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The Lean Brain Theory. Brain-like Lean Manufacturing Systems.

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Abstract

Strategic LM efforts almost always fail because Leaders often lack a map of their own organization. The reason for this might be that scholars have so far mostly provided qualitative or rigid one-size-fits-all frameworks for strategically designing organizations. The purpose of this paper is to provide a comprehensive quantifiable framework for strategically designing organizations for LM. Combining knowledge about SOD and LM, we introduce a novel theory called "Lean Brain Theory" (LBT). LBT considers organizations as networks with organizational structure, functional connectivity and effective dynamic patterns in the quest of attaining an optimal SOD towards the strategic goal of LM. To reinforce the new paradigm, the analogy between a Lean organization and a human brain is depicted. The future of Lean organizations relies on strategically designing its structure, function and effective dynamics so as to emulate the Human Brain.

Keywords: *Lean Management, Strategic Hoshin Kanri, Strategic Organizational Design, Structural Organization, Functional Organization, Efficient Dynamics*

1. Introduction

CEOs and Leaders of a wide range of industries set as strategic goal to implement LM in the organizations they serve hoping to achieve competitive advantage [1]. Methods and practices for implementing LM in organizations are well documented [2,3], however a considerable number of studies show that many of these change efforts fail to deliver expected results [4].

Nomenclature

LM	Lean Management
SOD	Strategic Organizational Design
LBT	Lean Brain Theory
SHK	Strategic Hoshin Kanri
HK	Hoshin Kanri
(CPD)nA	Check-Plan-Do-…-Act
SQDCME	Security, Quality, Delivery, Cost, Morale, Environmnet
SFM	Shopfloor Management

The problem is not that lean theory is wrong, the problem is that probably CEOs and Leaders are asking the wrong questions. The question CEOs and Leaders should be asking is "How should an organization be strategically (re-)designed in order to implement and sustain LM?". This pressing urgent challenge is all about a holistic understanding of organizations as systems and here is where SOD kicks in.

Scholars define SOD as a "deliberate process of configuring structures, processes, reward systems and people practices to create an effective organization capable of achieving the business strategy" [5]. An important part of SOD´s body of knowledge [6,7] emphasizes the importance of choosing a particular multi-dimensional structural and functional context for organizational design [8]. The context we choose stands on a solid ground of research [7,9,10] is to view organizations from an information flow perspective. An Organization is hence an information processing living system formed by people that dynamically aim to optimize a certain function formulated in a strategy, seeks to solve a certain problem or attain a certain goal.

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[7] state that organizational design starts with a goal and others [11] propose to start the SOD process with a clear picture of the problem to solve in order to subsequently then define a strategy to achieve that goal or solve that problem [12]. The sequence GOAL/PROBLEM-STRATEGY-DESIGN seems to be generalized for what we call the neoclassic organizational architects. Other scholars, add evolutional circularity (or spirality) to such thought [10] by stating that the awareness of a goal/problem that leads to the formulation of a strategy and the subsequent SOD changes that follow, will have again a dynamical impact upon the goal/problem. This interdependence is made tangible through a network´s perspective towards organizations [13]. Scholars [14] define three types of network connectivity for complex systems: (1) **structural connectivity** representing the information exchange connections between organizational agents, (2) **functional connectivity** capturing the spatiotemporal patterns of connectivity between organizational agents and (3) **effective connectivity** describing the effect of organizational clusters over another. These three connectivity types are close related to the provided definition of SOD because it tackles structure, process and effective organizational dynamics

Established SOD theories [7] explicitly formulate a top-down approach in the quest of shaping and coordinating alignment towards certain strategic goals the "structural, processual and human" dimensions of an organization. Scholars [15,16] have already recognized the strategic shortcomings of LM body of knowledge and propose a LM SOD approach called SHK [17]. Best in class manufacturers such as Toyota have recently announced SHK as world-wide strategic "Toyota Way" [18]. Scholars have given a comprehensive framework for SHK [15,17]. SHK seeks alignment of the formulation and deployment of strategic goals along the organizations through the correct spatiotemporal allocation of power and resources shaping the organization for successful management of multi-dimensional strategic and operational evolutional forces such as changing business models, innovation, global expansion or efficiency pressures [11]. Based on seven strategic tools (7S) - environment, product, market, product-market, product portfolio, strategic element and resource allocation analysis - the integration of classical HK [16] and strategic planning is achieved.

