Organizational learning effects in productivity: a dynamic hypothesis proposal for shipyard learning

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Resumo

The purpose of this paper is to propose a dynamic hypothesis for shipyard learning in terms of productivity gains. This hypothesis was the result of the modelling process after five modelling iteractions and whose starting point was the inventory-workforce model by Senge and Sterman. The system dynamics model resultant from the proposed dynamic hypothesis and the learning achieved by authors during the modelling process served as basis to think shipyard as learning systems and to define guidelines for policy designing in shipyards. Despite this model was developed and apllied to a shipyard case, authors believe that in future works it can be tested and apllied to study behavior of other types of social organizations.

1 Introduction

Profound changes in Brazilian energy policy have motivated the revitalization of the shipbuilding industry in Brazil. New shipyards are arising in different regions of the country and all of them have to face the challenge of learning from experience and gradually qualify their workforce. At this decisive moment for these shipyards, it is expected by brazilian society that they wiill follow the same growth path of shipyards that are now in a prominent position in the world shipbuilding market, but for that they will also be exposed to a basic rule that selected those established yards, that continuous productivity improvements are decisive for shipyard survival in the long term. Japanese shipyards, for instance, raised its bases in a post-war economic environment extremely restrictive and full of difficulties, but they were compelled to develop a new industrial paradigm that eliminated waste and enabled a leap in technological development and productivity in the shipbuilding process.

Since then, especially after the two oil crises, the race for productivity in world yards, is not just a matter of competitiveness and differentiation against competitors, but a survival factor in the shipbuilding industry, now a global industry and extremely competitive in price, time, quality, technology and performance. In the shipbuilding industry, productivity is usually expressed as the inverse ratio of partial labor productivity (or MH/CGT), not only by the influence of best production practices, but also by workforce performance that plays an important share in a shipyard productivity indexes. Therefore, this research proposes to develop a simplified model using System Dynamics practices that allows to simulate the dynamic behavior of production, labor and productivity in a shipyard to assess, through the experience of modeling and simulating, a set of scenarios and show directions to promote learning in productivity and ensure shipyard sustainability in terms of its performance in the long run. The reason for this proposal is to explore some of the causes that determine the dynamic behavior of shipyard learning curves, and then draw some guidelines that could help shipyards to achieve this learning pattern. But this is only possible through the learning of the system

2 Shipyard Definition

The shipyard is a system. More than the place where ships are built, it is an industrial organization which employs thousands of workers organized in a hierarchical structure formed by several working groups. It is a diverse organization, formed by people with different backgrounds, professional qualifications and in some cases, different origins and cultures, with the need to pursue a common goal and work aligned with the corporation values . The objectives, as well as values, may vary from site to site, but in general shipyards seeks to sign new shipbuilding contracts, to build vessels with good productivity and optimum use of infrastructure and production equipments and thereby have profits that will ensure business continuity. This results in an industry whose behavior is complex, non-intuitive and characterized by a significant flow of information between departments and huge material flow between shops, docks and quays. Like any other system made up of people, the shipyard also learn, evolves, self-organizes and regulates itself. Therefore, the shipyard is much more than the sum of its parts and could fit the following definition:

System: is a set of elements coherently organized and interconnected in a structure that produces a characteristic behavior, commonly classified as its function or purpose Meadows (2008).

