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LEAN DENDROCHRONOLOGY: COMPLEXITY REDUCTION BY REPRESENTATION OF KPI DYNAMICS LOOKING AT STRATEGIC ORGANIZATIONAL DESIGN

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Abstract

One of the main challenges to solve in an Industry 4.0 context for manufacturing leaders worldwide is increasing product and value-stream complexity. In this paper we present a standardized visualization methodology through multichannel plots applied to complex organizational design network configurations. Combining network theory and strategic lean management oriented organizational design through Hoshin Kanri Forest technology, this approach is expected to allow scholars and organizational leaders to systematically visualize strategic organizational design KPI (key performance indicator) dynamic states and hence significantly reduce KPI interpretation complexity. An example is briefly shown for explanatory purposes.

Keywords

lean management, Hoshin Kanri Forest, complexity, $(CPD)_n A$, strategic organizational design, KPI dynamics.

Introduction

Industry 4.0 is a recent adopted paradigm answering the challenge of product and process complexity by creating "cyber-physical systems" that benefit both from digital computation power and automatization as shown by Vogel-Heuser et al. [1]. The number of challenges that can be tackled using these emerging technologies is staggering and go from the dynamic reconfiguration of complex production networks through for instance 3D printing [2] to the internet of things [3] among others. Actual manufacturing factories are embracing these concepts as the only way to cope with different pressures (environmental, competitor's behavior, etc.) Product customization, sinking throughput times, increasing quality level and a reduction of cost are only some of the expected benefits [4] that are starting to arise in several industries due to its application.

However, such paradigms cannot succeed just from the technological dimension. Success will require the active coordinated participation of researchers, organizational leaders and practitioners at different organizational levels in order to achieve an a new level of JIDOKA (自働化) or intelligent automation [5]. Such automation "with a human touch" emerges from the Lean Management body of knowledge [6, 7]. Therefore, the existing need is to make this new industrial era understandable for organizational leaders and practitioners at different organizational levels, in order to ease the implementation and gain managerial perspective. The challenge for researchers is enabling a similar level of evolution both, at shop floor and managerial levels, hence making an integrated evolution possible and aligned.

With this end in mind, the conceptualization of the organization through a model is convenient. For this reason, we adopt an organizational network paradigm provided by Cross et al. [8], in which organizations can be understood as networks. Therefore, the organization can be seen in form of a graph G = (V, E) in which V is the set of vertices or nodes and E is the set of edges.

Such approach can be combined with the insights provided by Nonaka et al. [9] encompassed with Galbraith [10] in which organizations are considered information exchanging entities. Here, it is important to remember the Conway's law [11], which states that "*organizations that design systems are constrained to produce systems which are copies of the communication structures of these organizations"*, Nilsson et al. [12] stated that "standardization in information management capabilities across an organization can enable communication to be reinforced". Finally, Kidron et al. [13] have found significant correlation between formal human resource management (HRM) aspects of teams (HRM goals and strategy, formal communication and formalization) and informal HRM aspects (perceived proximity and trust). Another significant correlation was found between trust and HRM integration.

Based on the previous knowledge, the adopted network to represent the organization is the one representing the formal communications through it. However, more decisions must be adopted to define nodes and edges. However, it is convenient to keep in mind that Shah and Ward's lean management [6] has the strategic vision of systematic process variability reduction given. Immediately linked to these questions, and having an enormous impact, it appears the strategic organizational design, as presented by Burton et al. [14].

To manage representing all the sources of formal communication, all the owners of any process at any level in the organization will be named as process owners (PO), The set of process owners will become the V set in the Graph concept. For the edges, the $(\mathrm{CPD})_n$A representation of the formal communication adopted in [15] has been chosen. The advantage of selecting such communication element is because it supports the formal communication fully aligned with the lean principles, Indeed, it enables the dynamic behavior for establishing new links or dismiss them when not needed, after the standardization step. Finally, such communication element enables the empowerment of PO, as they increases the understanding of the value stream (VS) of their processes, and because of the discussion with the PO requesting standardized information, better alignment will be found (see Fig. 1).

