APPLYING SYSTEMS THINKING AND ACTIVE LEARNING STRATEGIES TO A LEAN MANUFACTURING PROGRAM

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Abstract: Lean Manufacturing seeks to eradicate waste. This pursuit is conducted changing many pre-conceptions inherited from the mass production traditions. It is necessary to understand immediate and delayed impacts of the changes, as well as direct and indirect results of these changes. This systemic approach should enhance the learner's understanding of the system (the manufacturing company), its variables, its outcomes, and the relationships among the system's components. This paper presents the process of designing a course to teach Lean Manufacturing to working professionals using systems thinking. This design process is conducted for the development of job competencies and using Active Learning Strategies.

Keywords: Lean Manufacturing, Systems Thinking, Curricular Design.

1. INTRODUCTION

Lean Manufacturing is an already well known operations philosophy that focuses in reducing waste in operational and administrative processes to make them more efficient. It has evolved during 50 years in Toyota. In spite of Toyota's recent woes, Lean Manufacturing's principles and tools have been successfully applied in different companies around the world.

To achieve these objectives, it is necessary to keep a general look to find the real causes of waste, not only the symptoms but the root causes. Only an integral understanding of Lean Manufacturing as a system will achieve real productivity breakthroughs. Every lean tool and technique generates an impact on the company's performance and these relationships must be uncovered and understood.

The diffusion of Lean Manufacturing as an operations philosophy is still in its infancy in Colombian universities. Lean has only been a part of Industrial Engineering curricula since some five years ago. It is also taught in graduate programs related to Industrial Engineering and Management. Systems Thinking has been more widely taught in different universities and it is a mandatory class for many Industrial Engineering curricula. Also, Lean Manufacturing emphasizes on-the-job training, quick application of concepts learned. This makes it interesting to offer learning opportunities in these subjects to professionals currently working in operative areas. This paper presents the design of a lean manufacturing continued education program to present active learning opportunities to professionals working in operations.

The structure of the paper is as follows: In section two we briefly present main concepts related to lean manufacturing, systems thinking and the methodology that was chosen for curricular design. Section three presents the curriculum development process for the program, and section four presents the contents and learning activities for the course. Finally, in section five the main learning achievements that students should attain are presented, and some questions for future research are outlined.

2. BACKGROUND

2.1. Lean Manufacturing

Lean Manufacturing needs no introduction in the operations community.It is an operations philosophy developed by Toyota. This philosophy and its associated techniques came to be due to the constraints and requirements brought upon Toyota due to its market, the resources available and demands from the banks and the government of Japan.

A lean manufacturing implementation model (Rivera, 2008) is presented in Figure 1.

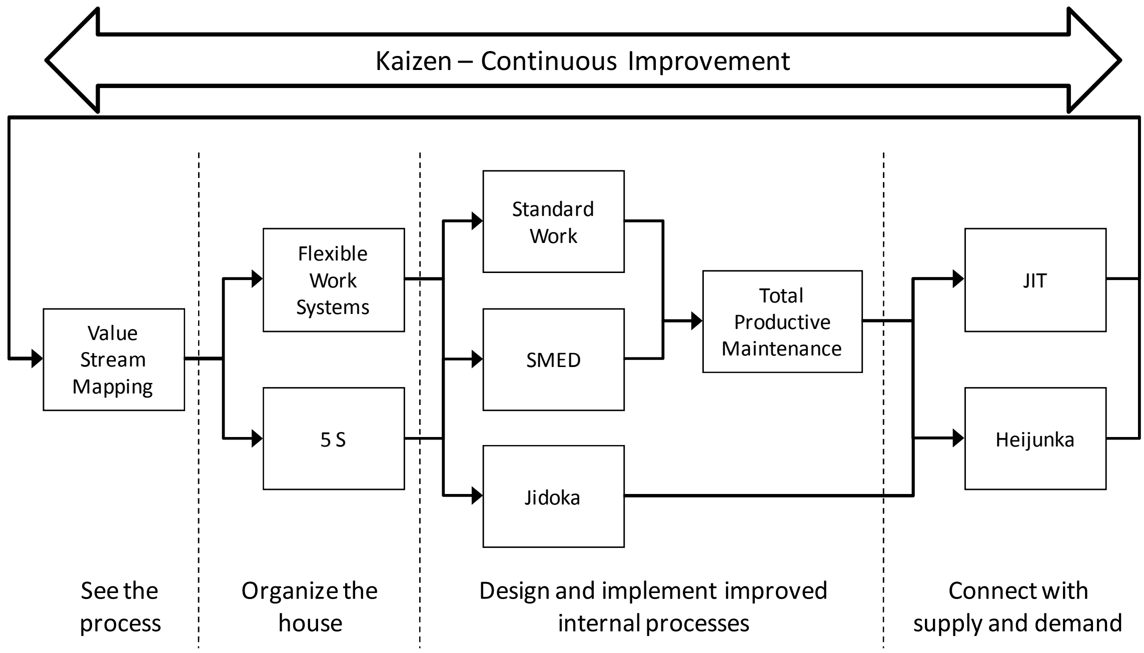


Figure 1: Lean Manufacturing implementation model (Rivera, 2008, adapted from Groesbeck, 2006).