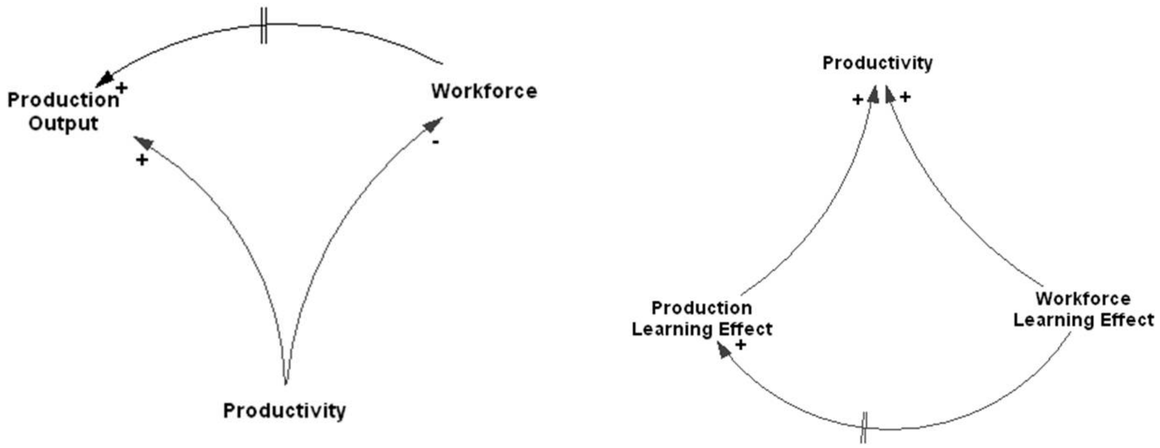
Shipyard: It's a group of people, information, resources - facilities, equipment - and products in different stages of production, coherently organized through a production process that are related and have the common goal of building vessels with a performance that enables the survival of the system in the long run.

3 Dynamic Hypothesis Formulation

The starting point for the formulation of the dynamic hypothesis was the relationship between production and labor force, as modeled by Sterman (2000) in the *inventory-workforce model*. First, the labor force work provides its effort applied through a production process is transformed into intermediate or finished production. The relationship between the workforce and the production process results in a productivity, which increase results in greater production and lower demand for labor as shown in Figure 1a.

It was assumed the hypothesis that shipyard learning is the resultant of two learning: workforce learning, about decisions and actions at the individuals level, such as direct work of a welder, and the knowledge that is inherent to him; and production learning, that is about decisions and actions at the organization level, especially through improved production processes and practices that characterize the knowledge which belongs to the organization.

According to Kim (1993a), organizations learn, in its origin, through individuals and also Kim (1993b) have proposed a transfer method that explain learning transfer from individuals to organizations, through shared mental models. This composition of learning and learning transfer ratio of the labor force for production are shown in Figure 1b. Therefore, a fundamental point of the dynamic hypothesis is that the workforce does not just provide effort but also acts as a source of learning.



(a) Productivity Effects and Transfer of Effort

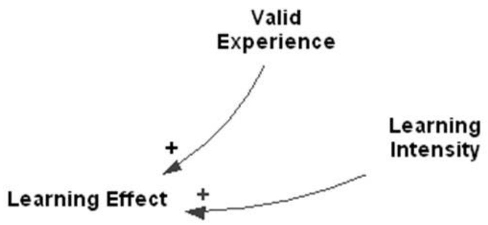
(b) Productivity Causes and Transfer of Learning

Figura 1: Productivity Causes and Effects

Furthermore, it is known that the productivity in a shipyard varies over time in the form of a learning curve as observed by Nagatsuka (2000) and Craggs et al. (2004). These learning curves in manufacturing, according to Argote and Epple (1990), have two important properties as accumulates production experience:

1. Decreasing effort to perform an activity
2. Decreasing rate of effort reduction to perform an activity

According to Sterman (2000), a learning curve can be modeled through the structure shown in Figure 2a empirical function that provides the learning of labor force productive effort (MH/CGT), which by definition is the inverse of the partial labor productivity shown in Figure 2 where Le is the learning effect, Ex is the experience, E0 is the initial experience, and F represents the learning intensity, that is the improvement fraction obtained by doubling experience.



(a) Learning Curve Structure

$$L_E = \left(\frac{E_X}{E_0}\right)^{\log_2(1-F)} \quad (1)$$

(b) Learning Curve Formula

Figura 2: Modeling of Learning Effects

Argote and Epple (1990) observed on entire learning curves literature that this pattern of behavior is observed in many other industries than shipbuilding such as aircraft construction, oil production, power generation, nuclear plant reliability, among others. However, also have found the existence of some organizations that had little or no learning by experience, which is consistent with the statement of Senge (1990) which is not every experience that generates learning.

