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Changes in Communication Patterns When Implementing Lean

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Structured Abstract

- *Purpose*
  This paper explores the changes in communication patterns when companies implement Lean, and how those changes relate to Lean implementation success.

- *Design/methodology/approach*
  This is a multiple site case study involving four business units of a manufacturing company in South America, including two repeated measurement instances separated 24 months for approximately 600 direct workers and 65 supervisors. The analytical models include Social Network Analysis measures and Ordinary Least Squares (OLS) regression.

- *Findings*
  When implementing Lean: 1) teams have a higher frequency of communication among members. 2) Teams become more decentralized 3) Teams communicate more with supervisors and 4) Supervisors communicate more amongst themselves and collaborate more. Also, 5) Better performing teams change more pronouncedly.

- *Research limitations/implications*
  The study contains data for four business units but within only one company, limiting the external validity of the conclusions. The sample was predominantly male. Participant attrition and other potential covariates not included in the study can be additional limitations.

- *Practical implications*
  Lean implementations could be practically helped by managers by embracing and supporting the more intense communication patterns associated with lean success, and alternatively they could proactively detect barriers to communication by measuring how these patterns change or fail to change and try to unlock communication by working on those barriers, and supply communications infrastructure and opportunities for collaboration to try to boost the chances of success.

- *Originality/value*

This is to our knowledge the first study measuring communication networks from the point of view of team members and low-level supervisors in Lean implementations. This is also the first study showing that communication patterns change more rapidly in more successful teams, and that communication pattern changes when implementing Lean can be an indicator of success.

1. Introduction

Lean is a system of tools, techniques and philosophies that seek to eliminate waste from the production value stream, increasing safety, quality, efficiency and cost. Lean originated in Japan at Toyota Motor Corporation in post-second World War and was made popular in the Western Hemisphere by the publication of translated works by Shingo (1989) and Ohno (1982), among others. The Lean system for production is arguably a current benchmark for modern production systems (Ciano et al., 2019).

Despite the popularity of the overall Lean concept, after more than 40 years of its adoption in Western companies, it is clear at this point in time that the success rate of Lean implementations is dismal: according to the Association for Manufacturing Excellence the failure rate for Lean implementations is about 90%, (Morgan, 2016), and a survey conducted by Industry Week discovered that only 2% of Lean implementations obtained the expected results within a year (Pay, 2008). Looking at key performance indicators, not only implementations of the system have been much less than successful, but also they are difficult to sustain (Saja et al., 2014, Hopp, 2018). The failure to obtain the purported benefits from Lean has been ascribed by researchers to diverse contextual factors (Netland, 2016), but a general conclusion from the literature is that we still do not understand completely what makes some implementations successful and others not so much (Stone, 2012).

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Most extant research looks at how managers may drive the success of Lean implementations, for instance by selecting and implementing practice bundles associated with the system (Shah and Ward, 2003). This paper adopts a different point of view: it takes a shop floor perspective in examining changes in collaboration patterns at the worker and low-level supervisors to explain success. This paper argues that we need to look deeper than observing broad-based key performance indicators such as quality or productivity, or generic contextual factors, and rather observe how workers collaborate and communicate amongst themselves and with management as a sign of progress and potential success correlate in Lean implementations. Through the analysis of data from collaboration networks at four manufacturing units newly implementing Lean it is shown that communication network characteristics evolve with the implementation of Lean and those changes are associated with Lean success or lack thereof.

In the remainder of the paper, section 2 reviews relevant literature and puts forward the broad research questions. Section 3 develops the rationale for the hypotheses to be tested; Section 4 explains the empirical methodology and analytical results. Section 5 discusses the findings and reviews some limitations and future ideas to augment or complement this research.

2. Literature review and general research questions

2.1 Describing Lean in the literature

There are two main technical concepts or "pillars" sustaining the Lean system (Toyota Motor Corporation, 2019). The original two pillars are:

1. Jidoka (Japanese word meaning "autonomation" or "zero defect")

2. Just in Time

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A newer version of these two main tenets (in this case "Continuous improvement" and "Respect for people") was published in 1998 (Toyota Motor Corporation, 1998) although the two versions still coexist in company literature. But regardless of the version of the two pillars considered, they are supported by lower level constructs such as work standardization, work load leveling, waste detection and elimination, elimination of overburden and variability, visual controls, various shop floor management techniques, quality circles and others (de Mast, 2019). The understanding of the system in the Western Hemisphere was in the first couple of decades after its inception in the 1950's very limited and the system was only assimilated to some of its most visible tools or techniques, such as the Kanban system for inventory management or the concept of Just in Time (Monden, 2011).

Interest in the system rose sharply when the oil price crisis in the 1970's hit the US automotive industry, which pressed to increase efficiencies, observed that Toyota was able to manufacture cars with better fuel mileage, better quality and at a lower cost than US-based companies, even after discounting the effects of different exchange rates and other comparative advantages. After some fruitless attempts to understand the "secret" of the Japanese method, MIT's International Motor Vehicle Program, produced in the early 1990's the first of several editions of "The Machine that Changed the World" (Womack et al., 2007) comparing automakers in Japan, USA and Europe. These authors popularized the term "Lean Manufacturing" to describe a production system with interdependent subsystems of techniques that reduces or eliminates all waste, or non-value added, from the production process, thus generating a "Lean" operation.

