BENCHMARKING LEAN MANUFACTURING AND THEORY OF CONSTRAINTS IMPLEMENTATIONS

Naval Air Systems Command, Industrial Operations Group,

NAVAIR Depot Maintenance System Program Management Office

5 August 2003

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AUTHORS

This document was prepared by:

Patrick Hickey, PMP, Senior Manager
BearingPoint, Inc.
22454 Three Notch Road, Ste. 202
Lexington Park, MD 20653 T: 240-725-7513
phickey@bearingpoint.net

Marcos DaCruz, CPIM, CIRM, PMP, Senior Consultant
BearingPoint, Inc.
22454 Three Notch Road, Ste. 202
Lexington Park, MD 20653
T: 240-725-7604
mdacruz@bearingpoint.net

Susie Seaver, CPIM, JONAH, Senior Consultant
BearingPoint, Inc.
22454 Three Notch Road, Ste. 202
Lexington Park, MD 20653
T: 240-725-7529
lseaver@bearingpoint.net

Significant contributions provided by:

Stephen Simpliciano, JONAH's JONAH
Avraham Y. Goldratt Institute
442 Orange Street
New Haven, CT 06511
T: 203-624-9026
steve.simpliciano@goldratt.com

Dr. Jeffrey Liker, Director and Senior Lean Consultant and Director of the Japan Technology Management Program at the University of Michigan
Optiprise, Inc.
1346 Waukazoo Drive
Holland, MI 49424
T: 800-780-3051
liker@umich.edu

TABLE OF CONTENTS

INTRODUCTION

Over the last few years, the Naval Air Depots have been pursuing a variety of methodologies to reduce cycle times and to increase readiness of fleet aviation assets. This pursuit has given birth to several initiatives across the Naval Air Depot landscape that entail implementing methodologies, IT systems, and business process improvements currently being exploited in the commercial sector. These initiatives have provided benefit but have not lead to an integrated system for continuously reducing lead time. Two initiatives that when combined show promise for providing an integrated framework for continual lead time reduction are the deployment of Theory of Constraints at Naval Air Depot Cherry Point, NC and Lean Manufacturing at Naval Air Depot Jacksonville, FL.

Both depots are pursuing these methodologies after completing the implementation of Manufacturing Resource Planning / Maintenance, Repair and Overhaul (MRP II / MRO) philosophies and applications. Across both Naval Air Depots, MRP II / MRO forms the foundational information system and provides a useful information infrastructure to either Theory of Constraints (TOC) or Lean Manufacturing. In fact the power of MRP II / MRO can be further unleashed when used within the broader framework and philosophies of improvement methods like TOC and lean.

In conjunction with the MRP II / MRO processes and procedures, Naval Air Depot Cherry Point has been pursuing TOC and the implementation of Critical Chain project management and Drum, Buffer, Rope (DBR) techniques. Likewise, Naval Air Depot Jacksonville has been deploying Lean and Six Sigma Manufacturing principles. To date, Lean principles have been employed across the F404 High Pressure Turbine, F404 Low Pressure Turbine and the Water Jet Stripping process lines. Each of these methods alone have had some success in improving the process and reducing lead time. The early experiments have sufficiently demonstrated the potential. The true results across entire repair and overhaul programs will depend on broader and deeper implementation as an integrated system.

Commensurate with commercial companies who have gone before them, each Naval Air Depot is beginning to see operational benefits from their respective deployments of TOC and Lean. However, currently no plan exists to capitalize upon the separate initiatives and export TOC to Jacksonville and Lean Manufacturing to Cherry Point or integrate these methodologies.

A great part of the reticence to export and cross-share these methodologies and their operational practices is each Depot's commitment to a certain methodology, philosophy, and framework and difficulty communicating the boundaries of their methodology. This leads each depot to assume its methodology is best. Neither depot wants to "take a step back" or reduce the effectiveness of their current TOC and Lean activities; furthermore, no roadmap for their integrative use has been offered.

While NAVAIR may not have a plan to use TOC and Lean Manufacturing in concert, commercial companies have been integrating TOC and Lean Manufacturing techniques for years. Many of these firms have found greater improvements can be obtained by combining the principles of both methodologies.

Because the Naval Air Depots and NAVAIR's Industrial Production Support Department (AIR 6.3)[1] are continuingly charged with improving operational performance and support to the warfighter, AIR 6.3 desires to exploit their investments in TOC and Lean Manufacturing across the enterprise. Accordingly, AIR 6.3 initiated this benchmarking study to ascertain what experiences the commercial sector has had with TOC and Lean Manufacturing – both as stand-alone and integrated operational principles.