Argote and Epple (1990) pointed out that these variations in learning curves behavior were caused by organization forgetting , labor turnover, knowledge transfer from other products and organizations and economies of scale. Benkard (2000) studied a case associated with the aircraft industry and observed variations in the learning curve that led to forgetfulness or loss of learning in the organization, caused mainly by production disruption, followed by loss of people and loss of experience.

Thus, we can complete the diagrams shown in Figure 1 closing the loops, using production experience as the connection between production and production learning and labor experience as the connection between workforce and workforce learning. This will result in the dynamic hypothesis diagram, represented in figure 3. These links make sense, not only from the standpoint learning curves theories, but also according to the definitions of learning given by researchers of learning organizations. According to Senge (1990), learning is more than simply adapt or get information. Learning is much more related to gain skills, develop skills, create and acquire the ability to create what you previously could not create. Thus, the learning process, is closely linked to action. Kim (1993b) summarizes learning in how to increase someone's ability to take effective action.

Experience can be measured as a function of the number of units produced or the amount of hours worked. In the case of a shipyard production, experience can be measured by the number of ships produced in CGT (compensated gross tonnage) and the increasing experience of the site will result in the consolidation of shipbuilding processes and best practices or knowledge that belong to the company. Lamb and Hellesoy (2002) determined from a sample of shipyards that the adoption of shipbuilding best practices is one of the factors that have highest influence in productivity. In the case of workforce, experience can be measured by the amount of hours worked and useful to learning, which in this case, workforce experience and learning are attributes that belongs to the people. There are two possible approaches and, in this study were considered complementary and placed side by side in the same model formulation to evaluate the dynamic behavior of a shipyard learning.

Therefore, the hypothesis of the dynamic model illustrated in Figure 3, it is hypothesized that the productivity varies over time in the form of a learning curve resulting from the composition of the purposes of the organizational learning occurs in the form of routines and processes of the organization and workforce learning that occurs through increased skills, competencies and intrinsic knowledge of the labor force and, after a delay due to the diffusion of learning among all peoples and the adoption and formalization of practices, are transferred to the organization. These two types of learning are influenced by two factors each, their accumulation of experience and intensity of learning.

4 Transfer of Learning

It is also relevant to detail the the causal structure that provide the transfer of workforce learning to production learning. Both workforce learning and production learning have influence in a shipyard shared memory, which is a stock of knowledge oriented to productivity (assumed in the dynamic hypothesis as the common objective of workforce and production). This memory is composed by workforce frameworks and routines and by production processes and shipbuilding practices. If the shipyard memory is close to 1, the shipyard shared mental model is more oriented to productivity and the production learning through processes and practices will be more intense and developed. By the other hand, higher production learning will provide a better experience to production workers and also will reinforce workforce lear-