A key driver of Lean is the systematic identification and elimination of the "3Ms" (Muda, Muri and Mura, or waste, overburden and unevenness), and, in particular, of waste. Waste in Lean is classified into seven categories:

1. Overproduction (producing too early or in excess of actual demand)

2. Overprocessing

3. Inventory

4. Movement

5. Transportation

6. Inspection

7. Rework / Repair / Correction work

The "3 Ms" are the object of reduction and elimination by continuous improvement or Kaizen (Imai, 1986). The concept of Kaizen is in turn supported by an emphasis in work standardization and real time experimentation (Spear and Bowen, 1999). Work standardization provides a solid baseline over which processes can be improved minimizing the risk of recurrence and experimentation following Deming's cycle of Plan-Do-Check-Act (Morgan and Stewart, 2017) provides the foundation for continuous, incremental improvement. Many of the Lean tools and concepts are actionable at the shop floor level mainly by team members or team leaders, such as value stream mapping, standardized work documents or visual controls (Cottyn et al., 2011, Spear and Bowen, 1999).

Scholarly work has in general overlooked the fine-grained complexity of the Lean system and described it roughly as sets of macro practices, or "practice bundles" (Shah and Ward, 2003) without explicit interconnection, or by overemphasizing the importance of some of the best known tools or techniques such as the Kanban system for inventory management (Piplani and

Ang, 2017), the idea of Single Minute Exchange of Dies (SMED) to reduce setup times (Bhamu and Sangwhan, 2014), "5S" (standardized housekeeping) (Bayo-Moriones et al., 2010), workload leveling or "Heijunka", and other techniques (van Assen and de Mast, 2019).

Although the Lean system has manufacturing roots, many of its core ideas have been also applied to different sectors, under different monikers depending on the area of application, such as Lean Manufacturing, Lean Services (Furterer, 2009, LaGanga, 2011), Lean Healthcare (Graban, 2011, Dobrzykowski et al., 2016), Lean New Product Development (Liker and Morgan, 2006), Lean / Agile Software Development (Misra et al., 2012), Lean for Industrial Services (Furterer, 2009), or combined with principles of Six Sigma under the name of "Lean Six Sigma" (Jacobs et al., 2015).

2.2 Previous work on factors for Lean success and failure

Acquiring "Leanness" seems to be quite difficult in practice and success in the implementation of Lean is quite variable, both within Japan or Japanese subsidiaries located in the Western Hemisphere (usually called "transplants") (Holweg, 2007) as well as in originally Western firms that tried to implement the system from scratch (Worley and Doolen, 2006). This variability had researchers busy trying to find contextual variables associated with success and barriers to the same, which were the subject of abundant research and quite a few comprehensive reviews such as Netland's (2016).

Chronologically, early research into lean success focused on technical and contextual factors. Owing to an initially atomized rather than a systemic view of the Lean paradigm, the degree of lean success was explained and measured by the number of "lean practices" in use such as quality circles, kanban, total productive maintenance, total quality management, etc. (Shah and Ward, 2003). In addition to the number of practices implemented, factors explored included the

age of the plant prior to the implementation, whether the plant is unionized or not, the overall degree of support from top management, factory size and others (Slomp et al., 2018, Tortorella et al., 2016, Shah and Ward, 2003).

Another stream of research, appearing later in time, recognized that changing towards leanness involves a substantial degree of cultural adaptation and the so-called "human factor" (Magnani et al., 2019). There is abundant research linking Human Resources (HR) practices to operational effectiveness (Boudreau et al., 2003, Bonavia and Marin-Garcia, 2011). It has been observed that in Lean companies the HR area is more integrated with the operational function (de Menezes et al., 2010), and a proactive and involved human resources area is a significant factor to achieve Lean success (Yauch and Steudel, 2002, Grima, 2018). In terms of organizational design, we know that a rigid hierarchical organization design is bad for Lean success since it exacerbates different worldviews among functions or departments (Bamber and Dale, 2000) rather than collaboration, and that Lean performers develop their human resources more comprehensively than less lean companies (Narasimhan et al., 2006). Leaner companies seem to manage well employee stressors (Grima, 2018) and have been found to have a more collaborative and integrative culture (Nahm et al., 2004) where workers are closer to management than in non-lean companies (Liker and Hoseus, 2009).

More recently, researchers concluded that both technical and human aspects of lean are indeed intertwined and their interactions should not be overlooked but considered in unison (Magnani et al., 2019). But in reviewing the literature, some interesting gaps appear that merit further exploration.

First, the known success factors represent the view of managers, since all of these factors were overwhelmingly either measured from secondary sources or collected as the result of

surveys from top managers and operations executives (Sim and Rogers, 2008) only rarely including the perspective of middle managers (Manville et al., 2012) and never, to our knowledge, data coming from workers themselves. This point of view has been broadly overlooked in the scholarly literature, though some previous works hint that the worker point of view may indeed be very important and perhaps critical to understanding Lean success. Lean organizations have been described as following what is called the "inverted pyramid" of management (Liker, 2005). It is said that whereas in "regular" organizations the executives are at the top directing the workers, who are at the bottom receiving directions, in a true Lean organization the hierarchical pyramid is inverted, where workers (called "team members" at Toyota) are at the top of the hierarchy because they are the primary value adding stratum, while managers are in the bottom of the pyramid, charged with supporting the value added efforts by team members and performing improvements to the system itself (Imai, 2012) in a similar concept to the one of servant leadership (Greenleaf, 1970). The concept of servant leadership and the empowerment of workers have been studied from the seventies, and there is evidence that in better performing plants, managers delegate more of the problem monitoring and solving to their employees (Stimec and Grima, 2018), along similar lines of what happens in Lean organizations.

Further evidence of the importance the Lean system gives to shop floor initiatives is related with the prevalence of the concept of craftsmanship or "monozukuri" (Vamsi Krishna Jasti and Kodali, 2014) and manual work, with many references by Japanese originators of the system to manual labor and the need for engineers to "get their hands dirty" and understand what workers do (Ohno, 1982). Also, of critical importance to Lean is the concept of Genchi-Genbutsu (go and see) and "5-whys" (Murugaiah et al., 2010) which compels managers to communicate with

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workers to elucidate how the process is performing, instead of relying on reports and metrics (Netland et al., 2015).