[1] AIR 6.3 is responsible for the people, processes, knowledge, skills, facilities and equipment required to support the industrial business processes for Naval Air Depot level maintenance, repair, and overhaul.

This document, Benchmarking Lean Manufacturing and Theory of Constraints Implementations, has a four-fold purpose:

1. Review TOC and Lean Manufacturing (hear-after referred to as Lean) principles and document actual results from their individual deployment;
2. Compare TOC and Lean principles to each other and identify the conflicts and similarities between them;
3. Bench mark if (and how) TOC and Lean have been integrated by other organizations and document the results of this integrative deployment; and lastly,
4. Propose how TOC and Lean could be used in concert across a Naval Air Depot.

APPROACH

In the creation of this benchmarking study, BearingPoint conducted a detailed review of professional journals and publications, interviewed internal BearingPoint delivery teams and commercial companies, and consulted with the Avraham Goldratt Institute (AGI).

The results of this benchmarking study are presented in five major topics. First, TOC and Lean principles are briefly defined to provide a basic understanding of the methodologies. Results from stand-alone TOC and Lean implementations are given to exemplify the type of returns companies who properly apply the methodologies should expect. Second, TOC and Lean principles are stacked along side each other, compared for conflicts and similarities and the operational consequences of the comparative findings are defined. Third, results and lessons learned from companies that have attempted to deploy both TOC and Lean are provided. Lastly, the benchmarking study concludes by extending commercial findings to NAVAIR and proposing how TOC and Lean could be used together for the benefit of the Naval Air Depots.

LEAN AND TOC: AN OVERVIEW

Before proceeding with how practitioners have implemented Lean and TOC implementations “in the field” and an overview of the results some of them have attained, it is useful to define the major tenets of both philosophies. The following discussion quickly presents the theoretical concepts and key focus points of Lean and TOC.

Lean Manufacturing

Lean Manufacturing is a total systems philosophy that seeks to maximize value added to the customer in order to make a business successful by aligning people, processes, and technology toward eliminating *muda* – waste – in the value stream. A waste-free process is a process that is working correctly and delivering only the value-added products and capabilities required by customers.

Lean involves identifying and eliminating non-value adding activities in design, production, supply chain management and customers’ interactions. Lean producers employ teams of multi-skilled workers at all levels of the organization and highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety.

The term “lean” was coined by a team from MIT to describe the principles of the Toyota Production system. The Toyota Production System (TPS) is typically represented by a house. The roof is the goal of best quality, cost, and speed through reducing the production flow by eliminating waste. One pillar is just-in-time which includes continuous flow processing, pull systems, and leveling the production schedule. A second pillar is *jidoka* or built-in quality which focuses on detecting and isolating problems and then solving them at the root cause. The foundation is stability through standardization, productive maintenance, stable, reliable suppliers, and engineering for manufacturing. At the center are flexible, capable people who engage in continuous improvement. TPS emphasizes people and continuous improvement as the driver of the system.

The tools and methods are designed to support people in continually improving processes. TPS is a systems philosophy holistically approaching work and organization.

Lean Tenets and Operational Techniques

Lean Manufacturing seeks improvement by empowering people and providing the tools to identify and eliminate waste. The technical focus is on streamlining the material and information flow. The human focus is on creating a safe and engaging work environment to motivate people to continuously improve.

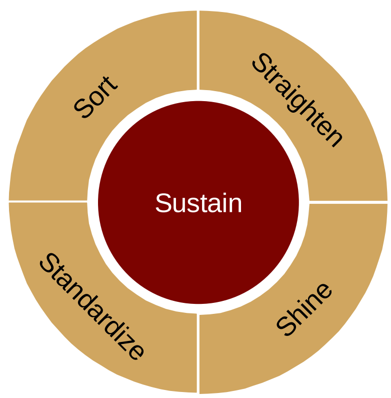
Value Stream Mapping

The material and information flow can be represented through a well defined, structured approach. First, a Macro-Value Stream Map of the entire business system is created to identify and prioritize an organization's opportunities for improvement. In the first step of this process the current situation is represented by walking the flow to identify each process step. Material flows and information hand-offs are identified and labeled as value added, non-value added but required, and non-value added. A common mistake is to try to use the current state picture to identify where lean activities should focus. Lean experts stress this will not lead to a lean system but rather to fixing problems in the non-lean batch and queue structure. Instead, a creative leap is taken based on lean principles to develop a future Value Stream Map that reflects lean operations as a system. The system includes the lean material and information flow, a time line representing lead times, and the specific kaizen activities needed to get to the future state.

