Lean Structural Network Resilience

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Abstract. Lean Leaders may face a tremendous amount of resistance when implementing and sustaining Lean in their organizations. The complexity associated with the dynamic of organizational processes in the 21st century: mobility of the work force, ever-changing product portfolios, and their related value stream adjustments are some of the reasons for this. Taking an organizational network view, this paper provides leaders with both a definition of Resilience, as well as coherent criteria to quantify the Lean Structural Network Resilience (LSNR) to the lean transformation that is associated with the mentioned changes in the organization. By implementing LSNR as a metric to measure resistance to change to Lean, Leaders can make informed Value Stream related business decisions in order to support sustainable growth.

Keywords: (CPD)nA · Lean structural network · Resilience

1 Introduction

The capacity of an organization to survive, adapt and sustain business in the current turbulent environment, becomes a key organizational capability [1]. Therefore, being resilient and, hence, capable of recovering the original state after deformation is becoming a perquisite for today's firms [2].

Holling [3] was one of the pioneers who conceptualized resilience 'as the ability of system to absorb changes'.

When we consider the enterprise context, we can find an exhaustive definition of Firm resilience in the study of Kamalahmadi and Parast [4]. They analyzed more than 100 papers and developed the following definition: "The dynamic capability of an enterprise is highly dependent on its individuals, groups, and subsystems, to face immediate and unexpected changes in the environment with proactive attitude and thought, and to adapt and respond to these changes by developing flexible and innovative solutions." It is relevant to highlight that the focus is resilience, not robustness or responsiveness. Robustness is a structural

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performance requirement in most designs. While robustness enables systems to cope with accidental actions, resilience appears to be a broader concept that requires the system to address/mitigate the consequences of failure and recover its former capabilities [5].

Focusing attention on the growing number of organizations that are starting or sustaining a Lean journey, the concept of resilience takes on the meaning of being efficient with stabilized processes, reduced supply chain variability and low inventory levels [6–8].

Even if many studies [8–10] mention the important role of people communication, coalition and training to be essential in building a resilient firm, there is a lack of consideration of lean organization resilience from the structural configuration point of view. Moreover, metrics for firms' resilience have never been computed as a combined effect of organizations' behavior and network structure.

In order to address these gaps in research, and in accordance with Villaba-Diez and Ordieres [12] where $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ concept is introduced, lean organizations will be described as inter-process networks that are able to exchange information under the organizational structural-directed graph, that represents the interesting value stream mapping (VSM). They can be seen as a set of nodes that are formed by the processes and represented by their related process owners (POs) of the organization and a set of edges that are reported from several POs to others (such edges are named as $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ in [12].) Such arcs represent technical information that is related to the process, which is directly related to the production processes.

Hence, this research will focus on Lean Organizations that are understood as Lean Structural Networks (LSN). They are described as Lean because they seek the standardization of all sorts of processes, knowledge sharing, and internal variability reduction [12]. They are Structural because they create an inter-process communication structure [11]. Finally, they are Network because we can bond nodes through those edges $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ [13].

Indeed, considering an organization as a network could be a powerful tool for visualizing, monitoring and understanding patterns of collaboration and networking between individuals and organizations across complex systems [14,15].

However, our interest here is to evaluate Lean Structural Network Resilience (LSNR), which describes the variation of system performance after occurrence of a disruption event. Such events that could affect the LSN are represented by the variation of values in one or more key performance indicators (KPIs)—described by their $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$. Such events can occur because of sudden production problems or because of substitution of a process owner (PO), and therefore, of an employee.

A direct application of this study helps production managers to better understand sensitivity of positions according to the network representing the Lean organization. Indeed, the proposed approach will assist human resource managers to understand and evaluate global effect of the personnel relocation in organizations that are facing a Lean Journey, regardless of is the application field.

The organization of this paper is as follows. Following this introduction, a literature review of LSN and Resilience metrics is presented in Sect. 2. Section 3 focuses on a description of the methodology used to address the identified gap and the mathematical model developed to compute LSNR. Section 4 illustrates the results reported with our data and Sect. 5 provides concluding remarks.

2 State of the Art

Shah and Ward [12] defined Lean management as an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability.

Resilience metrics are mainly qualitative and quantitative [15]. The first ones attempt to assess the resilience of a system without a numerical description, whereas the second ones define a metric for measurement.