Second, empirical studies have described communication and collaboration in terms of aggregated metrics rather than on perhaps more appropriate relational data. In fact, adopting a network perspective seems promising if one considers hints from the academic literature that point to the building of communication networks as an important factor for lean success and sustainability. For instance, it has been observed that successful implementations create a learning network between the company and its suppliers (Nobeoka et al., 2002) and Lean companies very actively seek ties to external information sources (Boyle et al., 2011). Lean companies have an increased level of communication with key suppliers, even providing engineering support and trying to actively improve the suppliers' processes to make them as Lean as they are in the focal company (Liker, 2005). These studies looked at the aggregate company level, but although it has been noted that cooperative work and teamwork performance associate with Lean success (Kull and Narasimhan, 2010) only one study to date could be found looking at network traits of teams in Lean (Easton and Rosenzweig, 2015) and none evaluating how network characteristics change in time along the Lean transformation and how this change is associated with implementation success.

This paper's main thesis is that full benefits from Lean cannot be realized when there is a radical change in the way workers and managers share information about the process, thereby changing their communication and collaboration patterns. This seems logical if one explores how the tools associated with Lean work, but there has been next to no research trying to confirm it empirically. This paper attempts to partially fill that void.

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In order to explain what, if any, deep changes occur within a company that undergoes a Lean transformation this work posits that part of a sustainable Lean transformation is related to changes in work team dynamics, specifically to the way workers within those Lean teams and management communicate. We will propose that as companies successfully go Lean there is a concomitant change in communication patterns across the company that is a necessary condition for the system to work in a successful and sustainable way. This prompts the first research question in this paper: *How do communication patterns change at the shop floor level when implementing Lean?*

Specifically, it is contended that changes can be expected in communication patterns:

- Among workers

- Between workers and supervisors

- Among supervisors of different areas

2.3 Communication theory and social networks

Communication theory and social network analysis are of course relevant to this study and although we do not intend to comprehensively review the wide area of communication theory, a few important studies are particularly important: These papers indicate that communication patterns in teams are indicators of other important team dynamics characteristics such as knowledge propagation (Peng et al., 2017) within the group, which is related to problem solving effectiveness. Also, communication network shape is related to the willingness of team members to participate in shared activities (Chwe, 2000). The shape of communication networks relate to the fit between task, problem solving process and communication style (Cho et al., 2007) as well as to the media used for communication, which relates to the strength of the ties formed

(Haythornthwaite, 2005). Eventually, the topology of the network has been found at least in some areas as related to team outcomes (Maznevski and Chudoba, 2000) such as software development productivity and quality (Colazo, 2010, Colazo, 2018). Investigating whether and how communication patterns change as teams become leaner may open a window into the more intimate reasons for Lean success, as it has been argued that the success of Lean may be tied in theory to the prevention of "failure to communicate" (Gîfu and Teodorescu, 2014) and to changing the leadership's view of communication from a tool serving managerial elites towards serving value added process actors (Kouzmin and Korac-Kakabadse, 2000) . If the changes in communication patterns posited before were to actually be detected, then arguably, the intensity or degree to which those changes occur might be related to success in implementing Lean. Then the second overarching research question in this paper is: *Are specific changes in communication patterns related to success in implementing Lean?*

These two research questions are explored in this paper in the form of testable hypotheses with data from four business units of a mid-size industrial company that has been undergoing a Lean transformation during the last few years.

2.4 Gaps in the literature

The literature review in the previous sections point to the following specific gaps in the study of lean success, which this paper aims to at least partially remedy drawing from previous knowledge on lean manufacturing, lean success and social and communication networks:

1) No relevant studies have looked at lean success from the point of view of workers and teams of workers, with most studies relying on managerial evaluations or company-level data.

2) With few exceptions, and none of those studying lean success, the prevalent view of Lean is mechanistic, top-down, and toolkit-based, instead of the proposed view here as an intricate communication and collaboration network, which needs to use relational data to describe success factors.

3) Of the few network-based studies, none have looked at pre/post lean implementation success and concurrent network evolution.

3. Hypotheses

To think about how the lean organizational structure and the different concepts enacted in the system may affect communication and collaboration patterns when they are implemented, first let's have a look at the typical manpower arrangement at a Lean plant. Typically, the structure of the production line is composed of working teams roughly assigned by functional sector, such as, in the case of the company studied, materials receiving, mixing, pressing, enamel line, quality, packing, etc; with about 5 workers or "team members" per team, supervised by a Team Leader that can also work the line and whose main purpose is enforcing the concept of Jidoka (autonomously not letting defects pass downstream) and training and coaching workers, among other functions. Every 2 to 5 teams there is a higher level supervisor called Group Leader and depending on the organization there may be several other managerial levels all the way up to plant manager or the equivalent position (Liker, 2005). In this paper the Group Leader and above are considered part of the supervisory body, whereas Team Members and Team Leaders are direct labor or workers.

The intensity to which teams communicate internally or with management, and how supervisors communicate with each other can be observed by examining network-related

characteristics of their communication patterns where team members or managers can be actors of a network and there is a link between two actors when there is a communication instance between them. The mathematics of graphs allow measuring different traits of these networks such as network density, network centralization and other metrics that can be used to characterize the unique communication interactions in a given team or group of teams and differentiate one team from another (see the measurement section for more detail).