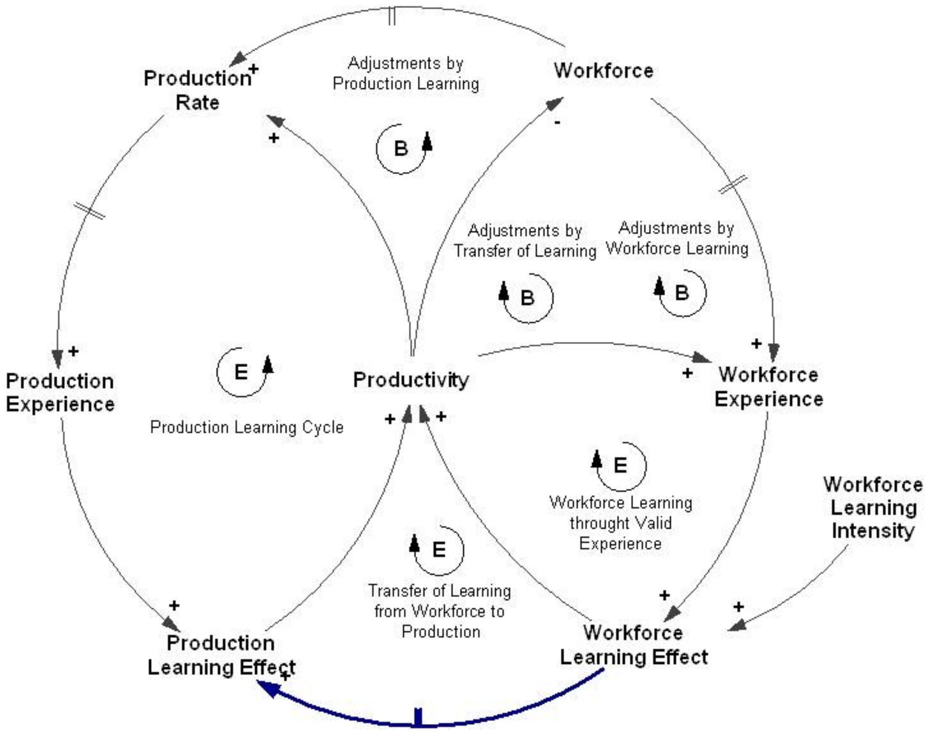


Figura 3: Proposed Dynamic Hypothesis

ning. Shipyard memory effect in workforce learning intensity is not considered in this model, but it is considered what organizational learning theory states that people are the source learning.

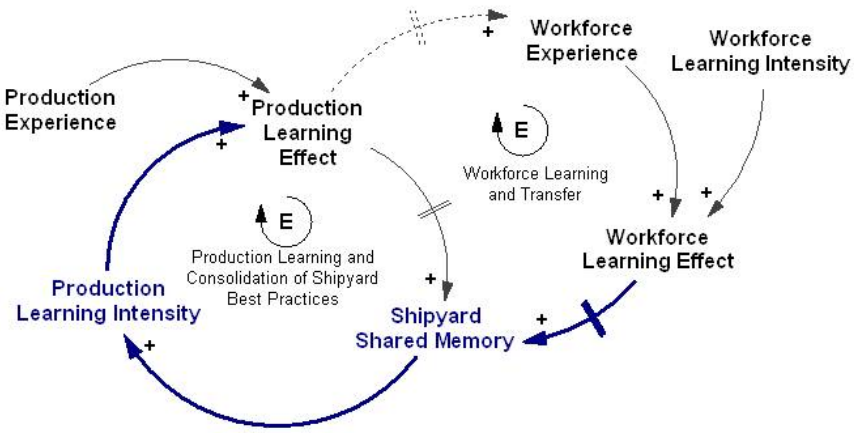


Figura 4: Detailed Learning Relations

5 Model Subsystems

The formulation of the model has started from the dynamic hypothesis as announced in section 3 and shown in Figure 3 so that the first step is to distinguish the following key elements of modeling: Workforce, Production Rate and Productivity. Each of these key elements determines a subsystem that is formed by a group of elements, coherently organized and interconnected in a structure that produces a characteristic behavior, corresponding to its function or purpose within the system to which it belongs. (adapted from Meadows (2008)

Each of these subsystems, however, have the same characteristics of systems, structures with elements that are related through closed loops and have a dynamic behavior depending on their function. The three subsystems of a shipyard and their functions are:

1. Production Subsystem: have the function to transform production orders in intermediate products and finished products. Consists of cycles of balance responsible for controlling two production stocks, work in process and work completed or approved. The production subsystem also have a stock which represents production experience and corresponds to the delivery rate indefinitely accumulated.

2. Workforce Subsystem: have the function of providing effort from the workforce to the production as defined by production manpower forecasts. Consists of balance cycles corresponding to the processes of hiring, firing and limitation workforce growth based on the budget of hours available for the projects. The workforce subsystem also consists of a stock that represents the sum of the individual experiences at the labor force.