Based upon a review upon 53 Deming-Prize Winning Small, Medium and Big size organizations scholars [17] propose a strategy based upon a rigid SOD frame, namely SQDCME being this frame placed upon all SBU "strategic business units". This frame places fractality upon a specific organizational configuration and not upon the governing laws of organizational information exchange. The standardization of such a frame along all SBUs makes the resulting lean management system regular and less evolvable as desired. Such lack of evolvability could have serious undesirable consequences in the quest of the LM paradigm [19]. Therefore, a new strategic model that provides more evolvability to a LM system is urgently needed.

In the light of these shortcomings, we raise following research questions:

RQ1. How should an Organization be strategically (re-) designed in order to implement and sustain Lean Management? **RQ2**. Can we suggest mathematical models for information flow and connectivity that help organizations steer successful SOD process under the dynamic effect of evolutional forces towards LM sustainable implementation?

Our presentation includes a theoretical model and a discussion about conclusions and future research implications. In the theoretical section, we propose a novel SOD theory the "**Lean Brain Theory**" (LBT), an "intelligent" comprehensive, quantifiable and evolvable 道 (way) to attain LM. In order to help process owners in the SOD process towards a sustainable implementation of LM, the LBT proposes a mathematical model for the quantification of structural, functional and effective design configurations. Finally we draw conclusions, build analogies and suggest some fields for further research.

2. LEAN BRAIN THEORY (LBT)

The challenge of attaining alignment through SOD is about designing certain structures that enable functionalities which ensure organizational consensus towards a given set of strategic goals. With the formulation of the LBT we seek in the following paragraphs to formulate a novel theory that gives an answer to the alignment challenge in the quest towards Lean organizations. For this matter, we formulate hypothesis, devise principles and propose a framework to operationalize the theory.

Organizations are complex systems [20] that, from an information exchange perspective, can be considered as networks under the "organizational network" paradigm [13]. A network is a set of objects called nodes or vertices that are connected together. The connections between nodes are called edges or links. In mathematics, networks are often termed graphs. One can formally define a graph as G=(N,E), consisting of a set N of nodes and a set E of edges, which are ordered if the graph is directed. For LBT graphs are considered directed to indicate that information flows from one node to another. The degree of a node is the number of edges incident to that vertex. The clustering coefficient for node i with ki edges as $C_i=2n_i/k_i(k_i-1)$, where ni is the number of edges between the ki neighbors of i [21]. The diameter of a network is defined as the average distance between any two sites on the graph. The scaling of such diameter with the network size N is highly relevant to phenomena such as diffusion, conduction, and transport, in this case of information, throughout the organizational network [22].

For LBT an organization can be designed over the coexistence and interplay of three types of networks: the structural network, the functional network and the effective network. The networks supporting the LBT have inter-node edges but also accept external connections of cooperation/competition with the environment [23]. LBT presents in this paper solely an intra-organizational SOD view, acknowledging interaction with the environment but not discussing it in detail. In accordance with the "relational approach" to SOD proposed by [24], LBT emphasizes the standardization of communication through (CPD)nA between process owners forming a set of structural nodes (NSo) and defines the set of edges (ESo) of **structural network** based on the information exchange standard (CPD)nA cycle as described in [25]. Additionally, the **functional network** pattern of an organization can be then defined as a as a set of functional nodes (NFo) formed by POs and functional edges (EFo) formed by the actions defined in the ***Do*** phase of the (CPD)nA that connect the PO responsible for the action (Source) and the PO (CPD)nA Sender (Sink). Furthermore, **effective network** patterns can be described as a network which nodes (NEo) are structural network clusters around hubs of high cluster coefficient and which set of edges describe (EEo) the underlying causal influences between them measured through certain Key Performance Indicators (KPIs).

2.1. LBT Hypothesis

We hypothesize that, **H1**, in order to minimize the metabolic cost of information transfer, that formal or informal communication between people in the organization will be more likely to happen within organizational clusters such as departments or business units. We also hypothesis that, **H2**, the higher the trust levels, the flatter the organization [26] and the less often the communication ought to be [27].

From local to global in an organization, the nature of VSs can be considered as fractal [28]. Local processing within high efficient functional network clusters together with some long range global connections that ensure effectiveness and integration of organizational strategies on a global scale are desirable characteristics for organizations to have. We hypothesize that, **H3**, if local and global Lean performance is to be simultaneously achieved, the distribution of the organizational VS network will have coexisting long-range and short-range connections.