The network perspective of work teams has been repeatedly validated, with results from network-based studies shedding light on important issues such as which actors are more important for knowledge diffusion (Licorish and MacDonell, 2015) or what kind of communication patterns are associated with quality or productivity (Kim et al., 2011, Easton and Rosenzweig, 2015).

In the case of intra-team, or member to member communication network, intensity of communication is related to the team network density (Wasserman and Faust, 1994), represented by the average number of communication instances between actors in a given period of time. Mathematically, network density is the ratio between the links observed and the maximum possible number. The links have a value of zero when there has been no communication between those two actors and "n" where those two actors have communicated "n" times during the specified period of time. Density basically represents the average link value across actors in the network. Density is zero if all actors are isolates and the average link value otherwise.

Although density captures the overall intensity of communications within a network, another parameter, centralization, captures how dispersed the communication pattern is. Network centralization is conceptually a measure of dispersion of the centrality (importance) of the individual actors. Centrality may be based on different core concepts, i.e. definitions of the

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importance of actors. Following one definition, a more important actor is one that has more links to any other actors, and we would be talking about degree centrality (Wasserman and Faust, 1994). Following a different definition, a more important actor is one more "in between" pairs of other actors, and here centrality would be called betweenness centrality. The most common measure for centrality is degree centrality, which is the number of links reaching the actor, which will be the metric used here. A detailed explanation of its calculation is in the measurement section.

3.1 Worker-worker communication networks

In general, worker involvement in operations is positively related to operational effectiveness in particular when work is organized around the team's output -as it is in Lean, with the emphasis in Safety, Quality, Cost, Delivery - (Dennis, 2016). Operational performance increases when there are multiple opportunities for informal communication, and workers are exposed to novel problems which they can directly solve counting with management's trust (Pagell and LePine, 2002). We will review that these and other related dynamics should be present in Lean implementations, and how this should in turn be related to changes in the network characteristics of communications among team members.

Several are the characteristics of Lean that promote a higher level of communications (higher communication network density) than traditional systems. The concept of Jidoka, or "autonomation" prevalent in Lean operations can be defined as the ability of the production line to not pass defects downstream in the value-added chain. This concept was initially related to automation, but it is much more than that (Ohno, 1982). In order for the line (workers and machines) to not let defective product downstream, they need to be able to detect the defects or

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the conditions conducive to defects, prevent those defects from occurring, and if they have occurred, stop production until the problems have been solved, solve the problem, and restart the line, and look for and eliminate the root cause of the problem in a more or less autonomous way. Mechanisms to perform these activities include andons (Shook, 2010, Treville and Antonakis, 2006) and pokayokes (Shingō and Dillon, 1989) but a key dynamic is the human feedback loop that occurs whenever defects are stopped. For instance when a workers pulls the cord of an andon system, there is a visual and sonic alarm that alerts the Team Leader, who communicates with the worker who activated the andon to find out what the problem is, helps fix the issue in order to restart the line and later leads an additional set of activities in concert with the workers to find the root cause of the defect (MacDuffie, 1997) in order to eliminate it and prevent the problem's recurrence. Clearly, this system cannot function without the back and forth between team members, team leaders and supervisors.

Developing standardized documentation promotes communication within the team as well. In Lean , there are elaborate standardized documentation describing work in minute detail (Liker, 2006). Although many times team members do not produce the documents by themselves, they do offer input and recommendations to team leaders and group leaders involved in the production of those documents (Liker, 2006), which obviously requires a degree of communication.

The use of multi-skilled workers also should promote communication. Within a team, workers are developed to be multifunctional and be able to perform, eventually, all the activities within that team. The Team leader, and many times team members, are the ones who train workers in new processes (Liker, 2006, Inamizu et al., 2014). This entails training sessions with the corresponding communication requirements. The end goal is to produce workers who are truly

flexible, and the existence of specialists in a particular process is shunned, reducing the relative importance of one member in detriment of others, this being related to diminished centralization in the team.

Another instance where communication within the team strengthens is when they work in quality circles. Quality Control Circles (QCC) or Kaizen Circles are groups of workers and sometimes supervisors who team up to solve relatively complex problems applying simple analysis tools such as Pareto diagrams, Fishbone charts, etc (Ishikawa, 1985). These Quality circles are different from "improvement project teams" of Six Sigma in (Easton and Rosenzweig, 2015) in that the former are self-convened, select their own topics to work on, are process oriented and are relatively autonomous, with the opposite traits associated with Six Sigma teams, where there is a results-oriented top-down process. When workers meet to carry out a QCC, they decide their meeting times, conduct their own meeting, and working as a team, brainstorm possible causes for the problem, implement countermeasures to solve the problem, and update work standards to reflect the new situation. These activities obviously entail increased communication requirements among team members.

Other less known -or less written about- activities also promote communication within the team. For instance, every beginning of the shift the team leader will convene the team's workers to do warm up exercises, check on their physical and attitudinal wellbeing, talk briefly about last shift's performance and perhaps convey a key point of the day about some quality or safety issue (a "five minute talk") (Saari et al., 2016). This "morning meeting" or asakai has an important role in letting the team leader observe if a workers should be assigned to a different process, if there are any absentees, and to gauge the morale of the team, their safety awareness and their readiness to work. Small talk is an expected part of asakai meetings (Imai, 2012). Similarly, at

the end of the shift there is the evening or "yuichi" meeting where the day's performance is reviewed. In many teams, parts produced by that team the previous shift are brought back to the team's workplace and exhibited as is it were a market, in the morning before their new working shift starts, called "asaichi" or "fist thing in the morning", or "morning market" (Imai, 2012). The idea is that by looking at what they did the day before, workers will get immediate sensory feedback to improve the current day's operations (Imai, 2012).

