilize several internal and external measurement tools to obtain feedback on the organizational performance. The internal ones are the information gathered through the results of exercises, drills and maneuvers performed by units in their actual deployment zone, under real environmental conditions and against a simulated enemy. A second type of information gathered internally is that provided by war games played in combat simulators. These simulators are intended to train and evaluate the decision-making skills of leaders of units ranging from battalion up to army corps. In general, internal measurement systems have partial effect as simulations only test leader’s skills and maneuvers usually comprise small-scale troop deployment because of the high cost implied and limited resource availability.

The external measurement tools are the feedback obtained by the Army leaders from the Chilean people and their representatives in Congress. Though subjective and sometimes highly politicized, the judgments made by congressmen and the media, if well interpreted, are an accurate and useful tool. They tend to focus on assessments of the benefits of defense against the costs it generates and to compare this assessment with that of other alternative uses of fiscal funding, such as health care, education, etc. Hence, this measurement tools provide relevant information on the efficiency in fund usage and convey some hints on the fate of future investments. It is important to recognize,
however, that it is very difficult to extract useful feedback from these sources since in many instances the information in the media is fragmented, influenced by exogenous interests or simply wrong. In the case of congressmen, on the other hand, political interests are likely to pollute their opinions.

Another external source of performance measurement are the reports submitted by international task force commands when an Army unit participates in this type of operations. Although these reports say nothing about the performance of the Army as a whole, they provide good information about the units participating in the task force and about the Army doctrine and procedures. Most important, the degree of involvement in action reflects the capabilities of the units compared to those of the rest of the task force since commanders tend to utilize those units that ensure success in the front lines while keeping the rest as reserves. From this information the Army command may draw relevant conclusions about the technical capabilities of the unit in question and then generalize these ideas for an assessment of the capabilities of the rest of the Army.

A third external source is the comparison with potential enemy armies. This is the measurement that affects technical knowledge the most since it often is the starting point for new equipment acquisitions, upgrade or development projects. It does not measure efficiency but it does provide a good idea of the status of the Army technical knowledge. The information used for these evaluations is easily available in developing countries as, unless systems are developed or modified at home, open sources such as specialized publications broadcast the main technical characteristics of the equipment. If this comparison yields a disadvantage beyond acceptance limits, actions are taken and engineering knowledge comes into play.

In summary, the organizational performance measurement system is partially effective but is the best available. Unfortunately it is not easy to find an accurate performance measurement tool for the Army of a small country as a whole other than a real deployment and combat participation. However, there exist some indicators for technical capabilities that foster equipment acquisition or development. These are the instances when engineering knowledge is assessed either deliberately or unintentionally.

3.2.5.2. Individual Rewards and Incentives

Recognizing that the reward and incentive system is one of the most powerful tools to drive changes and accomplish improvements in organizations, I would say that the Chilean Army has an apparent misalignment in this regard. This organization bases its reward and incentive system on seniority. Ranks and base salaries are assigned mainly
according to the length of continuous time served in the organization. Other factor affecting salaries (not ranks), but in a milder fashion, is education. An Army officer adds a certain percentage to his or her salary when graduating from specific courses. Some of these courses entail assignments of higher levels of responsibility; but some others don’t. Therefore it seems that what is being rewarded is commitment and specialization rather than the efficient application of skills.

The difficulty assessing individual performance is the fact that this attribute is not deemed measurable in individuals but in units, namely the group of three to thirty people in which he or she works. Thus, the organization has developed a clear procedure through which each unit commander assesses the performance of his subordinates against established standards, however, its results are not linked to incentives. Only in the long run and after different commanders have reported low performance of an individual, his or her incentives may be affected. Therefore, the lack of linkage between performance assessment and incentives is intentional. The purpose is to keep out of the unit environment the source of tension generated by individual incentives.

The specific case of engineers does not differ from the rest of the organization. Engineers are rewarded mainly according to seniority and secondarily according to specialization, but actual performance is not an important component in this matter. It also exists, though weak, the tendency to reward successful engineers through career development opportunities and further education options. This is an incentive means that the high command is starting to utilize but it does not have a clear and generalized application yet.

All in all, the incentive system in the Chilean Army appears to be misaligned with the strategic intent, as it does not reward performance but a degree of commitment and specialization. However this misalignment is intended to apply incentives with equity and to keep the environment within units free of sources of friction. With regard to engineers, incentives tend to follow the general rule; however non-monetary incentives rewarding performance have emerged lately in this case.

### 3.2.5.3. Resource allocation

For the Army in general, resource allocation procedure follows, in general, the strategic grouping so that each unit is provided the resources it needs to accomplish its mission. However, it is possible to observe in some cases that there are units that have to accomplish too much with too little while others enjoy a much more balanced situation. Those units placed in the most remote locations, some of them playing very important roles in the DPGF, often have scarce resources due to their low visibility. Further,
sometimes their demands have to climb several echelons in the chain of command until they reach a level where a significant decision may be made. This results in diluted arguments and therefore low probability of success.

Historically there has been certain misalignment in this regard, however as communications have improved the problems have been gradually taken care of. The tendency shows that these issues are likely to disappear in the long run.

This factor impacts engineering knowledge too. As mentioned above, engineers are usually assigned to factories, directorates and commands at the Army level located in Santiago, the capital city, and also to major units located all along the country. Given the fact that Chilean industry is highly centralized in Santiago, the portion of engineers that are in this location have better access to external sources of knowledge. Any technical problem detected in complex weapon systems at the more distant sites must be solved utilizing mainly Army infrastructure. It is relevant to notice, however, that connectedness is easier to accomplish at distant, less populated locations than in the Santiago area; but the effectiveness of such connectedness is much lower.

### 3.2.5.4. Human resource development

Great efforts are made in the Chilean Army to develop human resources, however it is not clear how effective those efforts are for accomplishing the organizational intent. The Army develops its human resources by gradually educating people as they climb to positions of more responsibility. The underlying purpose is to specialize people through a hands-on learning process. In this development journey people are moved around many locations in order to prepare them to join task forces in any place within the national territory. Still, because of the particular characteristics of our geography and climate, the same tasks must be performed in a very different way in the extreme south (tundra) than in the extreme north (desert). Hence, the desired specialization is, at best, partially accomplished. The Army indeed needs to establish a way for people performing the same task in the various locations to share their concerns, experiences and creative solutions. Especially interesting is the case of engineering knowledge. The Chilean Army educates its engineers in its Military Polytechnic Academy and in some cases in local or international universities. After graduation, engineers are assigned either to one of the Army run factories that are to satisfy the Army combat needs or to one of the Army directorates, commands or major combat units. Although education has proven to be a well developed process, the execution stage has not been efficient or, at least, has not satisfied the expectations of both the organization and the engineers themselves. For
some reason it is very difficult to develop, diffuse and infuse engineering knowledge. The number of technical breakthrough initiatives per time unit is perceived not to match the investment the organization makes in technical education. These initiatives are measured as the number of engineering projects involving equipment, infrastructure and process improvement that succeed each fiscal year. 

Undoubtedly, there might be some kind of misalignment with regard to human resource development in the organization. This situation is especially interesting in the case of engineers and engineering knowledge. The sources of this misalignment will be investigated as part of this thesis.

3.2.5.5. Informal systems and processes

The informal system in the Chilean Army is regarded as an essential component of the organization. As mentioned earlier, it is considered necessary that every soldier be able to perform his or her task in any possible setting. However there exist a wide variety of settings, which require that original procedures be adapted to the particular environment. In addition, in order to improve unit performance and to prepare people to overcome difficult situations, it is deemed important to develop esprit de corps within units, which entails the development of informal processes. Actually, as units get more trained, soldiers get to know each other better and informal processes become stronger. The synergistic effect generated in this process is what makes Army life so enjoyable. People feel they are getting the best of themselves. This process, however, takes time and is easily disrupted when key people are removed or the organizational design is changed.

The alignment of the informal systems and processes described above is evident. Even so, informality presents some drawbacks especially in the case of a hierarchical organization. First, in this case it is easy for commanders to improve his or her unit performance in peacetime drills based only on authority and make the improvement look as the result of a well-developed training process. This kind of improvement is not sustainable in a real combat situation. And second, if personal interests are not well aligned with organizational objectives people may use the close relationship they develop in one assignment to obtain personal benefits in subsequent career positions. Due to these two disadvantages, informal processes are sometimes considerably misaligned with the organizational objectives.

Regarding engineering environment, informal processes are scarce and tend to develop within units, divisions or teams. Working in very specific tasks and having no access to efficient information technology means, engineers develop a much lower number of
informal interactions at the organization level. Instead, they tend to develop intense informal processes at the more localized level, where they can easily communicate and be understood.

3.2.6. Summary
The Chilean Army is an organization with a well-defined intent and a clear set of tasks. The organization is correctly designed to perform these tasks in a geographical grouping. Its linking mechanisms are adequate to its purpose but unfortunately tends to prevent sharing knowledge across unit boundaries as experiences take place locally and there is no diffusion mechanism in place. This factor strongly affects engineering knowledge given the dispersion of engineers geographically and also organizationally. Grouping and linking strategies are somehow aligned with the organizational strategic intent except for the rewarding system and the human resource development system. The former is extremely difficult to improve in the general sense but some attempts have arisen lately in the technical field. The latter should be possible to improve as it seems to be rooted in a managerial problem, the causes of which will be investigated and a solution proposed.
3.3. Political Lens

In the following paragraphs I will present a high level perspective that views the Chilean Army as composed and influenced by multiple stakeholders that bring resources to the organization but who also have interests and goals and utilize different amounts of power in the interactions. As in the previous lens, I will explicitly mention those political aspects that most importantly affect engineering knowledge.

3.3.1. Stakeholder Identification and Interactions Mapping

The following table list enumerates, in no specific order, the stakeholders that are identified from a high level standpoint:

1. Central Government
2. Citizens
3. Congressmen
4. Media
5. Local government
6. Other governmental organizations
7. Non-governmental organizations
8. Army suppliers
9. International organizations
10. Army high command
11. Major unit commanders
12. Commissioned officers
13. Non-commissioned officers
14. Military engineers
15. Draftees

These stakeholders interact within the Army, outside the Army, from the Army to the external environment and vice versa. In Figure 15 below it is shown who is where. The figure below is overly simplified though for two reasons. First, there are some stakeholders that are really at the boundary between both environments and interact in both directions. The graph in Figure 16 shows who interacts with whom regardless of where each stakeholder is located. By looking at both figures (Figure 15 and Figure 16) the reader may identify who are at the boundary and also what are the high leverage nodes.

The second reason why Figure 15 is oversimplified is because the internal stakeholders are grouped in only one of the many types of categories that these people can be grouped. In real life these graphs are extremely complex since people integrate more than one group and, even worse, their affiliation is dynamic, that is, it changes over time.
Figure 15: Stakeholder location inside and outside the Army

Figure 16: Bilateral interactions between stakeholders
I acknowledge that simplification, however, for the purpose of describing the general atmosphere and uncovering the most relevant interactions this simplified model is an acceptable and practical approach.

3.3.2. Stakeholder interests
The set of interactions detailed above stem from the fact that each stakeholder has some goals, the fulfillment of which depends on his or her ability to make the rest of the interested parties align their efforts in the desired direction.
In the following paragraphs I will describe the most relevant interest that the stakeholders bring to their interactions.

1. Central government
   a) It is interested in maintaining a defense system capable to guarantee the country’s sovereignty, territorial integrity and institutional order as mandated in the constitution.
   b) It also seeks to have a well-trained force to participate in multinational military task forces as deemed necessary.
   c) In times of low international tension and scarce internal threats, the government likes to show the people it is managing well the available resources. Then, it puts pressure on the budget and hinders new equipment acquisition or development as other governmental organizations claim for more funding.

2. Citizens
   a) They want to satisfy their basic need of security against any external or internal threat.
   b) They are interested in internal order for the various organizations of society to function smoothly.
   c) They want to preserve the national identity and culture.
   d) They like to see their tax money spent in what they perceive as affecting them the most. Military equipment acquisition is not usually regarded as a good investment, unless the threat is more than evident.
   e) Most of them do not want to give their time in training and preparing for military service.
3. Congressmen  
a) They want to show the people they are interpreting what their needs are and that they are able to fulfill, or at least to struggle for, the satisfaction of such needs.  
b) They want individual visibility and seek for personal prestige.  
c) They have traditionally felt they should have the power to approve, modify or reject military equipment investments, which is not the case right now since the Reserved Copper Law\(^{47}\) does not require their approval for such investments. It is a task the executive power must carry out. Thus, their opinions on the topic are rather critical. Still, this is a topic that generates debate as military services also have their allies in congress and have some power to lobby at this level.

4. Media  
a) They like to sell their news, reports, comments, analyses, etc. Thus, they are eager to scrutinize what is being done with tax money. They tend to favor social programs over military equipment expenses because of the popularity of the latter.  
b) They want to be regarded by people as inquisitive, accurate, timely, fair, and truthful sources of information.  
c) In disputes, they often tend to benefit the position of the one that looks weaker (normally not the Army).

5. Local government  
a) They are usually pleased of having military forces in their jurisdiction since young people with little opportunities can join the military service, which in turn reduces unemployment and crime, and improves basic education.  
b) Those in the most isolated sections of the territory also want Army units to establish in their areas in order to get the critical mass necessary to attract businesses and services and so drive development.  
c) Usually local governments oppose to any kind of drills using real weapons in their territory as they fear for accidents that might affect the civilian population. In this respect, they are often under the pressure of environmentalist groups who also resist training activities using bombs, grenades and explosives because of their effects on forests and wild life.

\(^{47}\) The Reserved Copper Law is a Chilean legal mandate in force since 1958 that authorizes defense investment of up to 10% of the copper export made by the government-run company “Codelco Chile”, one of the most important fund resources of the Chilean Government. For more details see http://www.geocities.com/warbook2000/nohayfondos.htm and http://www.cesim.cl/pags/investigacion/pags/20000606175132.html
6. Other governmental organizations
   a) They compete for funding against the Army.
   b) Some of them want to develop some sort of synergy and coordination with the Army in order to fulfill their mission during wartime (Air Force and Navy) and emergencies or catastrophic events (health care, transportation, communications, etc). Thus, they might be interested in the development of technical knowledge within the Army.

7. Non-governmental organizations
   a) Environmentalists contend the Army activities that may have a detrimental effect in the environment. Besides, patriotism is not part of their motto. Hence, the most common position of these groups regarding acquisition and development of new weapon systems is one of criticism and opposition.
   b) Human Rights organizations usually investigate and criticize military service, which is mandatory in Chile. The fact that young people are forced to get training on how to use weapons is emphatically argued by this groups.
   c) All of these groups seek visibility and want to be regarded as the voice of those who do not have a voice (forests, animals, poor people).

