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Integrating the Theory of Constraints and Six Sigma in Manufacturing Process Improvement

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Abstract**—**Six Sigma is a well known discipline that reduces variation using complex statistical tools and the DMAIC model. By integrating Goldratts's Theory of Constraints, the Five Focusing Points and System Thinking tools, Six Sigma projects can be selected where it can cause more impact in the company. This research defines an integrated model of six sigma and constraint management that shows a step-by-step guide using the original methodologies from each discipline and is evaluated in a case study from the production line of a Automobile engine monoblock V8, resulting in an increase in the line capacity from 18.7 pieces per hour to 22.4 pieces per hour, a reduction of 60% of Work-In-Process and a variation decrease of 0.73%.

Keywords**—**Constraint Management, Manufacturing Process Improvement, Six Sigma, System Thinking.

I. Introduction

THROUGH Six Sigma, companies like Motorola, GE, Kodak or Sony, have created a trust in current and potential customers that any product or service obtain by them will have good quality. A major drawback of Six Sigma, is that for the process to be completed, most quality problems have to be resolved with the purchase of tools, machinery, technology, or just a significant amount of investment, which can be a painful issue for a small company. Other weakness of Six Sigma is the fact that there are so many potential projects to choose from, and the desire to reduce variability everywhere makes it hard to choose the project that will make a significant change, which makes it critical for a company that can only consider limited budget for an improvement program.

In this paper, a strategy will be shown using a merger between the strategy utilized by Six Sigma, along with its resourceful tools, and the focus points used in Constraints Management for companies or businesses that have the need to improve not only the quality of their products and services, but their production lines´ efficiency and productivity as well. An integrated model will demonstrates the path to encounter environments where financial resources are limited, or the line is not profitable enough to program a full Six Sigma project that will solve problems with a large budget on a product that returns very little dividends to the business.

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II. Literature Review

A. Six sigma

Six Sigma uses a set of statistical tools as their main weapon to fight variability inside the company. These statistical tools help measure and analyze the areas with the most variation in the process. Variation is a normal element of any company, so Six Sigma will not eliminate variation, it will reduce it as much as possible. Six Sigma uses a set of statistical tools as their main weapon to fight variability inside the company. These statistical tools help measure and analyze the areas with the most variation in the process. Variation is a normal element of any company, so Six Sigma will not eliminate variation, it will reduce it as much as possible.

Many project teams have models that aid to approach them; these methodologies are guides or manuals that resolve a problem due to variation. According to Gitlow and Levine [1] the most common model or strategy followed by teams is the DMAIC (Define, Measure, Analyze, Improve, Control), this method follows a guideline that lets the project team know what and when are the statistical tools used, as well as other tools that are used to understand priorities of the project according to the variation and effect to the company.

B. Constraints Management

The theory of Constraints converted form a manufacturing scheduling method to a management philosophy that focuses on systems improvement. The best way Dr. Goldratt [2] explained a system is through a chain, he said that the chain is worth the strength of the weakest link found, it does not matter if all the other links are strong enough, the system or chain will break at the moment the weakest link is forced. The system chain extends form market demand to suppliers; everything that interacts with the industry can be the weakest link. The Theory of Constraint suggests that the weakest link gets found by upper management and controlled to a point that everything works around it. The tools designed to analyze the process through TOC, fall mainly in the name given, Systems thinking. Schragenheim [3] mentions that to understand a process, management must always look at it like a part of a system, and every decision can change the route of the system. These Systems Thinking tools are used around or prior to the process or strategy to implement TOC begins. In order to properly implement the Theory of constraints in a company or industry, a strategy is needed, and CM calls it the Five Focusing points.

i. Identify the Constraint
ii. Exploiting the Constraint
iii. Subordinating the Constraint
iv. Elevate the Constraint
v. Back to step 1, but watch for Inertia.

C. *Combination of Disciplines*

Eventhough Six Sigma and Constraints management have different philosophies; several industries complement one methodology in their business or use both methodologies to solve their needs. In one side we have Six Sigma that can solve complex problems that requires deep solutions, and in the other hand we have Constraints Management that can unveil bottlenecks in the system and expand them. Nave [4] makes mention of the most common integration used by these two disciplines, which consists in identifying the constraint of the company, and once the system is located Six Sigma will take over the link to reduce variation or resolve the problem. This methodology makes sense in which, looking at a system overview, the bottleneck should be the first area where a Six Sigma project should put its interest, since it is in this area where it hurts the most and more profit should be obtain from a successful project. Another upside to this implementation is the individual tools from each method combined together, for example, the bottleneck will have the benefit of being analyzed, measured and control by data analysis and graphics that will expand the understanding of guidance. Other example is the fact that the Six Sigma project will not be chosen or measured in only one area of the business, the project will be guided by a systems thinking provided by the TOC that will connect the interaction and results of the project throughout the entire system, clarifying more effects that can be caused by the project. However there is always the uncertainty of knowing if the combination of methodologies will for sure throw the results expected.