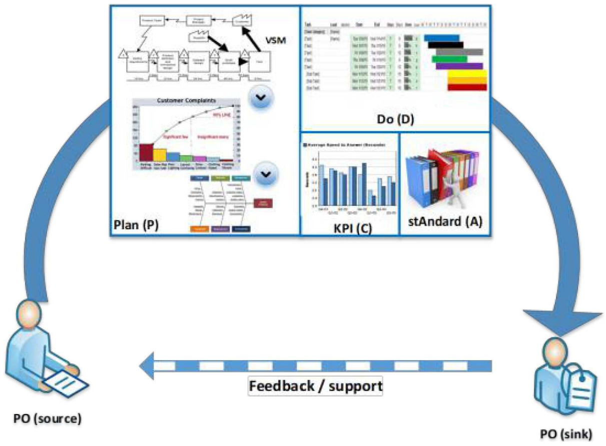

Fig. 1. $(\mathrm{CPD})_n$A communication element as adapted from [18]. It integrates the KPI value but also the suggested improvements and identified causes.

From this systemic perspective, new organizational design considerations become, as not only individuals are concerned but also the overall organizational behavior of the facility. By enabling organizational leaders to holistically see their organizational VS dynamics, we purposely depart from myopic and simplistic VS approaches, however aggregated [16, 17].

This paper aims to contribute filling this gap for a specific complexity related organizational challenge: visualizing strategic organizational design related KPIs dynamics through a multichannel plot standardized representation. This was done with a clear end in mind: enable organizational leaders and decision makers perform a reliable recognition and classification of complex dynamic organizational patterns and so provide them with suitable manufacturing organizational design solutions that cope with such complexity. The problem is of great significance for organizational leaders that are faced with a host of challenges throughout the strategic business decision-making process, for instance decisions on corporate growth, strategic product portfolio or analysis of organizational internal alignment, among others.

Adding a metaphorical touch to the scientific approach presented, the visualization shall be represented as to resemble the section of a tree in which the rings can be visualized. The main idea is to reduce computation complexity, and hence facilitate the analysis of the evolutional behavior of the strategic organizational design configuration during different periods in time. For this reason, we dub our approach *Lean Dendrochronology*.

Literature review and contextualization

Classic organizational design configurations such as the matrix have been intensively and extensively studied by reputed scholars towards Burton et al.'s multidimensional arrays [14]. The regularity of this model has made it very simple to understand and has become pervasive and standard in the industry. However, in the light of information exchanging organizational network theory, when the topological characteristics (i.e. average path length, diameter or network robustness) of such matrix organizations is compared to other topologies, this approach presents itself as evolutionarily inferior as recently shown by Villalba-Diez [19].

These scholars have demonstrated how organizations can perform in a more effective and efficient manner by attaining complex scale-free networked structural organizational design configurations that are able to better strategically attain and sustain lean management. This approach is based on previous research on a specific complex networked lean strategic organizational design configuration called Hoshin Kanri Forest [20]. The complex networks emerging within this context are formed by people – which are the nodes – and by lean management oriented information exchange standard behavioral patterns called $(\mathrm{CPD})_n\mathrm{A}$ (Check-Plan-Do-…-Act) [21] – which are the edges and represent an evolution of the classic Shewart-Deming circle PDCA (Plan-Do-Check-Act) [22]. In Figs. 2a and 2b a real example of such a network subset is shown in the form of a Hoshin Kanri Tree [20] shop floor management visualization in a manufacturing facility.

Lean Management aims to systematically reduce internal process variability [6], so in order to understand the complex networked organizational design configuration dynamics, we need to understand how well each KPI contributes to explaining the system's overall variability. One of the most widely used methods is PCA (Principal Component Analysis) which is an orthogonal linear transformation that allows for a dimensionality reduction method. It produces the orthogonal projection of the data onto lower dimensional linear spaces (known as the principal subspace), in a way that the variance of the projected data is maximized. Thus, it will find the principal components that best explain the complex networked organizational design dynamic's variability [23]. The contributions of each one of the n variables (KPI) to the $k = 1, ..., 3$ three main PCs is given by Eq. (1)

$$\mathrm{contrib}_{kl} = (100 \cdot \cos^2_{kl})/(\Sigma_{l=1,\dots,n} \cos^2_{kl}), \quad k = 1, ..., 3. \tag{1}$$