8. Army suppliers
   a) Their main interest is to sell their products. For that purpose they are keen to lobby at all levels with some degree of influence on decisions.
   b) Being equipment manufacturers representatives and used equipment brokers, they are more inclined to sell military equipment as finished products than to promote conjoint development contracts since the former is easier, less time consuming and often more profitable.

9. International organizations
   a) They seek the participation of many countries in international task forces they organize in order to execute peacekeeping, peace-making or humanitarian relief operations. These operations are approved by their councils and normally promoted by the more powerful nations of the world, who become aware of which countries have supported their initiatives and consequently improve bilateral relations.
b) The more powerful nations that dominate these organizations also want to sell the equipment they are not utilizing any more. From that perspective, they are not supportive of internal development of weapon systems and, even when they sell, they do not transfer much knowledge on maintenance, failure history, testing techniques and equipment, etc.

10. Army high command
   a) They have usually served their entire lives to the country and its people through this organization and are truthfully devoted to the fulfillment of its intent. Hence, they tend to be supportive of technological improvement.
   b) As natural, with the exception of the Commander in Chief, they are also interested in their personal success. They want to play a salient role in their functions, lasting for 2 or 3 years, so that they may access the next step up the ladder.

11. Major unit commanders
   a) They are interested in keeping their units in an optimum status of readiness and preparedness during their command period (2-3 years), so that they can fulfill their mission in case of conflict. Therefore they seek immediate solutions and long-term technical learning is less important for them.
   b) They have committed their lives to the organization, which they would like to command. Thus, they also seek personal success for career advancement.

12. Commissioned officers
   a) They have voluntarily committed to serve the country by joining the Army. Hence, it is their interest to accomplish the tasks they have been assigned in order to fulfill their unit mission.
   b) Many of them are usually in search for improved education and assignments of higher responsibilities. They are, in general, supportive of technological knowledge improvement as they see themselves as the leaders of tomorrow and would like to inherit an organization with high technical capabilities.
   c) Most of them also want to succeed in their careers and ascend the organizational ladder.
13. **Non-commissioned officers**
   a) They willingly joined the Army to serve the people of the country. Therefore their interest is to accomplish any mission they are assigned.
   b) They want to specialize in specific tasks and train others to perform them. They like it better to be in the field and to have direct contact with recruits and other soldiers.
   c) They search for technical improvement and knowledge acquisition in a very specific segment regardless of what the origin of the technology is.

14. **Military engineers. (They are also commissioned officers)**
   a) They want to develop as many engineering activities as possible in order to learn and progress individually and also to show the rest of the organization their usefulness.
   b) They are conscious of the importance of maintaining their technical absorptive capacity as a means to be able to purchase adequately and also to be prepared to acquire specific knowledge necessary in potential development projects.

15. **Draftees**
   a) There is a group of them that has volunteered to join the military service for one year. They are interested in serving their country as well as getting a basic technical education that they can utilize in the future. Many of them also aim to join the Army as commissioned or non commissioned officers.
   b) Those that are not volunteers, initially have the only interest of getting to the end of the year. Afterwards, they learn about the value of conscription and the benefits they can get from the experience and their interests become more aligned with those of the group above (volunteers). Even so, there is a group who never gets to like life in the military and just wait for the last day to come.

In the above list, for the sake of brevity, I haven’t included the natural interest of every individual of satisfying his or her basic needs, which is mainly accomplished through a fair salary.

Knowing what are the high level interactions around and inside the Chilean Army functions and what are the relevant interest surrounding engineering knowledge, the next step is to visualize which interests conflict with which. In Figure 17 I have mapped the relationship between the interests of each stakeholder, showing which of them generate
conflicts, which are aligned and which depend on the circumstances or have no relationship under normal conditions.

It is evident that there are many conflicting interests. Some of them will be satisfied some others won’t. The final outcomes will depend on the amounts of power every player brings into play and their abilities to negotiate and find creative solutions that make most of them comfortable.

![Stakeholder interest alignment and conflict matrix](image)

**Figure 17: Stakeholder interest alignment and conflict matrix**

The above matrix shows that there exist an important number of conflicting interests in the environment surrounding the Army activities. Especially populated of conflicting interests is the area that is more relevant for engineering knowledge. Here, we can see
that engineer’s interest to increment technical knowledge is conflicting with the interests of every stakeholder except for some of the interests of the central government, the other services and Army players. Still, there are other interests that are conflicting with them too.

### 3.3.3. Stakeholders power assessment

As Henry Mintzberg (1983)\(^\text{48}\) summarized, the sources of power may be classified in three groups:

- First, the power obtained by those who control resources that are essential, are concentrated and/or in short supply, or are non-substitutable or irreplaceable (resource power).
- Second, the formal power that is exercised by virtue of legal rights, formal position, responsibility or Ownership (formal power).
- And third, the power obtained through access to individuals or groups that have power.

Now, going back to our stakeholder list, we can select the ones that more clearly have access to the above sources of power. The resources that are essential for the Army are personnel and equipment, which are acquired or developed with funding. Therefore the stakeholders who have control over these two resources also have high levels of power in the Army. The essential and irreplaceable personnel are the more educated and experienced commissioned officers and military engineers. Their discipline and vocational commitment prevents them from exercising this power as an organized group in such a way that might threaten the accomplishment of the Army goals. Now, the power of controlling this group of essential officers and in general all of the Army personnel is in the hands of the Army high command, headed by the commander in chief, who in turn is loyal to the central government. The funding, on the other hand, is mainly under the control of the central government as the president provides the final approval for any expenditure of funding coming from the Reserved Cooper Law or any other source. In short, the Army high command and the central government are the most powerful stakeholders with regard to resources.

Similarly, formal power is also in the hands of the Army high command due to the hierarchical structure and discipline based doctrine observed in the organization. The

formal power is granted to the unit commanders at every level in such a way that the
direct boss and those over him compose the chain of command that have formal power
over any member of the Army. The top of the chain of command is the president of the
Republic of Chile who exercises his power over all members of the Army through the
commander in chief. Hence, the formal power is also enjoyed by the central government
and the Army high command.

With respect to access power, the situation is much fuzzier. The point is that depending
on each particular situation there might be different stakeholders that have better access
to those who have power, especially to the government. The press is always very strong
since they have access to the minds of the people who are the ones that go to the polls
and select who becomes the president of Chile. But besides the press there is the
international organizations, the non-governmental organizations and the local
governments, who may take actions that threaten the success of the central government
and so putting pressure to satisfy their demands.

Situations in which the government is under pressure, especially for funding, are quite
common. The resources are limited and there are other public services that enjoy more
visibility and popularity than defense, such as education, health care, housing and
employment programs, among others. Then, governments tend to postpone military
equipment acquisitions, working positions increases or salary raise. This attitude is
counteracted by the potential need to deploy units or the action of Army high command,
who become aware of needs urgency, and start lobbying or definitely putting pressure
over the authorities to solve the Army problems.

This is one of the reasons why the Army high command and the government are different
stakeholders. They should have common interests but many times those interests are not
really aligned. Another reason to list them separately is the fact that the Constitution
mandates the Armed Forces (Army, Air force and Navy) to “guarantee the institutional
order” and there might be the case in which the acting central government is promoting
the internal chaos. Though extremely rare, it did happen in one instance in history. The
details and circumstances are beyond the scope of this thesis; but it is worth mentioning
that the situation may occur.

3.3.4. Summary

This section has described, in a very general fashion, the political environment within and
surrounding the Chilean Army. It has been shown that there are multiple stakeholders
interacting in a rather complicated network with the purpose of fulfilling their own
interest. In this interactions two players have been identified as the most powerful and
thus the ones that most probably impose their interest. They are the Army high command and the central government. They should have, in theory, their interests fairly aligned. However, this alignment fades as the rest of the stakeholders come into play. Then, the government favors the more popular programs and delays the satisfaction of the Army needs. This generates concern, which triggers the Army high command actions to remedy the problems. They then, utilize all formal means to encourage the government to provide the needed resources, as they feel it is their responsibility to maintain the Army units in a satisfactory level of morale, readiness and preparedness.

It also appears to be evident that engineering knowledge is a topic that is out of the agenda of the great majority of the stakeholders. Actually, many of them are opposed to technical improvement in the military field because of its high cost, which they don’t really see as a cost but rather as an expense. The topic is clearly appreciated by those who are directly affected, namely engineers and, to a certain extent, the central government, Army high command and Army Officers. Therefore, it is evident that, if progress is to be accomplished in this regard, it will have to be generated within the Army and with the support of its high level authorities, who will have to attract support from the central government.
3.4. Cultural Lens

To complete the organizational analysis of the Chilean Army, I will now develop the cultural perspective. This point of view explains human behavior as based on the situations affecting people and, most important, based on what those situations mean to them.

This approach will be conducted through the observation of the organization at three fundamental levels in which the culture manifests itself: (a) observable artifacts, (b) values, and (c) basic underlying assumptions\(^49\). These observations will enable a general description of some underlying dimensions of the organizational culture in the Chilean Army and the clarification of their effects in engineering knowledge management. The author does not intend to perform a complete cultural analysis but rather a general view of the main cultural characteristics and a description of their effects on technical knowledge.

The Chilean Army is a 184-year-old organization holding a tradition of efficiency and battlefield victories. Its history exhibits an undefeated route through the adversity of wars that Chile has undergone. This course has shaped its culture of bravery, patriotic spirit and discipline.

3.4.1. Artifacts

At the artifact level, the signs of a hierarchical organization are quite evident. There exists a high degree of formality in the interpersonal relations. People call each other by “Sr” and use ranks or titles even in social events or private environments, unless it is a conversation among close classmates (same rank and seniority) in a one-to-one communication. Interactions are also characterized by high respect for hierarchy. Sometimes people in meetings take care of what they say and how they say it as part of defensive rituals fostered by both respect for the authority chairing the meeting and concern of harming his or her personal reputation.

Status symbols are also abundant. Each base has a commissioned officers’ mess separated from the one used by non-commissioned officers. Only those with a rank higher than that of the ones using a specific mess can access these amenities. Parking spaces are also, in many cases, distributed according to ranks or positions. The higher the rank the better his or her parking space will be or the better chances he or she will have to park in an in-door garage for instance. Another illustration is the grouping and allocation of artifacts.

of Army-provided housing. Among other factors, dormitories and family housing facilities are differentiated depending on ranks. The boundaries separating groups are roughly the same as those described for officers' messes. Again, the higher the rank, the better the housing an officer may have access to.

Hierarchy and formality are also shown in the way people dress. Everyone, except civilians, wear uniform with his or her rank on it and usually some affiliation symbols such as the unit the individual belongs to, the pins indicating the kind of specialization he or she is trained in, and ribbons showing specific studies or participation in important events of the history of the country. Uniforms, like in every army, have special purposes. Every event is matched with a certain type of uniform so that every attendee uses the same attire.

Preservation of traditions is highly noticeable too. Some practices have been performed for more than a century and, even though they do not make much sense in the information age, they are still in place. To illustrate I will mention a ceremony that takes place every year in all the major units in which specially assigned inspector from another major unit inspects and verifies that all the people assigned a position in the Army really exists and works for the organization. Today this is only a ritual that is carried out selectively with a reduced number of people in a very fluent fashion, still it takes time, uses resources and has no other purpose than preserving the tradition.

Another distinctive aspect is communication patterns. The flow of information is almost exclusively vertical, in both top-down and bottom-up directions. Commanders communicate orders to their subordinates while the latter keep their commander informed about tasks fulfilled and on the situation in their units. Besides, nobody is told more than what he or she needs to know for accomplishing his or her mission. A commander order is understood to have been analyzed with all the best information available, carefully thought and accurately coordinated with the rest of the forces in the area. Therefore, unless explicitly ordered, no lateral communication is necessary.

In short, a general view at the artifacts level reflects a profound respect for hierarchy, high degree of formality, religious conservation of traditions and strict vertical communication patterns.

The abovementioned artifacts are some examples of the many that exist in this organization that act as rigidities that obstruct knowledge generation and diffusion. Unless well managed, an authoritarian hierarchical system implies low tolerance of errors; therefore technical experimentation becomes a risk that is seldom taken. Likewise, people might become very cautious to give opinions and freely express ideas as the ones at the most powerful positions might become less tolerant to criticism.
Formality also creates a detrimental effect on knowledge management. Creativity needs an informal environment where people concentrate on thinking of good solutions rather than in anything else and where ideas flow smoothly without any required ritual to be passed on. Formality fosters the feeling of waste of time in creative people, especially in the technical field where the speed of technology improvements makes time a scarce resource.

Finally, tradition conservation reflects resistance to change and if changes are resisted then, why generating new ideas? The explanation about this issue and the example above shows that in this organization it is very difficult to infuse innovative ideas, novel practices or even new technologies. Any innovation whose value is not immediately evident is likely to be rejected for being disruptive, unless it is strongly supported by the high command. Thus, technical initiatives are quite difficult to develop and even more to implement.

3.4.2. Values

Values espoused by the Chilean Army do not differ much from those advocated by other armies in the western world. They are explicitly worded and taught to new recruits as one of the most fundamental foundation of their military training. They include:

Patriotism: faithfully commit to render your life in defense of your country and its citizens.

Loyalty: let your actions be guided by the true allegiance of the Chilean Constitution, the Army and your unit.

Honesty: do what is correct according to the Chilean law, the Army regulations, and to the moral rules of our society.

Selfless-service: favor the welfare of the Chilean citizens, the Army, your unit and your subordinates before your own.

Duty: fulfill all your tasks and do so putting your best effort.

Bravery: Overcome fear, hazard or hardship.

Honor: live up to all the Army values.

Observing the way people in the Army act in everyday life it is obvious that some of these values are claimed but not truly followed. One evident reason for this divergence is the fact that they conflict with personal or group interests or even with common practices. The value of “Duty”, for instance, might not be practiced in certain settings as the group might have developed their own performance standards in order to avoid fierce competition among peers. Or, as another case in point, the value of “Loyalty” might be
applied in a weakened fashion if someone does not oppose to an unfair act of a superior for respect to his hierarchy. Or, as yet another example, someone might disregard the value of “Selfless-service” by informally resisting an assignment that implies moving to a remote location because his or her family will be affected.

All of the above examples affect in one way or another technical knowledge creation or diffusion. In the first case mediocrity reduces the level of effort thus productivity and creativity are affected. In the second one, people do not speak their minds so communication of ideas and opinions is only partial. And in the third case, people reject assignments which generates lack of resources where they are needed, which obstruct the accomplishment of the high level intent.