Based on the future state map, an action plan is created identifying a "who", "what", and "when" for each activity. Some of these activities can best be accomplished as engineering projects while others can be done through "kaizen events." Kaizen is a Japanese word which means "change for the better." Kaizen events are focused 3-5 day events involving a full-time team represented by operators, engineers, quality, etc. to radically transform a focused area in a week. The week includes analysis of the current state of the process at a greater level of detail than the value stream map, generation of improvement ideas, and actual implementation. It is typical to re-layout equipment, identify a new work flow, develop standardized work, and use other methods like 5S below to organize the work place.

5S Method

Lean's 5S methodology is comprised of five activities - all beginning with S in Japanese – used to reduce the waste associated with clutter and disorganization in process. The five S's, translated in English are Sort, Straighten, Shine, Standardize and Sustain.



<u>Seiri (Sort)</u>

Sorting means separating necessary from unnecessary items, disposing or relocating unnecessary items and keeping only necessary items at the workplace.

<u>Seiton (Straighten)</u>

Straightening means neatly arranging and identifying things for ease of use (a place for everything and everything in its place.)

<u>Seiso (Shine)</u>

Shining means to always clean up, to maintain tidiness and cleanliness – to clear your workplace completely.

Seiketsu (Standardize)

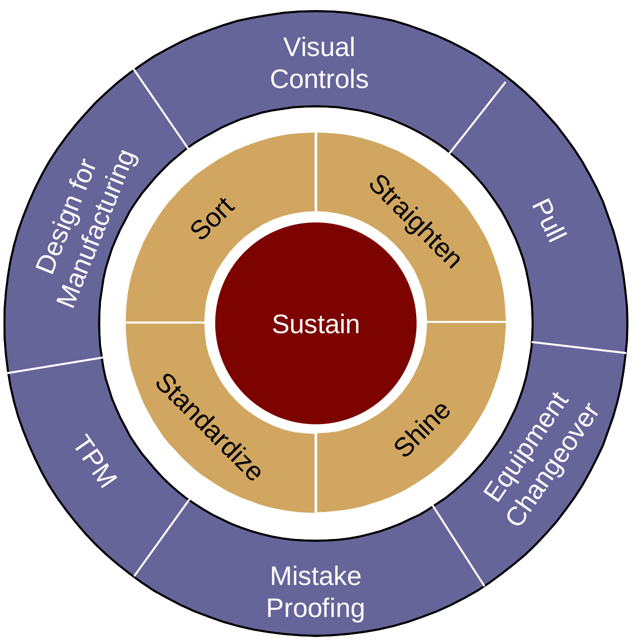
Standardizing means constantly maintaining the previous three S's (Sort, Straighten and Shine).

Shitsuke (Sustain)

Sustaining means making a steady habit of properly maintaining correct procedures and conforming to rules.

Operational Techniques

The Five S's alone can lead to a neat and organized workplace but not necessarily a lean one. Again the goal of lean is to add value to the customer with a minimum of waste. It is possible to have a very neat and very wasteful process. To truly eliminate waste requires a variety of operational techniques.



Visual Control

Unwritten, unspoken devices (e.g., signal lights and charts) that quickly communicate to everyone the state of normal and abnormal operational conditions. Visual control can be enhanced by a plant layout that places equipment and people close together. Visual controls signal deviations from the standard. This requires that a standard be established. Visual control brings 5S to life and helps control the quantify and quality of work.

Pull

In a Lean enterprise, inventory is considered waste; therefore producing anything ahead of when it is needed is waste. Thus, it is important that real customers *pull* product through the system. This is in contrast with traditional push approach where the system encourages each resource to produce as much as possible, thus pushing products through the system. The pull phenomenon is made operational via the following processes and procedures:

- Kanban: A device used to signal the need for production in a pull environment. Kanban avoids the tendency of over-production.
- Takt Time: The rate of production needed to match the rate of customer demand. Takt time is calculated by dividing the available production time by the rate of customer demand.

Equipment Changeover (Set-up reduction)

A key to making just what the customer wants when they want it is the flexibility is to change over quickly between products. A Lean enterprise will focus on reducing equipment changeover - the time between the last good piece off one run and the first good piece off the next run.

