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LEAN MANAGEMENT PRINCIPLES AND STIGMERGY

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ABSTRACT

Stigmergy is a mechanism comprising a sensing agent that responds to the settings of the environment by performing an action. Lean is defined as a philosophy that aims at eliminating waste in production processes without compromising value. The two concepts appear in the literature as independent with little attempts to study a possible relation between them. The purpose of the paper is to explore synergies between two seemingly distinct concepts. This is performed by investigating both Stigmergy and Lean separately, transforming each notion into its dynamic functional system, and comparing the functions of each against one another. Findings reveal that the natural mechanisms of Stigmergy can facilitate the operations of a Lean environment. Organizations can enhance performance by realizing and implementing some of the overlapping features between Stigmergy and Lean.

KEYWORDS

Lean management principles, Stigmergy, agents, environment, dynamics, actuators, sensors.

INTRODUCTION

Stigmergy and Lean Management Principles are two independent systems. The first describes a biological mechanism; whereas, the second describes principles that could be applied in processes, products, and collaborative activities. Although the two are separate systems, there are synergies that go beyond their basic definitions. To what extent do Lean principles rely on natural mechanisms of Stigmergy? How can Stigmergy enhance the

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implementation of Lean principles? Before developing the answers, it is necessary to study the established ideas of both systems in the circles of academics and researchers.

The term Stigmergy roots from Greek words “stigma” and “ergon” meaning sign and action, respectively. Grassé, a French entomologist, defines Stigmergy as “a broad class of multi-agent coordination mechanisms that rely on information exchange through a shared environment.” Theraulaz and Bonabeau (1999) state that Stigmergy offers a framework to understand coordination. This phenomenon explains self-organization at the level of societies. It mediates and regulates collective activities. This phenomenon explains how insect colonies look wonderfully organized and coordinated as a whole when every insect is naturally pursuing its own agenda without realizing the bigger picture.

Ant algorithms were derived from the Stigmergy phenomenon between insects. The algorithm is based on how ants choose between different pathways to get to the food source, for colony reparation or expansion purposes. For instance, Forcael et al. (2014) utilized ant colony algorithms to optimize evacuation models during Tsunamis to decrease chaos and evacuation time. From a broader view, this system can be also applied to solve complex problems within the field of civil and construction engineering for optimizing processes.

Although Stigmergy relates to insects, its importance exceeds these simple organisms to affect human beings. The significance for humans resides by how simple organisms are capable of constructing complex habitats only through their dynamic interactions. For instance, Parunak (2006) developed surveys of a wide range for human Stigmergy. Some examples of human Stigmergy mechanisms are the movement coordination that dictates humans to choose among existing trails, the market systems where prices govern the behavior of sellers and buyers, and joint authorship when each author is stimulated by what has been previously written or commented.

Other researchers aimed at studying Stigmergy phenomenon to employ it for construction (Petersen et al., 2011). Moreover, Stigmergy was applied using CAD 3D through a case study by Christensen (2014). The author shows that the work is subdivided into areas where actors (electrician, plumber, mechanical engineer, construction engineer) build upon each other to create the whole project (Christensen, 2014). Also, Ben-Alon et al. (2014) compared insects’ building behavior to man’s behaviors. Human projects are usually planned contrary to insects which have emergent construction. The study shows that social insects communicate indirectly through Stigmergy by responsiveness to natural simulation and sensation. However, people communicate through direct verbal contact, documents and models, and nonverbally through feedback. Moreover, simple insects’ construction is self-governing and involves multitasking, while human projects have centralized control and defined professional roles.

Social insects’ behavior is similar to core concepts of Lean construction Management. Koskela (2000) believed that waste in construction arises from focusing on the activity while ignoring flow and value. Understanding the dynamics of production, “the effects of dependence and variation along supply and assembly chains” is the most important goal of Lean management. Howell (1999) explains that Lean allows communication directly without having to rely on the central authority for the information flow, provides collaboration by involving downstream players in upstream decisions and reduces variability in work flow. Moreover, from a Lean perspective, burdens are shifted along supply chains and the ultimate aim would be to optimize the whole instead of just optimizing the parts.

The literature shows a few interesting scenarios of combining Lean and Stigmergy concepts. However, the relation of the two concepts was not spelled out clearly in any of the previous works. How are the two independent systems related? Can institutes utilize Stigmergy to facilitate Lean's implementation? This paper provides a thorough analysis of Stigmergy and Lean relation. Afterward, we present a thorough explanation of the two concepts separately. Then, we analyze the two concepts against each other to identify the areas where the Stigmergy mechanisms work in favor of Lean Principles and where one could hinder the other. Finally, we interpret the practical implications of the results of the analysis and conclude with some recommendations.