There are also some instances in which technical knowledge is affected more directly. One would say that the value of “Loyalty” fosters decision makers in the Army to think of maintaining a technical absorptive capacity by any means. However, as highlighted in the political analysis above, there are conflicting interests that prevent this from happening. The need to show results in terms of tangible physical accomplishments is so strongly instilled in common practices that it becomes difficult to convince someone he has performed very well if the results of his efforts will only be seen in the future.

Technical knowledge also demands leaders that listen and learn, a behavior that the value of “Patriotism” seems to foster. Nevertheless, an authoritarian system does not stimulate this kind of attitude. People tend to think that rank and seniority yields wisdom, when what it really yields is risk of loosing it. Officers often recognize this but sometimes it becomes difficult for us to act accordingly. This is a very significant issue in the utilization of engineering knowledge since sometimes we do not seek specialized technical advise when we should, as we believe we have a complete grasp of what we actually have a partial understanding.

All in all, then, as in every other organization, in the Chilean Army it is easy to notice inconsistencies between the espoused values and the way people act. The former are ideal guidelines designed to drive action in general terms but they do not consider the context in which actions take place and interest brought into play. Nor they take into account the evolution of ideas, procedures and beliefs that stems from the experience gathered as problems have been solved over time. They where established and accepted, and from then on they are advocated, since they reflect the superior interests of the organization and its people. However, the way they are applied and understood varies over time and also from one setting to another.
This inconsistency between values and actions leads to think of the existence of another layer of concepts that is guiding the way people think and act. That is what the literature calls assumptions. They are the topic of the next section.

3.4.3. Assumptions
Assumptions are the real foundation of a culture. As defined by [Schein50], culture is a: "(a) pattern of basic assumptions, (b) invented, discovered or developed by a given group, (c) as it learns to cope with its problems of external adaptation and internal integration, (d) that has worked well enough to be considered valid and, therefore (e) are to be taught to new members as the (f) correct way to perceive, think, and feel in relation to those problems".
Assumptions are, then, underlying and usually unconscious suppositions that guide the way people perceive issues, how they approach them, how they feel about them and the way they behave when facing them.
The Chilean Army is an organization in which people have adopted many underlying assumptions about different topics. I will cover in the next paragraphs, however, only those dimensions affecting those aspects that are of interest for developing this thesis.

3.4.3.1. The organization's relationship to its environment
The Chilean Army is perceived by its members neither as dominant nor as submissive. It is obedient to what the central government demands as long as it follows the constitutional mandates.
People in the organization identify both the organization and themselves as having a function of service to the community. Under any circumstances and whenever the country needs it the Army and all its members are willing to assist the Chilean citizens, as long as it doesn’t hinder the accomplishment of its main purpose of national defense and normal functioning of the fundamental institutions of the country.
At the technical level the organization sees itself as independent and self-sufficient. This profoundly instilled belief prevents the organization from seeking connections with outer sources of knowledge, which are often willing to transfer knowledge to and learn from the Army.

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3.4.3.2. The nature of human activity

The “correct” way for people to behave is composed of two main aspects. On the one hand, unit commanders must be charismatic and good leaders, that is, proactive, sensitive, smart, self-confident and, to a certain extent, dominant. These are the characteristics of those that are successful in getting things done and accomplishing high performance within their units. On the other hand, they must be highly disciplined and respectful of hierarchy, therefore when dealing with the chain of command above them commanders must be much less proactive and dominant, and open to follow instructions. This assumption reflects, again that it is difficult to find leaders that are eager to learn from his subordinates and a poor pattern of communication. When exaggerated, dominance by leaders and high respect for hierarchy shows that bottom-up initiatives have less probabilities of success as they have scarce means to reach the minds in the higher levels of hierarchy.

3.4.3.3. The nature of reality and truth

Generally truth is believed to reside in the wisdom of the more experienced people. The more senior commanders are the ones that have the experience to solve conflicting situations. They usually ask for information and advise in different technical aspects but they are the ones who decide what should be done. Once they have decided, his subordinates are supposed to agree and execute what is ordered with the means provided and in the place and time indicated. No further questioning is expected.

3.4.3.4. The nature of human nature

People are assumed to be neutral and to improve on stimulation and training. Any average citizen is capable to perform well in the Army if exposed to the right training and if conducted and motivated by the adequate leader. Even so, every activity needs to be controlled by the commander in charge as mistakes might imply casualties. Every commander is accountable for what his unit or his subordinates do or don’t do.

3.4.3.5. The flow of communication and information

Unless otherwise indicated, everyone receives orders (and information) only from his unit commander and gives orders just to his subordinates. People is provided only the information they need to know in order to accomplish their mission. Disciplined soldiers do not search for information they don’t have the need to know. Further, it might be
suspected that someone has a hidden intention when he or she asks for information they don’t need.

The above way of dealing with information comes from the fact that the enemy may capture soldiers in the battlefield. In such circumstances, the less the soldier knows the less he can tell and therefore the lower the risk for his unit and its mission accomplishment.

This communication pattern is observed not only in maneuvers and exercises but also in everyday working activities. According to military doctrine, behaviors that are good practices in the battlefield are never contradicted in day-to-day life. Soldiers are supposed to behave in a certain manner no matter how critical the situation is. It must not be necessary for them to think to act according to doctrine; they must just act as an instinctive reaction. Real combat situations are so stressing and demanding that soldier’s minds have to concentrate in just a few things, namely those that are unique at each situation. Therefore lateral communications are quite rare; they are avoided unless commanded.

This interaction style promotes internal discipline and fosters internalization of doctrinal principles and practices, however it hinders the diffusion of data, information and knowledge across organizational boundaries, which in turn prevents learning. Initiative is also affected by this communication style. In this kind of environment, people prefer to follow the clearly established rules rather than risking making mistakes. For the same reason, initiatives that prosper are difficult to implement as it is safer to do what the doctrine and regulations mandate instead of experimenting new procedures.

3.4.3.6. The nature of human relationships

In the lateral direction relationships are mainly competitive. The number of staff positions decreases as career ascends the ladder resembling the shape of a pyramid. Thus, the longer people stay in the Army the higher the probability to lose the job.

Consequently, people are always competing against their generation peers to stay in the Army and keep climbing up the ladder. From this perspective, possessing some kind of knowledge that is vital for the organization may yield job assurance to its owner, thus it is not uncommon to see people that acquires some kind of knowledge and does not want to share it as they see it as a source of stability. This is especially noticeable in the technical field where knowledge may be very specific and positions for senior engineers are even more scarce than those for staff officers.
In the vertical direction the relationships are mostly autocratic/paternalistic with some weaker integration of collegial/participative practices. As explained before, there is a commander that tells what needs to be done and asks questions when he needs advise but he is the one who makes decisions. Again, here we see that the flow of knowledge in the vertical direction is quite difficult.

3.4.3.7. The nature of the relationship between the Army and its members

The Chilean Army sees itself as a family, in which each member must follow its discipline, espouse its values and profess its mandates. In exchange it provides the honor of working for the superior interests of the Nation, attractive job experience, economic security, access to Army provided welfare and a good retirement. Indeed, a highly structured environment in which technical innovation is welcomed only if it is presented to the right person and following the appropriate formal channels. Receptiveness of technical initiatives depends, in many instances, on the ability of its champion to convey his message to decision makers with scarce engineering background.

3.4.4. Summary

The most salient aspects of the Chilean Army culture indicate that this an organization that sees itself as being intended to serve the citizens of its country, obedient to the central government as long as it conforms to the directives prescribed in the Constitution. Its most appreciated members are charismatic leaders that strictly observe the Army discipline and respect its hierarchy. This last aspect is especially important since truth is derived from the wisdom of the more senior and experienced minds, the unit commanders. They are the ones that make decisions, conduct, motivate, supervise and are accountable for what their subordinates do. This authoritarian scheme, if not well managed, hampers engineering knowledge generation and diffusion since it does not tolerate errors and obstruct free flow of ideas.

Unit commanders are also the ones that keep a constant flow of communications in the vertical direction with their subordinate units, providing them only the information they need to know in order to accomplish their mission. Any inquiry of information besides that provided must be justified as it is against the Army doctrine to obtain and provide extra information. This practice makes it difficult to take advantage of the synergy generated by teamwork in technical problem solving, as people in different units do not cooperate with each other. Also, the lack of interactions makes knowledge diffusion very
difficult especially in the technical fields where the topics are more complex and rich interactions are needed to convey ideas and to accomplish good understanding. At the interpersonal level, the relationships among people are competitive in the lateral direction and, as described above, mostly authoritarian/paternalistic in the vertical direction. Competition among people fosters individual learning but hampers organizational learning since people become reluctant to share knowledge. The religious observance of discipline in the relationship between the Army and its members is also a factor that may prevent learning and progress since innovative ideas have to be presented in the right way, at the right time and to the right person.
4. System Dynamics Modeling

4.1. Background

Due to the complexity of the system under study and the number of influences existing among its variables, the author chose to build a dynamic model to simulate the behavior of the system when all the relationships —captured through interviews as described in the previous chapter— act simultaneously.

More and more people are realizing that social and business systems are too complex to be understood by intuition, compromise and superficial debate. But, the traditional social and managerial sciences are providing little help in designing policies for better behavior of large dynamic systems. The rapidly growing field of systems dynamics is increasingly seen as the best hope for dealing with multiple-feedback-loop, non-linear systems that extend across many different intellectual disciplines.

System dynamics modeling is a technique that sets the conceptual tools that enable us to develop formal computer simulations and utilize them to better policies within organizations. It enables us to analyze, understand and manage the structure of interactions within complex systems, especially those with feedback circuits. Feedback here refers to variable A affecting variable B, which in turn affects A, perhaps after a delay and through a number of other cause-and-effect relationships. In these instances, the analysis of individual components does not yield a satisfactory result. Instead, only the study of the whole system can improve our insight and lead us to correct outcomes. The author recognizes that the model presented below however does not represent a complete view of the relationships affecting engineering knowledge management in the Chilean Army. It is extremely difficult to capture all the variables affecting the issue and, even if that could be done, the complexity of the model would escalate to the point that it would become as complex as reality. Besides, the modeler is limited by what Simon termed “bounded rationality”. Simon contends that human minds are bounded in their capacity and hence can only understand an approximate picture of the world surrounding them. Therefore the model presented can only be as complete as the rationality of those who provided the information used to build it.

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Bearing the above limitation in mind, the author has devoted his efforts to represent as accurate as possible those relationships that were mentioned more often during the process of data gathering (survey and interviews). Hence, the system dynamics model presented was developed by decision makers at the high command level and by front line engineers as described in Sections 2.4 and 2.5 of this report. It also includes some ideas that stem from the author's experience within the organization, which in every case were validated by the opinions expressed in both the survey and the interviews. The modeling process used went through the steps below. It is necessary to notice that as the model was developed, much iteration took place among individual steps.

- Identify the problem
- Identify variables affecting the problem
- Establish cause and effect relationships through interviews and survey
- Develop a simulation model of the system
- Compare the model with available historic data
- Devise optional policies and test their effect on system behavior
- Make recommendations based on system response

The above steps are described in the next paragraphs.

4.2. Cause and Effect Relationships

Cause and effect relationships that resulted from the quantitative research and especially from the interviews described in the qualitative research section may be summarized in five causal loops. These structures describe the most relevant interactions affecting the issue under study. For the sake of simplicity, some of the variables identified in Section 2.5.5 were gathered together and given a common name.

4.2.1. Technical Need Identification

Five causal loops and a number of interactions as shown in Figure 18 act together to allow technical needs recognition.

In order to accomplish its fundamental objective of defense, the organization seeks to maintain its forces at a high level of readiness and preparedness. For that purpose, it is constantly developing drills and maneuvers with its combat units. Such exercises provide visibility, through press coverage, and also increase the perception of benefits as readiness and preparedness of the forces are improved. However, the more drills and

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maneuvers developed the more the equipment is used and the shorter its remaining useful life becomes. At a certain point, equipment starts to fail more often than acceptable negatively affecting readiness and preparedness. Then, the Army recognizes the need for replacement of the materiel in question and hence a need is identified. Alternatively, readiness and preparedness may be affected by the lack of certain infrastructure or equipment necessary to react against a potential threat. In this case a new equipment requirement is surfaced and a need is also identified.

Once a need is acknowledged, the organization allocates the funding to initiate its satisfaction process.

Figure 18: Need identification causal loop

4.2.2. Investment Decisions

Relationships surrounding investment decisions are presented in Figure 19 below. In order to satisfy equipment or infrastructure needs the organization either acquires finished products or develops equipment in-house, totally or partially (up-grade purchased equipment, modernize existing equipment, etc). Each option has different implications for engineering knowledge. If equipment is bought ready to use, then little engineering skills are used and so no new knowledge is developed or captured. Instead,
some of the existing knowledge might be lost, as time will pass before it gets used again. By then, it might be forgotten already or those who posses it might have left the organization. If, on the other hand, the development is made in-house, then engineering projects are performed, which is the circumstance when engineers may learn through practice. It is in these instances when they get together; develop teamwork; and experimentation and hands-on engineering takes place.

Figure 19: Investment decisions causal loop

4.2.3. Human Resources Management
This loop shows the reinforcing relationship generated by HR management policies in place in the organization and its effects on engineers' morale (See Figure 20). If engineering activities are reduced, engineers enjoy less professional development opportunities, which in turn affects their morale. Engineers then compare their current situation with that of engineers in the private sector, and might decide to migrate. If they do so the number of engineers in the organization is reduced, workload is increased and morale goes down again. Besides, as the number of engineers is reduced less engineering
projects may take place and again less development opportunities are perceived, which triggers another cycle around the loop.

![Diagram](image)

**Figure 20: Human resource management causal loop**

### 4.2.4. Communication Pattern Effect

An important number of relationships affecting communications were identified. These influences were grouped and given representative variable names in order to draw the simplified array of causal loops presented in Figure 21.

These loops describe the reinforcing relationship generated by efficient communications. As diffusion of technical knowledge takes place, engineering competencies improve and so does engineers’ morale. Morale then affects quality of engineers’ work and engineers’ productivity, which also affect knowledge stock. Morale also affects itself through word-of-mouth effect, which represents a reinforcing loop by itself. If knowledge is perceived to increase through effective communications, then more interactions take place and diffusion is accomplished.
4.2.5. Relationships with the External Environment

Figure 22 shows the set of relationships generated when the organization interacts with external sources of knowledge. Interactions may lead to engineering knowledge increase either via conjoint projects or directly through information exchange. The more capabilities the organization has the higher the possibility of developing successful projects. When more successful projects are realized the total number of projects increases, as decision makers become more inclined to in-house developments. This will, in turn, increment connectedness since more engineers will be seeking knowledge to solve the problems they are facing within their projects.
4.3. Development of Simulation Model

The simulation model built represents all the interactions described in the previous sections. Although the fundamental variables used are the same, a number of drivers and effects not originally considered were included. They were found to be important as the model was developed and tested and also as a result of the interactions among the stages of the modeling process. As noticed before, during the modeling process the interactions with interviewees continued in order to make sure the model was reflecting accurately the way the system behaves.