3. Learning Subsystem: formed by productivity as function of the workforce learning and production learning. Each learning has two attributes, one related to the experience and another related to the intensity of learning, according to the formulation of learning curves. In this model, both organizational and workforce learning have only one common objective that is in acquiring productivity.

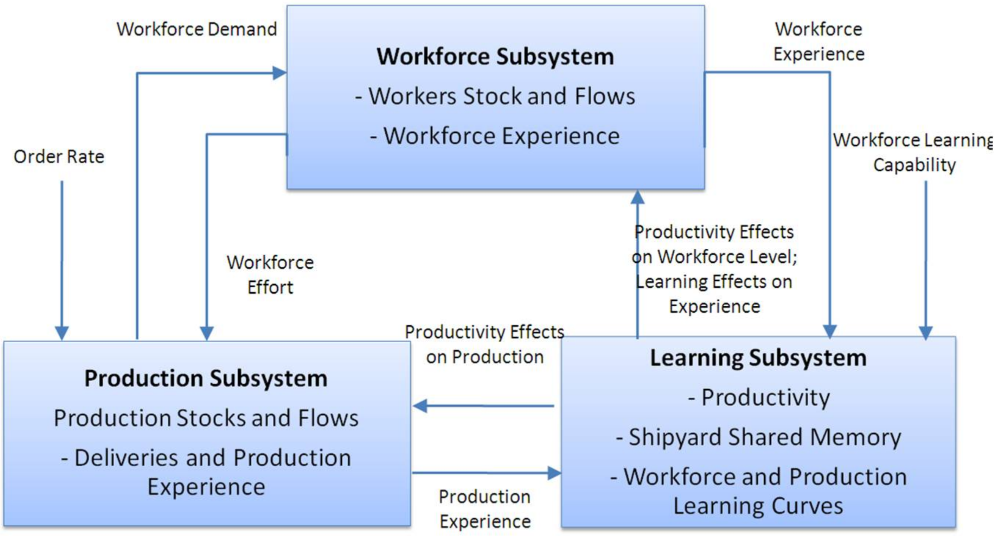
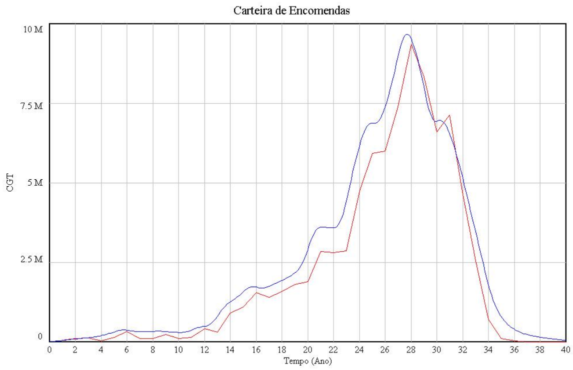