Mistake Proofing

This is a method that uses simple, low cost devices to check each part at each operation and actively works to prevent mistakes from occurring. Building in quality is always more effective than inspecting and repairing in quality.

Total Productive Maintenance (TPM)

We move from preventative maintenance to TPM when all parties involved in the manufacturing process participate in maximizing equipment effectiveness. They all tend the equipment - how it is kept, operated and maintained – and work together to eliminate and prevent the main causes of equipment breakdown and other inefficiencies.

Design for Manufacturing

Design for manufacturing integrates engineering and manufacturing functions during the design phase for new products. By aligning these functions, organizations can reduce the number and variety of parts in product lines. The reduced number of items alleviates parts management and frees personnel and financial obligations for other positive actions. The characteristics of design for manufacturing are:

- Focus design on families of products with common parts and processes.
- Design products for easy configuration during assembly.
- Design products immediately before the start of production.

Theory of Constraints

TOC is a management philosophy that improves the performance of a system by focusing on its constraint.

TOC views organizations as systems consisting of resources, which are linked by the processes they perform (interdependencies). Inherent in such systems are variability in its processes, suppliers and customers. Within that system, a *constraint* is defined as any element that restricts the flow of the system, consistent with demand; otherwise, its throughput would go to infinity. Performance is measured relative to the system's goal.

The interdependencies and variability between and within processes make a chain a very descriptive analogy of the system. And just as the strength of a chain is governed by the weakest link, TOC maintains that the ability of the organization to achieve its goal is governed by a single (or very few) constraint.

TOC Tenets and Operational Techniques

While the concept of constraints limiting system performance is simple and its impact on performance profound, it is far from simple to implement. To identify the constraints limiting system performance and keeping the organization from achieving its goal, TOC requires a fundamental shift in how the organization is viewed, understood and measured. Its 5-step focusing process systematically pursues ongoing improvement around identifying and managing its constraint(s).

Understand the System

Prior to the identification of the constraint, it is important to understand the basic facts about the system.[2] Part of the TOC implementation is to identify the following facts to permit the organization to identify and manage the system's constraint.

The System and Its Purpose (Goal)

TOC requires the organization have a clear and concise verbalization of its goal because constraints are best identified and dealt with in relation to the system's objective. For instance, in manufacturing organizations, often the system is defined as the manufacturing operation, or the plant, its suppliers and vendors, and its market and customers. The purpose of the manufacturing operation is to enable the entire organization to achieve its goal (e.g., make money). Constraints will be identified that keep the manufacturing from achieving its goal.

The Measurement of the System's Goal

TOC teaches that companies are "making money" when they are selling product and/or service at a rate faster than they are spending it. In order to measure if the organization is achieving its goal (e.g., making money), TOC starts by categorizing what a firm does with its money in three ways:

[2] Moore, Richard I. And Scheinkopf, Lisa. "Theory of Constraints and Lean Manufacturing: Friends or Foes." Teamtec Solutions Page 1998.

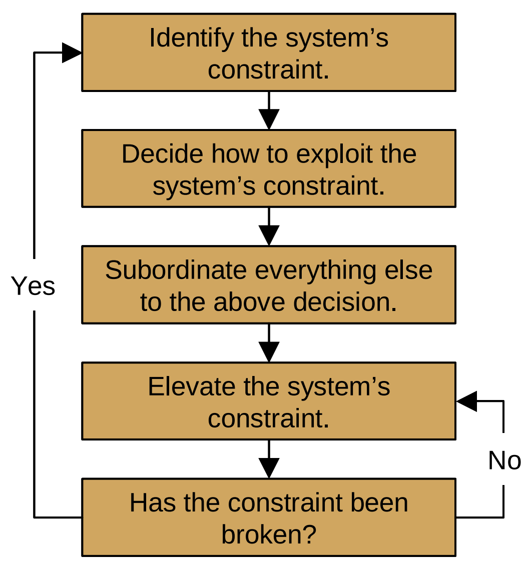
Accessed 5 March 2003 <http://www.teamtec.be/solution.htm>.

- Throughput (T): The rate at which the organization generates money through sales.
- Inventory/Investment (I): All of the money that the organization spends on things it intends to turn into throughput.
- Operating expense (OE): All of the money the organization spends in order to turn inventory into throughput.