The model was built using the theory and modeling guidelines of system dynamics in the specialized literature by Forrester\textsuperscript{54}, Sterman\textsuperscript{55} and Coyle\textsuperscript{56}, and represents the structures of interactions taking place in the Chilean Army. This model corresponds to the progression from qualitative research and fieldwork with decision makers and front line engineers, to a formal simulation tool intended to aid alternative policy evaluation. The software used to build and run the model was Vensim PLE from Ventana Systems.


The entire model included over 130 variables and stocks (levels), which resulted in more than 400 causal loops. To construct the model, individual views were used in order to handle small portions of the model at the time:

- Funding Allocation / Readiness and Preparedness
- Equipment and Infrastructure Needs / Equipment Acquisitions
- Staffing / Engineering Projects
- Engineer’s Morale
- Engineering Knowledge

Further details of what has been included in each of these views are explained in the following sections.

4.3.1. View 1: Funding Allocation / Readiness and Preparedness

Figure 23 below shows that readiness and preparedness is incremented by the development of the organization’s normal activities, i.e. drills and maneuvers, however it increases only up to the point when equipment aging and new needs generation starts affecting it. At this point, equipment needs emerge and its satisfaction is considered. This behavior is modeled using a readiness and preparedness sensor, which monitors this parameter and generates needs as it decreases below a desired level. Thus the model produces needs in a reactive mode, as readiness and preparedness is affected by technical needs. Such reactions have been estimated to happen around every 18 months.

Drills and maneuvers have been modeled as depending on the average readiness and preparedness instead of on the stock itself. This modeling scheme was adopted with the purpose of smoothing the oscillations in the stock and replicating a subjective perception, which is normally not affected by quick oscillations.

This view also includes the level of available funding, which is presented as incremented by the annual budget and decreased by the various costs incorporated in the model and a general figure, termed “Other Monthly Costs”, which comprises the rest of the costs the organization incurs. Figure 24 presents the tree of influences over this variable that have been modeled. It is also important to notice that this variable has a lower bound of M$ - 300. The model sets to zero acquisitions and engineering projects increase rates once this value is reached in order to mimic what the authorities should do in case this level of debt is reached.

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Figure 23: View 1. Funding Allocation/ Readiness and Preparedness

Figure 24: Tree of variables affecting Available Funding
It should be understood that equipment acquisitions and operational activities not always rely on the same funding sources; therefore they do not always compete against each other for funding allocation. However sometimes they do under certain conditions, which are not under the control of the organization. For this reason funding availability has been modeled simply as a stock that is increased as the annual budget is approved and depleted as costs are generated.

4.3.2. **View 2: Equipment and Infrastructure Needs / Equipment Acquisitions**

Figure 25 shows the process developed after equipment and infrastructure needs are identified. They are accumulated in a buffer while they are studied and satisfied. Needs remain under study for a 4-month period, after which they become either an acquisition project or an internal development project. If the former is selected, needs are transferred to the stock of “Equipment and Infrastructure Being Acquired”, otherwise they become “Engineering Projects”.

![Figure 25: View 2. Equipment Infrastructure Needs / Equipment Acquisitions](image-url)
The above decision is part of a rather complicated network of influences. It is affected by a number of factors, which are in turn function of many others. Thus, the variable Fraction of In-House Development, the driver of this decision, is part of 68 modeled loops. Figure 26 below shows a tree representation of the immediate influences in question.

![Diagram of immediate drivers of the decision of in-house developments]

**Figure 26: Immediate drivers of the decision of in-house developments**

Some of the drivers above, such as funding availability and knowledge stock, are fairly intuitive, however some others are less common. Need urgency, for instance, is considered to affect this decision since acquiring a finished piece of equipment means it is available in the short term, whilst development takes time and the outcomes of this process are unknown. Urgency in turn, is driven by two factors. First, a perception of threat, which provides the awareness of how soon the equipment might be required for a real deployment situation. And second, it is affected the desire of the decision makers to show results in the short term for career advancements. This effect is rather subtle in the organization under study but there are cases in which it becomes an important driver.
4.3.3. View 3: Staffing / Engineering Projects

This view, presented in Figure 27, shows the staffing process, which affects the number of engineering projects as does the already described processes of funding allocation and needs satisfied through internal developments. The number of engineers in the organization is driven by the graduation rate from the Army-run school of engineering, which is fairly constant, and the engineer depletion rate. The latter is a function of morale and the incentive gap between the private and public sectors and retiring rate.

Available engineers are assigned to engineering projects and other engineering activities, —represented by the word ‘maintenance’ in the model. The number of projects in the stock of engineering projects is reduced by a project-finishing rate, which depends on the average duration of projects and on the availability of engineers. Since R&D efforts are very scarce in this kind of organization, engineering projects become the most important practical engineering activity where totally new technical
challenges are encountered. Thus, this is one of the most relevant variables in the model. It is part of 79 loops within the model and its impact on engineering knowledge is significant. In Figure 28 below is a diagram indicating the variables that directly affect engineering projects.

Figure 28: Variables driving the number of engineering projects

This view also represents the way knowledge diffusion takes place within the organization. Engineers seek knowledge, especially those working in engineering projects, who have to solve problems that many times are unique. For this purpose, they meet with other specialists in the organization, mainly with the highly capacitated ones. Some of this contacts are fruitful thus engineers get satisfied; but some others are less effective, then engineers keep seeking knowledge and reiterating the process. This structure is modeled in such a way that engineers do not seek knowledge with the same enthusiasm if they don’t have the pressure of problems to solve; therefore the number of engineering projects have a significant impact on knowledge diffusion.

4.3.4. View 4. Engineer’s Morale

View 4 in Figure 29 shows engineers’ morale affect by a number of human resource management circumstances in place in the organization. It is affected by factors such as development opportunities, learning instances, engineer’s prestige, workload and expectation formation, all of which depend in turn on a number of other aspects.
Figure 29: View 4. Engineers Morale

Another factor included in the model is the word-of-mouth effect. The current state of morale affects its future state in a reinforcing pattern. This is intended to replicate the influence of collective morale status — at the organizational, functional or team level — on individuals’ morale.

It should be understood that the aspects affecting morale in this model are only those that are relevant for a knowledge management analysis. By no means has it been intended to model all factors affecting morale for the sake of simplicity. Hence, morale variations in this model are different from what might happen in reality, when many other factors affect this variable simultaneously.

Morale also appears in this view affecting other factors that impact knowledge directly and indirectly. In the first group we find variables such as quality of engineers work and engineer’s productivity, while in the second we find engineers’ migration rate, which
affects knowledge via the number of engineering projects that can be done given the available number of engineers.

4.3.5. **View 5: Engineering Knowledge**

In Figure 30 below, the various factors affecting engineering knowledge are presented. Knowledge is increased by internal and external elements. The former factors are learning through diffusion and learning through practice as engineering projects are executed. These two factors are influenced by the efficiency of these processes and also by the quality of engineers’ work and engineers’ productivity. The external factors are the means to import knowledge such as connectedness with organizations devoted to knowledge generation and usage (universities, labs, provider companies, etc.). In this regard, the model also includes an effect of efficiency of these knowledge imports, which is kept constant in this case given that external contacts are rather scarce.

In the model, engineering knowledge is depleted by obsolescence, engineers’ migration, forgetting and lack of knowledge usage due to acquisition of finished equipment or infrastructure.

![Figure 30: View 5 Engineering Knowledge](image)

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It is important to notice that acquiring competencies is a slow process that requires education, maturation and practice. Also, once a competency is acquired its time of residency is rather extended even if it is not used for a long period, say two or three years, therefore engineering knowledge variations are rather slow when examined as a function of time.

4.4. Model Correlation with Available Historical Data

To validate the model, the emphasis was set on correlating the output from the model to historical data from the organization. Unfortunately, the author faced two limitations. There was data available for only a few of the most relevant variables. The correlation of those variables is shown below, while the rest of the variables where correlated by means of qualitative description made by interview participants, which was analyzed by the author and then discussed with some of them to verify if the interpretation of their ideas had been correct.

Collected data provided annual figures instead of monthly measurements such as those provided by simulation outcomes. Thus, in the charts below a straight line was drawn between the figures corresponding to consecutive years. This method may hide sudden variations or short period oscillations that may have occurred within a year.

Correlation between historical data and the outcomes of the model base case are presented in Figure 31 through Figure 37 below.

![Figure 31: Total number of engineers, data correlation](image-url)
Figure 32: Highly Capacitated engineers, data correlation

Figure 33: Engineers graduated, data correlation
Figure 34: Engineers depletion, data correlation

Figure 35: Engineering projects, data correlation
Figure 36: Average Engineers, data correlation

Figure 37: Equipment acquisitions, data correlation
4.5. Base Case Model Results

Figure 38 below presents the outputs the model yields for the most relevant variables when no modifications to the current conditions of the system are introduced. This situation will be called “base case” when compared with modifications introduced to test different hypothesis in the next chapter.

Given the fact that scarce data was available to correlate some of the most relevant variables, the base case has been modeled adopting a rather pessimistic interviewee description of the current situation in the organization. This position has been adopted with the purpose of highlighting the effects of policies that will be tested and contrasted with the existing conditions.

Readiness and preparedness is incremented as drills and maneuvers are performed; but from time to time it suddenly plummets as equipment ages and breaks down. Then, technical needs are generated, which may be satisfied either by buying finished equipment or by developing in-house. In fact only a small fraction of those needs are developed in-house and the proportion seems to be following a slow downward tendency.

Both of the above trends are reflected in the total number of engineering projects being done. This variable shows the oscillations exhibited by equipment and infrastructure needs and slowly falls over time. This situation affects a number of variables whose interactions result in a mild deterioration of engineers morale and engineering knowledge. The latter decreases because if engineers have less projects to work on, they focus on different problems, thus they do not seek engineering knowledge.

Available funding, on the other hand, is kept under control as the organization is satisfying a considerable fraction of its needs through acquisitions of finished (or used) equipment. This method provides access to good quality and inexpensive equipment. Hence, the organization’s funding balance does not become negative.
Graph for Readiness and Preparedness

Readiness and Preparedness: Base — RP Units

Graph for Needs Generated

Needs Generated: Base — Needs

Graph for Equipment and Infrastructure Needs

"Equipment & Infrastructure Need": Base — Needs
4.6. Model Limitations

As pointed out earlier, the boundaries of the system the model is able to simulate have been set within the organization. This decision was made based on the fact that the organizational authorities can only modify a number of the internal variables affecting engineering knowledge management but they do not have the power to introduce changes in the external environment. In addition, among the internal variables, only the most relevant ones were modeled with significant detail, while leaving those deemed less important out of the model boundaries or modeling them in a simpler fashion. However, external influences—many of which were described in the previous chapter—do play a role in the behavior of the system, which the model is not able to simulate. The boundaries of the system were selected with the best knowledge available and with the purpose of avoiding model complexity escalation.

A second limitation stems from the fact that the modeled reality is the one that this research captured from a population of roughly 30 experienced people out of about 1,000 officers that might have provided their opinions. Participants in interviews, survey and conversations the author carried out to collect data comprised a significant percentage of engineers; but a somehow limited number of decision makers. Therefore, since the model can only be as complete as the perceptions of the people who participate in its construction, it undoubtedly simulates an incomplete view of the system it intends to emulate.
A third limitation is the scarce availability of real data to correlate the behavior of the model. Unfortunately many of the variables in the model describe parameters difficult to measure thus only qualitative data was collected. These data were incorporated in the model in the form of constant values, lookup tables or equations that reflected the best interpretation the author could make of the opinions provided by participants. This interpretative process is a subjective one; hence it might have introduced unintended deviations affecting the model outputs.

It should also be recognized that some limitations might be encountered within the model variables themselves. For instance, defining the units of key variables as something different from “Morale Units” might have led to establishing variable equations yielding different results. Besides, the model itself resulted fairly complex as a result of the limited experience of the author in the system dynamics modeling technique. It certainly might have replicated the same dynamics with a simpler structure if a more experienced modeler or group of modelers had worked on it. This is an initial model that accepts many refinements that can be made in the future for simplicity and also in order to improve its capacity to replicate reality.
5. Hypothesis Testing

5.1. Introduction
As described by the specialized literature (see Section 1.4), there are specific areas of organizational activities that affect knowledge management. Further investigation about the environment surrounding engineering knowledge management in the organization under study allowed the author to frame the modeling process around four areas of relevant influence at the organizational level: decision making, learning through practice, internal communication patterns and connectedness. In order to identify the areas affecting knowledge management of higher leverage in the organization, several hypotheses were developed and tested. Each hypothesis comprises a number of variables in a common area of influence. The testing process consisted of improving the values of each set of variables and observing the impact of these modifications on the system in general and particularly on the stock of engineering knowledge. Then more specific testing was run in order to analyze effects of changes on engineering environment. Abrupt changes in variables were avoided in order to emulate realistic policy implementation.

5.2 Hypotheses Statement
The following sets of actions are believed to significantly increase the stock engineering knowledge in the organization being studied:

Hypothesis 1
The organization is able to foresee its equipment and infrastructure needs; therefore it is able to plan ahead its acquisitions and internal developments so that it doesn’t update its technical capabilities in a reactive mode.

Hypothesis 2
Decisions regarding satisfaction of equipment and infrastructure needs in the Army are made with a vision of incrementing engineering knowledge in the areas of best interest for the organization. Only the existing technical competencies and funding availability affect decisions. All other factors surrounding the decision making process are assigned no influence.
**Hypothesis 3**

a) The organization implements a number of measures to improve technical HR management. They are able to define a clear career path for engineers, workload distribution is improved, and engineers' work and accomplishments are praised at the high command level.

b) The organization takes the same actions described for hypothesis “3a” and also increases engineers’ economic incentives to reduce the gap with those offered at the private sector

**Hypothesis 4**

In an attempt to increment knowledge diffusion, high command has implemented an organization-wide program of seminars, conferences and social events for technical people in each engineering field. In addition, highly capacitated engineers have been hired and significant improvements have been made in communication tools. Finally, the IT network is able to support fast and permanent interactions between distance sites and file sharing has become easy and reliable.

**Hypothesis 5**

The organization has established channels of fluent interaction with some of its providers. A number of its projects have become conjoint efforts. It has also improved its connections with universities and has provided funding for a few R&D initiatives at university labs.

**5.3. Hypothesis 1 Testing**

To do the testing of Hypothesis 1, the oscillations generated by the balancing loop including Equipment Aging associated to the stock of Readiness and Preparedness was eliminated. Then this stock was set to take a constant value so that technical need generation became also constant.