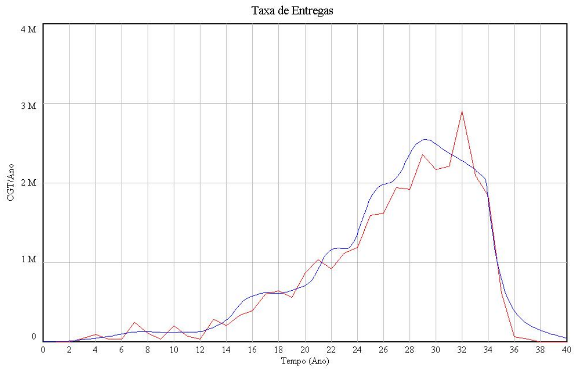
Figura 5: Subsystems Diagram

6 Comparison with a Reference Mode

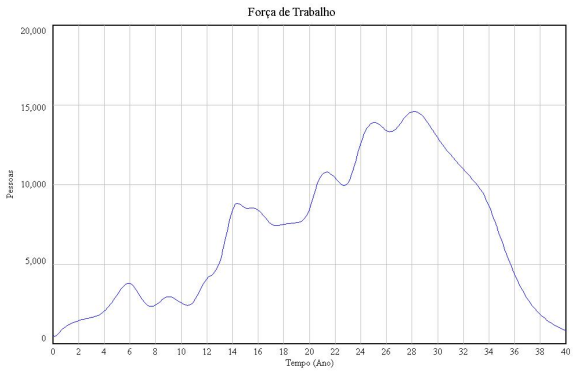
A comparison test, whose graphs are shown in Figure 6, consisted in the comparison of the simulated data with real data from a shipyard. The main requirement used in choosing a site that could serve as a reference mode was the availability of production data (order rates, deliveries rates and shipyard backlog) and historical productivity data in a time horizon sufficient for an shipyard life-time analysis. As Nagatsuka (2000) published historical series of average productivity of major Japanese and Korean shipyards so it was picked up one of the three biggest south Korean shipyard production data for validation, in the time horizon of 40 years, from 1980 to 2019 (through projection of current backlog), and was not assumed no additional order after Apr/2011, date of data collection.



