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Constraint identification techniques for lean manufacturing systems

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ABSTRACT

The first step in the Theory of Constraints (TOC) methodology is to identify the constraint. Several methods have been recommended in literature, such as looking for a backup of inventory (i.e., the operation that the inventory is waiting for is the constraint), or using linear programming or other analytical models. Yet, these methods may not be useful in a matured lean environment, which may have moving assembly lines where constraints are not obvious. This paper proposes three new methods for this purpose. The first method, Flow Constraint Analysis, takes a holistic view and evaluates whether the customer's demand is being satisfied. This evaluation is made by comparing the takt times and the cycle times of resources in the manufacturing system in order to identify the constraint(s). The second method, Effective Utilization Analysis, can be employed to pinpoint the location of the system constraint to a specific process or station. The actual production throughput is compared against the ideal capacity of the system to locate the bottleneck. This method is based on the relationship between WIP, bottleneck rate and lead time for a constant work in process (CONWIP) system. The third method, Quick Effective Utilization Analysis, can be used when there is little or no historical line performance data available. A case study of these methods applied to an actual production facility is presented.

1. Introduction

The manufacturing system output is a function of the whole system, not just individual processes. When we view our system as a whole, we realize that the system output is a function of the weakest link. The weakest link of the manufacturing system is the constraint. Consequently, there needs to be focus on the co-ordination of efforts to optimize the overall system, not just individual processes [1]. When a system matures in lean implementation, the production flows smoother and the main constraint becomes less obvious. However, the impact of performance of constraining resources in a lean system, especially one with moving assembly lines, is still evident. Because "every value stream has a primary bottleneck (constraint) that limits its ability to reach its goal" [2, p. 175], it is even more critical to be able to identify system constraints in a lean environment.

Theory of Constraints (TOC) is a well-known methodology for systems improvement that includes principles and practice guidelines that can be adopted by practitioners [3]. The famous novel for operations management, *The Goal*, written by Eli Goldratt [4] caught the attention of process improvement professionals and began the use of this methodology. From this book, the five focusing steps (5FS) were brought out: 1) Identify the System Constraint, 2) Decide How to Exploit the Constraint, 3) Subordinate Everything Else, 4) Elevate the Constraint, and 5) Go Back to Step 1, but beware of "Inertia".

The concept of integrating Lean, Six Sigma and the Theory of Constraints is being explored more and more while simultaneously being applied to various industries [5]. The integration of Lean and TOC will be the focus of this manuscript. Constraint identification at a lean manufacturing plant using TOC will be the method of integration.

In mass production environments, constraints are usually easy to find; just look for large stockpiles of Work-In Process (WIP), backlogs, and frequent expediting [2]. But in a lean manufacturing environment, none of these conditions should exist; therefore a different approach has to be taken in order to identify the system constraint(s).

Currently there are four major constraint identification methods [6]:

1. The machine with the longest active state without interruption.
2. The machine with the greatest percentage of cycle time and fail state.
3. The machine with the longest average upstream queue length.
4. The machine with the largest percentage of utilization.

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Nomenclature

TOC — Theory of Constraints. A management philosophy that stresses removal of constraints to increase throughput while decreasing inventory and operating expenses.

WIP or W — Work in Process. Product or inventory in various stages of completion throughout the plant, from raw material to completed product.

CONWIP — Constant Work in Process.

$CT_{avg.}$ — Average Cycle Time. A time duration calculated by using the time weighted average process time.

$DT_{avg.}$ — Average Downtime. A time duration calculated by using the total downtime for a given period divided by the number of products produced during the same period.

$CT_{process}$ — Process Cycle Time. A time duration that is the summation of Average Cycle Time and Average Downtime.

CT_{pitch} — Pitch Cycle Time. A time duration that represent the likely longest time the product will remain in that pitch.

r_b — The assembly line bottleneck rate. Is the rate of the resource having the highest long-term utilization.

r_b^P — Practical Production Rate. Is the anticipated throughput of the line.