The names in the boxes are the techniques associated with lean manufacturing. The learning program would present the philosophical framework, the characteristics of the techniques and enable students to discover and identify the relationships between techniques, critical company variables and functional areas. A quick reference to the key terms follows:

- *Kaizen:* It is the discipline of continuous improvement. It is the continuous accumulation of small improvements made and sustained by all employees.
- *Value Stream Maps:* These are high level visual representations that show the flow of materials and information through the manufacturing process.
- *5S:* These are five key concepts to implement cleanliness, order and discipline in any company. They are so called because the five Japanese words that designate the techniques all begin with the “S” sound.
- *Flexible Work Systems:* It refers to the grouping of resources, people and product families in workcells. This grouping leads to multi-skilled workers that, with the right management style, develop responsibility and autonomy in their processes.
- *Standard Work:* To make continuous improvement practical, it is necessary to implement a system where best practices are documented and standardized. This enables maintaining improvements, training and learning.
- *SMED (Single Minute Exchange of Die):* This is a set of principles and tools applied to reduce the time required for setups when there is a change in the product being manufactured.
- *JIDOKA:* This is the error-proofing of the methods, equipment, tools and products to ensure quality in the manufacturing or services processes.

- *TPM (Total Productive Maintenance):* TPM aims to transform the time "wasted" in maintenance into "productive" time. Its main goal is improving process reliability and availability through autonomous maintenance and 5S implementation.
- *JIT (Just in Time):* As its name implies, it means making and moving the precise amounts of materials at just the right moment. It seeks to avoid accumulation of WIP (Work In Process) and to smooth out the flow of materials through the system.
- *HEIJUNKA:* It is the search for smoother production flow through the scheduling of production lots that reflect the real proportions of demand in the smallest increments that are possible.

These different techniques are well documented; for further information the reader is referred to Ohno (1998), Womack et. al. (1990, 1996), Shingo (1985, 1986), Monden (1998), Villaseñor and Galindo (2007a, 2007b) and many other useful Lean Manufacturing materials.

2.2. Systems Thinking

Many of the entities found in daily life are systems. In a certain situation there are input variables, components interacting under certain rules, desired and undesired outcomes, and great efforts and resources are invested in knowing, understanding and predicting the behavior of these systems to achieve the desired results. Systems Thinking is a System Dynamics tool that allows the understanding of a system's behavior through the identification of rules, patterns and events. Thanks to the knowledge of these elements it is possible to assert more control over the system, plan for its future evolution and influence and modify the elements of the system and their interactions.

Systems Thinking must break with traditional approaches that follow a “logical” behavior characterized by three main deeply held beliefs:

- Cause and effect are separated and the effect happens after the cause.
- The effect follows the cause both in space and time.
- The effect is proportional to the cause.

For Systems Thinking, these relationships are not necessarily true. An effect can be the future cause of further effects in a cyclical pattern. This is why a systemic outlook must analyze the secondary effects of a change in an element of the system, because it can have an impact that is not expected under a traditional approach.

2.2.1. System Complexity: Every system rests in the interactions between the parts that make it up, therefore, the relationships between the system’s elements and their influence on each other are more important than the number of parts in the system or the dimension of these elements (O’Connor and McDermott, 1997). *Detail complexity* is the amount of parts that comprise a system, pieces on a puzzle. *Dynamic Complexity* refers to the manner in which system elements relate to each other. A system is considered a complex one when both kinds of complexity are high, because it contains many different parts, theit interactions are rich and any action can have diverse impacts and results.

2.2.2. Feedback loops: Sometimes an action can have an impact that later will reflect over itself. The behavior of subsystems can be presented in feedback loops that are the “system’s reaction that regenerates in the form of a stimulus or return information that influences a subsequent step” (Op. Cit., p 51). These feedback loops can be

- *Positive reinforcement loops*, where a change spreads throughout the system creating more changes in the same direction, amplifying the cause from which everything started. This behavior can lead to virtuous or vicious cycles.
- *Negative reinforcement or balancing loops* are those in which changes in the system oppose the original change and therefore dampen its effects.

2.2.3. Causal Diagrams: One of the most useful (and therefore preferred) tools to present and understand systemic behavior is the Causal Diagram. These diagrams are useful to show internal system variables, outside forces, delays in behavior and other system components in such a way that it is possible to observe the effect they have on each other. Emergent behaviors and reinforcement loops become visible in this way (Figure 2).