Not only communication should intensify among team members of a given team but also with members of different teams. Consider the idea of root cause discovery (MacDuffie, 1997) critically important in the Lean paradigm. This cannot in real life be executed if workers do not ask questions whose answers many times involve other teams or sectors, who will need to actively collaborate with the focal team members in order to find and solve the real cause for a process glitch.

Similarly, team leaders must actively check with the upstream team and negotiate with them incoming quality standards that allow the team leader to accept or reject processing work that has been sent to them below agreed quality, besides confirming and if necessary giving feedback about defects passed from the upstream process. In the same way, team leaders must check downstream for the impact of his team's work on their internal customers and on the final product.

All the activities described above, which either do not exist or are not as strenuously enforced in non-lean operations, when introduced should sharply increase the intensity of communication within the team and with other team members as well (captured by network density) as well as the level to which knowledge is shared among members (which equalizes their importance reducing centralization). This supports the first two hypotheses:

H1: Network density in a worker - worker communication network is positively associated with Lean success.

H2: Network centralization in a worker - worker communication network is negatively associated with Lean success

3.2 Worker-supervisor communication networks

In the case of communication between workers and supervisors (group leaders and above), communication intensity is captured again by density, i.e. by the average degree but this time between actors of the two modes, i.e. the average number of communication instances between team members and managers.

For instance, the Lean concept of Genchi Genbutsu (go and see by yourself) (Imai, 2012) can be reductionistically explained as asking supervisors to spend more time in the shop floor watching the process instead of relying on reports, but it is only completely fruitful if those observations are fed back to different worker teams. Supervisors are expected to spend most of their time at the shop floor watching the process, understanding problems and getting and giving feedback to and from team members. Supervisors are even expected to note their observations and their proposed countermeasures in the team's or group's control dashboard, called FMDS board, for Floor Management Development System (Suh, 2015).

Other activities formally require additional communication between supervisors and team members, such as coaching for quality circle activities, feedback for creative suggestions and supervision of 5S and standardized work. When QCC are implemented, supervisors are expected to coach the teams and help them untangle any technical problems the members are not qualified

to attack, such as complex economic evaluations or reading engineering drawings. Supervisors also are expected to broker resources and connect with suppliers and external vendors as needed, on behalf of the teams.

Also, in Lean there is a very high rate of approved suggestions from workers, normally upwards of 95% (Imai, 1986). This is not, as some believe, proof that Lean workers have only excellent ideas. Contrary to what happens in other systems, such as Six Sigma, in Lean suggestions are only approved after they at least have been tried and shown to work. The process of trial involves frequent feedback between workers and supervisors, to the point where there is no doubt that the suggestion will work. The approved suggestion will in many cases be different from the original idea, after many rounds of feedback between workers and supervisors.

Another characteristic of Lean systems is audits from supervisors for things like standardized work and 5S. Regularly, supervisors will check if work is performed according to standards and in case of discordance, give and take feedback from the workers who are executing the work. The same happens for standardized housekeeping, or 5S (Liker, 2006).

The activities mentioned above are not optional in a rigorous Lean implementation and cannot be skipped if the system is going to work as expected, yet most of these activities do not exist formally in a non-lean plant. The correct execution of these concepts should involve increased communication between managers and team members, suggesting the following:

H3: Network density in the two-mode network between workers and supervisors is positively associated with Lean success

3.3 Supervisor to supervisor networks

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In this case we will consider a communication network where the actors are supervisors, from all possible areas, and there is a link between actors when those supervisors communicate. We will argue that similarly to what was hypothesized before, density and centralization will change when Lean is effectively implemented.

The practice of Obeya meetings actively promotes cross-communication among sectors. The Obeya (big room) (Aasland and Blankenburg, 2012) is a physical space in the plant where visual aids such as charts are posted on the walls to depict the past and particularly recent performance of the plant and supervisors meet to review the previous day's events and to discuss opportunities for improvement as well as needs for cross collaboration.

Cross-audits are also usual, and a vehicle for supervisor to supervisor communications. Safety patrols and 5S audits are routinely conducted not only by supervisors belonging to the area under audit but by supervisors from other areas, since looking at the environment with fresh eyes is considered critical (Hallum, 2007). The implementation of a creative suggestion system also provides opportunities for communication between workers and managers. For instance, supervisors are expected to analyze suggestions from all over the plant and deploy in their sectors those that have merit and can be utilized even if they are adapted.

Supervisors also have additional opportunities for communication when they conduct Jishuken activities (Marksberry et al., 2010): these are focused kaizen events led by managers where a group of managers with or without assistance from other sectors tackle a focused, higher level problem in a more concentrated and intense way than traditional quality circles.

Harmony and camaraderie are important values in all team activities in Lean whether conducted by workers or supervisors, and within a given rank, all individuals are equally respected, and collective action is consensus or "nemawashi" is expected and individuality

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discouraged (Bhamu and Sangwan, 2016) which entails a low level of centralization since "star players" are frowned upon in favor of a more harmonized, collectively oriented problem solving process. Actors that are salient of more important than the rest are seen as negative, which is reflected in the old Japanese saying "The nail that sticks out of the plank will have to be hammered back down".

Finally, Lean companies have a particularly high level of horizontal rotation, where promotions are slowed down to allow for supervisors to rotate among areas and gain knowledge across the functions (Liker and Hoseus, 2009) which makes their skill levels more comparable and broader as they gain experience in the lean environment.

All of the above observations support the following two hypotheses:

H4: Network density in a supervisors' network is positively associated with lean success

H5: Network centralization in a supervisors' network is negatively associated with lean success

4. Methods

4.1. Research background

Data for the empirical tests were extracted from field work executed at a company where the authors have been consulting to help implement a complete Lean Manufacturing system.