Due to the absence in the literature of an LSNR metric, for this specific study, quantitative deterministic resilience metrics for Network and Firms have been considered.

Fisher [16] defines network resiliency as a ratio of network "performance" of all nodes/links available to that of certain nodes/links that are no longer available. Indeed, Wang et al. [17] find that a network with a small quantity of hub nodes and high degree of clustering, may indicate good performance to random failures, high efficiency of information exchange and, hence, be more resilient to perturbations.

Omer et al. [18] proposed a resilience metric for infrastructure networks that is calculated as the ratio of the closeness centrality of the network before and after the disruption. A limitation of this formulation is the lack of any time aspects in their concept of resilience.

Henry and Emmanuel Ramirez-Marquez [19] propose generic metrics and formulae for quantifying system resilience that has been considered to be a time dependent function in the context of the system. That system experiences three distinct states: original state (S_0), disrupted state (S_d), and recovered state (S_f).

Considering the organization's perspective, Dalziell and McManus [20] propose an approach that first requires Key Performance Indicators (KPIs) to be identified. The resilience of the system is measured as the area under the curve that is defined by the change in the selected KPI, plotted against time from the start of the impact until the change becomes zero. The severity of the impact (or maximum change in KPI) denotes system vulnerability, whereas the time to recover denotes the adaptive capacity of the system. A limitation of this formulation is that resilience is strongly dependent on the KPI dimension.

Even McManus [21] used performance indicators. He defined 15 resilience indicators for firms that have been grouped into three attributes. Based on surveys and analysis, qualitative values are given to the indicators. Finally, he used this information to plot a resilience envelope for the organizations.

3 Methodology

3.1 Research Objectives

Representing an organization that is facing a Lean Journey as a structural network of people, where nodes represent Process Owners and edges standardized communication $(CPD)_nA$ between those individuals, the following objectives will be pursued:

(1) To define a Resilience Metric for LSN.
(2) To study how the perturbation of a specific node impacts the le network's resilience.
(3) Investigating how personnel relocation in the different learning phases of the network could impact differently on resilience.

Some benefit can be derived from the representation of the organization chosen as the $(CPD)_nA$, is it promotes a synchronous behavior in time.

3.2 Model Quantification and LSNR Definition

In order to define a metric of resilience, we considered the McManus [21] theoretical proposal. We adapted and applied it to a dynamic system, such as an LSN, and tried to overcome the limitation of his theory.

When a node in the LSN is affected by a disruption event on the local KPI that is associated with the edges (CPD_nA), propagation of effects begin to occur.

Impacts on different nodes are seen at their KPIs throughout their $(CPD)_nA$ until the KPI outcome for the VSM is reached. A comparison of effects on the KPI outcome and the initial one will make it possible to measure the Resilience. Hence, the first step will be to calculate the Resilience of the LSN at the node level.

Indeed, considering the KPI trend of a node against time, the resilience of the node depends on how changes affect the variation of the KPI until the KPI returns to its the last value prior to occurrence of the event (KPI_e). Thus, the resilience (shaded area on the NODE side of Fig. 1) is calculated as the area between the KPI trend during the time of the disruption event and the straight line parallel to the time axes, passing through KPI_e. The denominator of Formula 1 is the mathematical formula for this concept, where t_1 is the time at which the disruption occurs and t_2 is the time where the value of the LSN's KPI is equal to KPI_e ($t_2 = t_1 + k$) because of the synchronism of the (CPD)nA.

However, considering the Resilience of a LSN based only on the reduction of the nodes' KPI could be limiting. Indeed, a relocation of a node with many paths to the output should have a different propagation than that of a less connected node.

Moreover, the different paths from the node in question to the ending node produce, in different instances of time, several impacts in the KPI outcome for the network (shaded area left side of Fig. 1). In addition, depending on the paths' length, the expected times when impacts occur will differ as well. Thus, in order to take into account the previous aspects, the KPI trend of the network against time is considered. Moreover, the trend forecasting of the network KPI is represented by a straight line named $KPI_f(t)$. This does not assume anything special about the behavior of the organization. It simply helps to estimate the induced impact of the closed unaffected KPI values before and after the disruption.