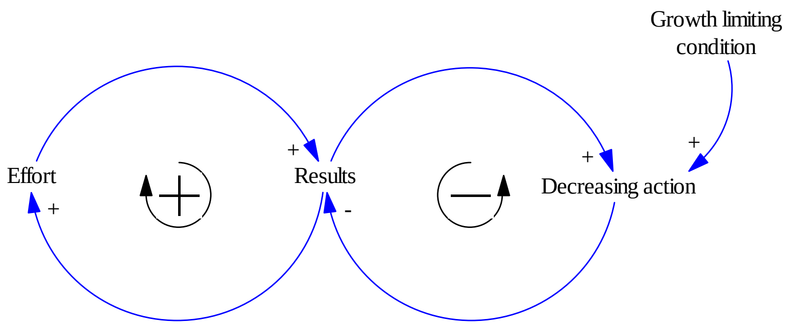


Figure 2: Causal Diagram

There are many other aspects in Systems Thinking. However, the main tool used as an educational resource was the causal diagram. For further Systems Thinking and Systems Dynamics reference the reader is directed to Sterman (2000).

2.3. Curricular Design Paradigm

The third distinctive element of the learning experience presented in this paper is the paradigm of curricular design under which the course was developed. Its two main points are Active Learning and the Constructive Alignment Model.

2.3.1. Active Learning: The Active Learning paradigm was chosen with the conviction that “no one can really impart knowledge into someone else. Each individual will build his/her own knowledge; educators and institutions can do little more than designing and administering the contents and learning experiences through which the students will make knowledge their own” (González, 2003). In a traditional, lecture-based learning model, students are passive subjects that come to the class to witness a “show”, a presentation of some sort that will (hopefully) help them to store key concepts and material into their memory. Application and connections are left for homework, projects and the student’s own ability to make connections and generalizations. In Active Learning, the instructor designs and delivers learning experiences that give the student her autonomy back. Each student will then construct their own knowledge through study, reflection and experience.

To achieve these ends, it is important to present students with a combination of activities and experiences that stimulate them to go beyond content memorization. González (2003) suggests some specific points:

- Relate material to the what was previously discussed and to the material yet to come.
- Balance concrete information (facts and data) with abstract concepts (principles and theories).

- Present material that emphasizes practical problem-solving methods and material that stresses fundamental principles.
- Use drawings, schemes, conceptual maps in all phases of material presentation. Have students develop their own graphs and maps to *explain* learned material.
- Use activities such as paired and group work, practical discussions, problem solving, computer simulations, dynamic and experiential exercises, in-class and out-of-class projects, oral presentations and written documents to support learning and experimentation of the skills that are in play in each class.
- Traditional lectures should not be the main class resource. They should be used to introduce new concepts, solve doubts and integrate issues and conclusions of the exercises that have been conducted.

2.3.2. Constructive Alignment: This model is used to build a curriculum at any level of detail, be it the individual class or a whole program of studies. It is based on a *constructivist* view (active learning is a constructivist philosophy) used for outcomes-based education (Figure 3).

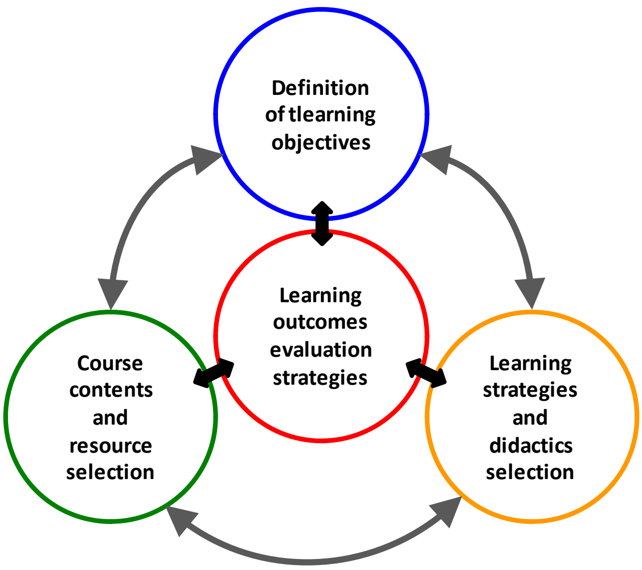


Figure 3: Constructive Alignment Model (Biggs, cited in Bahamón, 2007)

The curriculum design steps are as follows:

- *Definition of objectives:* Learning objectives tell the student what he is expected to achieve in terms of content and abilities (terminal objectives) and what steps must be taken to accomplish them (specific objectives). “Learning objectives define the behaviors or actions that students will be able to perform at the end of a course” (Bahamón, 2007).
- *Definition of learning elements:* Each learning objective must be defined in terms of three main knowledge categories: to know the material (grasp concepts), to know what to do with it (acquire abilities) and to know how to “be” (change in attitudes and personal behaviors).
- *Selection of contents and resources:* After the definition of the learning elements and their sequence, contents and resources required to achieve each element are chosen and designed.
- *Definition of learning strategies:* The “how” of learning experiences is defined here. It is necessary to define course activities that support the learning elements and their contents and resources in such a way that active learning principles are upheld. The instructor must choose at this point readings, class discussions, practical projects, field visits, presentations and other activities.
- *Design of evaluation strategies:* A moment of evaluation must also be a moment of learning. Evaluation strategies must be coherent with the objectives, elements, materials and learning strategies that have been previously defined. “The fundamental purpose of evaluation is to obtain information to guide the student in such a way that he/she can achieve the learning objectives for the course” (Bahamón, 2007).