METHODOLOGY

The objectives of this paper are to 1) derive correlations between the two seemingly independent concepts: Lean and Stigmergy 2) utilize Stigmergy phenomena to achieve Lean work-environment. In order to achieve the objectives of this research, the following method was devised and followed: 1) define and understand Stigmergy and Lean as two independent dynamic systems 2) compare and contrast the two mechanisms 3) deduce the correlations 4) present the practical implications of the correlation.

STIGMERGY

As previously defined, Stigmergy is a stimulus-response feedback phenomena. Before explaining its mechanism, it is necessary to differentiate its components as: agent and environment (Parunak, 2006) . These two components are further divided into elements as shown in Figure 1.

First, an agent is the living organism experiencing Stigmergy. Agents have three elements at the core of Stigmergy mechanism: sensors, actuators and dynamics.

The sensor gives access to information available to the agent. It is similar to a router or to a capturer of the stimulus.

The actuator enables the individual to respond and to implement changes in the surrounding.

The third important component of the agent is its dynamics. Dynamics are the programs that translate the information received by the sensor into actions to be applied by the actuator.

If we consider that the agent is a human-being, they rely on listening, visualizing, smelling, or even inception of feelings or emotions to perceive stimuli. Actuators for human-beings can vary depending on the case from a response mechanism of the joints and muscles, to the ability of articulation, and even verbal and nonverbal communication. Man's dynamics can be understood by the control that happens at the level of the brain: interpretation of information and sending orders to execute actions.

Second, the environment is the shared medium in which the agent will be found localized or mobile and through which the interaction occurs. Environment can be understood through its two elements: state and dynamics.

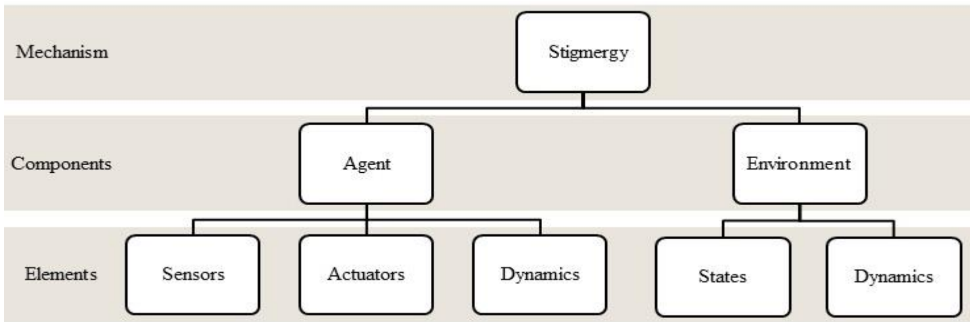

Figure 1 Division of Stigmergy mechanism into components and elements

The state has a deposit of stimuli that are eventually captured by the agent's sensors. The stimulus can be another agent's action, an inciting activity or structure, or even a provoking product like a chemical catalyst; for example, pheromones in the case of an ant-agent Stigmergy.

The environment's dynamics are the programs that govern its change over time (Parunak, 2006).

In case of humans, the state of the environment could be defined according to the situation; however, it shall be noted that the condition of the environment influences the inception of stimuli. For instance, in an enabling environment one will be able to sense and react upon stimuli better than in a suppressing one (Liker, 2005). As for the dynamics of a human Stigmergy, the evolution over time will be an enhancement, optimization, decay or maintenance of the conditions of a certain environment.

Figure 2 shows the mechanism of Stigmergy as the elements interact with one another. The environment is the medium through which the process happens. Agents and stimuli are found dispersed within this medium. The stimuli partly define the state of the environment and trigger the sensors of the agents. Once the sensors are triggered, sensory messages are initiated to feed the program. At the level of the program, the sensory messages will be analyzed and translated into instructions. Later, these instructions direct the actuators to act and execute changes in the state. The actions can be reflected in a corresponding change of the stimuli which might activate a loop of the described mechanism. On the long run, as the state follows a trend of changes, the environment will undergo a dynamic evolution that will affect its state including the stimuli and consequently the agents' reaction to them.

Parunak (2006) distinguishes Stigmergy phenomenon according to the stimulus type and the stimuli-response sequence. The differentiation according to stimulus type comprises two categories: a marker- based or sematectonic Stigmergy. The agent in a marker-based Stigmergy relies on special markers deposited in the environment (chemical or physical); whereas, the agent in sematectonic Stigmergy relies on current state of the environment. The other distinction which is based on the stimulus-response sequence divides Stigmergy into two types qualitative and quantitative.

