EDUCATING IN MODERN TIMES: THE COMBINATION OF HOLONIC MANUFACTURING AND SIX SIGMA

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Abstract
This paper proposes an innovative teaching methodology for the understanding of new operation theories such as Holonic Manufacturing and Six Sigma. Its goal is to contribute to the quest for quality, efficiency, and effectiveness in business education and industry.

This study provides useful insights about how to successfully create a "holonic" network to enhance quality systems in a worldwide setting. In the process of discovery and implementation of new philosophies for improvement, effective instruction represents the cornerstone for accomplishment. The findings include a suggested strategy that would be suitable for the direction, preparation, and education of the workforce. The advances in Holonic Manufacturing bring interesting obstacles to be overcome and a fresh, contemporary kind of leadership. Coordination is the key for achievement.

Holonic systems can vary and hold a different a view among diverse businesses. Interactions between networks can also fluctuate. This research has been completed for industry in general because its main purpose is to observe the applications of holonic structures in Six Sigma projects. The main objective of the Six Sigma philosophy is to control defects in a great deal of production processes and/or services. For instance, nowadays it is not uncommon to find Six Sigma schemes within healthcare, finance, and government or military projects. In that sense, this study analyses the application of holonic structures and proposes that they could be employed in general commercial endeavors.

This technical analysis pursues the important goal of discovering new industrial procedures and experiences for the international cooperation. Quality improvement is always an essential requirement. In addition, there is a continuous need for being acquainted with innovative methodologies. The purpose of this investigation is also to understand these theories as a contribution for the quest for success.

Keywords: Holon; lean thinking; Six Sigma; SIPOC (suppliers, inputs, process, outputs, customer segments); CTQ (critical to quality); CIM (computer integrated manufacturing) MAS (multi agent system).

1 INTRODUCTION

Hungarian philosopher Arthur Kostler conceived the term "holon". The concept originated in the field of Biology. A holon is a cell that performs its own functions, but at the same time forms a network with other cells to create a tissue. Later, the expression was utilized in computer science to refer to bytes and communication systems. Finally, the word holon was adopted by Operations Management and Supply Chain. Holons are work stations that achieve production and manufacturing goals by sharing information among them.

Holon is a combination of the Greek word holos, meaning whole, and the suffix on, meaning particle or part. Koestler observed that in living organisms and in social organizations entirely self-supporting, non-interacting entities did not exist. Every identifiable unit of organization, such as a single cell in an animal or a family unit in a society, comprises more basic units (plasma and nucleus, parents and siblings) while at the same time forming a part of a larger unit of organization (a muscle tissue or a community). A holon, as Koestler devised the term, is an identifiable part of a system that has a unique identity, yet is made up of sub-ordinate parts and in turn is part of a larger whole.' [Jarvis et al., (2008), p.7].

On the other hand, Six Sigma is the quality control approach by excellence. Under this tactic, the goal is to reduce, or possibly to eliminate completely, defects in production or services. Probably the most well-known methodology within Six Sigma is the DMAIC process, which means define, measure, analyze, improve, and control.
This article advocates for a direct application of holonic systems and DMAIC process in an academic setting. Students and professors construct these modern structures in a simulation that allows them to encounter the characteristics, benefits, and possible flaws of these tactics directly. The pedagogical advantages of this proposal are obvious. Through such an educational experience, pupils will be ready not only to participate but also to lead the application of holons and Six Sigma in industrial scenarios.

2 METHODOLOGY

This study comprises a literature review about holonic systems, computer integrated manufacturing, which is the preceding step of this new strategy, and Six Sigma. A review of the precepts of these philosophies is important as the cornerstone for an effective education in these models. Further, the same structures of holonic systems and Six Sigma, especially the DMAIC process, are simulated in a practical project in which students and professors interact to experience the benefits of these organizations. Primary sources of knowledge are crucial for a valuable pupil experience of “discovery”.

3 RESULTS

3.1 Holonic Manufacturing Systems and Computer Integrated Manufacturing

Computer Integrated Manufacturing is a versatile, automated technique designed to improve productivity. With CIM, it is possible to replicate fabrication situations to make the best possible decisions. This system is hierarchical and the plan is performed by the upper levels of command. CIM takes full advantage of technology to achieve efficiency in companies. Under this scenario, mechanization and computerization play an important role in manufacturing processes.

“The concept of integrated enterprise and the implementation and interoperability of networked enterprises are a key concept to face new challenges in manufacturing sector” (Hsieh and Lin, 2013, p. 3).