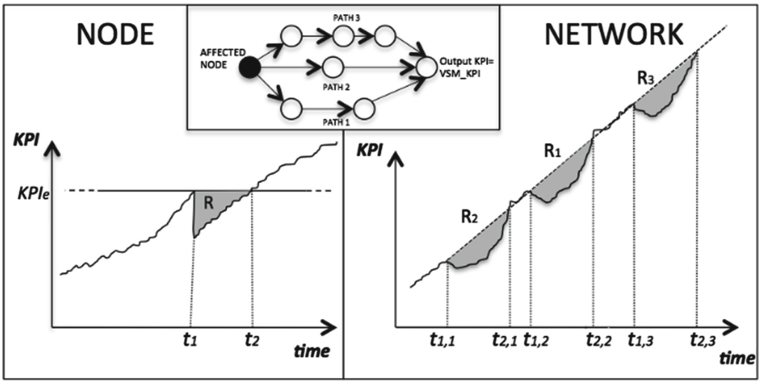

Fig. 1. Representation of node Resilience and Network Resilience.

Hence, we compute the effect of the disruption event at a network level as the sum of the areas between the variations of network KPI trend against time and the straight line $KPI_f(t)$ (shaded area on the NETWORK side Fig. 1). This concept is expressed by the nominator of Formula 1, where N is the number of paths that link the hit node to the ending node, and $t_{(1,i)}$ and $t_{(2,i)}$ represent respectively time t_1 and t_2 plus the length of path in question (i.e., $t_{(1,i)} = t_1 + \text{path}$ length (i). Note that for any path $k_i = t_{(2,i)} - t_{(1,i)}$.

In order to make the LSNR independent from the KPI dimension, the effect of the disruption event at the network level, throughout all the N periods affecting the output KPI, has been divided by the effect at the input node level. Formula 1 is the mathematical representation of LSNR, in coherence with Fig. 1.

$$LSNR = \frac{\sum_{i=1}^{N} \int_{t1,j}^{t2,j} [KPI_f(t) - KPI(t)]dt}{\int_{t1}^{t2} [KPI_e - KPI(t)]dt} \tag{1}$$

To demonstrate the efficiency of formula 1, LSNR will be tested for different node relocation by means of a flexible simulation model.

Moreover, when a complex network learns tasks, the learning process is mathematically modelled as a sigmoid “S curve” [11], [23]. This bell-shaped form has been explained in three phases: awareness, learning and maturity [12].

Thanks to the simulation model, the occurrence of a disruptive event will be considered for different nodes, in order to investigate whether the LSNR is influenced by the maturity stages of the network and, hence, of the PO.

3.3 Simulation Model Characteristics and Assumptions

Adopting a simulation approach allowed us to create dynamic views of the LSNR and to study the effect on resilience of different disturbances when a LSN is subject to personnel relocation. In order to overcome the complex firms' internal dynamics and develop a model that is as flexible as possible and will take into account of all the aspects described previously, some assumptions were made:

- The network considered has a fixed topology as time passes;
- Each node operates in units of time;
- The KPI values associated with each $(\mathrm{CPD})_\mathrm{n}\mathrm{A}$ will be normalized (values between 0 and 1);
- A value (OPT) equal to +1 will be associated with each KPI if the optimal status is growing and −1 if the optimal status is decreasing; Optimality refers to move the system to be more lean.

Hence, each node will have its own transfer function T(z) and, depending on the OPT value, will be equal to $\mathrm{e}^{(-\mathrm{kz})}$or $1 - \mathrm{e}^{(-\mathrm{kz})}$, where, the variable z depends on the maturity of the operator, and the value k moderates the transfer function and is expressed by Formula 2.

$$k = \sum\nolimits_{i=1}^{N_j} f(kpi(i,t))w(i,t) \tag{2}$$

$\mathrm{N_j}$ are the total links entering into the node j, whereas f(kpi(i,t)) represents how to proceed (average, last, max, etc.) when a node has several KPIs in input. Lastly, w(i,t) represents the method of weighting that could depend on time (i.e., seasonality).

4 Case Study

The company that was selected for the case study is a Japanise-based manufacturing company that produces goods for the food & beverage industry/ It will be called MotorCo for reasons of anonymity. The selected facility is has a work force of 500 people and 34 managers in three management levels E1–E2–E3, with E1 being the highest in the hierarchy. The inter-process standard $(\mathrm{CPD})_\mathrm{n}\mathrm{A}$ was implemented among the 34 managers and the evolving dynamics followed a hierarchical and value-stream oriented preferential attachment.