The power of allocating all of the money in the system into one of three mutually exclusive and collectively exhaustive categories lies in the improved ability of the organization to evaluate the impact of decisions relative to the goal of making money. For example, an increase in I and/or OE without a significant increase in T is not an improvement. Conversely, a significant increase in T with substantial decreases in I and OE defines improvement, as does a significant increase in T with no change in I and OE.

The Five Focusing Steps

TOC follows a 5-step, focused process to pursue ongoing improvement.[3]



[3] Goldratt, Eliyahu M. Theory of Constraints. Great Barrington, Massachusetts: North River Press, 1990.

Decide How to Exploit the System's Constraint

Having an understanding that the throughput is a function of the constraint, the next step is to manage the constraint so that the throughput is maximized now and in the future. Below are typical activities that can be implemented depending on the constraint.

- Market is a Constraint
  - Determine what the market values relative to the industry's current offerings and align the organization to deliver value as solutions to the market's high value problems.
- Vendor is a Constraint
  - Determine what the vendor values relative to the industry's current practices and align the organization to be the vendor's preferred customer by solving the vendor's high value problems.
- Internal Resource is a Constraint
  - Eliminate waste activity performed by the constraint.
  - Reduce setup on the constraint resource.
  - Minimize downtime on the constraint.
  - Add inspection steps so that only good material is processed by the constraint.

Subordinate Everything Else to the Above Decision

Once the constraint has been identified, do not allow other improvement initiatives to interfere with the high priority of the above decisions. Alter or manage the system's policies, processes and other resources to support the decisions to address the constraint.

Elevate the System's Constraint

The first three steps are targeted to ensure the organization gets as much as it can from its existing resources. Only then is it in a position to evaluate investments. To "elevate" the constraint means to buy more or get more capacity on the constraint. If the constraint is in the market, then sales and marketing will need to raise additional business. If the constraint is materials, then new sources will be acquired. If the constraint is internal, then acquisition of more capacity will be needed (additional shifts, process improvements, setup reductions, hiring people, relocating the constraint, etc.) *relative* to the impact on the constraint; otherwise, any improvement on a non-constraint will yield insignificant ROI and no increase in the throughput of the chain.

Has the Constraint Been Broken?

Don't allow inertia to become the system's constraint. When one constraint is broken, go back to step one and begin again.

Operational Techniques

For make-to-order (MTO) and make-to-stock (MTS) manufacturing organizations, it may mean the implementation of TOC's drum-buffer-rope (DBR). DBR is the production application of the TOC and its elements are defined as follows:

- Drum: The detailed master production schedule that emerges when market demand is matched with the capabilities of the system's constraints.
- Buffer: The protection given to the constraint to ensure that - despite disruptions in the manufacturing process - workload is always available to the constraint. Buffers may be either time buffers or stock buffers.
- Rope: The mechanism for synchronizing all resources in the system to the pace of the drum. An important function of the rope is to generate the timely release of just the right materials into the system at just the right time to support the drum's schedule.[4]

As a system design consideration, it may desirable to implement TOC Project Management instead of DBR. This TOC solution is geared towards low volume custom-made manufacturing organizations with high variability, or in low volume, custom-made manufacturing organizations involving highly expensive and specialized equipment. It includes the definition of the chain of work (also called "Critical Chain"), the variable component (also called "safety") and of the buffers. The buffer protects the project from the effects of execution variability along the Critical Chain.[1]

Benchmark Results of Stand-Alone Implementations

Lean and TOC are popular production support and continuous improvement methodologies because they can be relatively inexpensive to implement, traditionally do not require supporting application software, and effectively deliver results when correctly applied.

For this study, BearingPoint gathered information from firms that have implemented either Lean or TOC to determine the typical results an organization that effectively applies the principles of Lean or TOC should expect. The results can and have been divided between objectively and subjectively observable outcomes.

The information presented in the following table comes from questionnaires provided directly to the organizations by BearingPoint as well as studies that have appeared in professional journals.

It is important to note that while many of the same metrics can be used between Lean and TOC to indicate the benefit they deliver to the company, following the TOC principles will change the measures that a company finds important. In following sections of this study, the reason and manner of these differences in focus and measurement will be made more apparent.

[4] Corbett, Thomas and Csillag, Joao Mario. "Analysis of the Effects of Seven Drum-Buffer-Rope Implementations." APICS Production and Inventory Management Journal. 42.3-4 (Winter 2001): 17-23.