The company (which wishes to remain anonymous) is located in South America and has several business units, of which four manufacturing plants, all of them unionized, were selected for this study (plants A, SL, P, SJ by the initials of the area they are located in) that produce ceramic tile products for residential and commercial flooring applications. The company is the

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largest ceramic flooring products producer in the country. General data about the plants appears in Table 1.

Table 1: Plant characteristics

	Plants				
	A	SL	P	SJ	Overall
Annual volume, Ksqm	7000	2400	2000	6000	17400
Indoor production area, Ksqm	120	20	21	66	227
Direct workers	281	135	151	235	802
Indirect workers	66	23	25	48	162
Quality, before lean	90%	90%	88%	93%	91%

The process to produce ceramic tile is basically the same in all four studied plants, and comprises the mixing of clays, pigments, other minerals, water and additives to produce a base paste that is molded in presses in the shape of individual tiles which go through a digital printer that prints patterns on the tiles and another process that covers the tiles with enamel. After the enamel stage, the tiles are baked in an oven, cooled down, their shape rectified if necessary, classified by quality, packaged and distributed to customers.

The implementation of Lean in the company began in 2014 with plants SL and SJ starting in February and plants A and P later in August. None of these plants had an organization chart with team members / team leaders / group leaders, but rather a variable ad-hoc supervisory organization with a plant manager and supervisors of different work classifications before the line worker level. After the first data collection exercise, and prior to implementing Lean, in agreement with management and the union, the plants were reorganized following the architecture found in Lean (team members, team leaders and group leaders).

4.2. Data collection

Before the reorganization, during the first month of Lean implementation, all workers and supervisors, up to the level of plant manager, were indicated to drop by the HR office where they were given an electronic survey instrument with a set of questions asking for the names of people with whom they would typically expect to communicate either in person or by two way radio, internal phone or e-mail, either outgoing or incoming, every day of the week. Everyone was instructed to record who they would be communicating with and by which medium, in their normal shift, Monday through Friday. At the end of this, demographics and other control variables were collected, such as type work (production / maintenance / quality / other), production line number or name, education level, age, gender, time in the company, etc. Demographics can be seen in Table 2.

Table 2: Demographics

	Plants			
	A	SL	P	SJ
Respondents to first survey	88%	85%	80%	92%
Average age	42	29	33	35
Average years in the company	12.1	5.9	8.8	4.8
Male, %	96%	98%	95%	90%
Direct workforce				
Education: Less than Elementary	8%	5%	6%	3%
Education: At least Elementary	65%	58%	55%	48%
Education: At least High school	28%	35%	34%	44%
Education: More than High School	7%	7%	11%	8%
Indirect workforce				
Education: 1= At least Elementary	2%	0%	1%	0%
Education: 2 = At least High school	55%	65%	49%	48%
Education: 3 = More than High School	45%	35%	51%	52%

The communication frequency information was then manually reviewed to match it with HR payroll records in order to clearly identify all individuals, whose data were anonymized and

transformed into a sparse matrix representing communication intensity, where the link between two actors had a value equal to their weekly number of interactions (Moreno, 1934). At the same time, a baseline measurement of Lean success was taken in all plants (see measurement). Measurements were repeated, except for the demographics, approximately 24 months after the initial round, and Lean success recorded at that time too.

In the end, 699 direct workers belonging to 76 teams and 22 different production lines, and 79 supervisors were surveyed. Teams with less than 50% production workers (22 teams out of 76) workers were assigned to "Non-production" (typically Quality, Materials Handling or Maintenance). When there was personnel attrition and/or personnel replacements by the second measurement (approx. 4%), missing personnel were replaced by the category's mean and new personnel were excluded from measurements. The sample captured 95% of the direct workforce and 90% of management as per payroll records.

4.3. Measurement

4.3.1 Lean success

As companies become leaner, their evolution can be observed by measuring the degree to which the different techniques associated with the Lean paradigm have been implemented and results are being obtained. Lean success was measured using the company's internal performance measure of Lean achievement (available upon request), a composite score that is the average of 12 dimensions, all of them on a 1 to 5 scale. These dimensions cover the whole realm of Lean effectiveness:

1. State of 5S

2. State and enforcement of standardized work documents

3. Implementation and maintenance of a FMDS (visual dashboard and visual controls)

4. State of key performance indicators for the line / team relative to goals

5. Compliance with daily meetings

6. Compliance with supervisory weekly planning

7. Implementation of total productive maintenance

8. Implementation of SMED (where applicable)

9. Implementation of Kanban (where applicable)

10. Implementation and evidence of Genchi Genbutsu

11. Number and impact of worker suggestions per capita

12. Number of quality circles per capita

Lean success was collected at the production line level for the pre-implementation instance and at the team level for the post implementation instance (24 months after implementation). To make pre-post measurements compatible, and because workers were assigned to teams that matched their usual roles, workers were classified post-hoc in teams for the pre-implementation measurements following the structure resulting after the reorganization, i.e. workers were measured as if they already belonged to the same teams that were decided later[1], and the production line lean success score was equally assigned to all pre-implementation teams belonging to that particular production line. This is admittedly a subjective manipulation but is necessary to measure network parameters and we believe it is logically justified (see limitations).

Success in implementation was defined as the percentage change in the Lean score from the baseline at the time of the second measurement. Given that most operations nowadays have incorporated, if inadvertently, some Lean concepts prior to formally embark on a Lean

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[1] Results are similar if instead of this manipulation, network parameters were calculated plant-wide, without assigning workers to any teams in pre and post measurements equally

transformation, and also given that Lean does have elements of other production systems predating it, it is expected that there will be some non-zero activity associated with Lean in the plants before the system is launched formally, i.e. there will be some visual controls, some attempts to standardize work, some housekeeping done, which would produce a non-zero baseline score. In fact, the baseline score for the four plants on average was 17.5% or 0.875 in the 1 to 5 scale. At the end of the studied period the four plants scored 1.2, 1.8, 3.1 and 4.2 from worst to best, with an average of 2.575 in the 1 to 5 scale, or approximately 51.5%.