Quantitative Stigmergy means that the stimulus is of the same type with a variance in the probability of the response of individuals to this stimulus. For example, humans are triggered by the car density to choose an optimal trail. The density of the cars interferes with the probability of the response to it; the higher the number of cars on a given route, the higher is the probability that the driver will be responsive by not choosing the trail with high traffic.

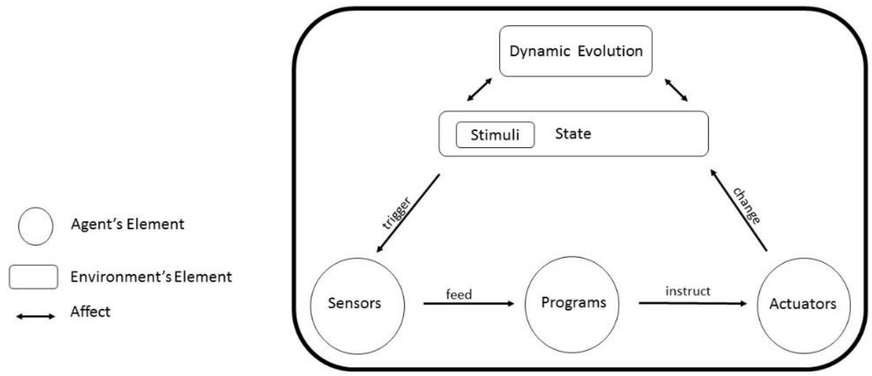

Figure 2 Stigmergy Mechanism and Elements

However, a qualitative Stigmergy means that the signal has a variable nature i.e. qualitatively varies. For instance, humans react differently to each of the traffic lights. Red light simulates the driver to stop his car; whereas, the green light triggers people to drive. It is worth mentioning that the two types of differentiations are not mutually exclusive. In other words, Stigmergy can be defined by the stimulus kind and stimuli-response sequence simultaneously (marker-based /sematectonic and qualitative /quantitative).

LEAN MANAGEMENT PRINCIPLES

Liker (2005) describes Lean management principles through Toyota's manufacturing process. The concept emphasizes waste elimination throughout activities and operations without compromising the client's value. Muda, Mura and Muri are the three kinds of wastes to be eliminated in a Lean process. Ohno views Muda as steps that do not add value to the product or process. Before eliminating wastes, the value in the eyes of the costumer must be identified. After identifying costumer's value and wastes, a continuous flow is to be created whenever possible; otherwise, pull flows are advisable.

Liker (2005) organizes the Lean management principles by a 4-P pyramid model at its base lies "Philosophy" then comes "Process" followed by "People and Partners" and on top is the "Problem Solving." All the pyramid's components hint to the existence of two main elements at the base of any Lean environment. These two elements are agents and system. Each of these elements possess a set of specific characteristics and are involved in certain interactions to constitute a Lean environment.

Starting with the agents of a Lean system, these are the individuals that perform actions required in an operation or a process. In Lean managed systems, the agent's work serves the ultimate goals of adding value; hence, these agents act according to specific characteristics summarized in the list below.

- Working with wise eyes promotes the agent to proactively detect errors, to suggest improvements and to avoid wasteful actions.
- Reason, creativity and passion help the agent develop critical thinking and an ability to solve problems.
- By being trustworthy and ethical, the agents will perform well in collaborative teamwork and in interaction with outside players such as suppliers or clients.
- An agent who possesses good communication skills can easily transmit his ideas to the teammates and other players.
- Additionally, leadership does not only allow the communication of ideas with others but also gives the potential to influence and convince others.
- Finally, a perfectionist agent will continuously seek improvement and will never settle for the best solution.

The second element of a Lean environment is the system. The system is the medium where operations and processes occur. The system which applies Lean principles shall also have a set of differentiating characteristics listed below.

- A Lean system is one characterized by a long-term philosophy which is at the base of Liker's pyramid (2005). Long-term philosophy is similar to the True North; it sets the purpose of the business, process or operation. Hence, a Lean system does not only aim to succeed on the short-term key performance indicators but rather aims for sustainable growth and builds right relationships with clients, employees and suppliers for long-lasting benefits.
- Enabling bureaucracy is an essential characteristic of the system. This characteristic gives accountability and a sense of responsibility to people while empowering them. Rules and procedures are facilitating and not limiting tools.
- Lean systems are coupled with visual aids to help the employees detect errors and eliminate wastes. For instance, Andon signals the arousal of a problem. Andon is not the only used visual control, Kanban and A3 process are other examples implemented in Lean facilities and processes. For instance, Kanban serves pull systems and indicates the need for replenishing certain stations.
- Lean systems are ones that utilize pull flows to avoid overproduction in operations. Continuous flow is the optimal requirement to expose inefficiencies in processes and to make it easier to track the cause/effect of errors. However, the pull-system flow is another possibility whenever continuity cannot be possibly incorporated.
- The system is described through a set of standardized processes. The standards only serve as means to initiate further improvements and not to limit them.
- Lean systems have levelled workload (Heijunka) to eliminate unevenness (Mura) in work distribution. As unevenness is eliminated, Muri (overburden) and Muda (wastes) will accordingly be alleviated.