By eliminating oscillations in technical need generation, the system simulates a situation in which no sudden need emergence happens. The organization is able to foresee its needs and has planned in advance which equipment and infrastructure needs will be developed in-house and which ones will be acquired as finished products.

The results shown in Figure 39 indicate that **HYPOTHESIS 1 DOES NOT HOLD**, as the stock of knowledge does not increase significantly when needs are generated in a

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58 Hypothesis 3 was divided into two parts to capture separately the effects of professional motivation and those of economic motivation.
regular basis instead of in a reactive mode. The simulation shows that visualizing needs in advance and being able to plan ahead improves resource management and therefore Engineers’ Morale increases and the organization is able develop more engineering projects. These two improvements affect Engineering Knowledge; however the impact is rather mild. Besides, as the organization starts doing a few more internal developments, the cost increase and Available Funding becomes negative, which indicates that the organization borrows financial resources.

Graph for Readiness and Preparedness

Graph for Needs Generated
5.4. Hypothesis 2 Testing

In order to test Hypothesis 2, the variable Fraction of In-House Developments was set up to depend only on Funding Availability and the stock of Engineering Knowledge in the organization. The influence of other factors affecting this variable in the base case was made neutral. The effects of the following variables were nullified: Authority Turnover, Threat Perception, History of Successes and Failures of Engineering Projects and Other Operational Aspects.
The above modifications set the model to simulate a situation in which any decision regarding equipment or infrastructure need satisfaction will favor the option of in-house development. The only condition to reject that option is lacking technical competencies or financial resources. Technical competencies influence the decision through the variables Normal Fraction of In-House Development and Effect of Knowledge Stock. It should also be noticed that the variable Fraction of In-House Development is bounded by the maximum debt level.

The simulation results in Figure 40 below provide evidence that HYPOTHESIS 2 DOES HOLD TRUE. The stock of knowledge increases significantly when decisions are made as explained above. The model outcomes show no difference with the base case in Readiness and Preparedness, and Needs Generated. Fraction of In-House Developments increases significantly, which increments Number of Engineering Projects being developed while decreasing finished equipment being acquired. This behavior reflects that due to the change in the style decisions are made, equipment needs are satisfied internally each time it is possible.

When more engineering projects take place, engineers seek knowledge to solve the issues they face thus knowledge diffusion and contacts with external sources are incremented. The number of professional opportunities that engineers visualize also goes up and so does their morale.

Funding available, on the other hand, is depleted and becomes negative as internal developments are more expensive than acquisitions.
Graph for Finished Equipment Being Acquired

Graph for Engineering Projects

Graph for Engineers Seeking Knowledge
Figure 40: Hypothesis 2 simulations results
5.5. **Hypothesis 3 Testing**

The following changes were made in the model in order to test Hypothesis 3a: the shape of the lookup table affecting Effect of Development Opportunities was modified to yield an improved effect of this variable over Morale Increase Rate. This change is intended to introduce the effect of a clear career path definition that includes professional development opportunities. Similarly, Engineers’ Prestige effect is changed to introduce the consequence of recognition of engineers’ work and accomplishments at the high command level. In addition, the influence of Workload is reduced in order to show the effect of a better work distribution.

To simulate Hypothesis 3b, the changes above were kept and the following additional modifications were made: the difference between the variables Army Incentives and Private Sector Incentives was reduced to mimic an economic reward improvement. Besides the costs of engineering projects were increased in 17% and other monthly costs in 0.5%.

Simulation runs for both parts of the hypothesis, shown in Figure 41 demonstrate that **HYPOTHESIS 3 DOES NOT HOLD**. The stock of knowledge does not increase significantly when the above changes are made. Important changes are observed in the following variables:

- **Total Number of Engineers**: a mild change is observed when hypothesis 3a is implemented. However when hypothesis 3b is incorporated the change is significant. This indicates that the decision to migrate to the private sector is driven mainly by economic factors instead of motivational ones.

- **Engineers’ Morale**: considerable improvement, as intended, is observed in this variable when hypothesis 3a is implemented and even more when 3b is also in force.

- **Engineering Projects**: though not significantly, this variable improves given that migration decreases, thus the organization has more resources to implement engineering projects.

- **Engineering Knowledge**: changes in the stock of knowledge driven by the above modifications are not severe despite the fact that motivational aspects affect knowledge through many relationships. However, since no organizational policies can introduce dramatic changes in the system, modifications in the model have not been drastic. Thus, these modifications are insufficient to drive major improvements in the stock of engineering knowledge.

- **Funding Availability**: as foreseeable important decrease in this variables were shown in the results as a consequence of economic improvements for engineers.
5.6. Hypothesis 4 Testing

Testing of hypothesis 4 included variations in several variables affecting knowledge diffusion. Contact Rate and Fruitfulness of Contacts were increased in order to increment diffusion rate in approximately 37%. These changes emulate the effort made by the organization in arranging seminars, conferences etc. In addition, the number of Highly Capacitated Engineers has been changed from 16% to 20% of the total number of engineers. Furthermore, to introduce an improvement in available communication tools, the variable Time to Start Interactions has been reduced in 45%. Finally, Other Monthly costs are incremented to recognize the expenditures of new hires and diffusion events.
Simulation results in Figure 42 below show that **HYPOTHESIS 4 PARTIALLY HOLDS TRUE**. No significant improvements in the stock of engineering knowledge are obtained through the above changes. However, the positive effect of communication improvement is quite important for the general context. The most relevant variations observed in the system are:

- **Engineers Morale**: engineers obtain a higher level of satisfaction when able to search and find satisfactory answers from experienced people. This satisfaction is then reflected in the improvement observed in Engineers Morale.

- **Engineering Projects**: this variable is incremented but in a very small proportion. Decision makers increase slightly the number of engineering projects, as they perceive some improvements in the stock of knowledge in the organization.

- **Engineers Seeking knowledge**: The residence time in this stock is reduced. Engineers seek and find knowledge more rapidly due to the improved communication tools. However, since the number of projects does not change much, engineers seeking knowledge are soon exhausted. This behavior reflects the fact that engineers work very focused on their technical problems. Thus, diffusion of knowledge that is not targeted to their specific area of investigation is much difficult to infuse.

- **Engineering Knowledge**: the stock of knowledge is incremented but the impact is not really significant. Even though the means for diffusion are implemented, the number of people interested in the knowledge being disseminated is low. Hence, competencies are incremented only in a gentle fashion.

- **Available Funding**: This stocks decreases in a small proportion due to the expenditures associated to the measures implemented.

![Graph for Engineers Morale](image)

**Graph for Engineers Morale**

- **Time (Month)**
- **Morale Units**
5.7. Hypothesis 5 Testing

In order to test this hypothesis, variables representing interactions with external sources of knowledge were changed. External Contact Rate was incremented in 25% to include the effect of improving interaction channels with providers, universities, etc. The variable External Sources was increased in 33% to replicate the increment in the number of external sources contacted. In addition, Fruitfulness of contacts was improved in 15% to show that interactions produce better results as conjoint projects and research contracts are taking place. As a result, importing knowledge rate is increased in approximately 50%. This is not an exaggerated improvement since the organization had a very low connectedness. Lastly, Other Monthly costs are incremented to introduce the effect of new expenditures in research funding, and conjoint projects. Simulation results shown in Figure 43 provide evidence that HYPOTHESIS 5 DOES HOLD TRUE. Increments observed in the stock of knowledge in the organization are important after making the aforementioned changes in the model. The most relevant variations are observed in the following variables:

- Engineering Knowledge: almost all changes made affect Importing Knowledge Rate, which in turn increment the stock of knowledge. This stock is part of a number of reinforcing loops that help knowledge to grow even faster. However, knowledge does not rise to infinite since the number of engineers is limited and available funding is also bounded. Therefore, it increases rapidly up to a certain level where it remains with little variations.
- Engineering Projects: as decision makers observe the stock of knowledge is being incremented, they become keen to do more in-house developments. Hence, the number of projects goes up until at a certain level the capacity is depleted.

- Engineers Morale: increased interactions with external sources of knowledge provide a perception of more professional development opportunities; therefore Engineers' Morale becomes higher. However as more projects are generated, Engineers' Usage goes up and so does workload, which in turn affect morale. Therefore morale increment is not very significant.

- Available Funding: financial situation is affected significantly. Costs of the actions taken in this hypothesis are high and results are seen only in the long term. Thus, this stock becomes negative showing that the organization must accept a certain amount of debt to adopt this hypothesis.
Figure 43: Hypothesis 5 simulation results
5.8 Insights Gained from Hypothesis Simulations

Hypothesis testing shows that only two of the policies devised have significant effect when applied in isolation. Simulating Hypothesis 2 and analyzing its effects provided evidence indicating that decisions on ‘developing versus buying’ equipment impacts knowledge from several angles. First, since these decisions drive the number of engineering project to be performed, they determine the opportunities engineers have to learn by doing. Second, projects provide the need for engineers to solve technical problems; thus they foster learning. Third, as more technical activities take place, more professional development opportunities are perceived; hence higher levels of satisfaction are accomplished. Increased satisfaction, in turn, affects engineering knowledge through productivity and quality of work. Combining all the above effects while influences of other factors were also in force proved that the former play a decisive role.

Hypothesis 5, on the other hand, exhibited high leverage but proved expensive. This hypothesis showed that if well managed interactions among selected organizations might yield valuable synergistic effects. It must be understood though, that these benefits are obtained when specialists can do actual work together. Then, interactions are kept within the area of interest of both parties and there is some pressure to solve problems together. However, the cost of financing research and fostering this kind of interaction is high as specialists are expensive and the infrastructure utilized is rather sophisticated. Therefore this is an option viable only for a narrow scope of study.

Testing of Hypothesis 4 validates the idea that technical people work very focused on their particular field and therefore diffusion of knowledge in a generalized fashion does not yield significant effects. However, this testing process also showed that improvements in communication might produce important progress if motivation to seek knowledge is fostered at the same time. Therefore, communication tools may be useless in isolation but are quite important within the adequate context.

Hypothesis 3 also demonstrated that purely motivational methods do not improve knowledge stock per se. They must be applied as part of a more complete effort. In the analyzed case the portion related to professional motivation could be included in policy design, however economic incentives are more difficult since they nee the approval government and congress.
5.9. Engineering Environment Testing

This section will address interesting relationships mentioned during the interview research and incorporated into the system dynamic model; but not tested in the above hypothesis. These relations imply behaviors more focused on engineering environment than organization-wide policy implementation as addressed by hypothesis testing. Five effects were the most frequently mentioned and selected by the author to be tested. Their impact was assessed by applying modifications to the base case and observing the system reaction.

5.9.1. New Hire Quality

The organization hires engineers by graduating them from its engineering school. This process takes five years (four years of academic work and one year of internship and thesis). The observation in this regard is that the Army might combine this procedure with hiring retired military engineers that have excelled in their functions or engineers that have migrated and acquired relevant knowledge in other organizations. Such a combination would enable management to keep a more experienced labor force while acquiring new knowledge. Compared to the base case, this option represents no significant cost increment. Salaries and education expenses of non-experienced engineers are equivalent to the higher wages of experienced ones. Besides the organization reduces the number of officers that migrate from combat units to the engineering branch. This option was tested by simulating a situation in which the number of engineers is the same as in the base case; but some of those that migrate are replaced with new hires with similar experience and competencies. Graduation Rate was reduced by 10% and Migration Rate by 15%, while Number of Highly Capacitated Engineers was incremented by 15% and History of Successes and Failures was set to increment trust by 5%.

Simulation results in Figure 44 show that these changes have no impact on the number of engineers while the effect on engineering knowledge is evident. The author contends that these results accurately predict what the actual system behavior would be in this situation. Hiring more experienced engineers would enhance diffusion, improve performance within project teams, and increase knowledge imports. Some more indirect effects would be improvements in quality of engineers work and in engineers’ productivity.
5.9.2 Average Time of Engineers on Job
Time of engineers on each job varies depending mostly on career development stages. The effect of this method is that sometimes turnover harms engineering efforts. Projects stretching for longer periods may be run by a totally new team when just half of the job is done. The intent here is to test a situation where engineers stay longer on jobs in engineering projects. The more engineers do the same job, the more capacitated they
become in the specific area. Hence, tasks are performed more efficiently and faster. However engineers want to access assignments of higher responsibility and climb the organizational ladder. Thus their morale is affected if their career becomes too slow.

In order to test the above option, the model was set to show more efficiency at project teams while affecting engineers’ morale. The former was represented through hastened speed to finish projects (10% time reduction) and enhanced number of insights accomplished at project work (10% increase in project findings). Morale, on the other hand was affected through decreasing career development opportunities per project 20%.

Simulation results in Figure 45 below indicate that even though engineers’ morale is adversely affected, engineering knowledge is enhanced. However, if opportunity perceptions are reduced more than desired — say by 50% — morale is decremented to the point that it starts harming knowledge (see Figure 45). Therefore this approach is rather risky given that the effect on morale is non-measurable, based on perceptions, and reinforced by word-of-mouth. Abrupt morale deterioration may take long time to recover and detrimental effects may spread out to other areas of organizational performance.
5.9.3. Discipline and structured procedures

Some interviewees pointed out that they would like to see more structured procedures within engineering practices. They argued that there are certain methods that can be standardized in systems engineering and project management processes (end-user need detection, early project planning, project staffing process, etc). They also contended that within this organization project documentation differs in quality from project to project, ranging from acceptable to low quality records. Consequently, some knowledge the organization might be able to retain is lost due to lack of understanding about what was originally done and why it was done.

The author believes the above argument is true, as long as flexibility is not compromised. An appropriate set of engineering procedures would reduce workload and forgetting rate. Workload decreases because quite often significant amounts of time are spent trying to figure out something that was done through an odd procedure and is poorly documented. Forgetting rate, on the other hand, is reduced by codifying a higher amount of knowledge in well-developed project documentation that enable third parties to replicate project experience. Guidelines should be general though so that they don’t reduce autonomy.

This proposition was tested in the model by reducing time to forget and competencies lost through engineer depletion by 10%, and reducing time to finish projects and workload only by 5%. These last two changes are milder since, even though time is saved when
information explaining previous actions is available, following procedures and preparing meaningful documentation generates extra burden.

Figure 46 below shows the reaction of the system. Change is not very significant but the effect does improve engineering knowledge. Engineers' morale is also slightly increased due to workload reduction.