Face validity of the success metric was measured by asking three expert Lean consultants to rate whether each item in the scale measures some dimension of lean success. The interrater Cohen's kappa (Cohen, 1960) was 0.82 indicating strong agreement. Since this study measures the same outcomes before and after an intervention, it is important to check pre/post reliability. Test-retest reliability was measured by Pearson's correlation in the pre-post test groups composed of all the teams which did not change in composition more than 20% before and after the intervention obtaining a correlation of 0.81 indicating a good pre/post test reliability for the success metric.

4.3.2 Communication network density and centralization

The statistical package R (R Development Team, 2017) was used to calculate network parameters. For worker to worker parameters, the measurements were average team-based and normalized by team size. For worker to supervisor data, and for supervisor to supervisor data, network density is the average frequency of a tie in the network and centralization is the standardized variance of the degree centralization as defined before (Wasserman and Faust,

1994). Density (Δ) is, given g nodes and k arcs in a graph, where v_k is the value assigned to arc k, which in this case is equal to the number of weekly interactions

$$\Delta = \sum v_k / g(g-1)$$

Density is standardized and hence independent of team size, and it will be zero if all actors are isolates, and the average of their weekly interactions if all actors have links to all other actors. In this case, a link exists between any two actors if they communicated during the problem solving process as recorded in the survey they filled as explained above. Density captures the overall intensity of communications within a network.

Centralization captures how dispersed the communication pattern is. Network centralization is conceptually a measure of dispersion of the centrality (importance) of the individual actors. The most common measure for centrality is degree centrality, which is the number of arcs reaching any given actor. Let $C_D(n_i) = d(n_i)$ be the actor degree centrality for actor i. Then the centralization C is:

$$C = Var[C_D(n_i)] = \sum_{i=1}^{i=g} [(C_D(n_i) - \overline{C_D})]^2 / g$$

If all actors in a network had the same degree centrality, then the network itself would be perfectly decentralized, and the distribution of degree centralities in that network would have zero variance and a centralization of zero. The larger the degree centrality variance, the more centralized is the network.

4.3.3. Control variables

Control variables included demographics such as tenure at work, age, education level and since some workers has previously worked at companies with some form of Lean program, we also included whether they self-reported previous experience with Lean (1=yes or 0=no). The sample was overwhelmingly male and then gender was excluded as control from the models with the limitation that results apply only to an all-male workforce. When the unit of analysis was the team, averages are used. Basic bivariate correlations and descriptives can be seen in Table 3.

Table 3: Bivariate correlations

#	Variable	1	2	3	4	5	6
1	Lean Success score change, %	1.00					
2	Team Density	**0.11**	1.00				
3	Team Centralization	**-0.21**	-0.08	1.00			
4	Tenure in organization, years	-0.05	0.01	0.03	1.00		
5	Education level	0.09	0.01	-0.02	**-0.12**	1.00	
6	Age	0.05	0.00	0.06	**0.55**	-0.09	1.00
	Mean	33.98	0.67	0.48	7.86	2.24	34.8
	SD	10.02	0.08	0.13	2.33	0.71	3.35

Boldface: p< 0.0 5

4.4 Analysis and Results

4.4.1 Worker to worker networks

For this section the unit of analysis is the team. For simplicity and parsimony we decided to go with a simple ordinary least squares (OLS) model with lean success score change as dependent variable as a function of network characteristics plus control variables. All teams belonging to all four plants were included. The figure below represents the regression model tested.
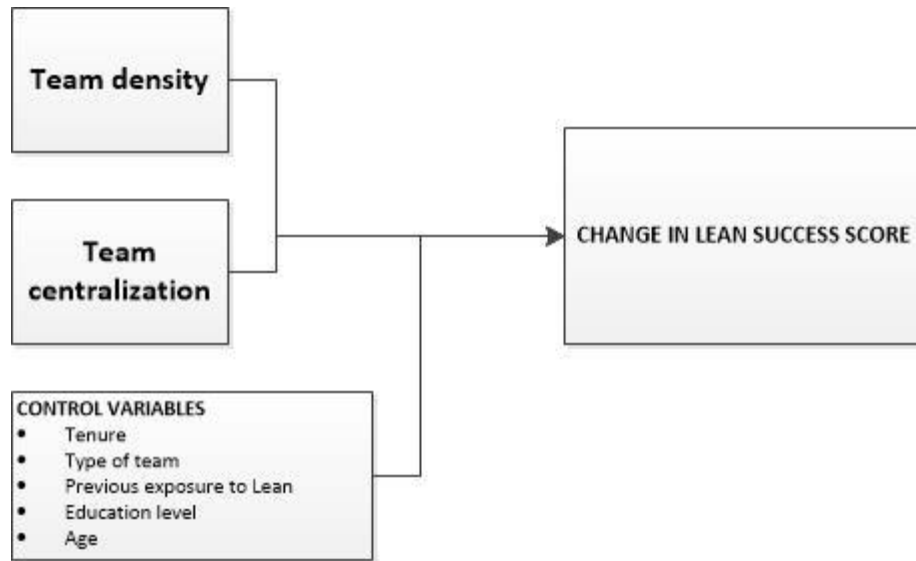
Figure 1: Theoretical model for regression

Results of ordinary least squares (OLS) show that difference in success is positively associated with team network density and negatively associated with team network centralization, supporting hypotheses 1 and 2[2].