	Lean-Only Implementations				TOC-Only Implementations[5]						
Company (All US$)	Heart & Home Tech.	Boeing[6]	Kenna-metal Inc.	Boeing Commercial Airplanes	A	B	C	D	E	F	G
Employees	600	154	14,500	60,000	550	140	12,000	700	270	250	2,500
Revenues			$1.8 B	$28 B	$40 M	$6 M	$1 B	$63 M	$20 M	$16 M	$240 M
Implementation year	1992	1995	1998	1995	1997	1993	1995	1997	1995	1996	1995
Time to implement[7]		30 months	In-process		2 months	6 months	2 months	1 month	4 months	3 months	7 months
Cost			$80 K		$10 K	$10 K	$80 K	$80 K	Zero	$45 K	$80 K
Lead-time decrease[7]	75%	20%	50%	30%	50%	44%	31%		67%	50%	17%
Due-date performance (before and after)		50% – 100%		100% - 100%	87% - 99%	60% - 90%	70% - 95%	85% - 98%	65% - 99%		Frequent delays – 100%
Increase in Revenue					20%	0%	20%	9%	114%	0%	25%
Savings			$8.5 M/yr								
Increase in effective production capacity	100%		75%		20%	40%	20%	13% and 17%	50%	0%	
Decrease in WIP		77%		30%	58%	77%	40%	25%			53%
Decrease in FG Inv.					25%				50%	50%	
Employee Revenue / year (before and after)					$64 K – $76 K	$30 K – $50 K		$83 K – $90 K	$31 K – $67 K	$56 K – $64 K	$82 K – $92 K

[5] Corbett, Thomas and Csillag, Joao Mario. "Analysis of the Effects of Seven Drum-Buffer-Rope Implementations." APICS Production and Inventory Management Journal. 42.3-4 (Winter 2001): 17-23.

[6] Sub-assemblies for C-17 Globemaster III.

[7] Based on anecdotal evidence.

LEAN AND TOC COMPARISON

As shown above, both Lean and TOC philosophies and their subsequent practices can offer significant operational benefits when properly and appropriately applied. For operational managers who seek performance improvements, the fundamental question is "which methodology is the *appropriate* one to pursue for a given environment or condition?"

While Lean and TOC practitioners can argue over which methodology is best suited for a specific operation, the following comparison of the methodologies themselves sheds some light on the suitability of Lean and TOC for specific settings.

Overall Objective

The objective of improvement efforts between Lean and TOC is one of the primary differences. Simply stated, Lean is passionate about reducing *muda* (waste) while TOC is fervent with increasing throughput.

In companies that use either Lean or TOC, net profit is calculated in the same way: throughput minus operating expense. It is logical to seek net profit improvements by cutting costs. In Lean, cost reductions and productivity improvements are achieved by eliminating waste (e.g., excess inventory, quality problems, wasted motion).

However, Lean's approach to waste reduction can be contrary to the tenets of TOC advocates. The TOC advocate focuses on improving net profit by increasing throughput. When making decisions to change inventory or operating expenses the primary purpose is for increasing throughput and secondary is for reducing waste.

This fundamental difference in paradigm – the view of continuous improvement via reducing waste or increasing throughput – is at the root of very different behaviors and practices.

Scope

The scope of the typical TOC implementation is considerably wider than the typical Lean implementation. In TOC, a constraint prevents an organization from achieving more of its goals and may exist anywhere in the system. The Five Focusing Steps could result in finding a constraint anywhere within the company (e.g., a lathe operation, order entry, engineering support) or outside the company (vendors and customers). In this regard, TOC is deployed as a business unit strategy.

Lean is equally at home at the organizational and shop floor levels. Value Stream Mapping can identify waste "above the shop floor" as well as on the shop floor. Once identified during Value Stream Mapping, 5S and the Lean operational techniques can be applied to reduce non-value added activities wherever they exist.

Buffer Management

Both Lean and TOC are "pull" systems. However, each takes a different approach to achieving a single-piece or just-in-time flow and protecting the system from disruptive variations.

To achieve the production plan and the company's goal, TOC protects the bottleneck (or CCR) from starvation by creating a buffer in front of the bottleneck. While a buffer can take many different forms, it usually takes the form of either work-in-process inventory queued in front of the bottleneck or time. All other work-in-process inventory that does not buffer the CCR is reduced. The amount and content of the queued inventory or time is determined by the shipping schedule (demand) in concert with the timed release of raw materials from the gating operations.

Lean reduces all "buffers" until they are just large enough to preserve capacity at each of the work centers to achieve production goals. While strategically placed inventory buffers are used, along with pull systems to replenish the buffers, over time the goal is to reduce the buffers through continuous improvement. In the best cases, no buffer inventories exist and parts leaving one workcenter are used directly at the next workcenter.