Holonic Manufacturing Systems (HMS) are quickly replacing CIM as the most flexible, resourceful, and modern techniques to be applied by factories. HMS allow a higher interaction of the workforce with computerized systems, therefore, achieving better results. The advantages of automation in speed and precision go together with the decision making that the workforce can provide. Since no one is a better connoisseur of the processes than the worker who completes the tasks day after day, the role of the employee is important and his or her interaction with automated systems is crucial in modern industry. Consequently, HMS could be considered more sophisticated than CIM and a step forward toward perfection. Antony et al. (2012) identify data management and communication systems as possible flaws within CIM systems. With the use of holons, which would benefit from multinational exchange, additional communication channels are opened and data are managed and shared in a more effective way.

Changes in the market and fast product lifecycles require strategies that are capable of satisfying needs and reacting to big fluctuations in demand. In that sense, global HMS, with efficient virtual team management, can exceed CIM in manufacturing applications by emulating multi agent systems (MAS), an entire programmed network with independent representatives capable of completing tasks. Hsieh (2008) acknowledges HMS as a flexible and decentralized architecture that is qualified to adapt and quickly respond to the many challenges of industrialized companies. Ulieru et al. (2001) consider MAS a suitable prototype for the execution of HMS. Hsieh (2008) expands such criterion by advocating for a combination of MAS with additional models. Such evocation is reiterated in his further research. “A promising approach is to combine MAS with suitable optimization theories and formal workflow models in agents to dynamically schedule the production activities” (Hiseh and Lin, 2014, p. 367).

The incorporation of MAS to commercial tactics offers gains of great magnitude. A manufacturing strategy, oriented to gain competitive advantage in a particular market, can arrange the working stations as holons and, consequently, use the network to measure and control defects in production or services, following the model of MAS. In industries, the holarchy can be a more sophisticated and efficient driving force than just the quality controller. In the same way, the several capable agents of MAS can achieve more complex tasks than the massive system based on a single instrument. Finally,
the virtual teams of HMS, acting coordinately and cooperatively, exhibit the benefits of decentralized systems.

Traditional centralized hierarchical organizations cannot effectively respond to rapidly changing demands, innovative production processes and highly dynamic business partnership in the supply chain because they do not fully exploit the benefits offered by advanced information and communication technologies. How to take advantage of the advancement of technologies to effectively support the operation and acquire competitive advantage is critical for enterprises to survive. To reap the potential technological benefits, new organizational structure and strategy must be developed to effectively manage the business processes/workflows, resources and changes in business environment to support inter-enterprise collaboration (Hsieh and Lin, 2013, p.1).

In accordance with these ideas, the Holonic Manufacturing Systems Consortium regards HMS as a more decentralized technique than CIM. Table 1 is a summary of features for both CIM and HMS in which the advantages of HMS appear to be greater than those of CIM.

Since HMS is the next step of CIM and given the greater participation of the human resource in processes, it is important to consider that global business can be easily performed with the use of holonic structures. The use of virtual teams for communication has paramount significance. In that sense, the organization and interface among cybernetic groups must adopt the flow of manufacturing stations. Hsieh and Lin (2013) identify a direct and an indirect interaction in such course. In the former one, members of the network send and receive information straightforwardly. In the latter, virtual teams act independently. CIM and holonic structures should be arranged under direct interactions.

3.2 Simulating a Holonic Manufacturing System for a Six Sigma Project in an Academic Setting

The best way to learn about holonic systems is by being part of one. A simulation can be performed in a classroom setting in which the instructor acts as the control unit and guides students to detect a problem area, manage a Six Sigma Project, and apply the necessary tools for quality improvement. “Multi-agent based distributed simulation is one of the most effective tools to model and analyze supply chains” (Hiseh and Lin, 2014, p. 367).

A suggestion for class would be to see each one of the DMAIC stages as a holon and have students interrelate and work together as part of an entire Six Sigma project. Apprentices will be divided into teams. Each group would constitute a holon with precise missions to accomplish. In other words, each team will become one part of the DMAIC scheme and perform the corresponding task of this Six Sigma methodology. Consequently, holons, with their corresponding duties, can be designed as shown in Figure 1.

In some projects, it is not obvious where the processes should focus. It is necessary to identify a crucial plan and complete it to solve a problem. Each team, or each holon, will contribute with information from the database. The work of all holons are integrated together to complete an entire Six Sigma project. An explanation of the information that each holon enters the internal database follows:

The Define holon will deliver these documents:

- Project Charter. It is a determination of the initial scope and team members who should be employed.
- SIPOC Map. It is a useful linear representation of the process. This tool can help to divide the project into manageable pieces.