When embedded in such structural and functional configurations, the **effective** goal achievement sought by different organizational clusters may be however many times conflicting. Strategic behavior of individual rational people trying to achieve a local optimum may lead to organizational disasters as [29] show referencing to [12]. From an organizational network´s perspective, it is crucial to understand the organizational dynamics towards a consensus on the quest towards such goals. We hypothesize that, **H4**, the strategy process [30] relating the achievement of organizational consensus between POs aiming certain strategic goals depends dynamically on the performance of all other related process owners.

2.2. LBT Principles

2.2.1. The LBT Structural Principle. Act local, think global: Designing Small Worlds

The mantra repeated in numerous business schools of management when strategically designing organizations is “act locally and think globally”. The forces of specialization and competition on a global market shapes SOD towards an integration of local efficiency and global effectiveness [31]. This challenge is all about the structural design of an organization and it could be formulated like this: how to effectively bring information to a vast number of team-members and how to efficiently operationalize this information where value is created?

The quantification of the small-worldness of the organizational design brings desirable characteristics to the network as described “think-global and act-local”, independently of the size of this network. Because the APL is similar to a random network, the structural configuration presents several long range connections enabling global value stream effectiveness. Because the CC is similar to a lattice network, the structural configuration presents many short range connections enabling local value stream efficiency. This important step challenges classical organizational configurations such as M-form or U-form [32].

The structural complexity measures the level of inter-dependence between system components [33]. A network that presents long range global connections between highly connected nodes or hubs together with the network clusters shape highly modular configurations is called small-world (SW) networks [34]. Such networks present a high clustering coefficient (*CC*) and a small average path length (*APL*) which account for the topological properties already mentioned: a high *CC* means that the network tends to form clusters of highly dense connectivity, this serves for local efficient cliques, a small *APL* accounts for a small number of steps to connect distant agents, and this property helps gain global effectiveness and robustness to the overall network. The effect of modularity gained through such a structural configuration is an increased dynamical stability: robust functional dynamics against perturbations while performing with local efficiency and global effectiveness towards consensus of intra-organizational alignment as shown by [35].

A metric to measure the SWness of networks was proposed by [36] who proposed a SW metric, *w* index, $w=[APLrand/APL]-[CC/CClatt]$. This metric compares network clustering (*CC*) to an equivalent lattice network (*CClatt*) and path length (*APL*) to a random network (*APLrand*). That is why values of *w* that are close to 0 denote high SWness, values that are close to 1 denote high randomness and values that are close to -1 denote high regularity. The diameter of a structural SW network scales with the network size *NSo* as $\mathbf{d \approx \ln \mathit{NSo}}$ [22].

2.2.2. The LBT Functional Principle. The cost of Trust

“Organizations are no longer built on force, but on trust” as P. Drucker stated [26]. But trust is an evasive factor that is difficult to define and measure [37]. All organizational agents depend for their proper functioning on the constant supply of the information necessary to perform their activities in an efficient fashion. In the process of creating a functional network with standardized (CPD)nA edges, not all nodes will be connected at once, but the process will be progressive, with a constant addition of new nodes to the functional network. Based on H1 the probability of new nodes of attaching to others is proportional to the clustering coefficient of the existing nodes, so that a sort of preferential attachment is given. Barabási and Albert demonstrated [38] that power-law degree distributions could be generated by a "preferential attachment" growth process.

According to H2, the suggested allometric power-law can be formulated mathematically as follows: $\delta I_i/\delta t=\delta I_0/\delta t{\cdot}M_i^{T_i}$ (1) in which M_i represents the "mass" of the ith node or number of nodes reporting to the ith node with (CPD)nA, including the nodes under such direct reports, $\delta I_i/\delta t$ represents the information exchange rate of the ith node with her reports, $\delta I_0/\delta t$ represents the minimum information exchange rate found in the functional network and $T_i \in [0,1]$ represents the trust that this agent inspires in her subordinates, accounting lower trust environments for smaller values of T. Equation (1) gives us powerful insights on functional SOD. For instance that the "mass" that a given agent is reported to, and consequently the "flatness" of the organization, depends strongly on the trust level of the organization. This could be applied to SFM: if we assume that the standardized routines [39] happen in the natural cultural time cycles of year/quarter/month/week/day/shift, and we set an homogeneous trust level across the organization, we can mathematically predict the optimal number of employees that depend on a given hierarchy level, and so foresee the amount of resources needed to drive the HK.