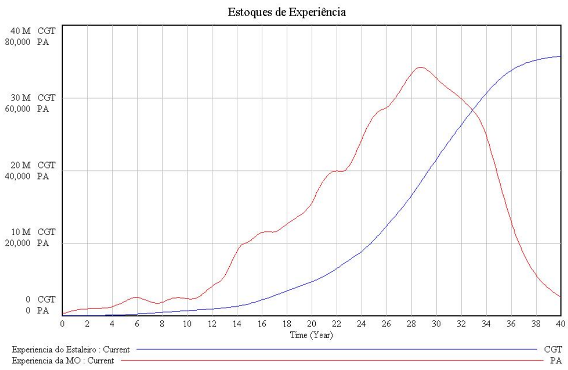
(a) Backlog



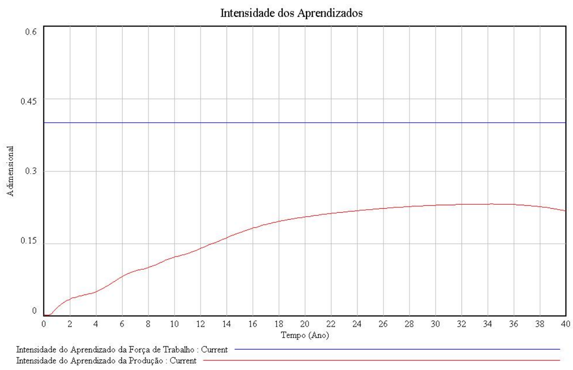
(b) Delivery Rate



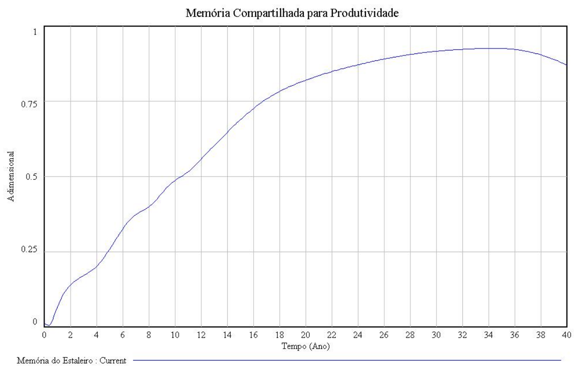
(c) Workforce



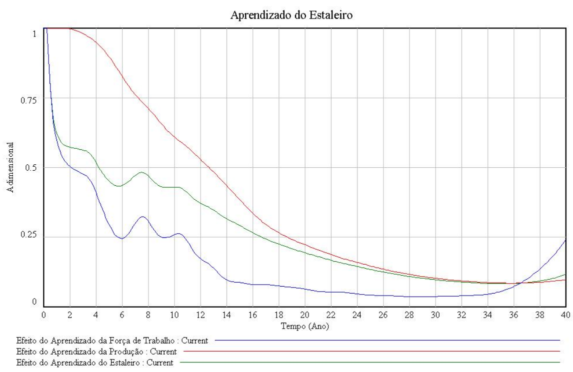
(d) Experience



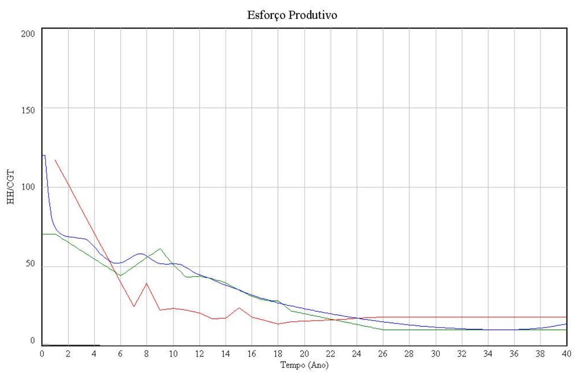
(e) Learning Intensity



(f) Shared Memory



(g) Learning Effects



(h) Inverse Productivity

Figura 6: Reference Mode Comparison - Graphs A, B and H
Reference Mode Comparison - Graphs A, B and H

It can be observed in Figure 6 that it was possible to replicate the actual behavior of the system with an acceptable level for the generic purposes of this study. The highest level of the workforce reached was consistent with a shipyard with this capacity (considering no production outsourcing) and the model showed how oscillations in production and workforce affected learning and also productivity. It is possible to conclude that this hypothesis explain why occurs variations and even ”forgetting periods”in real productivity curves.

7 Guidelines for a Learning Shipyard

In addition to the experience gained in the modeling process, scenarios simulations were carried out with changes in parameters related to specific points of the model as: workforce size, workforce experience, intensity of labor, transfer of learning effectiveness and intensity of production learning. These tests, from the systemic perspective offered by the model, resulted in a list of five recommendations or guidelines that simultaneously can benefit the learning of the shipyard:

- avoid workforce growth without productivity increase
- retain workers and preserve workfoce experience
- encourage experience that promotes learning of workers
- increase workforce learning intensity
- assure transfer of learning from workforce to production practices

The idea in presenting these directions is not to generate isolated actions, but to assist coordinated actions that could jointly compose a systemic solution to the problem of poor learning. Shipyard systems designers must look for cooperation between shipyard internal policies. Policy is a broad term, but Forrester (1994) objectively defined it as a set of decision rules in which information is converted into actions. In this sense, a policy description corresponds to the discussion about the reasons for the action. Thus, the reasons or values that move shipyard managers actions should be the same.

These guidelines, although generic, are the objective conclusions that can be taken for the current level of detail of the model. However, each of these items have relationship with decisions and actions that can effectively contribute to the improvement of a real shipyard improvement in productivity. For clarification, some items related to the guidelines obtained by the model could be:

1. Sustainable growth of the workforce size:
   - Preserve resources of productive effort for devoloping learning capabilities (work better rather than work harder as the archetype presented by Repenning and Sterman (2001))
   - Workforce size under control allow faster diffusion of knowledge and helps to initially establish a common goal and culture
   - Respect time necessary for creating wealthy self-organization rules that the system will replicate by itself when expanding.
2. Retaining of workforce experience:
   - Retention policies, especially older professionals with valid experiences and a individual mental model oriented to shipyard objective
   - Avoid breaking individual learning cycles (OADI-IMM cycles Kim (1993b)) and increase the number of experiences that generates learning.
3. Increasing of workforce learning intensity:
   - Establish a good relationship with employees to have worker commitment, including fair salaries and benefits, career development perspective,
   - Develop employees capability, with education programs, as training and qualification in the required operational and conceptual fields
   - Develop sense of union, with integration of employees around the common goal (productivity) and culture of cooperation
   - Hierarchical structure with autonomous working groups for production management and control at all levels (as Schumacher (1973) mentions the importance to find the small structure inside the big structure)
4. Transfering of learning from workforce to production (of selected shipbuilding routines and practices):
   - Implement indicators and measures of production and management to record conceptual and practical history of the shipyard.
   - Standardization and automation of management process and reduction of system complexity to workers and managers