There are several VSMs per management level, depending on the interesting defined KPIs. The LSM considered for testing the simulator of a node modelling behaviour is part of such a network and is reported in Fig. 2. For anonymity, the specific meaning of the individual KPI is not reported/ However, the selected approach still permits us to produce the analysis.

The simulation model is run using the LSN of Fig. 2 during a time interval equal to 100 time steps. Above each node and link. the label is reported. Moreover, a sign that indicates if the optimal status is growing (+) or decreasing (−) has been assigned to each $(\mathrm{CPD})_\mathrm{n}\mathrm{A}$.

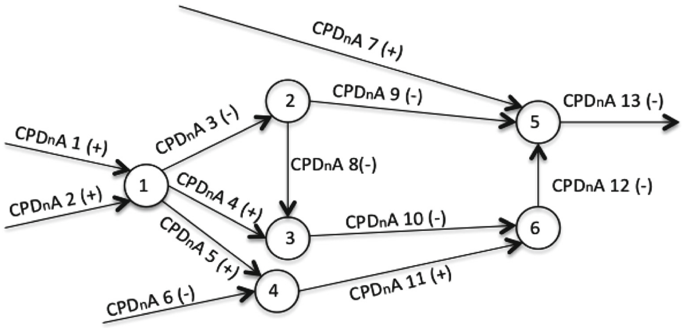

Fig. 2. Representation of the LSN used for the simulation. The number after the edge name represents an incremental ID reference. The signs refers to the OPT parameter.

The frequency of the $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 1 and 2 has been imposed equal to 2 $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ and is reported at the following node every two instances (units of time). The frequency of $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 6 and 7 has been set at 1, but all of the other frequencies have been calculated. Moreover, the weights (w(i,t)) have been considered constant along time with values ranging between 0.25 and 0.75. The function f(kpi(i,t)) has been represented by the mean or the maximum value of the KPIs in the entrance to a node. The maturity of the operators has been considered. depending on time and increasing over time, as they become more confident in exchanging information in a standardized form $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$. The simulation model was developed using R.

5 Results

In order to calculate the LSNR of Fig. 2, we decided to consider node 1 as the first node affected by a disruption event and, hence a relocation of its PO. Moreover, we assumed that this relocation would only generate a peak in $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 3 equal to 1 during the arbitral instance of time 54–56.

The imposed peak is shown by the red line on the top-left side of Fig. 3 and the grey shaded area represents the node resilience equal to 2.75 for this specific case. As explained in Sect. 3.2, in this specific case, the peak will generate two waves at the end of the value stream $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 13) due to path $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 3-9-13 and path $(\mathrm{CPD})_{\mathrm{n}}\mathrm{A}$ 3-8-10-12-13. The effect is shown by the red line on the top-right side of Fig. 3. The grey shaded area represents the network resilience equal to 0.055 for this specific case. Hence using Formula 1. the LSNR for this specific event is equal to 0.020.

Using the same assumption and computing the LSNR in different instances of time as shown at the bottom of Fig. 3, it is possible to see how the area that is generated by the peak in previous instances of time increases. However, a peak that is caused in later stages produces a smaller value of LSNR and, hence, a more resilient network.