Under the described organizational network paradigm, in order to topologically categorize the complexity of systemic networks, we compute the probability P(k) that any given organizational agent has k (CPD)nA connections to other agents. Interestingly enough, scholars [38] discovered the ubiquity in social and technological complex networks of a **power-law** connectivity distribution, with a power exponent depending on the "metabolism", [40], or exchange cost of the interaction [41]. A typical value for such exponent in nature is ¾ [38]. It happens that the highest-degree nodes are closely connected to smaller ones, that in turn are followed by smaller ones and so on. This means that scale-free structure can be considered hierarchical with respect to its clustering coefficient forming clusters around certain hubs of higher clustering coefficient [21]. "This self-similar nesting of different groups or modules into each other forces a strict fine structure on real networks." The diameter d of a functional scale-free network scales with the network size NFo as $\boldsymbol{d\approx ln(ln(NFo))}$ [22] for certain values of the power law exponent.

2.2.3. The LBT Organizational Principle. Lean Intelligence

The most important aspect of strategic planning is, according to reputed scholars [30] the strategy process: "a dialog through which knowledge is shared and consensus is achieved and commitment towards action and results is built". In recent years, consensus in organizations as legitimation of action towards certain strategic goals have attracted increasing levels of attention [42] for legitimation facilitates the access to necessary resources to achieve such goals. According to H4, a model that describes such consensus problem is given by NEMAWASHI [43].

From a fairly abstract perspective, VS arise as metastable, spatiotemporal behavioral patterns of an organization´s activity that emerge as a response towards environmental challenges and are performed by interactions among organizational clusters. These interactions are in fact winnerless processes that gives rise to coherent spatiotemporal information trajectories towards certain saddle-points. Under the LM paradigm such trajectories represent a certain combination of VSs and the saddle-points can be understood as standards or best known consensus solution. Such saddle points are the desired states that we seek with LM because they provide the platform for future improvement.

2.3. LBT Framework.

After describing the principles of LBT, we present a framework to operationalize the SOD described by of LBT as described in Figure 1.

As stated previously, the formulation of a strategic goal, purpose or problem is something that LBT does not deal with and is considered as input for the organizational design. LBT proposes firstly the structural VS connectivity should be arranged for $w\approx 0$. Secondly, to construct a structural connectivity that ought to be designed to satisfy (1). Finally, the effective connectivity should be tackled to minimize the time to achieve the best consensus between the agents. After achieving the standard, the strategic goal, purpose or problem achievement should be revised in order to start the LBT cycle again. The quantifying condition for advancing within this algorithm can be described as follows: (i) for the structural network, the condition would be to have a network diameter scaling the network size following $ds\approx ln(NSo)$, (ii) for the functional network, the condition would be to have a network diameter scaling the network size following $df\approx ln(ln(NFo))$, (iii) for the effective network, the condition would be to find the described WLC dynamics oscillating statistically within a distance de between effective values in time subsequent moments ei and $ei\text{-}1$ is smaller than an Effective Threshold (ET) so that $median(de(ei,ei\text{-}1))<ET$.

Such approach is underpinned by the sequence "Strategy-Structure-Process-Coordination" proposed by [7] for organizational design, and expands it so that the SOD process is made quantifiable and not qualitatively based upon process owner´s answers to diagnosis questions. Furthermore, LBT is not constricted to a rigid frame such as the QCDSE proposed by SHK, gaining in evolvability and robustness as a strategic management system.

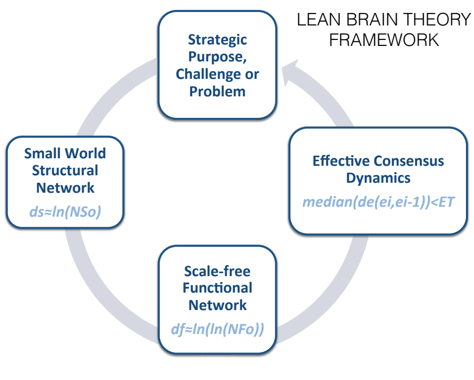

Fig. 1. LEAN BRAIN THEORY FRAMEWORK

3. Biological transversal associative paradigm

In science, the convergence of conclusions based on vastly different sources is highly valued because it lends credibility to predictions and points to universal principles underlying diverse complex systems. The search for such universal principles shared by superficially different systems is at the heart of the new field of complexity emerging at the edge of science and philosophy [44]. By deliberately looking at another discipline such as neuroscience, we intend to underpin the LBT, and claim the universality of the principles for SOD proposed. We believe it is promising to envision a human organization shaped in his own image, and it is the brain, more specifically the human neocortex (NC) which gives humanity to humans. It is still a lot that needs to be discovered about the structure, function and effective dynamics of the NC, however from a network´s perspective, we find many striking parallels are becoming increasingly apparent between LB T and the design of the human NC. These are summarized in Table 1 and graphically in Figure 2.