T^P — Practical Lead Time. Is the practical minimum time to traverse the line (no queuing).

T_e^P — Effective Practical Lead Time. The summation of the assembly line pitch cycle time values.

T_q^P — Quick Effective Practical Lead Time. The average of a sample of individual jobs' lead times.

U — The Utilization. The utilization of a resource is the fraction of time it is not idle for lack of parts.

U_e — Effective Utilization Rate. The resource utilization calculated using the Effective Utilization Analysis method.

U_q — Quick Effective Utilization Rate. The resource utilization calculated using the Quick Effective Utilization Analysis method.

W_e — Effective Work in Process. A constant work in process value calculated using the Effective Utilization Analysis method.

W_q — Quick Effective Work in Process. A constant work in process value calculated using the Quick Effective Utilization method.

As can be seen from the above list, all of the major bottleneck detection methods are useful for individual machines.

For moving assembly lines, equipment failures and repairs are not the main reasons for line stoppages. Operators using the equipment, people maintaining the equipment, the people supplying parts to the assembly line and poke–yoke devices are the main causes. In most instances the assembly line stops only for seconds and in some cases it does not come to a complete stop but only slows down.

There are no major methods for identifying the constraint in systems with paced moving assembly lines. The question, “How do you identify the system constraint when the typical methods do not apply?” will be answered in this manuscript. This is important because continuous improvement is necessary for a company's survival and the gains of the blended methodologies have delivered results that were at least four times higher than any one approach alone.

1.1. The use of Theory of Constraints

The effectiveness of TOC has been reviewed extensively over time. For example, the extended literature survey by Naor et al. [7] provides a great insight into the theoretical foundation of TOC. Furthermore, the second evolution is taking place now. Pretorius [8] has identified several shortcomings with the five focusing steps (5FS). To address these shortcomings, the 5FS are transformed into a decision map that includes all five steps and two prerequisites, this allows decision points to guide the user through the process. The answer to the first decision point, “Is the constraint physical?” is yes. Therefore to analyze the manufacturing system being studied, the first two steps of the five focusing steps do not change.

When exploiting the constraint, we should wring every bit of capability out of the constraining component as it currently exists. In other words, TOC urges us to rethink what we can do to get the most out of this constraint without committing to potentially expensive changes or upgrades and be able to implement the changes in a short period of time [5]. Constraints can be both external and internal. External constraints are often beyond the control of management because they are market driven. External or market constraints affect demand, they influence product mix, which in turn affects resource utilization [10]. The product mix for the manufacturing system being studied in this paper is 60% of product A and 40% of product B. Internal constraints come in many forms, e.g., management philosophy, labor skills, inflexible work rules and limited capacity at various resources [10]. During this study only limited capacity will be considered.

Two major benefits are achieved by following the TOC methodology: (1) realizing the maximum system improvement from the least investment in resources and (2) learning exactly how much effect improving a specific system component has on overall system performance [5].

1.2. Overview of the literature

The literature search for this paper began with the publication period from 2000 to 2014. The following list of journals were selected as a field of candidates that could provide potential reference material:

- *Journal of Operations Management;*
- *Production and Inventory Management;*
- *International Journal of Production Research;*
- *Industrial Engineering;*
- *International Journal of Operations & Production Management;*
- *European Journal of Operational Research.*

These selected journals did not provide any articles directly related to the industry and manufacturing system being studied; therefore a second mini literature search as performed with the primary focus being constraint detection and production assembly lines. The time period was widened and several applicable articles surfaced. Books and websites on TOC were also reviewed during the literature search.

1.3. Three new methods

In this paper, three new methods are proposed to pinpoint constraints in matured lean systems. The first method, named Flow Constraint Analysis, is a holistic approach that evaluates whether the customer's demand is being satisfied. This evaluation

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