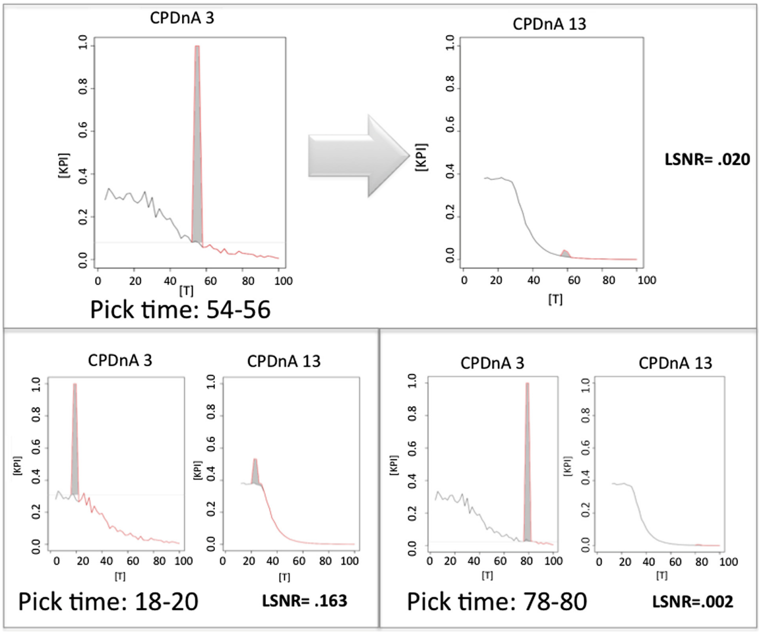

Fig. 3. KPI local trend ($(\mathrm{CPD})_{\mathrm{n}}$A 3) and at the end of the value stream ($(\mathrm{CPD})_{\mathrm{n}}$A 13).

Moreover, in order to show the impact of different node relocation, we analyzed the case in which the substitution of the PO of Node 1 generates a peak equal to 1 in $(\mathrm{CPD})_{\mathrm{n}}$A 4 instead of $(\mathrm{CPD})_{\mathrm{n}}$A 3. Figure 4 illustrates the trend of the KPI before and after the peak in $(\mathrm{CPD})_{\mathrm{n}}$A 4 and at the end of the value stream.

Hence, it is possible to observe that a peak of equal duration and intensity of the one imposed in $(\mathrm{CPD})_{\mathrm{n}}$A 3 impacts less on the system due to its fewer connections.

6 Discussions and Conclusions

The results obtained in Sect. 5 could be motivated by the fact that, even if in this particular case the network topology remains unaltered, the network increase its maturity during time. Therefore, even operators became more confident with $(\mathrm{CPD})_{\mathrm{n}}$A and more aware of a firm's processes.

Hence, we can conclude that a standardized communication about process as presented in this paper allows companies not only to improve their Management Processes (MOP), but also to become more resilient.

On the other hand, we can affirm that a mature network is even more sensible to resilience. Villalba-Diez et al. in [12] affirmed that the learning phase occurs when the interconnectivity of the system is increased. Hence, we have a

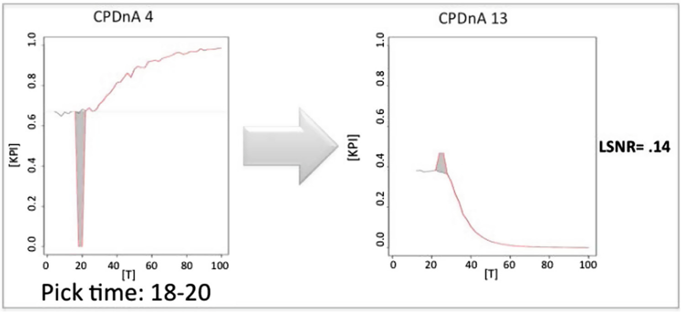

Fig. 4. KPI local trend $(CPD)_nA$ 4 and at the end of the value stream $(CPD)_nA$ 13.

faster improvement of MOP. The maturity phase starts when the network's connectivity increases further and the network performance variation is expected to become flat again.

A peak in a highly interconnected network leads to different waves at the end of the value stream $(CPD)_nA$ 13 and, thus, to greater values of LSNR.

The presented method to measure Resilience can be useful not only for estimating the impact on just a single $(CPD)_nA$ but, to several of them or, by extension, the resilience because of the existence of organizational clusters in the network.

An important takeaway from this ongoing research is that it can be applied to any given Lean Structural Network cluster such as value streams, organizational departments or combinations of them. This is potentially useful for organizational leaders in order to quantify and compare potential Lean Structural Network resilience of different organizational units.

Finally, some limitations of this study suggest caution in interpreting its findings. as the behavior of the PO itself was not considered and was accepted as neutral to the resilience effects.

Some possible future developments would be to consider weight values and topology of the network, as they are not constant over time. Moreover, we hypothesized that the maturity of the network. as well as the maturity of the operator, increase with the passing of time. This simplification is only partially true. Indeed, future research could insert the operators' learning curve into the model for a more precise prevision of resilience due to operators' relocation. Moreover, it will be possible to evaluate the effect of different POs relocation on the same node.

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