III. Problem Definition

Some managers have decided to merge both principles together to get the benefits from both of them. This process have worked for some companies that have increased the flow inside the company as well as reduce variation form the process, but for a small company probably the most important effect lies in the selecting the project that will ensure improvement without risk. By combining these two disciplines managers assume that the bottleneck found in a production line is where the six sigma project should be implemented, and so, the six sigma project to be implemented should lie in this stage. This concept might seem like the most logical and easiest way to use both disciplines, but it is often forgotten that while Constraints management seeks to expand the production of the industry, Six Sigma looks to reduce variance in the product sold. This difference is tactile in the objectives of each discipline; Six Sigma’s final goal is the costumer, and Constraint Management focus on the industry. When a constraint is found is because there is an unknown reason that limits the area to either produce less than what is received and so it keeps the predecessor to overproduce, or it just cannot supply enough production to the following processes to satisfy the demand. A variance reduction project will not always expand the constraint to produce more, and even though both disciplines are very complex, causing secondary benefits to appear form the original objectives, it is not a guaranteed that the project will be successful. Another complication with this method, is that even if the constraint reduces its variation and more productions comes from the bottleneck, it is still open to become a rejection in a later process that was not measured because Six Sigma focused only in the Constraint found. A part that passes through the constraint is like gold to the company, ruining it in a later process is the same as having the constraint idle for the time it took to work on that piece. Questions arise when trying to merge both projects together, like when does Sig Sigma starts and Constraints management takes a step down, or if subordination should be before Six Sigma or after? Is the constraint going to be improved or elevated? Once the constraint is controlled through Six Sigma, should the company be concerned there could be inertia?

IV. Integration Model

The heart of this project lies in the need for a business with a restricted budget for improvement, to initiate Six Sigma projects in a stage after the constraint, committing to develop significant improvement before the constraint will not show as important results that might come from a later stage. The body of the thesis relates to a guide or a methodology that combines both disciplines together for this goal, this methodology will be a merge from the original models created but will follow an order that can keep the objectives for each discipline and outstand the benefits in the entire system of the business. Fig. 1 represents different sets of processes followed by one another, the curves is the capacity of the line, as the lines shrinks to the processes, the capacity decreases and the bottleneck appears; after the process the capacity will keep remaining the same to the end of the line and that is the best area to implement a six sigma project.

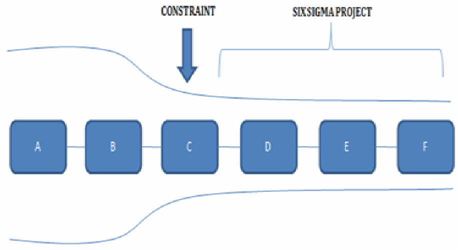

Fig. 1 Representation of the Integrated Model

The Integrated model in this project, base its principles on both disciplines, this enables to launch an improvement program with a familiar sequence. Both disciplines have their own steps and phases to follow, this model will merge both of them to follow one single model as shown in Fig. 2.

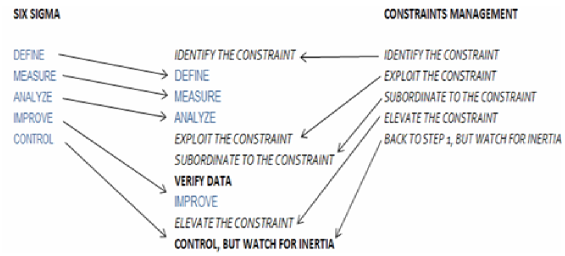

Fig. 2 Integrated Model

The steps are defined as follows:

i) Identifying the constraint looks at the situation of the entire industry or area to be studied; it is here where the major concerns are analyzed to reach the core problem. Most of the System Thinking tools are used in this step; the Current Reality Tree is the most common and most recommended tool to understand the problems and effects in the industry. Other tools derived from the CRT are the Future Reality Tree, which proposes new vision for what the system can become in a future reality, and the Conflict Resolution Diagram, which encounters the critical elements that can cause conflict. Depending on the problems found is how the next tool is used to find the constraint in the company, the Value Stream Map or Process Flow Chart can be of much aid.