**Figure 46: Simulation results for discipline and structured procedures**
5.9.4. Communication Among Engineers and End-Users

An important component of engineering knowledge is what the end-user needs and why he needs it. Weapon system performance is strongly affected by climate and geography. Accuracy in functional and technical requirements, then, becomes crucial for system value. Besides, as systems turn out to be more complex, technical knowledge become more important for proper system operation. When end-user and engineers do not communicate fluently the above effect acts to harm engineering efforts usefulness. Important engineering accomplishments may become useless because they do not satisfy operational requirements or because operators do not utilize them in the appropriate manner. By contrast, if this communication is fluent, system design is well targeted and the system is operated correctly, then system performance is optimized and the investment pays off. The difference among both outcomes is replicated by the model through perception of engineering project success, which is modeled in the variable History of Successes and Failures of Engineering Projects. The author contends that an important component of engineering project success is attributable to the factors explained above. This success (or failure) is perceived by decision makers who keep record of historical performance and consider it when making decisions.

To simulate this proposition, project history of successes and failures was improved by 5%, while time to study needs was increased by 25% and time to finish projects by 8%. In Figure 47 simulation results show moderate improvements in the stock of engineering knowledge. Even though longer time is taken to analyze needs and develop projects, the fact that decision makers perceive increased usefulness of internal capabilities generates more projects and therefore more learning opportunities take place.
5.9.5. Influence of Ranks on Engineering Assignments

Young competent engineers often complained during interviews that they do not have any possibility to access positions of more responsibility because of their rank. They also felt that sometimes they had to follow directions provided by engineers that had less experience than they did in their specific field.

This factor, though not very common, may happen when experienced engineers are moved from one field to another since no new projects are initiated in their original field. Another example would be when engineers go to special assignments such as going to school to study or teach and returning to a field different from what was studied or researched. In these cases, experienced engineers are assigned positions following their rank rather than their experience. This may hinder interpersonal understanding, which harms engineers’ productivity, generates more workload and delays outcomes.

In order to test this situation, mild changes were made in the model. Project team performance was slowed by cutting project initiating and finishing rates by 10%, engineers’ productivity was reduced by the same percentage and similar amount was applied to increase workload.

Simulation results in Figure 48 below indicate that morale is affected by this factor but engineering knowledge is not. The fact that the changes introduced in the model were only incremental prevented a stronger reaction. For this situation to have a significant
effect it must be a more generalized phenomenon that justifies more significant variable change; but that is not the case in this organization.

Figure 48: Simulation results for influence of ranks on engineering assignments
5.9.6. Insights Gained Through Engineering Environment Testing

Engineering environment testing provided relevant information regarding the influence on engineering knowledge of those aspects that were pointed out as important during interviews. Besides providing insights to consider for future actions, this testing showed the usefulness of system dynamics modeling. Most of the simulated options were found to yield significant effects. However some others, though appearing relevant, generated no important effects, demonstrating that intuitive thinking may lead to wrong decisions. Most important, there was one situation (average time of engineers on job) that confirmed to improve engineering knowledge; but it did so at a high cost in morale deterioration. This demonstrates that sometimes non-obvious and counterintuitive consequences of significant impact arise from decisions targeted to accomplish a totally different effect.
6. Recommendations and Conclusions

As a result of literature research, expert interviews, and an in-depth organizational analysis of one military service, a set of recommendations of general application for any Latin American military organization was derived. Further investigation, regarding patterns of behavior, modeling process and testing of different hypothesis and observations, yielded insights for establishing a second set of recommendations targeted at the organization analyzed as a case study. Finally, some pivotal points not covered in this research have been identified for further investigation and future steps, as this research by no means exhausts the topic under study.

6.1. General Recommendations

The following set of recommendations are intended to shed light at the policy making process so that it fosters engineering knowledge maintenance and enhancement. These suggestions have been derived from insights gained during the earlier segments of this research. They are targeted to overcome those factors that hinder efficient technical knowledge management and that are likely to exist in many Latin American military organizations. By framing policies within these guidelines the author believes that organizations will set the basis for optimizing the leverage of their investments. It must be understood, however, that these recommendations do not pay off in the short term but rather in a time frame of 5 to 10 years.

6.1.1. Recognize Technical Knowledge as a Key Asset

As discussed in Section 1.4, knowledge is nowadays identified as the most important asset for organizations facing a rapidly changing environment. This kind of setting is faced by military organizations when dealing with the hastened technological improvements implemented in new weapon systems. It is impossible for Latin American military services to keep updated knowledge of every new technology implemented in modern weapon systems. Thus, it is recommended that organizations strive to maintain a stock of knowledge that provides them an acceptable level of absorptive capacity. This capability will allow them to (1) determine which kind of equipment they can develop in-house and which they have to buy as a finished product, (2) identify the appropriate equipment when they have to purchase, (3) recognize useful knowledge developed outside the organization to target knowledge import efforts, and (4) understand and be able to utilize imported knowledge.
6.1.2. Establish a Shared Vision

Organizations must clearly define a strategic objective regarding technical knowledge that aligns and directs any effort made within the organization towards an intended outcome. To serve this purpose, a “Shared Vision” must be defined. Both of these words have a very specific meaning that should be understood beforehand:

**Vision:** is a high level and long term goal, or set of goals, that state where the organization wants to be in 10 or 15 years regarding engineering knowledge. This goal must be clear and complete, consistent, comprehensive, attainable, and measurable. The latter conditions are crucial for a vision to be effective. It must be easily understood at all organizational levels; it must not change over time; it must include all desired purposes; it must be possible to fulfill and to measure against certain standards.

**Shared:** a vision is shared if it embraces a common superior purpose established by all stakeholders playing a role in the process of fulfilling the vision. All parties must agree on what the vision states and must commit to subordinate other interests they might bring into play otherwise. It is recognized that establishing a “shared” vision is a difficult task; but it is not impossible. Military organizations present an especially adequate environment for this purpose given the strong identification with selfless values that characterize their culture.

A shared vision does not eliminate politics, nor does it make people strictly follow espoused values. What it does is to show the correct way to go and make it clear for everyone. It provides guidance to discern between correct and incorrect schemes to deal with problems and fosters the primacy of the whole.

6.1.3. Allow Engineers to Learn Through Practice

Learning takes place only when intellectual and physical capabilities have been developed and integrated to generate a desired outcome. This research has shown this is especially true in the case of complex systems, where theoretical knowledge is unable to describe the numerous relationships, effects and emergent properties that arise from performing multiple functions simultaneously. Knowledge is generated by observation, experimentation, testing and interactions among people. Once obtained, knowledge should be documented through an AAR-CALL type of process (See section 1.4).

6.1.4. Combat Misinterpretation of Hierarchical System

An authoritarian, hierarchical system is the best — and probably the only possible — relationship style to command units in military actions. It constitutes a pivotal component of military doctrine and must be practiced in any process taking place in these
organizations during peace or wartime. However information collected throughout this research indicate that this method allows significant misunderstandings that hinder organizational knowledge development. Such misinterpretation should be tackled before they become so ingrained in the culture that they are taken for granted. Among these problems there are two that affect engineering knowledge more directly:

- The power conferred to an authority tends to reduce his or her tolerance to criticism and the desire of his subordinates to criticize his ideas. Even worse, lack of criticism follow a reinforcing dynamic driving leaders to develop a level of certainty that robs their capacity to wonder, to see new interpretations, to become curious and to further investigate when facing recurrent problems. Then, no new creative solutions are generated, and rapid technological evolution is ignored until needs become urgent. In order to learn in a rapidly changing environment we must be willing to reveal our uncertainties, to show our incompetence, to seek divergent positions — knowing that our updated ideas today may become obsolete very soon and that every opportunity to learn must be leveraged.

- A second misinterpretation commonly found in hierarchical organizations is excess of formality. When formal procedures are exaggerated, along with order, respect and discipline they generate rigidity, then formality hampers communication reducing knowledge diffusion and creativity. For creative ideas to flourish, a fluent communication pattern is needed among decision makers, end-users and engineers. They must work together in an open environment where ideas can be passed on with no required rites and where personal defensiveness is discouraged. In this regard it is fundamental to consider that the speed of technology improvements and market opportunities make time a scarce resource. Thus teams are under pressure to produce results quickly. Therefore, excess of formality becomes an obstacle.

### 6.1.5. Foster Teamwork

As pointed out in the literature search section and confirmed in the qualitative and quantitative research sections, knowledge is generated through human intervention and multiple interactions. It is necessary, then, to adopt a structure that allows learning utilizing not only individuals but also interrelations between them, namely teams. These structures yield a synergistic effect that drives improved performance. Teams must be composed of specialists with different backgrounds and representing different stakeholders to assure solutions include all relevant interests and consider all cognitive and functional implications. If team dynamics include dialog and discussion, rich interactions take place and problem solving arises smoothly. As projects are finished,
team members form another team or return to their original functions, where they disseminate the knowledge acquired through the above interactions.

An interesting approach to developing teamwork and also useful to overcome the issues presented by misunderstanding of hierarchical system is that adopted by the US Army through their After Action Reviews (see Section 1.4). AAR’s allow free criticism, avoid formality, stimulate free communication and, most important, focus on learning through personal experience.

6.1.6. **Praise Errors and Encourage Experimentation.**

Organizations are adept to hiding negative news. By contrast, this thesis shows it is better that failures be uncovered and openly discussed as they represent an opportunity to learn. If people can’t take the risk of saying or doing something wrong there is no room for creativity. Therefore, organizations should encourage technical people to take the risk of experimenting and failing a number of times before they get a satisfactory result. Trial and error and prototyping should become common practices as they help keep absorptive capacity, foster learning through practice and eventually yield results. In many cases those results do not serve the original intent but they constitute past experience that almost always becomes useful when utilized in future endeavors. It should be understood though, that in organizations where lateral relations are competitive, like in many military services, it is difficult to have engineers take risks and their peers not to criticize them after failing. Consequently, it is not enough to tolerate errors; instead they must be praised when they take place during experimentation and prototyping stages.

6.1.7. **Import Know-How from Outer Sources**

Military equipment technology is so sophisticated, broad and expensive that it is impossible that Latin American organizations be able to build required capabilities to do in-house developments by themselves. Therefore, as shown in many passages of this research, successfully absorbing technical knowledge from beyond organizational boundaries is as important as it is to generate it internally. Since the effort to capture external knowledge is significant, this process requires as a first step a careful planning and source selection. Then, continuous interactions with the source organization should be provided so that every improvement made in the area of interest is captured and integrated. To accomplish continuous interactions the functions of gatekeepers and boundary spanners must be implemented. The former are outstanding technical performers that keep their colleges informed of the latest improvements in their fields. The later, on the other hand, are people that work at the boundary and understand the
world of both, the source and the receiver organization, and are able to translate and disseminate knowledge. Both functions must work as coordinated and complementary to each other.

As stated before, for knowledge imports to be successful, the receiver must have the necessary absorptive capacity to understand and utilize the acquired knowledge.

6.2. Recommendations for the Studied Organization

Many characteristics of the Chilean Army and its engineering environment have been analyzed to develop this body of research. The recommendations in the following paragraphs represent a condensed version of the insights derived from a thorough process of organizational analysis and system dynamics modeling and testing.

6.2.1. Suggested Approach for Engineering Knowledge

Given its limited financial resources, the organization must concentrate its efforts in maintaining a broad, but competent, absorptive capacity while specializing in a rather narrow area of technical expertise. Absorptive capacity should provide a solid base of knowledge in basic engineering sciences. This should enable rapid update in more specific areas that become of interest in particular situations such as the selection process for purchases of new equipment. More profound technical know-how must be developed in areas where the organization has already developed some core competencies and in those fields in which equipment and infrastructure must be tailored to the local needs. Some examples are digital geographic information systems, IT network systems and computerized commander-training systems.

6.2.2. Consider Long-Term Effect of Procurement Decisions.

At the decision level, the organizations must consider the systemic, non-evident and long-term effect of purchasing finished equipment. The current scarcity of advanced technical knowledge and manufacturing infrastructure, along with a meager accomplishment history, induce decision makers to buy ready-to-use sophisticated systems. Then, internal design and development competencies never have a chance to flourish, as it is in hands-on engineering where technical people in this organization learn. Therefore, each time the organization purchases finished equipment it is ignoring a number of learning opportunities. Instead, the organization should plan ahead what are the competencies that are of interest to develop and satisfy needs related to those areas through in-house developments. This should enable the organization to follow a process if incremental
reduction of external dependency in certain areas while complementing with other organizations to provide for the rest of its needs.

Even if the decision of purchasing finished equipment is made, the process should consider engineering knowledge as an important component. Contracts must include transfer of technical expertise for overhaul level maintenance, failure historical data, life cycle costs statistics, efficiency measurement results for different mission profiles, etc. Since most of the systems bought by Latin American services have been operated for several years by developed countries, these data should be available. Besides, this is a good method for establishing and maintaining connectedness with manufacturers and with military services having more advanced technical knowledge.

6.2.3. Improve Connectedness

In order to crystallize knowledge imports and mutual support with other organizations, the Army should devise a policy that fosters connectedness with external sources of knowledge. Since they utilize sophisticated infrastructure and highly experienced specialists, interactions are costly; hence they must target only the areas of real interest for the organization. In addition, in order to maintain productive interaction specialists of both organizations must do actual work together otherwise it becomes difficult to keep focus on the topics of higher leverage. These specialists fulfill the functions of gatekeepers and boundary spanners that enable knowledge transfer among organizations, as explained in Section 6.1.7. These initiatives should enable the organization to establish permanent interactions with universities, laboratories, industry, providers or other military services to generate a synergistic effect to circumvent its technical knowledge gaps.

6.2.4. Promote Knowledge Diffusion and Mentoring

Organizational processes within the Army develop a competitive relationship in the horizontal direction. This means engineers of equivalent seniority compete against each other for available positions and the higher their rank the fewer opportunities they have to access one of these positions. This scheme hinders knowledge diffusion as in some cases people utilize their expertise to assure their future access to a working position. In order to reduce this effect rewarding mentoring and knowledge diffusion is suggested. For diffusion to be effective it must be oriented to the area of interest of the receptor. Therefore disseminating knowledge while mentoring young engineers in their specific area is an effective method to instill new competencies. By doing so, less-experienced engineers are rewarded through increased learning opportunities. Mentors, on the other
hand, also need special incentives to become fond of sharing their knowledge. One way to implement these incentives—among many others—is to hire them after retirement, provided that they have excelled in their specific functions besides mentoring young engineers and disseminating knowledge.

6.2.5. Improve Patterns of Communication

The Army doctrine requires that normal communication flow take place in the vertical direction and only exceptionally (i.e. when mandated or authorized) in the horizontal direction. This pattern of interactions hampers horizontal knowledge diffusion and cross-functional coordination, which is of crucial value for engineering work. Special efforts should be made to overcome this issue without harming doctrinal principles. It is recommended that technical endeavors be treated as an exception in this regard and people be instructed to maintain fluent interactions among engineering functions and also between engineers, end-users and decision makers. To accomplish this, the author suggests forming teams with multifunctional and end-user representation.