Table 4: Team-based OLS Model

	Coeff.		SD
Team Degree centralization	-0.181	**	0.010
Team Density	0.222	**	0.021
Avg. tenure in company	-0.589		0.15
Type of team (1)	0.487	**	0.074

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[2] Similar results were obtained using non-parametric Huber-White robust standard errors for the regression.

Avg. previous exposure to Lean	0.052	0.047
Avg. education	2.522	1.845
Avg. age	1.852	0.988

DV: Change in Lean success score after twelve months	*	p<0.1
n= 76	**	p<0.05
(1) 0=Non-production, 1=Production	***	p<0.01

Taking all teams and splitting them into low and high performing at the median success increase score (3.52/5) allows comparing the network parameters of the two groups. Higher performing teams have in fact lower centralization and higher density.

Table 5: High vs. Low Performers

	Low perf.	High Perf.		t-score
Team degree centralization	0.588	0.355	**	2.8
Team density	0.441	0.738	**	-2.9

n=76	*	p<0.1
	**	p<0.05
	***	p<0.01

4.4.2 Worker to supervisor network

For this analysis only worker to supervisor links were kept, and a simple t-test was performed comparing density and centralization before and after, as well as the mean degree centrality.

Table 6: Overall Network, before and after Lean

	before	after	t-score	
Avg. worker - supervisor degree centrality	3.56	5.89	-5.265	***
Network density	0.38	0.57	-2.56	***

n=601			*	p<0.1
			**	p<0.05
			***	p<0.01

Average degree centrality (number of communication instances per dyad) increased post-intervention (after implementing Lean), and the same happened to the network density. This lends support to H3.

4.4.3 Supervisor to supervisor network

In this case only supervisors were considered, and similar t-test was performed with such network density before and after intervention:

Table 7: Supervisor – supervisor network, before and after

	before	after	t-score	
Network degree centralization	0.65	0.32	2..355	*
Network density	0.08	0.39	-8.524	***

n=65			*	p<0.1
			**	p<0.05
			***	p<0.01

The degree centralization decreased, and the density increased post intervention, supporting H4 and H5.

4.4.4 Post analysis interviews

Ten workers and five group leaders were randomly selected from both the lowest and highest performing production lines (total 30 subjects) and a were assigned a short post-analysis questionnaire delivered by an electronic instrument using Qualtrics (Qualtrics, 2005), two months after the second measurement. They were all asked the following questions (translated from original questions in Spanish):

1. You have been presented with your team's success relative to the average. What is in your opinion, the main reason that explains the relatively high (low) success in your team / line?

2. Have you noticed a change in the way you communicate with other workers of your same category and with management as your team evolved?

3. How could you or management improve the way you communicate in order to be more effective?

Answers to the first question were classified by three expert consultants into broad categories: Leadership (35%), Training / knowledge (25%), Teamwork (20%), and others such as grit, good luck, undetermined / miscellaneous (20%) with 100% inter-rater agreement.

Answers to the second question can be classified into Yes (95%) No (5%).

Answers to the third question were more varied and included: more resources, better compensation, more flexible times, less oversight, more top management involvement, more training, and others less frequently appearing.

5. Conclusions, limitations and future research

Results generally support that as a company turns leaner (it advances in its lean transformation) its communication patterns fundamentally change. This change happens within teams, between supervisors and workers and among supervisors.

The changes observed are 1) teams have a higher frequency of communication among members, increasing communication network density. 2) Teams share more of their communications, becoming more decentralized 3) Teams communicate more with supervisors 3) Supervisors communicate more amongst themselves and collaborate more and 4) Better performing teams exhibit those changes more pronouncedly.

In light of these results we can argue that a lean transformation could be evaluated not only by external indicators such as the assessment of how different practices are visible, but also by monitoring, measuring and looking at their communication patterns. A periodical survey similar to the one used here could be delivered to team members to measure the degree to which communication density and centralization are changing, and those teams exhibiting less than average progress or change, could be flagged for intervention or looked into in more detail, perhaps by interviewing their members, to analyze if there are impediments to the team's communications dynamic. Another possible managerial intervention could be scheduling training on effective communication, team building and offering opportunities to get to know other workers. It is interesting that in Japanese companies, the concept of hiring cohort, where workers are hired in large numbers at the same time, promotes in-group familiarity (Moriguchi and Ono, 2006) facilitating communication.

These results also open up the possibility of an alternative explanation for those unsuccessful cases of Lean implementation: instead of looking at macro level factors such as expressed top management support, hours of training, etc. (Netland et al., 2015), which may still be important, one could look at failures from embracing and supporting the more intense communication patterns associated with lean success, or one could detect barriers to communication by measuring how these patterns change or fail to change and try to unlock communication by working on those barriers, and supply communications infrastructure and opportunities for communication. Anecdotal evidence from post-intervention interviews seem to support that at least some managerial attitudes in those underperforming plants are related to resistance in changing how people communicate.

Measuring changes in communication patterns can be a potent indicator of the degree of Lean accomplishment at the shop floor that could complement other hard metrics and also shed light on the kind of core sustained changes that are critical to a successful Lean transformation.

This study shows several limitations, some of which could be alleviated in future research designs with access to more and different data. Although the sample size is not too small, it contains data within only one company, and more importantly, one company's culture. This and the few covariates included may be limiting the external validity of the conclusions. Also given the nature of the data it could be argued that for a more thorough study a fixed/random effects model or a hierarchical model should be used instead of OLS.

An interesting future study would be to look at communication patterns in clearly failed lean implementations and observe if they had a different kind of evolution compared to those in successful experiences.

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