Poka-Yoke is a necessary element of the system. It is the mechanism to draw human's attention in order to avoid errors. Poka-Yoke ensures quality-at-bay (Jidoka).

After dividing Lean principles into its two main components, agents and systems, we will explain the mechanisms between these two components. The interactions are categorized into three types (Figure 3) as follows:

1. Agent-related mechanisms: are actions initiated by agents who possess the set of Lean characteristic. These actions result in changes in the system. For instance, a creative employee offers suggestions to execute work in a better way.
2. System-related mechanisms: originate from the setup of the system to alter the agents' or its characteristics. For example, an enabling system helps the internal growth of leaders who are expected in turn to add more value to the system's operation or process.
3. Inter-agent related mechanisms: are actions initiated by agents who affect the behaviors of other agents. Collaboration in teams is an example of inter-agent mechanism.

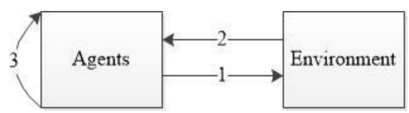

Figure 3 Lean components in dynamic interactions

COMPARISON

Defining Lean principles and Stigmergy each as a dynamic system allows their comparison. The two systems have common constituents, agents and environment. Moreover, these constituents interact dynamically either in Lean or Stigmergy System. Both systems interact similarly, Lean has three different types of dynamic mechanisms that form a dependent feedback loop; as well as Stigmergy where agents react to a stimulus that can be either an agent's actions or an environment's state.

The differences only lie in the nature of the mechanism and the makeup of the agents at the level of the two systems. For instance, in Stigmergy mechanisms, the agent has three components, sensors, actuator and programs that allow the interactions with the environment; however, in a Lean system the agent has to possess a set of characteristic to allow him to function accordingly. The environment for Stigmergy is defined by its states which are in turn a function of disposed stimuli and programs; however, a Lean environment has to possess a set of characteristics.

Having spotted the different nature of the two processes, one could not but conclude that the agent in a Lean system is one who possess Stigmergy elements actuators, sensors and dynamics. Lean environment is also instilled with stimuli forming states and dynamics dictating responsive mechanisms. Therefore, the two systems are related ones. Stigmergy interacts with Lean system to either synergize or inhibit the ultimate Lean objectives.

RELATION BETWEEN LEAN AND STIGMERGY

Despite being distinguishable concepts with different models, Lean and Stigmergy are comparable. It was deduced that the two systems are related and that Stigmergy can either have synergetic or inhibitory effects on Lean objectives. To spot these instances, we will discuss the intervention of Stigmergy in each of the three Lean mechanisms.

Stigmergy intervenes with the first Lean interaction-one through which the agent affects the environment- in several ways:

Stigmergy mechanism converges with the characteristic that requires an agent to have a wise eye. Sensing an error and accordingly taking an action ensures the occurrence of quality-at-bay in the workplace.

Through multitasking the agent can implement changes in the state of the environment around him. Multitasking is indirectly relevant to stigmergy through the agent's dynamic. An agent's program might allow multitasks; i.e., whatever the state appeals to the senses is integrated by the dynamic. The result of integration will be a corresponding action. This is how decentralization can be explained through Stigmergy.

Perfectionist agents will transform their environment into one which applies Nemawashi and Kaizen in their environment. Stigmergy meets the purpose of Lean interaction by continuously improving standards, solving problems by seeing for one's self and allowing decisions to go from downstream to upstream actors.

The second Lean interaction where the system influences agents is also affected by Stigmergy mechanism.

Affiliation of the environment with a long-term philosophy influences the agents to build their relations and to set their objectives based on the long-lasting benefit instead of the short term key performance indicators of success. This interaction entails the indirect convergence with Stigmergy at level of Dynamics of both the Agent and the Environment.

Lean environment is one that utilizes standards as a set point to develop further improvements. The agent's dynamic in Stigmergy mechanisms helps standardization. The agent seems to be programmed to optimize solutions to execute work. This optimization at the level of an organization is at the core of innovation.