3. DEVELOPMENT OF A COURSE TO TEACH LEAN MANUFACTURING USING SYSTEMS THINKING

3.1. Definition of the students' profile

Learning objectives must be defined according to the needs of the student towards whom the program is directed. In this case, since it is a Continued Education class, the student profile was defined as *Professionals in Logistics and Manufacturing areas, between 22 and 40 years of age. This program could be offered open to people from different companies, or a as a closed, in-house program for a specific company.*

3.2. Definition of the learning objectives of the course

The main categories of objectives (course, terminal and specific) were defined for the subject and student profile for this case:

3.2.1. Course Objective: At the end of the course, the students will be able to configure lean manufacturing-based improvement projects that are systemically desirable for their companies.

3.2.2. Terminal and Specific Objectives: Terminal (T) objectives present the main abilities the student will acquire during the course, and Specific (S) objectives detail how terminal objectives will be achieved.

A. (T) At the end of the course, given a real or hypothetical situation, the student will be able to find the main problem issues based on lean manufacturing principles.

    1. (S) At the end of the course, the student will be able to explain the philosophy of lean manufacturing, identifying the causes of waste, and the concepts of production flexibility and pull

2. (S) At the end of the course, the student will be able to interpret and apply the philosophy of lean manufacturing in different scenarios.

B. (T) At the end of the course, the student will be able to explain lean manufacturing techniques and explain their applicability in hypothetical or real situations.

   1. (S) At the end of the course, the student will be able to describe the fundamentals and elements of lean manufacturing techniques.
   2. (S) At the end of the course, the student will be able to predict and analyze the results of the implementation in an operations system.

C. (T) Given a real or hypothetical scenario, the student will be able to describe and analyze the behavior of the operations system with the interactions between lean manufacturing techniques and managerial decisions, and the results of the internal and external system variables performance.

   1. (S) At the end of the course, the student will be able to describe relationships between lean manufacturing techniques.
   2. (S) At the end of the course, the student will be able to design a causal diagram relating the main lean manufacturing techniques and performance variables of the operations system.

D. (T) At the end of the course, the student will be able to design a systemic, lean manufacturing-based plan of improvement from his work position.

1. (S) At the end of the course, the student will be able to analyze her current work position, identifying opportunities for improvement to reduce waste and enhance value creation.
2. (S) At the end of the course, the student will be able to create a Lean Manufacturing implementation plan, considering the organization's systemic behavior to direct efforts in the most productive way.

3.3. Selection of course contents

Contents were chosen taking into account that they should cover all the concepts necessary to achieve the learning objectives. An extensive literature review was conducted, taking advantage of material used in previous lean manufacturing classes. For the systems thinking subjects, the instructor who teaches the graduate courses offered his insight and materials.

Contents and materials are shown on several tables following next. Knowing the concepts and knowing what to do with them are presented in the tables; knowing what "to be" is still under development for this subject.

Table 1: Deployment of subject units for the course

Learning objective A1: At the end of the course, the student will be able to explain the philosophy of lean manufacturing, identifying the causes of waste, and the concepts of production flexibility and pull	
Knowing the concepts	**Knowing what to do**
Lean Manufacturing philosophy: History, context and objectives.	
Understanding the concept of waste	Analyze a case study and identify the main causes of waste.
Production flexibility and pull system.	Illustrate variability, dependency and Pull connection.
Learning objective A2: At the end of the course, the student will be able to interpret and apply the philosophy of lean manufacturing in different scenarios.	
Knowing the concepts	**Knowing what to do**
Success stories in other companies: • Countries • Industries • Companies	Analyze and compare lean manufacturing applicability un service industries. • Waste, Flexibility • Inventory level • Pull system

Learning objective B1: At the end of the course, the student will be able to describe the fundamentals and elements of lean manufacturing techniques.	
Knowing the concepts	**Knowing what to do**
Value Stream Mapping: • Basic concept • Simbology • Elements of analysis	Build a VSM in an actual process in their company.
5S: • Concepts • Tools • Application • Examples • Visual management	Analyze one's working space following 5S steps: • Sort • Straighten • Sweep • Standardize • Sustain
Kaizen: • Continuous improvement • Suggestion systems • Recognition • Training	Propose participation and recognition systems that promote idea generation and teamwork.
Flexible work systems (cells): • Multi-skilled workers • Line balancing • Takt-time- Pitch • Product families	Cell design following algorithmic procedures Cycle time calculations, number of workers, cell capacity. Takt time and pitch calculations.
Standard Work: • Times • Specifications • Processes	Explain the importance of standard work for process quality and efficiency. Use the Standard Work combination worksheet.
Jidoka: • Concept • Poka Yoke • Andon • Autonomation • Source inspection	Detect opportunities for error prevention and correction in work processes and product use.
SMED: • Concept • Internal/external activities • Implementation	Design improvement differentiating internal and external setup activities. Identify technical alternatives to reduce internal setup.
TPM: • Concept • Types of losses • Preventive engineering • Maintenance types	Explain the importance of autonomous maintenance and its importance in the production process. Describe different types of losses associated to the state of machines and possible solutions.
Just in Time: • Continuous flow • Inventory levels • Kanbans	Design a manufacturing system that includes visual controls and use of kanbans.
Heijunka: • Concept	Use a Heijunka box to level production based on demand. Evaluate costs and benefits of scheduling production with this tool. Analyze the conditions under which this technique is useful.