In addition, companies achieve improvement and excellence through quality endeavors. A Six Sigma plan includes several instruments that can be used for successful results. After identifying the convenient project, the Measure holon will provide the following:

- Gantt charts. They show the relationships among assignments, along with time constraints.
- Milestone diagrams. They are Gantt charts that provide additional information about the project status.
- Pareto analysis. It is a technique designed to rank opportunities.
On the other hand, the Analyze holon will work on:

- **Budget.** This represents an itemized summary of expected expenditures for a venture and possibilities of funding.
- **Matrix charts.** They are created to examine the correlations between two groups of ideas.
- **Arrow diagrams.** These graphs denote project flows.

A very important analysis in the Six Sigma process is the Design of Experiments (DOE), which is a set of statistical techniques for studying independent variables (Xs) and their interactions (or factors) with a dependent variable (Y, or CTQ). Among the benefits of DOE, it is possible to state the following:

- Fewer experiments.
- Information about relationships between variables.
- Possibility to be expanded or contracted to suit requirements of the project.
- Optimization of products and processes.

In DOE, there are several types of analysis designs such as:

- **Screening Plans.** These are used to analyze a great deal of factors with a small number of experimental runs. They separate the crucial issues from the inconsequential ones.
- **Full Factorial Designs.** They are used to identify key variables. They also study interactions and main effects among a small number of factors (two to six).
- **Central Composite Blueprints.** They are used to analyze curvature, interactions, and main effects.

The Improve holon prepares and presents the quality improvement recommendations to process owners and operators. In the class setting, this team will draw conclusions.

Finally, the Control holon will deliver the Process Decision Charts (PDC), which are diagrams used to develop emergency plans, and the Quality Function Deployment (QFD), which is a system for the product design based on customer needs and preferences.

In short, this is a proposal for a practical learning in which students will simulate a holonic organization. Participants will suggest a systematic treatment of a group of variables and analyze the effects of changes. Significant conclusions will be drawn that will improve quality, reduce time and defects, and increase customer satisfaction.

Additionally, a holonic representation could bring good understanding and familiarity with another production technique that constantly seeks for coordination and synchronization in operations to avoid the waste in scheduling: Just in Time (JIT). “Given a set of customer orders and workflow constraints, each agent attempts to find a schedule to fulfill customer orders just-in-time and minimize the costs” (Hsieh and Lin, 2014, p.367).

### 3.2.1 Teaching a Six Sigma Holonic System in an Academic Setting

Karapetrovic and Willborn (1999) implemented ISO 9000 procedures into a university setting. Furthermore, these authors advocated for the integration of such quality standards with ISO 14001 for environment-oriented management. A different teaching approach is proposed in this paper. Instruction can be given on a one-hour per day basis for five days a week. A scholastic set for holonic systems and Six Sigma training would start with the traditional method: lecturing. It is important that students receive the theories that define the concepts to be learned. Literature review about holonic systems and the Six Sigma strategy would be offered. Four weeks of one-hour per day classes would grant students a good understanding of models, ideas, and prototypes. After this period, assessment will consist of a regular, conventional test.

The next week of instruction would include visits to five real production processes (companies). Then, apprentices, already divided into teams, will present the observations, recommendations, and lessons learned from such fieldtrips. The quantity and quality of presentations will be graded by the professor. In the evaluation, emphasis should be given to the strengths and weaknesses observed in each production process, how strongly the techniques learned in the first month of classes support the recommendations presented, and originality in the presentation.
The assignment of teams to their corresponding part of the DMAIC system will follow. A Six Sigma project, put together from the observations obtained during the company visits, will be given to students. Each group or holon will deliver the ‘internal database’ as it was exposed in Figure 1. The idea is to work together as a holonic, coordinated organism to draw conclusions and deliver results for company quality problems. The professor will be the ‘control unit’ (see Figure 1) of each holon, guiding and advising students. The appraisal of this part of the course, which is the most novel regarding teaching and the most important concerning knowledge acquired, will consist of the portfolio assessment.

Portfolio is a planned collection of learner achievement that documents what a student has accomplished and the steps taken to get there. The collection represents a collaborative effort among teacher and learner; to decide on portfolio purpose, content, and evaluation criteria (Kubiszyn & Borich, 2003, p.174).

This is a grading tool in which the professor will keep a detailed record of apprentices’ progress. The instructor will judge the quality of the deliverables; that is, the databases provided by holons (learners). The advantage of this appraisal method is the opportunity to provide updated feedback with which students will certainly learn from mistakes.