- Implement customized information systems for knowledge sharing and management

5. Consolidation of proven routines, practices and rules thought the Shipyard Shared Memory (part of Shared Mental Model as defined by Kim (1993b))
    - Development of the conceptual basis (know-why) the Shipyard (Engineering, Planning, Procurement Processes)
    - Development of the operational basis (know-how) of the Shipyard (Production Processes)
    - Integration and cooperation between departments of conceptual and operational foundations of the Shipyard

8 Conclusions

From a selection of leverage points to invervene in this system, we selected five guidelines for shipyards that have the learning objective. It is interesting to note that all of this suggested directions are related to the workforce, which can be an insight to think about the important role of the workforce to determine this system behavior:

- avoid workforce growth without productivity increase
- retain workers and preserve workfoce experience
- encourage experience that promotes learning of workers
- increase workforce learning intensity
- assure transfer of learning from workforce to production practices

One contribution of this study is to demonstrate, through the process of modeling and simulation results, a concept widely publicized by the theories of learning organizations, that people are the source of learning and, therefore, they are a key element for the shipyard success in the long run. The model also replicates the paradox that the shipyard does not depend on any specific person, but depends completely on all shipyard people. Therefore, as defined by systems thinking theories about learning organizations, the shipyard should be thought of as a learning system and thus policies should be thought in a systemic way, where people at all levels are continuously developed and learning occurs in the same time as the production process.

Another contribution to this study is possibly to learning curve theory, once this hypothesis and model gives an explanation why a shipyard can have periods of ”unlearning”or oscilations in its learning curve pattern. This non-linear dynamics of real learning curves observations could not be explained by learning curve traditional formulation so far. And finally, to system dynamics, as it is impossible to predict and to model learning itself, authors believe this can be a way to model learning effects in industrial and social systems and open possibilities to further studies as indicated below.

9 Recommendations for Future Works

According to Meadows (2008) the current mindset of the industrial world and the great power of the computer information processing can cause the illusion that everything is predictable and controllable. But in fact, human systems, nonlinear, complex and self-organizing in nature, are unpredictable and uncontrollable. According to Schumacher (1973) learning generates variability and instability, which makes sense because, even in this case study, if did the cooperation between production and learning of learning of the workforce, the latter would be less effective, multi, stripped a common goal and productivity. However, there is a balance to be sought between predictability and unpredictability, between standardization and freedom.

Just as learning without guidance can build a chaotic environment, the extreme standardization and productivism in systems can lead to a danger zone and in a way that is not easy to be perceived. The search for the single and unrestricted yield assumed to work in this premise, eliminate waste and its structure becomes increasingly lean cycle balance with less than usual in the structure of the system, i.e. less alternative paths for the system to retrieve his state if something unforeseen occurs. This property of recovery systems, also known as Resilience is an important aspect to be considered in further studies, since it should not be sacrificed in favor of the productivity.

Another interesting point to continuing this work would be the improvement of the model to further study the phenomenon of resistance in organizations, which occurs when people learn but the organization resists. As Forrester (1998) remembered people do not freely make their own decisions as social systems have dominance over individuals. The approach used in this work through inventories of memory stock and memory flows through learning could be improved to simulates cases of organizational resistance - or reinforcement - , since this resistance has relation with the shared mental model or the organization and correspondent frameworks and routines.

Moreover, it is believed that the dynamic hypothesis proposed in this research can be applied to other cases of social systems, in which there is learning of individuals, collective learning and a common goal that is influenced by these two kinds of learning. This proposed hypothesis, whether arising from an industrial example, can serve as an alternative of modeling and studying any other collective learning system, or study the balance between productivity and resilience of natural systems, or studying policy resistance in social systems and, especially, may serve to demonstrate that people are the learning source in human systems, so it is in self-changing individuals behavior that lies the force of changing systems behavior. In this context, systems thinking disciplines are essential to raise awareness and encourage individuals in this change that leads to the good of the whole.

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