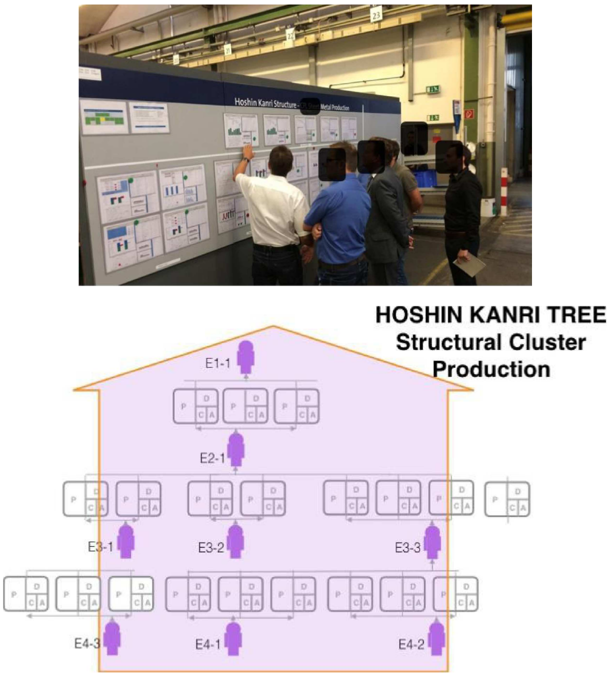

Fig. 2. Hoshin Kanri Tree as a Shopfloor Management Instrument to generate Complex Networked Organizational Design configurations (a) real example, (b) Mock up.

As shown by Villalba-Diez [19] KPI variability is vastly influenced by the organizational design topology. For instance, the same people and set of KPIs will not perform equally in a regular matrix and in a scale-free (SFN) organizational topology. This becomes obvious if we roughly compare both organizational design metrics such as the average path length (APL) (see Eq. (2))

$$(\mathrm{APL}_{\mathrm{SFN}} = \ln(\ln(N)) \gg \mathrm{APLmatrix} = N/2 \cdot \langle k \rangle), \tag{2}$$

where N is the number of nodes and $\langle k \rangle$ is the average connectivity degree of the network. Therefore the use of the organizational network paradigm to identify the most important elements in our organizational network topology is compulsory.

The simplest approach to computing and identifying the *central* actors inside an organization is to consider only local topological properties of a node or edge in the complex network graph. The most intuitive measure is the node centrality which is measured by the number of $(\mathrm{CPD})_n$As that come or leave a process owner. However, as shown by Carrington et al. [22], local measurements do not produce good results. Therefore, in order to capture the wholeness of the network and consider the whole network topology, scholars propose betweenness centrality as a measure to quantify how much information crosses a node [24] or an edge [25].

From an information exchanging perspective, it is more useful to consider '*edge betweenness centrality*' (*EBC*) because it considers the measurement as an information propagation problem [26]. These scholars propose a novel method to measure *EBC* by generalizing the concept k-path centrality in order to compute the importance of edges.

Once the desired complex networked organizational design of analysis has been established, we then need to visualize, categorize and recognize patterns in this information so as to enable a proper decision making. Although this is full value for the developed proposal, this paper focuses on the first part of the problem: the convenient capturing and visualization of large amount of business related data, as it was the declared ambition from the beginning.

This visualization task has been tackled previously by researchers at different levels of aggregation. Some examples are:

- the above mentioned VS standardized representations in the context of lean management [16] and [17], that although standardized and highly popular presents heavy shortcomings: on the one hand focuses solely on single VS and therefore is unable to represent complex networked organizational design dynamics, and on the other is highly intuitive and dependent on the viewers experience – the VS map is as good as the eyes of the observer.
- following the Lean maelstrom set by Womack and Jones [17] is also Markovitz [27] in which goals can be set and visualized following a horizontal (customer-oriented) and/or at a vertical (departamental) thinking. Using simplistic leader-centristic sports' metaphors in which the leader/runner keeps its organization "fit" through VS oriented goals. The problem, like with many other mainstream Lean approaches by Rother [28] and Rother partnering with Aulinger [29], is that organizational design, in reality is not 2D. It is complex and it is dynamic.
- as leading strategic organizational design scholars, Burton et al. [14] have recognized that and propose the visualization of specific case of organizational design such as the matrix by building blocks of two-dimensional regular graphs that, throughout an interlocking logic, connect quadrants in a clear and concise manner. The price to pay for this regularity and clarity is that the regular $(2D)^n$ proposed is only a special organizational design configuration case that clearly underperforms against other less regular and more organic approaches, as discussed in Villalba-Diez [20].
- more recently, an attempt to model and visualize socio-technical complex systems by Rouse [30] can be cited, which approaches multi level visualization of physical, socio economical systems Howeverm it lacks of standardized approach that can be fed into a machines for high level computation.
- the potentiality to relate big data and organizational design have been thematized more recently by Schildt [31], where the potential of "computer augmented transpa-rency" in the application of organizational design is outlined. However, no specific solutions are proposed.

Within this context, in order to fill the summarized representation gap, we aim to present a multichannel plot visualization of complex networked organizational design configurations.