Process Variability

Both philosophies advocate reducing the process variability that makes holding inventories necessary in the first place. However, the approach to tackling process variability is very different. In TOC, identifying or declaring a constraint, by definition, reveals true productive, protective and excess capacity on the non-constraints. TOC then strategically places buffers to decouple variation at key points (Aggregation Theory) and applies Buffer Management to reduce variability and increase flow without sacrificing due-date performance. Lean reduces buffers first and then attacks the variability as it visibly surfaces. In fact a main reason for reducing inventory in lean is to surface problems to force solving problems at the source.

Implementation Process Focus

In line with their different overall objectives, the focus of Lean and TOC implementation processes differ. Lean implementations first tackle processes internal to the organization, second address supplier processes, and lastly attend to logistics or customer processes. Lean deals with waste and performance improvement from the "inside out".

On the other hand, TOC implementation tackles the activities that provide greatest impact for the company. The constraint that is being tackled may exist inside or outside of the company. TOC deals with performance improvements by looking holistically across the enterprise for the "weakest link".

Efficiency

Both Lean and TOC challenge the notion that being efficient is desirable. By its very definition, efficiency - "a measure of actual output to the standard output expected"[8] - requires that production be performed according to a set standard. For a work center in a plant to be 100% efficient, it may have to produce parts that are not being demanded at that time by downstream operations (and customers).

In Lean, kanban cards constitute permission for an operator to produce. When no kanban card is issued, the operator is forbidden to produce. Efficiency may suffer, but waste is minimized.

Like Lean, TOC controls the flow of materials to the manufacturing floor via the "rope" in the DBR method. Work centers begin and complete work according to the drum schedule only, which determines time and quantity of work to be performed. To eliminate the bias toward local efficiency, TOC promotes abolishing the efficiency syndrome. Once work is received, non-constraint resources complete work as fast and as safely possible and pass it on to the next step. In addition, current practices such as saving setup cost per unit and large process batches are eliminated. Under TOC, only the constraint's efficiency matters (e.g., Throughput dollars per unit or Contribution Margin of a Scarce Resource) and must be maintained or improved.

Value Stream

Both Lean and TOC acknowledge that the chain of interdependencies that create value for customers extend far beyond the walls of the manufacturing plant and the organization. In the final analysis, both principles offer the capability and techniques to look both up- and down-stream of the implementing organization for performance improvements. Lean and TOC recognize it is the job of every person in the value stream to turn inventory into throughput.

Cultural Impact

Both Lean and TOC attempt to instill a culture of continuous improvement. Either by continually eliminating waste or finding, exploiting, elevating and removing the constraint (and then starting the process all over), both methodologies force users to question the current operating procedures and identify methods to improve operations.

[8] APICS Dictionary, 9th Edition. Falls Church: APICS, 1998.

BENCHMARK RESULTS OF COMPANIES DEPLOYING BOTH LEAN AND TOC

Customer and market pressures continually drive companies to reinvent their operations, deliver ever-increasing capabilities and return sustainable profits. As documented above, Lean and TOC are two of the tools available to organizations to identify and exploit opportunities that drive bottom-line results. Additionally, given the not-so-subtle difference in how - and where - Lean and TOC efforts are focused, it comes as no surprise that very few firms have implemented and continue to operate both principles side by side.

This section explores the benefits and lessons learned from dual implementation of Lean and TOC. BearingPoint worked alongside the Avraham Y. Goldratt Institute (AGI) to gather benchmark results and "lessons learned" from four companies that operate both Lean and TOC methodologies.

Benchmark Results of Dual Implementations

Each of the following four firms have deployed both Lean and TOC and experienced performance improvements. All four offered minimal - but telling - results of their Lean and TOC efforts but made no distinction on the contribution either Lean or TOC made to the results. For various reasons, some of the results offered by each of the four companies are more general than specific.

Brush Wellman

Brush Wellman is the leading global supplier of high performance copper, nickel and beryllium alloys and the only fully integrated producer of beryllium and beryllium oxide in the world. In 2002, Brush Wellman employed over 1,000 employees and reported $200M in revenue from sales across 36 different product families.

Brush Wellman first implemented TOC to identify business constraints and then followed up with implementing Lean to help exploit and elevate constraints. While they view their implementation as their continuous improvement process and don't ever expect it to be completed, Brush Wellman began to see results after three months.