6.2.6. Implement an IT Network

Several factors analyzed in this research made evident the need for an information technology network to support interactions. This network should provide transportation for information that combined with the action of human intellect should become knowledge. There are some fundamental aspects of knowledge management that cannot work properly if no adequate transportation means are implemented. Knowledge diffusion among distant sites becomes almost impossible since file sharing is the most relevant vehicle to formalize information transfer. Connectedness is also limited as it becomes restricted to local interactions. Previous experiences are also limited to local use unless there is enough time to find the original records and mail hard copies. The above situation is further worsened by the geography of the country (see figure 14) and existing physical transportation infrastructure. Under the current situation a ground shipment from the extreme north to the extreme south may take two weeks, a time frame not affordable for any efficient organization. In short, most knowledge management practices are inapplicable without an adequate communication system. Therefore this is one of the starting points for future progress.

6.2.7. Improve Knowledge Base Through Hiring Experienced Engineers

The Army’s unique recruiting style of educating its own engineers and incorporating them to the labor force implies that every year a number of experienced engineers leave
the organization and are replaced by non-experienced professionals. Besides, since the total number of engineers does not increase, those engineers that migrate to the private sector are also replaced by engineers just graduating from college. Therefore, each year the organization exchanges its most valuable professionals for rookies. It is then recommended that the staffing process be reviewed considering the option of hiring experienced engineers. This might include those that have previously migrated and acquired required knowledge at a private company or engineers that are retiring, provided that they possess relevant knowledge and whose performance has been outstanding. A combination of this hiring method with the existing one would improve the stock of knowledge in the organization through imports. It would also provide a reward tool for those engineers that excel in their functions while removing fewer officers from combat units to join the engineering branch.

6.2.8. Improve Procedures and Project Documentation

Procedure and documentation improvement has been found to increase the stock of knowledge in the organization. The point here is that within the engineering environment there are a number of procedures that can be standardized, as they are common to every endeavor. Among them are generic processes and early stage project activities. Some examples of the former are product design and development process, system architecting and system engineering process. Illustrations for the latter are project staffing activities, early project planning, end-user need detection procedures, etc. Improving procedures reduces workload and clarifies the way things should be done so that it becomes easier to understand records of previous experiences —for reuse purposes— while reducing the amount of information presented in those records.

It must be understood though, that standardization reduces autonomy. Therefore these guidelines should only target high-level processes so that adaptation to every particular situation becomes easy.

Documentation, on the other hand, must be optimized so that the maximum amount of knowledge gathered in projects is codified and kept in records for future utilization. In this regard it is important that documentation be as detailed as possible and follow standards in format and vocabulary so that it can be easily understood by specialists not in the project team. These records must be kept in databases for easy storage and widespread retrieval to make them available for any team that needs the hints and experiences of a previous effort. A good example of these databases, though not designed for storage of technical experiences, is the one implemented by the US Army at the Center for the Army Lessons Learned (CALL). Battlefield experiences are reported by
teams and reviewed by specialists who determine which experiences may be generalized
and incorporate them into the database. Then, the information becomes available for any
other member of the organization that needs it. It is accessible through the Internet and its
retrieval is only subject to identification via personal password.

6.3. Concluding Thoughts and Future Steps
This body of research explored a generic approach to engineering knowledge
management to be utilized by any Latin American military organization. It has also
analyzed with increased level of detail the special case of the Chilean Army.

The above sets of recommendations summarize the results of this study and provide
guidelines to support policy making and management.

General recommendations do not consider any particular setting; hence before applying
them a thorough analysis of their impact in any individual organizational environment
should be made. For this purpose the frameworks and tools used in this thesis for the case
study proved adequate, practical and efficient. However, accurate historical data and the
willingness to help of engineers and decision makers are necessary. These sources may
become very difficult to access; therefore the explicit support of the service high
command is crucial.

For further completeness and future steps of the case study the following points have
been identified:

- If the organizational funding process is found to be consistent and its behavior is
  observable, incorporate to the modeling process effects of funding constraints other
  than maximum debt level. Then, redo the testing process under new conditions.
- Define the process to establish an organizational shared vision with regard to
  engineering knowledge.
- Determine areas of best interest for the organization to direct importing knowledge
efforts.
- Define procedures for engineering knowledge management:
  - Develop standard models for engineering processes that can be standardized.
  - Formalize methods for documenting engineering projects.
  - Provide guidelines to homogenize project management early stages.
- List most relevant considerations regarding engineering knowledge to be included in
  purchase contracts.
- Devise a feasible advise method for the make-buy decisions making process.

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- Analyze potential disruptions that engineering knowledge management practices may induce on other organizational policies.
- Conduct a cost analysis on the proposed changes for the recruiting method.
- Develop a system architecture for an IT network.
APPENDIX

A. Bibliography


6) Chilean Army public website: http://www.ejercito.cl


B. Survey

Introduction

This communication is part of a research being developed at the Massachusetts Institute of Technology as mandated by the Chilean Army authorities. The research is specifically targeted to detect some of the issues surrounding engineering knowledge management in the Army. As part of the research, this survey collects information on some factors believed to affect the aforementioned. It is also aimed at detecting other factors that you may consider relevant and not mentioned in the survey, which you can declare in the last section of the survey. Your answers are very important for the success of this research, which will provide new ideas for improving our organization’s technical capabilities.

You have been selected to answer this survey for your experience within the organization, which identifies you as a knowledgeable member that can provide interesting opinions and ideas. The survey is designed to take no longer than 15-20 minutes to answer 32 simple questions. Please answer the survey and email it to me at least one hour before the time we have schedule your interview.

All answers are correct and confidential. Data collected will be used only in combination with those of other responders. By no means will responders be identified with their answers. Any sensitive information in this respect will be cleansed prior to publication.

The results of this research will be available for every member of the organization by July 2002. The author will be glad to share electronic copies of the written report after that date.

Thank you for your cooperation.

Hernan Joglar-Espinosa
## Survey

### Objectives

1. Verify if the problem of engineering knowledge management actually exists.
2. Confirm if there is agreement on the principal variables believed to affect engineering knowledge.
3. Determine the relative influence of each variable.
4. Investigate if there were any other relevant factors affecting engineering knowledge management that were not previously considered.

### Questions and Answers

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<tr>
<th>Number</th>
<th>Question</th>
<th>Answers</th>
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<tbody>
<tr>
<td>1.</td>
<td>Years of experience as an engineer</td>
<td>1 years</td>
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| 2.     | Locations where you have developed your engineering activities (indicate number of years in each location) | a) Santiago 3 years e) Concepcion 0 years  
    b) Arica 2 years f) Valdivia 0 years  
    c) Iquique 2 years g) Coihaique 0 years  
    d) Antofagasta 2 years h) Punta Arenas 0 years |
<p>| 2.     | Years working in engineering projects | 0 years |
| 3.     | Do you think the Army provides an adequate environment for developing your engineering knowledge? | Yes |
|        | If the above answer was &quot;No&quot;, then justify by answering about importance of the following reasons: | Irrelevant |
|        | a) Engineering activities are too constrained in time to be developed adequately | Irrelevant |
|        | b) We, engineers, are usually asked to do too much with too little funding | Irrelevant |
|        | c) Each day we develop less at home and buy more finished equipment | Irrelevant |
|        | d) It is difficult to leverage the knowledge of other engineers in our organization since we hardly talk to each other. | Irrelevant |
|        | e) We are not worried about developing engineering knowledge until we need to solve a problem | Irrelevant |
|        | f) We are too isolated. Our contact with the civilian world is very limited | Irrelevant |
|        | g) Engineering knowledge is not important for the Army, after all operations and training are the main purpose of this organization | Irrelevant |
| 4.     | Evaluate how important are for you the following activities for improving engineering knowledge | Irrelevant |
|        | a) Participating in equipment acquisition projects | Irrelevant |
|        | b) Participating in design and development projects | Irrelevant |
|        | c) Participating in maintenance activities | Irrelevant |
|        | d) Participating in battlefield repair activities | Irrelevant |
|        | e) Participating in managerial activities related to technical problems | Irrelevant |
|        | f) Participating in manufacturing activities | Irrelevant |</p>
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<th>Number</th>
<th>QUESTION</th>
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<td>5.-</td>
<td>How important have been the following factors for your ability to solve technical problems</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>a)</td>
<td>Contacting experts within the Army</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>b)</td>
<td>Bringing in consultants</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>c)</td>
<td>Working with provider engineers</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>d)</td>
<td>Working in cojoint projects</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>e)</td>
<td>Talking to other experienced engineers in your field</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>f)</td>
<td>Talking to other experienced engineers in a different field</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>g)</td>
<td>Working with experienced engineers hired for a specific purpose</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>h)</td>
<td>Contacting university professors</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>6.-</td>
<td>How relevant do you think are the following factors for keeping a high morale among engineers?</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>a)</td>
<td>Army incentives</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>b)</td>
<td>Private sector increased salaries</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>c)</td>
<td>Professional development opportunities in engineering fields in the Army</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>d)</td>
<td>Access to external sources of knowledge</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>e)</td>
<td>Interacting with experts or experienced engineers</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>f)</td>
<td>Word of mouth (news and stories told in informal interactions)</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>7.-</td>
<td>Evaluate the impact of engineers morale in the following aspects of their performance</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>a)</td>
<td>Quality of engineers work</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>b)</td>
<td>Productivity of engineers</td>
<td>Irrelevant</td>
</tr>
</tbody>
</table>
C. Model Equations

Fraction of In-House Developments=
If then else(Available Funding>-300,"Normal Fraction of In-House Development"*"Effect of Knowledge Stock on fraction of In-House Development"*History of Successes and Failures in Eng Projects*Need Urgency*Other Operational Aspects,0) ~ Dmnl

Acquisition Increase Rate=
If then else(Available Funding>-300,Needs in study Decrease Rate*(1-"Fraction of In-House Developments")/1.25,0) ~ Needs/Month

Needs in study Increase Rate=Need Increase Rate ~ Needs/Month

In-House Developments=
Needs in study Decrease Rate*"Fraction of In-House Developments"*Projects per need ~ Projects/Month

Time to Study Needs=
4 ~ Month

Needs in study Decrease Rate=
DELAY FIXED(Needs in study Increase Rate, Time to Study Needs ,1.2 ) ~ Needs/Month

Normal Number of Successful Eng Projects=
0.9*Engineering Projects ~ Projects

Needs Under Study=
INTEG (+Needs in study Increase Rate-Needs in study Decrease Rate, 15) ~ Needs

Project Initiation Rate=
If then else(Available Funding>-100,((Project Needs*"Effect of Eng Usage on Proj. Increase Rate")/Time to form a team),0) ~ Projects/Month

Number of Highly Capacitated Eng=
16.6/100*(Total Number of Eng) ~ Eng

Readiness and Preparedness Gap=
Desired Readiness and Preparedness-Readiness and Preparedness ~ RP Units

Time to Recognize Needs=
1 ~ Month
**Funding Decrease Rate**=
Engineering Projects*Average Monthly Cost per Project+Drills And Maneuvers*Drill Monthly Cost+Other Monthly Costs+Cost of Finished Equipment Acquired*Finished Equipment Being Acquired ~ M$

**Cost of Finished Equipment Acquired**=
1.5 ~ M$

**Need Increase Rate**=
Needs Generated/Time to Recognize Needs ~ Needs/Month

**Needs Generated**=
If then else(Readiness and Preparedness Gap>10, 2.4, 1.4) ~ Needs

**Obsolescence**=
EXP(0.1*Time/100) ~ Dmnl

**Visibility**=
0.5*"Average R&P" ~ RP Units

**Cumulative Readiness and Preparedness**=
INTEG (Change in Readiness and Preparedness,5) ~ RP Units

**Change in Readiness and Preparedness**=
Readiness and Preparedness/(2*TIME STEP) ~ RP Units/Month

**Average R&P**=
XIDZ(Cummulative Readiness and Preparedness,Time , 98 ) ~ RP Units

**Drills Benefit Perception**=
"Average R&P" ~ RP Units

**R&P Increase Rate**=
(Drills And Maneuvers*Contribution of drills to Readiness and Preparedness/Time for Drills to Impact Readiness and Preparedness) ~ RP Units/Month

**Morale Decrease Rate**=
(Engineers Morale*0.22/Time to form New Expectations)*Workload ~ Morale Units/Month

**Morale Increase Rate**=
(Engineers Morale*0.15/Time for Organizational Morale to Affect Individuals Morale)*
"Effect of Dev. Opportunities"*Effect of Diffusion on Morale *Engineers Prestige ~ Morale Units/Month
R&P Decrease Rate=

Equipment Aging and New Needs Emergence ~ RP Units/Month

Drill Monthly Cost=
0.9 ~ M$/Drill*Month

Drills And Maneuvers=
Visibility*Drills Triggered by Visibility+Drills Benefit Perception*"Drills Triggered By R&P Benefit Perception" ~ Drills

Army Budget Approved=
520 ~ M$

Drills Triggered by Visibility=
0.05 ~ Drill/RP Units

Other Monthly Costs=
11 ~ M$/Month

Time to Approve Budget=
12 ~ Month

Average Monthly Cost per Project=
0.6 ~ M$/Month*Project

Funding Increase Rate=
Army Budget Approved/Time to Approve Budget ~ M$/Month

Available Funding=
INTEG (Funding Increase Rate-Funding Decrease Rate, 150) ~ M$

Drills Triggered By R&P Benefit Perception=
0.15 ~ Drill/RP Units

Contribution of drills to Readiness and Preparedness=
4 ~ RP Units/Drill

Time for Equipment Aging to Affect R&P=
1 ~ Month

Time for Drills to Impact Readiness and Preparedness=
5.2 ~ Month
**Equipment Aging and New Needs Emergence**=
(If then else(Readiness and Preparedness>110,60,12))/"Time for Equipment Aging to Affect R&P" ~ RP Units

**Desired Readiness and Preparedness**=
110 ~ RP Units

**Readiness and Preparedness**=
INTEG (If then else(Readiness and Preparedness>1,+"R&P Increase Rate"-"R&P Decrease Rate",0),110) ~ RP Units

**Table for unused Kn Effect**
((0,0)-(2,1]),(0,1),(0.11315,0.982456),(0.192661,0.964912),(0.253823,0.960526),
(0.311927,0.951754),(0.366972,0.942982),(0.449541,0.916667),(0.5,0.9),(0.541284,0.885965),(0.599388,0.868421),(0.657492,0.850877),(0.727829,0.798246),(0.798165,0.72807),(0.88685,0.666667),(0.996942,0.587719),(1.11315,0.539474),(1.25382,0.495614),(1.48624,0.447368),(1.59633,0.412281),(1.737,0.381579),(1.87768,0.350877),(1.99388,0.337719)) ~ Dmnl