Learning objective B2: At the end of the course, the student will be able to predict and analyze the results of the implementation in an operations system.	
Knowing the concepts	**Knowing what to do**
	Describe the advantages and limitations of the Lean Manufacturing techniques.
	Analyze the company's conditions and design the implementation plan for these techniques.

Learning objective C1: At the end of the course, the student will be able to describe relationships between lean manufacturing techniques.	
Knowing the concepts	**Knowing what to do**
Prerequisites of the techniques	
Advantages of the implementation of a technique for the implementation of other techniques.	

Learning objective C2: At the end of the course, the student will be able to design a causal diagram relating the main lean manufacturing techniques and performance variables of the operations system.	
Knowing the concepts	**Knowing what to do**
Basic systems thinking concepts: • Causal diagrams • Feedback and reinforcement • Direct and inverse relationships	Design a causal diagram where the main lean manufacturing techniques and the internal and external variables of an organization are related. Analyze: • Relationships • Feedback loops • Balancing loops • System behavior • Outcome prediction

Learning objective D1: At the end of the course, the student will be able to analyze her current work position, identifying opportunities for improvement to reduce waste and enhance value creation.	
Knowing the concepts	**Knowing what to do**
	Starting from the Value Stream Map, analyze the process of value addition, considering: • Flow of information • Material flow • Production planning and control • Inventory • Times • Transportation
	Evaluate current conditions of one's work position to detect opportunities for improvement.

Learning objective D2: At the end of the course, the student will be able to create a Lean Manufacturing implementation plan, considering the organization's systemic behavior to direct efforts in the most productive way.	
Knowing the concepts	**Knowing what to do**
	Design a Lean Manufacturing implementation plan taking advantage of the systemic comprehension of its tools.

3.4. Selection of learning strategies

Learning strategies were selected under the constructive alignment methodology. These strategies will enable the student to achieve the categories of knowledge presented in the previous tables.

For *knowing the concept*, the main strategy will be the directed individual study of bibliographical material that is relevant for each subject. The material will be discussed in class through questions and examples. For *knowing what to do*, different strategies were defined, such as games, debates, case studies, supervised practices and design of causal diagrams. As an example, **Table 2** presents the learning strategies for each learning element in Learning Objective A1, along with the assigned readings for the subject.

Table 2: Learning Strategies for Objective A1

Learning Element	Material	Learning Strategy
Knowing the concept		
Lean Manufacturing philosophy: History, context and objectives.	*Pensar al revés* Chapter 1: El espíritu Toyota (Spirit of Toyota) Chapter 4: Subcontratismo y rentas relacionales (Subcontractors and relational revenues) *Manual de Lean Manufacturing, Guía Básica.* Chapter 1: La historia de la Manufactura esbelta (History of Lean Manufacturing).	Individual directed study: Students must perform analytical reading over assigned materials to comprehend main concepts. Class discussions: Debate about questions and viewpoints from the students. Use real examples where the application of the proposed subject is shown.
Understanding the concept of waste	*Manual de Lean Manufacturing, Guía básica* Section 2.3: Desperdicios (Waste)	
Production flexibility and pull system.	*Competitive Manufacturing Management* Chapter 8: Pull production systems	

Learning Element	Material	Learning Strategy
Knowing the concept		
Analyze a case study and identify the main causes of waste.	*Competitive Manufacturing Management* Case in point: agility at prince castle p. 96 Case in point: Toyota production system – Lean Production and JIT prototype p. 13	Case studies: Based on an instructor-assigned case the students apply their knowledge on different kinds of waste to identify problems and possible solutions. The game of the matches.
Illustrate variability, dependency and Pull connection.		

In the following paragraphs some examples of learning strategies will be presented to illustrate the activities that will take place during the class and after it.

3.4.1. Directed individual study: This relates to the reading of the class materials following a study guide assigned by the instructor. The guide is designed to stress important issues and highlight the takeaways the student should acquire on a certain material.

Reading Guide 1: "Pensar al revés" from Benjamín Coriat

UNIVERSIDAD ICESI

Faculty of Engineering
Industrial Engineering Department

Material:
Chapter 1 "El Espíritu Toyota" (The Spirit of Toyota) pages 19-38
Chapter 4: "Subcontratismo y Rentas Relacionales" (Subcontractors and relational revenues) pages 98-123

Rules of the assignment
This assignment has a maximum length of three pages.
Please be very observant of the document's length. Also, be rigorous with the source. It will not be acceptable to present a verbatim copy of the material if it is not duly cited. The instructors are interested in you making a good reading of the material and being able to understand correctly the author's ideas.