ii) Define; this step starts the six sigma approach; the define phase will focus on the areas followed by the constraint and because the model focuses on restricted budget the phase will only locate the most significant CTQ. This phase has many tools originally that repeat the same information as the tools to identify the constraint; but there are some good principles that are useful like the Dashboard which puts the problems into numerable indicators. A SIPOC analysis can be run in this chapter to understand the different relations between the factors that can contribute to the project, as well as the Voice of Customer analysis that will amplify the relation with the customer needs.

iii) Measure; this step describes the CTQ chosen after the constraint; it uses a variety of statistical tools depending on the need. But first is important to change the CTQ into an operational definition that can be understandable to the entire area. The Quality Control Graph, Histogram, Scatter plot and Pareto charts are the instruments most common used to read the current situation of the CTQ. If there is human interaction in the process, a Gage R&R study must be conducted to observe the variation from operator to operator among other factors like environment or equipment.

iv) Analyze; in this phase facts like movements, motions or causes are examined to get to the core problem of the CTQ; Process Flow Charts describe very well the area and pinpoints the variance factor to resolve. Fishbone analysis or cause and effect matrix can be used to organize the brainstorm of ideas to find causes that originate the problem. A FEMA study can gather all the factors and rank their occurrence, severity and detection rate, this to start searching for a solution. Once the factors have been organized a Regression analysis can test for a correlation between them and start separating irrelevant characteristics. An ANOVA study will also aid the project if there have been modification in the process that yell some improvement by comparing means of a data set. The importance of this step is that it has to find a solution for the problem to stop damaging the process, a solution that will later be improved.

v) Exploiting the Constraint; going back to the constraint, the function of this phase is to maximize its usage as is, the tools to use on the phase depend on the problem, since each problem can vary the team must analyze different approaches to get the most of the constraint.

vi) Subordinate to the constraint; all the areas will now follow the step of the constraint, avoid having excessive WIP in the areas is the goal of this step. To achieve this either a VSM or a buffer-drum-rope analysis can be used depending on the problem found.

vii) Verifying the Data; this part of the model has been added to validate the data upon the improvement will be performed. Since there have been changes in the constraint and the industry by exploiting an subordinating, the data from steps 3 and 4 must be revalidated to see if there has been any change in the CTQ due to the modifications. Verifying the data should not be exhaustive, if the numbers from step 3 keep appearing in the CTQ, it means no change affected the area. Is important that no Improvement is done before validating the data, otherwise the improvement can be based in analysis that is no longer real in the industry.

viii) Improving the Project; to resolve the CTQ, the model recommends using the Design of Experiments (DOE) structure or its philosophy to find a solution that satisfies the variance. A Pre-Test / Post- Test study can verify if the improvement has an actual impact in the area and whether is sufficient to keep moving forward or find another approach. This test can be conducted with a T-stat test, an ANOVA analysis or chi-square test, to mention a few; but it is preferable to utilize the tools that were originally used in the Analysis and Measure phase.

Once the CTQ has been improved, top management must decide whether there is enough budget to continue towards another Six Sigma Project, or expand the constraint. The decision must consider what is more important to the company, maybe the constraint does not have much impact on the industry, or the other CTQs have little significance. If there is no budget to continue to either one of the choices, the project can move towards the last step and leave both the constraint and CTQs until there is financial solvency to resolve them.

ix) Elevating the Constraint; this step looks for the best approach to break the constraint and move it from the area. The solution can include a new machine, a new office, an enabled process or an increase in workforce; there might be investment included but is not forced if there is a better answer. Tools from previous steps can be used to verify the transfer of the constraint to another area.

x) Control and watch for Inertia, the last step ensures that the improvements and modification keep working over time. The most important tool is the use of ISO or a similar system for a smaller industry that can audit the improvements and its maintenance. The team must create and turn in results and instructions to the areas to assure the project will successfully run. A Control Plan resumes the progress of the CTQ that by observing variations, sources or description; this plan can be complemented with Visual aids, graphic charts or statistical studies. Another critical point is that a Total Productivity Maintenance (TPM) program must be created for the area to assure that it will properly sustain.

This model will successfully increase the production of the constraint as well as reduce variation in the area(s) that must not turn a part into a defect. Once the constraint has been established in a new area, the model can start again starting from where the constraint is located, but keeping an eye open for inertia in the last constraint.