**Table Effect of Kn on In-House Development Fraction**
((0,0.6)-(4,1.3],[0,0.76886),(0.195719,0.793421),(0.318043,0.824123),
(0.440367,0.850439),(0.550459,0.887719),(0.648318,0.920614),(0.733945,0.949123),(0.819572,0.971053),(0.880734,0.986404),(1,1),(1.009388,1.1),(2.99083,1.2),(3.97554,1.27632)) ~ Dmnl

**Engineers Productivity**=
Effect of Morale on Engineers Productivity*Normal Productivity ~ Dmnl

**Authority Turnover to Project Duration Ratio**=
Average Project Duration/Time for Authority Turnover ~ Dmnl

**Need Urgency**=
Effect of Threat on Urgency*Impact of Threat on Need Urgency+Effect of Authority turnover on Urgency*(1-Impact of Threat on Need Urgency) ~ Dmnl

**Projects per need**=
2.3 ~ Project/Needs

**Table for Effect of Authority Turnover Urgency**
((0,0)-(3,1.5]],(0,1.3),(1,0.95),(1.98165,0.618421),(3,0.3)) ~ Dmnl

**Normal Productivity**=
1 ~ Dmnl

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Effect of Morale on Quality of Engineers Work=
Table Effect of morale on Quality of Engineers Work(Normalized Moral)  ~ Dmnl

Effect of Authority turnover on Urgency=
Table for Effect of Authority Tunover on Urgency(Authority Turnover to Project Duration Ratio)  ~ Dmnl

Normalized Eng Knowledge=
Engineering Knowledge/"Knowledge Stock Needed for In-Hose Normal Fraction  ~ Dmnl

Table for Effect of Threat on Urgency
([(0,0)-(1,1)],(0,1),(0.250765,0.991228),(0.35474,0.973684), (0.434251,0.964912),
(0.53211,0.951754),(0.620795,0.929825),(0.7,0.9),(0.761468,0.842105),(0.834862,0.763158),
(0.905199,0.675439),(0.954128,0.596491),(1,0.5))  ~ Dmnl

Impact of Threat on Need Urgency=
0.7  ~ Dmnl

Effect of Knowledge Stock on fraction of In-House Development=
Table Effect of Kn on In-House Development Fraction"(Normalized Eng Knowledge)  ~ Dmnl

Unused Knowledge Effect=
Table for unused Kn Effect(Forgetting Unused Knowledge)  ~ Dmnl

Effect of Morale on Engineers Productivity=
Table Effect of Morale on Engineers Productivity(Normalized Moral)  ~ Dmnl

Effect of Threat on Urgency=
Table for Effect of Threat on Urgency(Threat Perception)  ~ Dmnl

Table Effect of morale on Quality of Engineers Work
([(0,0)-(3,1.3)],(0.0030581,0.486842),(0.0642202,0.526316),(0.0825688,0.54386),
(0.107034,0.583333),(0.125382,0.622807),(0.155963,0.671053),(0.183486,0.714912),
(0.214067,0.763158),(0.25,0.8),(0.299694,0.837719),(0.357798,0.868421),(0.394495,0.885965),
(0.455657,0.912281),(0.504587,0.929825),(0.556575,0.947368),(0.66055,0.964912),
(0.746177,0.97807),(1,1),(1,1),(1.14373,1.02632),(1.28502,1.06579),(1.41284,1.08553),
(1.66177,1.13816),(1.8367,1.17105),(1.99817,1.20395),(2.99083,1.3))  ~ Dmnl

Knowledge Unsed When Acquiring Finished Equipment=
0.2  ~ Competencies/Project

148
Normal Fraction of In-House Development =
0.2 ~ Dmnl

Engineering Knowledge Development =
Diffusion Rate * Competencies Gained Through Diffusion + Engineering Projects * Engineering Project Findings + Engineers Productivity * Quality of Engineers work ~ Competencies/Month

Normal Quality of Work =
1 ~ Dmnl

Quality of Engineers work =
Normal Quality of Work * Effect of Morale on Quality of Engineers Work ~ Dmnl

Engineers Lacking Kn in Maintenance =
(1 - Fraction of Eng Working in Projects) * Total Number of Eng * 0.33 ~ Eng

Other Operational Aspects =
0.92 ~

Time for Authority Turnover =
24 ~ Month

Table Effect of Morale on Engineers Productivity

<table>
<thead>
<tr>
<th>Morale</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.1</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.2</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.3</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.4</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.5</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.6</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.7</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.8</td>
<td>0.131498</td>
</tr>
<tr>
<td>0.9</td>
<td>0.131498</td>
</tr>
<tr>
<td>1</td>
<td>0.131498</td>
</tr>
</tbody>
</table>

Threat Perception =
0.3 ~ Dmnl

Forgetting Unused Knowledge =
Acquisition Increase Rate * Projects per need * Knowledge Unused When Acquiring Finished Equipment ~ Ideas/Month

Knowledge Stock Needed for In-Hose Normal Fraction =
100 ~ Ideas

History of Successes and Failures in Eng Projects =
Normal Number of Successful Eng Projects/Engineering Projects ~ Dmnl

Acquisition Finishing Rate =
Finished Equipment Being Acquired / Time to Finish an Acquisition ~ Dmnl
Need Decrease Rate = 
Project Finishing Rate + Acquisition Finishing Rate ~ Needs/Month

Project Needs = 
In-House Developments ~ Projects/Month

Finished Equipment Being Acquired = 
INTEG (Acquisition Increase Rate - Acquisition Finishing Rate, 7.5) ~ Needs

Equipment & Infrastructure Need = 
INTEG (If then else("Equipment & Infrastructure Need" > 0.5, + Need Increase Rate - Need Decrease Rate, 0), 15) ~ Needs

Time to Finish an Acquisition = 
6 ~ Month

Engineers Prestige = 
0.8 ~ Dmnl

Workload = 
Effect of Eng Usage on Workload ~ Dmnl

Table for Effect of Eng Usage on Workload

<table>
<thead>
<tr>
<th>(0, 0)</th>
<th>(3.1, 1.5)</th>
<th>(0.0183486, 1.48684)</th>
<th>(0.0642202, 1.43421)</th>
<th>(0.155963, 1.38816)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.229358</td>
<td>1.32895</td>
<td>(0.321101, 1.27632)</td>
<td>(0.40367, 1.23026)</td>
<td>(0.504587, 1.19079)</td>
</tr>
<tr>
<td>(0.623853</td>
<td>1.15132</td>
<td>(0.761468, 1.11184)</td>
<td>(0.862385, 1.09211)</td>
<td>(0.972477, 1.07237)</td>
</tr>
<tr>
<td>(1.07339, 1.05263)</td>
<td>(1.21101, 1.07237)</td>
<td>(1.3578, 1.10526)</td>
<td>(1.49235, 1.13465)</td>
<td>(1.59633, 1.16053)</td>
</tr>
<tr>
<td>(1.68807, 1.18026)</td>
<td>(1.83486, 1.23728)</td>
<td>(1.99388, 1.2943)</td>
<td>(2.13761, 1.33553)</td>
<td>(2.27523, 1.38816)</td>
</tr>
<tr>
<td>(2.48624, 1.43421)</td>
<td>(2.74312, 1.46053)</td>
<td>(3, 1.5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Effect of Eng Usage on Workload = 
Table for Effect of Eng Usage on Workload(Engineers Usage) ~ Dmnl

Reference for Eng Satisfied through Diffusion = 
150 ~ Ideas

Retiring Rate = 
Total Number of Eng * 0.006 ~ Eng/Month

Time to forget = 
30 ~ Month

Normalized Eng Satisfied through Diffusion = 
(0.85 * Eng Processing Kn Satisfied) / Reference for Eng Satisfied through Diffusion ~ Dmnl

150
Army Incentives = 100

Incentive Gap = 0.9 * Private Sector Incentives / Army Incentives

Reference Moral = 100 Morale Units

Migrating Rate = Normal Migration * Incentive Gap * Effect of Morale in Migration

Private Sector Incentives = 150

Normalized Moral = Engineers Morale / Reference Moral

Normal Migration = 14/12 Eng/Month

Effect of Morale in Migration =
(Table for Effect of Morale on Migration (Normalized Moral))

Table for Effect of Morale on Migration
([(0, 0.6) - (4, 1.5)], (0, 1.3), (0.146789, 1.19605), (0.318043, 1.12895), (0.978593, 1.03026),
(2, 0.833333), (3.98777, 0.710526))

Effect of Diffusion on Morale =
(Table for Effect of Diffusion on Morale (Normalized Eng Satisfied through Diffusion))

Table for Effect of Diffusion on Morale
([(0, 0) - (2, 2)], (0, 0), (0.0733945, 0.324561), (0.159021, 0.526316), (0.250765, 0.640351),
(0.348624, 0.763158), (0.48318, 0.850877), (0.568807, 0.894737), (0.703364, 0.929825), (0.843193, 0.978074))

Engineers Morale = INTEG (Morale Increase Rate - Morale Decrease Rate, 100) Morale Units

Table for Effect of Development Opportunities
([(0, 0) - (2, 2)], (0, 0), (0.0733945, 0.324561), (0.159021, 0.526316), (0.250765, 0.640351),
(0.348624, 0.763158), (0.48318, 0.850877), (0.568807, 0.894737), (0.703364, 0.929825), (0.843193, 0.978074))
Effect of Dev. Opportunities =
Table for Effect of Development Opportunities (Normalized Development Opportunities)

Expected Development Opportunities =
((Total Number of Eng*Fraction of Eng Working in Projects)/Average Eng per Project)*Opportunities per Project ~ Opportunities

Time for Organizational Morale to Affect Individuals Morale =
8 ~ Month

Time to form New Expectations =
14 ~ Month

Engineers Lacking Kn in Projects =
Average Eng per Project*Engineering Projects*0.8 ~ Eng

Competencies Lost Due to Eng Depletion =
0.7 ~ Competencies/Eng

Engineers Seeking Knowledge =
INTEG (If then else(Engineers Seeking Knowledge>1,Seeking Increase Rate-Diffusion Rate,0),0.3*(Engineers Lacking Kn in Projects+Engineers Lacking Kn in Maintenance))

Importing Knowledge Rate =
(Engineers Seeking Knowledge*External Sources)*External contact Rate*External Contact Effectiveness ~ Competencies/Month

Eng Depletion Rate =
(Migrating Rate+Retiring Rate) ~ Eng/Month

Normalized Development Opportunities =
Professional Development Opportunities/Expected Development Opportunities ~ Dmn1

Engineering Knowledge =
INTEG (If then else(Engineering Knowledge>1, Engineering Knowledge Development+Importing Knowledge Rate-Engineering Knowledge Loss, 0),100) ~ Competencies
Opportunities per Project
3 ~ Opportunities/Project

Professional Development Opportunities
Engineering Projects*Opportunities per Project ~ Opportunities

Project Finishing Rate
(Engineering Projects/Average Project Duration)+(0.5*Eng Depletion Rate/Average Eng per Project) ~ Projects/Month

External Contact Effectiveness
0.15 ~ Competencies/Contact

External contact Rate
0.2 ~ Contacts/Month

Engineers Usage
5*Engineering Projects/(Fraction of Eng Working in Projects*Total Number of Eng) ~ Projects/Eng

Seeking Increase Rate
Further Seeking Decrease Rate+(Engineers Lacking Kn in Projects+Engineers Lacking Kn in Maintenance)/Time to Restart Interactions ~ Eng/Month

External Sources
2 ~ Sources

Fraction of Eng Working in Projects
0.5 ~ Dmnl

Total Number of Eng
INTEG (Graduation Rate-Migrating Rate-Retiring Rate, 190) ~ Eng

Engineering Project Findings
0.17 ~ Competencies/Project*Month

Diffusion Rate
Engineers Seeking Knowledge*Contact Rate*Fruitfulness of Contacts*(Number of Highly Capacitated Eng/Total Number of Eng) ~ Eng/Month

Competencies Gained Through Diffusion
0.12 ~ Ideas/Eng

Time to Restart Interactions
11 ~ Month
Further Seeking Increase Rate =
\( (1 - \text{Satisfied Fraction}) \times \text{Diffusion Rate} \times \text{Eng/Month} \)

Contact Rate =
5 ~ Contacts/Month

Unsatisfying Rate =
\( 0.2 \times \text{Eng Possessing Kn Satisfied/Time to Lose Satisfaction} \times \text{Eng/Month} \)

Eng Possessing Kn not Satisfied =
\( \text{INTEG (If then else(Eng Possessing Kn not Satisfied > 0.1, +Further Seeking Increase Rate, 0), 3)} \times \text{Eng} \)

Satisfying Rate =
\( \text{Satisfied Fraction} \times \text{Diffusion Rate} \times \text{Eng/Month} \)

Time to Restart Seeking =
1.5 ~ Month

Fruitfulness of Contacts =
0.5 ~ 1/Contacts

Further Seeking Decrease Rate =
\( \text{Eng Possessing Kn not Satisfied/Time to Restart Seeking} \times \text{Eng/Month} \)

Time to Lose Satisfaction =
6 ~ Month

Satisfied Fraction =
0.8 ~ Dmnl

Engineering Projects =
\( \text{INTEG (If then else(Engineering Projects > 0.9, +Project Initiation Rate, -Project Finishing Rate, 0), 13)} \times \text{Projects} \)

Effect of Eng Usage on Proj. Increase Rate =
Table for Effect of Eng Usage (Engineers Usage) ~ Dmnl

Time to form a team =
1 ~ Month

Table for Effect of Eng Usage
\[
((0,1),(0.342508,0.951754),(0.550459,0.921053),(0.746177,0.877193),(0.880734,0.79386),(0.929664,0.561404),(0.954128,0.403509),(0.966361,0.00877193),(1.00306,0),(2,0),(3,0))
\] ~ Dmnl

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Average Eng per Project = 
5 ~ Eng/Project 

Average Project Duration =
28 ~ Month 

Graduation Rate =
30/12 ~ Eng/Month 

Engineering Knowledge Loss =
((Engineering Knowledge/Time to forget+(Eng Depletion Rate*Competencies Lost Due to Eng Depletion))*Unused Knowledge Effect)*Obsolescence
~ Competencies/Month 

Eng Possessing Kn Satisfied =
INTEG (If then else(Eng Possessing Kn Satisfied>1,Satisfying Rate- Unsatisfying Rate,0),250)
~ Eng 

D. Simulation Control Parameters

**FINAL TIME** = 100 ~ Month 
(The final time for the simulation). 

**INITIAL TIME** = 0 ~ Month 
(The initial time for the simulation). 

SAVEPER = 1 ~ Month 
(The frequency with which output is stored). 

**TIME STEP** = 0.5 ~ Month 
(The time step for the simulation).