Questions.
1. What is the "Spirit of Toyota"?
2. In your own words, describe the fundamental differences between what the author calls "Fordism" and "Ohnism".
3. Why is it important to know the history of the spirit of Toyota?
4. In 100 words, present the main ideas of the author on the subject of subcontractor relationships.
5. In 100 words, present the main ideas of the author on the subject of inter-company relationships in Japan.
6. Discuss advantages and disadvantages of these subcontractor relationships. Would they be viable in Colombia?

Figure 4: Example of a Reading Guide for the course

3.4.2. Supervised Practices: These are a controlled, scaled-down representation of possible situations where theoretical concepts would be applicable. This strategy is applied to lean manufacturing techniques, because it allows the student to transform knowledge of concepts into a practical ability, into knowledge of what to do with the theory. Eight different practical experiences were designed for this course; **Figure 5** presents just an example, The Game of Matches (adapted from The Goal, Goldratt

Supervised Practice: "THE GAME OF MATCHES"

Faculty of Engineering
Industrial Engineering Department

UNIVERSIDAD ICESI

Subject: Waste

Objective: To show the effects that variability and dependency can have on a system.

Materials:

- 2 dice
- 4 boxes of matches

Procedure:

1. Two groups of 10 people are formed.
2. A member of the group rolls a die 100 times and records the average points. This should (theoretically) be 3.5 for a fair die.
3. The instructor tells the groups that the die represents their average production capacity.
4. Each teams then makes up a production line with 10 stations. The first person will take as many matches from a box as the points obtained in a roll of the die. The second person will then be able to process as many matches as the points obtained in their roll of the die. If he gets more points than the available WIP, he will only process whatever units are available. If he gets less points than the available amount of material, he will only process whatever he obtained in the die.
5. The instructor then proposes a wager to the group: If they can produce 36 or more matches in 10 rounds of the whole line, he will buy them a case of wine (or pay for dinner). If they can at least get 35, the instructor offers a solid A as a grade for the whole group.
6. At the end of the 10 rounds, each team will document how many units could they get through the whole process and how much WIP was left.
7. Each team must generate the conclusions of the activity and share them with their classmates.

Figure 5: Example of supervised practice.

3.4.3. In-class Exercises: In class exercises are conducted with combinations of individual and group work. Their objective is to have the student apply concepts and techniques that have been discussed (or some others that have not been discussed yet) to develop a concrete skill.

Some skills that students should acquire in this course are the calculation of production capacity of a work cell, takt-time and pitch, number of machines required on a cell and some others. **Figure 6** presents an example of an in-class exercise.

In-Class Exercise. Subject: Cells

SuperLean Ltd. manufactures its main product, SuperBroche, in a six-workstation cell. The image of their cell is shown in image one.

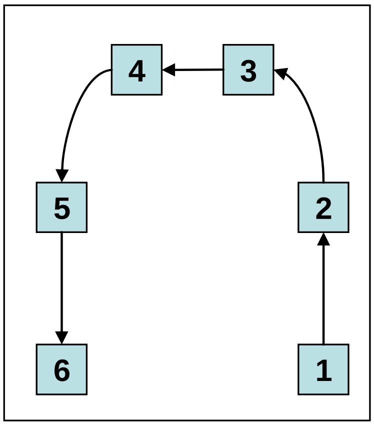


Image one: Production cell in SuperLean Limited.

SuperLean Works daily from 7:00 a.m. to 3:00 p.m. Employees have a break from 9:00 to 9:15, have lunch from 11:30 to 12:00 and have a coffee break from 1:45 to 2:00 p.m. Machine and activity times are presented in Table A.

Table A: Machine and operator times in SuperLean Limited

Workstation (times in seconds)	**Unloading**	**Loading**	**Setup and fixtures**	**Processing**
1	10	7	10	37
2	10	9	7	27
3	12	4	10	20
4	8	5	6	22
5	15	8	8	28
6	6	10	9	32

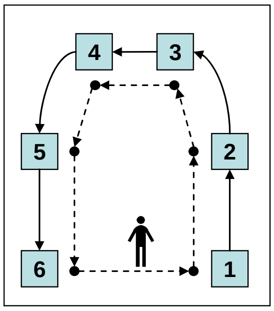
Work is performed in the following fashion: The operator arrives to the machine (that has already stopped), *unloads* the unit that was processed in that machine and sends it to the next destination, *loads* the next product unit, *sets the unit up* in the machine, and when *processing* starts he walks to the next workstation and leaves the machine running with the unit he just loaded (he does not stay in a workstation while it processes the unit of product). When he gets to the next workstation he repeats the same cycle.

Walking times from one station to another are shown in Table B.