Preparing for a lean dendrochronology

Given a complex networked lean structural network as a list of $(\text{CPD})_n$A edges and process-owner nodes, we look forward to perform a visual description of the evolutional dynamic states of the organizational design configuration. In order to perform the multichannel plot visualization we follow a simple four five by step approach.

Gather statistical and topological information of the lean structural complex network

For a given time frame $\Delta t_{ij} = t_j - t_i$, gather topological and statistical information about the lean structural network.

Topological information. We gather information about who reports what $(\text{CPD})_n$As and KPI to whom.

It is important to notice that for each time interval this graph evolves, but as it describes the whole organizational design configuration, the logic remains robust. For Δt_{ij} the frame of reference given by the principal subspace is a different one. This is expected because of the dynamic nature of complex networked organizational design configurations. At this point we consider these dynamics neutrally and are not going to judge wether this is good or bad. It is important not forget that at this stage, we just aim to visually represent the dynamics.

Statistical information: we gather information about what is the timely evolution of the KPIs related to each $(\text{CPD})_n$A involved in the network and represent it in form of a correlation matrix as shown in Fig. 3a.

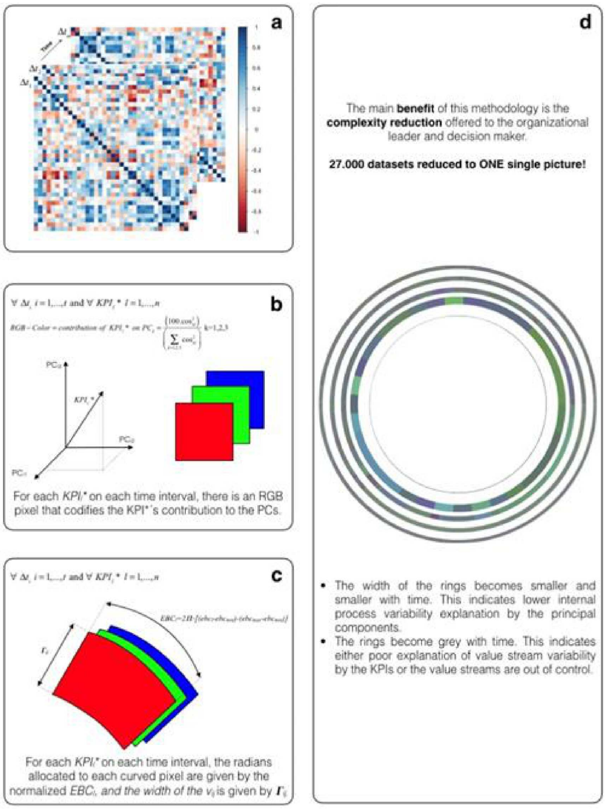

Fig. 3. Lean Dendrochronology (a) statistical information of the complex networked organizational design configuration; (b) decomposition of PC and projection of each KPI on them; (c) asign a width and radians to each KPI; (d) Lean Dendrochronology reduces complexity from 27000 datasets to ONE figure.

Three important aspects need to be highlighted here:

- First, notice that, in general, the KPIs can be reported within the $(\mathrm{CPD})_n$As in different frequencies and this shall force a certain interpolating procedure that allows for comparison.
- Second, in order to gain a certain level of statistical confidence, we need a certain amount of data. As a rule of thumb, we shall aim for $\Delta t_{ij} > 30$ periods.
- Third, in order to avoid scaling problems on step three, the KPIs need to be normalized. In our case it was performed according to Eq. (3)

$$\mathrm{KPI}^* = (\mathrm{KPI} - \mathrm{KPI}_{\min})/(\mathrm{KPI}_{\max} - \mathrm{KPI}_{\min}) \in [0, 1] \tag{3}$$

in which $\mathrm{KPI}_{\min}$ and $\mathrm{KPI}_{\max}$ are a given minimum and maximum boundary values of the KPI in the observed time period Δt_{ij}.

Find the principal components that best explain the overall complex networked organizational design configuration's variability

In order to best explain the overall complex networked organizational design configuration's variability, we apply PCA (principal component analysis) to identify the three PC_{ij} that explain a certain Γ_{ij} of the system's variability.