Moving to the visual control characteristic, it has a direct relationship with the sensors of Lean agents. For instance, designers who work on a joint model are able to see what the preceding designer has accomplished; thus, will be able to interpret accordingly for the next step to be delivered (Christensen, 2014).

Levelling out the workload is indirectly related to the actuator of the agent. The actuator is the element performing the action. The relation resides in the fact that the less variability of the workload, the less will the agent witness overburdens. Therefore, equilibrium in the workload will require less effort by the actuators to execute action.

Stigmergy can either hinder or facilitate Jidoka, the quality-at-bay Lean characteristic. The agents might coincidently detect a quality problem as the type of stimulus might vary due to quality problems; hence, altering the resulting sensory message and the corresponding response. For instance, in joint modelling, collisions between different trade designs can be quickly observed and re-worked if the designs do not overlap (Christensen, 2014). In this case, Stigmergy facilitates the achievement of quality designs. Nevertheless, Stigmergy hinders Jidoka if a quality problem does not alter the stimuli; therefore, agents might not sense the problem and the feedback loop might only amplify the scale of the problem.

Lean environment only adapts reliable technology. Stigmergy mechanisms will bring on more efficiency when reliable technologies become the stimulus. For example, BIM technologies are useful because people can learn and work amidst the BIM model. If BIM model was not very helpful then people will be wasting effort and time to sense and react upon these technologies.

The third inter-action which is about agents affecting one another is a form of Stigmergy. For instance, in teamwork the team players use their co-workers for stimulus. A leader gives directions and signs, or shows the way which triggers his followers to take action. Collaboration in teams requires communication which is another form of Stigmergy. As one agent sends a verbal or nonverbal message, the other receives it and responds to it by feedback. Lean agents can strength their inter-actions if they utilize their sensors to anticipate what the team needs.

PRACTICAL FINDINGS

After listing the relation between the two dynamic mechanisms, we find some instances where Stigmergy and Lean concepts diverge. However, there are more numerous examples that reveal convergence and dependence of the two concepts on one another. This shows that although the two models function differently, in reality they are not but interrelated. As a matter of fact, Stigmergy is a natural mechanism that is applied within Lean environments.

Practically, this overall dependent relation between Stigmergy and Lean can be helpful for implementing a Lean workplace as per TPS (Toyota Production System). The elements of Stigmergy mechanism can be deployed for faster and improved Lean applications. For instance, the state of the environment that is represented by the stimuli can be devised in a way to trigger the agents to learn more and improve (Kaizen). Also, the more the agents receive the right stimuli, the less the occurrence of negative iterations. Once stimuli appeal to the agent little effort and time will be wasted. Moreover, proper environment dynamics of the workplace, such as an enabling bureaucracy, can promote the long-term thinking. Enabling environments allow actors to work as one unit through cooperation. In addition, it empowers people to hold responsibility and take decisions.

The agent elements (sensors, actuators and dynamics) shall also be catered for as organizations embark on TPS principles. The visual systems must be designed to the sensations of their agents. The actuators can be trained for better reactions; for example, explicit articulation, collaboration and communication within teams and cross functional teams. Challenging people develops the human's innate dynamics which eventually renders the employees attentive to arousal of problems. The agent's dynamics can enhance a fast shift in the culture as Lean principles become adapted within the agent's biological programs. For example, construction sites can apply Lean practices if they train the laborers to analyze the sensory messages around them and to use them as guidance for work. This will decentralize the control of the ongoing activities and will shift the responsibility from the superintendents and site engineers to every laborer.

CONCLUSIONS AND RECOMMENDATIONS

Stigmergy is described as the coordination of different mechanisms that involves information exchange between different agents in a shared environment. Their actions are initiated due to the stimulus received from the environment or from other agents. Lean, on the other hand, represents a philosophy based on a long term thinking. Lean principles aim at optimizing the whole and not the parts to produce the desired value needed by the customer. We have discussed how the two independent systems are not but part of one another. The division of each concept into its elements or principles help us realize that Stigmergy and Lean interact in a positive net effect with one another. The mere realization of the natural Stigmergy mechanism can facilitate the incorporation of TPS and speed up the cultural shift required for Lean workplaces.

Future research can possibly utilize hardware technologies such as micro sensors for measurements of human interaction. Simulation techniques for design and analysis of human Stigmergy system are also recommended for future research. Is there an optimal pace of the Stigmergy mechanism to ensure a Lean workplace? What is the best Stigmergy type for development of Lean human culture? What can possibly hinder human Stigmergy interactions?

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