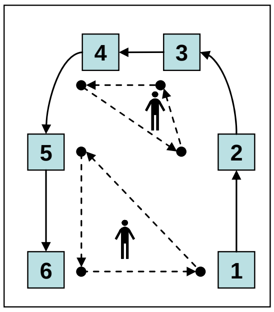
Table B: Walking times between workstations

Walk between stations (seconds)	**1**	**2**	**3**	**4**	**5**	**6**
1	-					
2	6	-				
3	11	5	-			
4	13	8	4	-		
5	9	5	8	5	-	
6	5	9	13	11	6	-

1. ¿How many units could this cell process per day if it is run by just one operator?



2. ¿How many units could this cell process per day if it is run by two operators?



3. ¿How many units could this cell process per day if it is run by three operators?

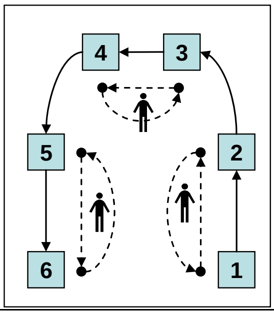


Figure 6: Example of an in-class exercise

3.4.4. Design of causal diagrams: This learning strategy is probably the most important and distinctive one from this course. One of the first skills that are developed during the course is the construction of these diagrams to help students uncover relationships between techniques and company variables. They are built towards the end of each of the subjects as a way to solidify learning of the concepts and improve complexity management on the students. An example of a student-designed causal diagram (presented with permission from the author) can be seen in **Figure 7.**

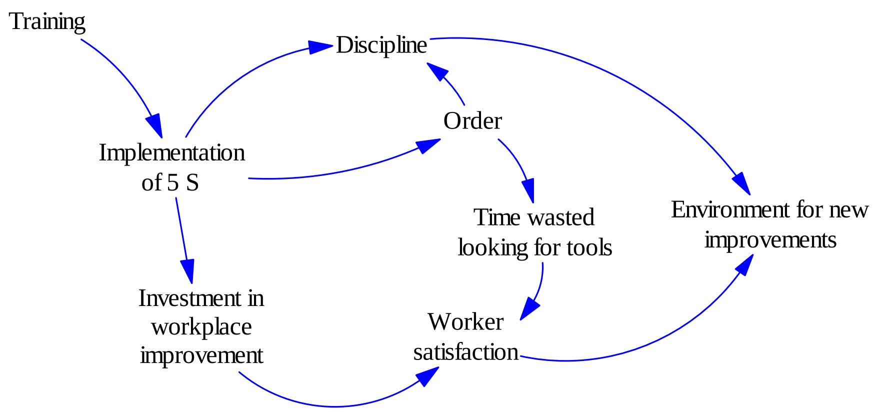


Figure 7: Student-designed causal diagram for 5S

3.5. Evaluation strategies

Moments of evaluation should also be moments of learning. Therefore, evaluations were designed for each subject unit in such a way that they measure the achievement of objectives as they were expressed in this curricular design. This also makes the whole process of the course to be consistent, coherent and fair. An example of an evaluation strategy for Objective A1 is presented in **Table 3.**

Table 3: Evaluation strategies for learning objective A1

Elements	Evaluation strategies	Performance criteria	Application
Knowing what to do	Case study solution	The student faces problematic situations that go against lean manufacturing philosophy. The solutions proposed by the students are consistent with lean manufacturing principles, including relevant issues about waste, production planning and control and other subjects that are presented in the case..	Class time

4. CONCLUSIONS – WHAT HAVE WE LEARNED?

4.1. Systemic relationships between lean manufacturing techniques and system variables

Towards the end of the course, we devote one and a half sessions and also some out-of-class work time to the development of a causal diagram that includes the major lean manufacturing techniques and some of the high-level system variables. It has been observed that never two diagrams from different groups look complete alike; however, the heart of the relationships and connections is always present. Then an additional task is assigned; it consists of the explanation of the main relationships in the causal diagram through some paragraphs of text. During this assignment students realize how hard it is to put in (linear) text what has been understood systemically; yet, they realize that the ability to convey systemic meaning to others must be developed. It is not a given that other people will automatically understand their systemic diagrams in the same way they do. At the same time, students realize that trying to understand and explain these relationships **without** having done the diagram first would be close to impossible in the first try. The universal comment that students make is that systemic diagrams and systems thinking have given them tools to better handle complexity and to make them more apt to communicate their intentions to implement lean manufacturing in their companies. Many times they are in charge of these types of improvement projects and have felt under-prepared because they had the intuition related to the complexities of the problems they would face, but were incapable of explaining them.

A typical causal diagram that was designed during a class and then improved upon by the instructors is shown in **Figure 8.** Note that main Lean Manufacturing techniques are presented in upper caps letters.