Both the human NC [14] and organizations [13] can be understood as information processing networks	The structure and function of the human NC is being mapped by neurobiologists [45].	The information processing model presented by Galbraith [46] states that the organization design regulates the information flow and thereby determines the organization´s performance.
Both brain and organizational dynamics strive for the optimization of a certain spatiotemporal function.	The human NC is constantly creating models and images of the reality surrounding it so that the individual is able to cope with the ever changing challenges presented to her by reducing uncertainty or free energy [47].	In the same manner, focusing directly on organizational design, [48] assertively conjectured that the principal managerial task is to reduce uncertainty by processing information. Under the LBT paradigm organizations seek the minimization of organizational internal variability [49].
In both the brain [14] and organizations [50] we find structural, functional and effective or organizational complexity.	• in the brain, structural complexification emerges from the need to minimize metabolic wiring cost [51]. • functional complexification of the brain emerges from the need to develop new abilities and so cope with the challenges of a demanding environment. • effective connectivity in a brain, as originally defined by Karl Friston [52], attempts to explain dynamic activity patterns of causal influence of one brain region over another.	• LBT has shown, that organizations follow a similar “metabolism of trust” and ought to achieve a structural complexification that optimizes such trust wiring cost. • From a functional perspective, an organization that strives to implement LM seeks an organizational design that minimizes non-value adding information processing in an ever changing environment [53]. • LBT describes how in organizations, effective connectivity as response to environmental challenges and are produced by interactions among structural network that gives rise to coherent spatiotemporal information trajectories towards certain NEMAWASHI consensus saddle-points.

Table 1. Biological transversal paradigm Human Brain - Organization

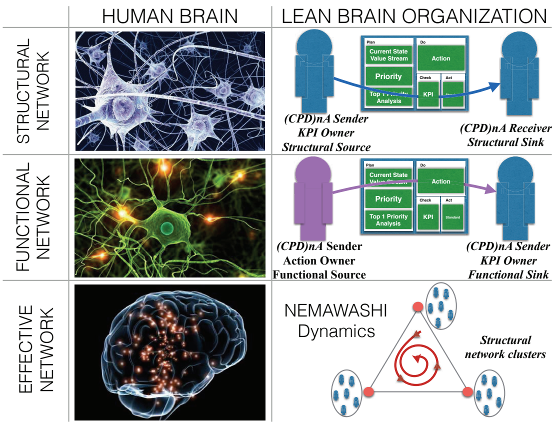

Fig. 2. HUMAN BRAIN and LEAN BRAIN ORGANIZATION

4. Conclusions and next steps

The capability of an organization to continuously achieve its strategic goals by eliminating non-value adding activities while responding and acting differently under different circumstances ought to be the LM organization´s answer to the ever changing challenges of a variable and only partly predictable environment. In order to develop such capability, we have proposed in this paper the **Lean Brain Theory**, a strategic organizational design strategy that seeks to build organizations upon a specific feature: **complexity**. Rather than avoiding it, this groundbreaking theory, seeks to embrace and embed complexity in the organization in order to cope with the complex challenge of designing for LM. LBT designs complexity in organizations by following an iterative process: **S**trategy-**S**tructure-**F**unction-**E**ffective Consensus. By purposely designing structures that enable functionalities that ensure organizational consensus towards a certain set of strategic goals, LBT proposes a systematic quantifiable framework for solving the alignment leadership challenge.

The information density shaping the structure, as well as the stability of the VS functionality and the subsequent macro-cluster consensus dynamics related are shaped by configuration changes and vice-versa. In this first sketch of the LBT we have not established the specific mechanisms of transformation in the organization. Additionally, we have shown numerous transversal analogies between the structure, function and effective dynamics of organizations and the human brain, what reinforces and provides robustness to our theory. The organization-brain analogy is far from being complete because the structure, function and effective dynamic patterns of both organizations and human brain are far from being fully understood. The brain-organization analogy could help develop new Strategic Lean Management theories.

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