Table 1. Comparison CIM and HMS (obtained from the Holonic Manufacturing Systems Consortium, 2007)

<table>
<thead>
<tr>
<th>Computer Integrated Manufacturing</th>
<th>Holonic Manufacturing Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierarchical (systems based) structure with the goals of the enterprise known at the top level (N) and communicated down in the form of tasks to the next lower level (N-1)</td>
<td>Holarchical (function based) structure with the goals of the enterprise known at the top level and communicated down as sub-goals to the next lower level</td>
</tr>
<tr>
<td>Coordination and integration of efforts at level N through hierarchical control from level N+1</td>
<td>Coordination and integration of efforts at level N through cooperation and goal congruence of the holons</td>
</tr>
<tr>
<td>Master (N) Slave (N-1) relationships</td>
<td>Peer (N) to Peer (N) relationships Customer (N) Supplier (N-1) relationships</td>
</tr>
<tr>
<td>One (N) to many (N-1) communications -- Logical Tree Topology</td>
<td>Many (N) to many (N) horizontal communications -- Logical Bus Topology</td>
</tr>
<tr>
<td>Predominantly deterministic communication patterns and fixed message structures</td>
<td>Varying communication patterns and flexible message structures -- Universal encoding scheme with minimal prior knowledge required for interpretation</td>
</tr>
<tr>
<td>Low resilience to failures other than those compensated for by design (because of fixed relationships)</td>
<td>High resilience to failure through dynamic reconfiguration and task re-negotiation</td>
</tr>
<tr>
<td>Intelligence concentrated in the ‘top’ layers</td>
<td>Intelligence distributed where needed through encapsulation of processes and knowledge within holons</td>
</tr>
<tr>
<td>Efficiency through specialization: Allocation of standard (fixed) task to specialized resources</td>
<td>Effectiveness through flexibility: Standardized resources performing specialized (varying) tasks</td>
</tr>
<tr>
<td>Most efficient for high volume/low variability</td>
<td>Most effective for high-low volume/medium-high variability</td>
</tr>
<tr>
<td>Labor being replaced by automation (removing people from the production process)</td>
<td>Labor being complemented by automation (enhancing and extending the intelligence and capabilities of people remaining in the production process)</td>
</tr>
<tr>
<td>Focused on the factory</td>
<td>Applicable to all functions of the manufacturing enterprise</td>
</tr>
</tbody>
</table>
Define Team
- Review existing process documentation
- Set project objectives and plan
- Define and plan as-is process
- Review and re-define problem if necessary

Control Unit: Professor

Internal Database: Project Charter, Suppliers, Inputs in a Process, Outputs, Customer (SIPOC) Map

Measure Team
- Identify quality improvement or critical to quality characteristics of a product (CTQs)
- Collect data on subtasks and cycle time
- Validate measurement system

Control Unit: Professor

Internal Database: Gantt Charts, Milestone Charts, Pareto Analysis
Analyze Team
- Prepare baseline graphs on subtasks/cycle time
- Analyze time, value and risk management
- Design of experiments
- Benchmark other companies

Internal Database: budget, matrix charts, arrow diagrams

Improve Team
- Formulate improved process pilot
- Test the improved process pilot
- Analyze pilot and results
- Develop implementation plan

Internal Database: Recommendations to process owners and operators

Control Unit: Professor
4 CONCLUSIONS

It is an undeniable reality that business relations are global nowadays. Under that perspective, computer integrated manufacturing has always been an invaluable tool for virtual communication and team coordination, which are the keys for success. In that scenario, holonic manufacturing rises as an alternative of orderliness to pursue the goal of achieving “just-in-time” results.

Six Sigma and, even more, Lean Six Sigma, can be considered as suitable instruments to avoid “waste” in production and services, which is commonly known as “muda”. Any activity that does not generate value for the customer is considered muda.

By organizing themselves under a holonic structure and by following the steps of the DMAIC process, trainees discover the “secrets” for an effective utilization of these stratagems. In the future, when the apprentices receive the challenge of applying what was learned to industrial settings, not only they could lead real and crucial transformations of paramount importance in multinational business, but also suggest actions for improvement.

The regulator unit of the holon, the professor in this simulated setting, plays a significant role of leader. The team by itself is the executive arm of the project. The group acts as either the define, measure, analyze, improve or control phases in a Six Sigma assignment.

For optimal results, the accuracy and timeliness of information are vital. The internal database of the holon should achieve those objectives. Tools such as the process decision charts and the quality function deployment, among other common instruments like the value stream mapping, the Pareto chart and control diagrams, could be priceless in the exchange of data among virtual teams.

Holonic Manufacturing is a reality in industrial settings these days. In many cases, it can reduce lead times and operational costs. This paper has proposed its use in academia. A global training or education could benefit from knowledge trade. A well-organized network could share and accomplish diverse stages in the instruction of different fields by sharing videos, reviews, case-analyses, simulations, lectures, and evaluations worldwide. Professors and pupils can rest on one part of the world, but the development and progress of academic projects, shared virtually and globally, will never sleep.
REFERENCES