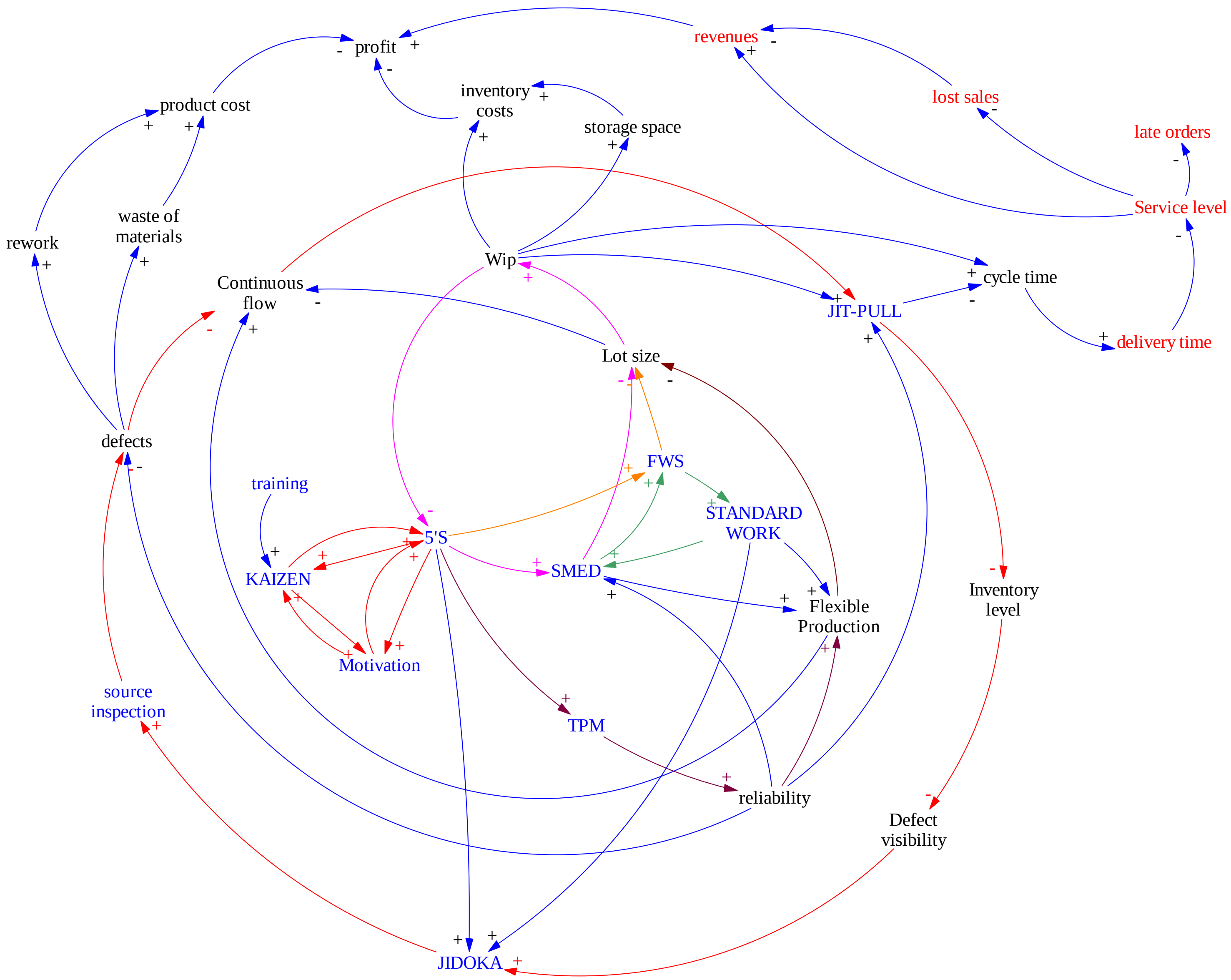


Figure 8: Typical Causal Diagram for Lean Manufacturing techniques

4.2. Instructor's guide for this course

Due to the engineering-friendly paradigm of curricular design that was employed, once the whole design of the course is completed, it is easy to configure an instructor's guide to replicate and improve upon this course. It is the intention of our faculty to develop specific versions of this course for target industries in our region (sugar cane, pharmaceuticals, paper and printing), and to have a group of faculty members that are trained to conduct this course and improve upon it.

4.3. Future Research

Based on the learning gained with the design and teaching of this course, it seems promising to develop an intervention methodology to consult for companies. Lean manufacturing implementations in Colombia are still few and far between, so a tool such as this one could increase the understanding of the people of the company, their ability to manage their own transformations, and thus become a more successful and repeatable consulting offering.

Also, more in-depth courses will be designed. The next target might be a research-oriented course for the Master's Program in Industrial Engineering, and maybe a joint offering for the Ph.D. program in the leading public university of our region. A more in-depth immersion in the techniques and quantification of variables and their behavior would be next. Maybe even the development of system dynamics models with simulation of a system's evolution could be the focus of a research-oriented course.

The authors believe that systems thinking, along with the paradigm for curricular design that was used would be a great pair of tools to teach any subject in engineering that transforms systems such as companies or operative areas. Probably subjects such as the design of distribution networks starting with logistics strategies could be another type of subject suitable for this design approach for learning courses.

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