Compute the projection of each KPI on each axis of the principal subspace and represent these visually

Each one of the KPI* presents a contribution to the PCs that lies within the interval $[-1, 1]$. The absolute value of each one of these contributions can be assigned to a RGB color within the interval [0, 255], thus obtaining a matrix A_{ij} of dimensions $(3 \times n)$ in which each of the KPI_l^* $l = 1, \ldots, n$ has been assigned three colors. As shown in Fig. 3b, if we now superimpose these three colors in one we obtain one single RGB color for each KPI_{l^*}, hence obtaining a vector v_{ij} $(1 \times n)$ for each Δt_{ij}.

Assign a width to each vector and a number of radians to each KPI*

An important consideration at this point is that, in general, the three main PCs use to represent a significant part of the variability of the system. For instance, in the unlikely case in which all KPI_l*s would be hyperspherical (all the PC with exactly the same contribution), the PC decomposition would be singular and any axis would be a PC.

In order to represent such fact, this method represents this vector v_{ij} $(1 \times n)$ in polar coordinates by assigning a width to the resulting ring equal to Γ_{ij}. The rest of the variability not explained by the first three PCs is represented by a white ring equal $1 - \Gamma_{ij}$. Therefore, the representation always informs about the amount of variability retained.

As previously described, organizational design configuration topology has an impact on organizational dynamics and each network edge, depending on its EBC behaves differently. In order to represent this fact in our visualization, a number of radians is allocated to each KPI_l* depending on its EBC_l. This is shown in Fig. 2c.

Lean dendrochronology. Ring visualization of data

If we repeat step 1–4 for equal Δt_{ij} intervals, then each of these vectors can be easily represented in a multilevel pie plot in which the distance to the center increases for each time interval. As shown in Fig. 3d, we then obtain a multichannel plot visualization of the organizational complex network dynamics in the form of a sequence of rings that resemble beautifully those of a tree section.

We now need to learn how to interpret these rings properly.

Benefits of lean dendrochronology

The main benefit of this methodology is the complexity reduction offered to the organizational leader and decision maker. The example shown in Fig. 3d, has reduced a dataset of 27.000 data points – coming weekly from 900 $(\mathrm{CPD})_n$As of more than 317 process owners over 5 periods of 30 weeks each – to a single figure[1].

Given the Lean Dendrochronology visualization methodology, several aspects of organizational design and KPI dynamics can be easily observed:

- Because the width of the rings becomes smaller and smaller with time, we can assure that the principal components explain less and less overall system's variance with time. This indicates that the complex organizational design configuration does not develop in.
- It can also be observed, that the rings become grey this indicates that the system increases its internal noise, which is an indication for management that something is not being correctly addressed either by the KPI definition (the KPIs do not describe the true nature of the value stream reality) or that several value streams are out of control.

Conclusions

Based on a careful selection of the type of representation convenient for describing an organization embracing lean management principles, this paper has developed a coherent and systematic way of representing the dynamic behavior of the organization.

The developed representation is able to handle different number of edges through time, despite of the number of KPI involved and the number of VS affected can be large or even increase through time. Therefore, top managers will have a tool summarizing the amount of disorder through time, related to the capability of representing the global variance of the system by a limited number of components. In addition, they can visually identify the evolution of the internal noise for the system, depending on the colors exhibited.

By using such a tools, top managers will be able to identify to what end the complexity is going to be reduced because of the evolution of the formal communication system adopted. Indeed, it also helps to suggest more detailed reviews over specific VS.

The final goal is to provide managers with adequate system showing and summarizing the dynamic organizational perspective from the adopted KPIs, as well as the network description.

Finally, the proposed representation supports an historical view for the organization's evolution through time, which can enable detailed analysis about resistance or resilience being exhibited by the organization, depending on the date of adoption of specific measures and the observed effects and their intensity. Intercomparison can help also to understand the specific behavior of organizations, which includes the proposed representation but also specific analytics coming from the mathematical analysis of the developed network.

Future research shall focus on categorization and pattern recognition of complex networked organizational design dynamics.

- Categorization. Pattern recognition that is based on these data requires efficient classification methods. In order to perform an adequate categorization of such patterns, we need to take an evolutionary approach to organizational dynamics. It is important to narrow the scope of analysis and frame the discussion in terms of how the evolutionary Darwinian principles of variation, inheritance, and selection and its related concepts of selection, replication and inheritance might plan an interactive role in the context of complex organizational design configurations as described by Hodgson and Knudsen [32].
- Recognition. Within this Darwinian socio-technical context, the recognition of complex business patterns in strategic management is an active research topic as shown by Durand [33] due to its wide application in various domains [34, 35].

The fast integration of machine learning and more specifically AI within complex networked organizational design configurations in recent years makes it convenient to study strategic pattern recognition with aid of AI algorithms [36].

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