V. Model Implementation

The implementation of the model proposed in this thesis is discussed using the production line of an engine Monoblock V8 casted and machined in a plant in Mexico. The team successfully identifies the constraint along with the CTQ in a production line with the following processes:

1. Sand Molds Fabrication
2. Casting
3. Heat Treatment
4. Mazarota Grinding
5. Machining
6. Final Inspection
7. Shipping

These processes are aligned and only at casting the process receives materials from two different sources, being the sand molds and the liquid aluminum, leaving the rest of the line in a consequential direction. The constraint is located at the Mazarota Grinding area that only has the capacity of processing 18.7 pieces per hour, and consequently the CTQ is searched in an area between grinding and shipping. The team detects an important CTQ in one station of the machining line that is attributed to 0.73% defects. Improving the CTQ requires to restructure the cleaning and security mechanisms stopping the area from processing more defects. After improving the area, the team decides to elevate the constraint by modifying a CNC that can process one of the two activities of the grinder. At the end of the cycle the project achieved the following results of improving, subordinating and elevating:

1) The result of improvement in the overall rate of production from 18.7 pcs/hr to 22.4 pcs/hr.
2) Work-In-Process reduction of 60%.
3) Variation reduction in a process followed by the constraint of 0.73% of 1.96%.
4) Reduction of Year-to-date variation to 0.73 %, reducing the breach to achieve the goal of 3.30%, going from of 4.09% to 3.33%.

VI. Discussion

The same case study was solved using the original DMAIC model and a combination model that selects the six sigma project at the constraint.

For the first trial the results were satisfactory at its level, as Casting quality improved 0.89% of 2.13% on one project; and a 60% less WIP in a second project. Even if there was a considerable reduction, bigger than in the Integrated model, of variation the area at which it was reduced is located before the constraint, leaving the same rate of production at18.7 Pcs/hr . Similarities and differences can be divided as follows.

- Selection of Projects: This model selected the projects according to the Prioritization Matrix which ranks the importance according to the company’s objectives and does not consider the production line weakness; the Integrated model reacts to the weakest link in the process, and improves the processes following that constraint to increase the chances that the production in the constraint gets to the customer.
- Investment: In the original model, the selection of projects is individually from one to another and to achieve improvements with little expense, the solution must be part of the DOE in each individual project; the Integrated model, lets the project benefit from the non-monetary resources in CM (exploiting and subordinating) and has a

decision point to launch another project after the constraint or hit the constraint.

- Guide: The DMAIC is a model proven to work; the Integrated model derives from the DMAIC and TOC five focusing points, two trusted models.
- Interaction in the Departments: The original DMAIC does not require any type of interaction between the different areas or departments, unless the CTQ or a factor in the DOE requires it; the Integrated model demands to subordinate all areas to the constraint to maximize usage.
- Knowledge of project in company: The original model has the option to diffuse the results and improvements to the company but is not required; the Integrated model must involve the entire company in the results and modifications, because of subordination, which increases the moral of the workforce and departments.

The second trial resulted in an increase in the hourly production from 18.4 pieces per hour to 22.4 pieces per hour, taking the one result that did not appear in the prior trial, but missing reduction of WIP or variation. The discussions regarding this trial are:

- Selection of Project: This model selects the project according to the constraint in the industry, forcing the Six Sigma to participate in a project that might not require the complex methodology that comes with the tools; the strength of the Integrated model lies in the essence that it is constructed with the characteristics from CM management and Six sigma to launch projects of their size.
- Investment: The Six sigma at the constraint model helps when having limited budget in which it attacks the problem that causes the most trouble in the entire line, assuring that, if launched properly, the results will bring enough benefits; a downside to this model is that there are constraints like demand or some that cost too high to break, which limits the project to exploiting and subordinating only by not having other options that can produce impacting results.
- Guide: The experiment model is not defined, it is to the user to define the usage and order of the phases, even when both models are proven to work individually, when a new model is not defined it can cause the project to reflect results at a lower level from its potential. The Integrated model follows a step by step guide that serves as instructions between the two models.
- Interaction in the Departments: Using constraints management guarantees the interaction between the departments by subordinating their areas to the constraint, but if the model does not subordinate, like in the experiment, the company does not participate with the project.
- Knowledge of project in the Company: The importance of subordination applies to this concept as well, if the model does not interact with the other departments, the results of the project have the risk to be unknown or unimportant to the overall company. The Integrated model includes the interaction of the departments as well as the importance of understanding and demonstrating results to the entire industry.

VII. Conclusion

A combination of two complex disciplines, Six Sigma and Constraints Management, has been described in this project to the use in a small business or a program with limited budget for improvement. The model establishes that a constraint is the guide to know where to launch a six sigma project; having located the constraint the most critical preoccupation is that the piece or service passed through it, guarantees to end the entire process successfully, therefore the improvement projects must be launched after the constraint, it also shows the phases that must be followed to approach the problem, phases that come from the original models from either discipline. The Integrated model showed more benefits from the two experiments and delivered more logic to the selection of projects with the limited budget. This model covers both disciplines fully and lets the company observe the potential results to be found at selecting the improvements.

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