The following results identified by Brush Wellman are an aggregate from across their 36 product families:

- Cycle time reduced 53%, from 43 days to less than 20 days.
- On-time shipments increased 73%, from 52% to 90%.
- Available capacity on their largest product line (worth 40% of sales) increased 25% without any capital outlay.
- Inventory turns increased 31% despite a declining market.

Gunze Electronics Manufacturing Division

Gunze is the industry leading touch panel and electroluminescent lamp manufacturer providing the latest technological solutions to touch panels and EL backlighting. Gunze supplies customers such as Sony, Palm, Panasonic and Sharp.

Unlike Brush Wellman, Gunze implemented Lean first and TOC second. Gunze tried to implement the "pull" principle of Lean by introducing just-in-time but had no success. The TOC implementation allowed them to focus their Lean efforts on key business problems.

Gunze's results are stunning. They reported the following aggregated results after implementing Lean and TOC across two production facilities:

- Inventory quantity decreased by 372% (from 119,032 pieces to 25,233).
- One month after implementing TOC, lead times decreased 425% (from 21 days to 4).

- One month after implementing TOC, due date performance increased 17% (from 69.8% to 82%).

General Motors

General Motors Corp. (GM), the world's largest vehicle manufacturer, employs 349,000 people globally in its core automotive business and subsidiaries. GM today has manufacturing operations in 32 countries. In 2002, GM sold more than 8.5 million cars and trucks, nearly 15 percent of the global vehicle market.

Two of their popular full-size trucks (the Chevy Silverado and GMC Sierra) are variants of their GMT-800 model. As part of their ongoing improvement process, GM introduced Lean to the GMT-800 production cells. Later, GM deployed TOC to the GMT-800 product line to identify capacity constraints.

GM offered the following results obtained from their Lean and TOC deployments across the GMT-800 Catalytic Converter and Rear Tail Lamp Assembly production cells:

- GM increased catalytic converter throughput by 52%, from 5,500 to 8,350 units per day while at the same time decreasing the number of hours required to produce 8,350 units by 40%.
- GM reduced number of employees and total hours required to meet rear tail light assembly requirements by 89%, reducing operational expenses by $1.8M per year.

GM's results with TOC and Lean have been so positive that they are now using TOC in designing their factories of the future and advanced planning systems.

Boeing Integrated Defense Systems

The Boeing company has pursued an improvement initiative model founded upon an overall "Lean Umbrella" supported by pillars of TQM, 5S, Six Sigma and TOC. While Lean principles are large, well organized and supported at Boeing, the successful implementation of other methods generated support and recognition that other methods can work well in a Lean-focused environment.

At Boeing, the F/A-22 product line was the first to implement TOC in connection with Lean. Boeing, like Brush Wellman and Gunze, use TOC to identify system constrains and Lean techniques to exploit and elevate the constraint. Today, the entire F/A-22 Team, from factory floor personnel and project managers using the tools on a daily basis, to the senior management team reading the reports, vocally support additional applications of Lean and TOC in both manufacturing and white collar environments.

While Boeing representatives communicated that they have evidence of the contribution Lean and TOC have made to overall improvement, they were only willing to share the following anecdotal evidence:

- Before implementation of TOC, Boeing was not able to achieve planned cycle times. After (and for the past two years) they have reliably met cycle times while increasing production rates and maintaining staff levels well below original forecasts.
- Before Lean was implemented, delivery performance was not good. After Lean and before TOC, delivery performance improved but was not enough. After adding TOC, Boeing has been setting new standards of performance and results are "unparalleled in known history of aircraft production." [9]
- While revenue has not changed, costs have dropped significantly with Lean events and TOC's Critical Chain Project Management.

[9] Christ, David. Boeing Integrated Defense Systems, Critical Chain Coordinator, F/A-22 Program. Personal interview. 24 March 2003.

Lessons Learned

During the research and interview process, as companies shared their approaches and results, they also shared some of the key lessons that they learned from their Lean and TOC implementations. While each organization's experience with Lean and TOC has been very positive, most of the lessons that they learned are based upon the context of how they implemented them. Thus, the lessons gleaned from the above companies have been placed in the context of which principle, Lean or TOC, was implemented first.

Lessons Learned Regardless of Implementation Order

Three messages came through during the research and interview process that were independent of implementation order.

Flavor of the Month

Because most all of the above firms have been pursuing business improvement for decades, they have all spent effort chasing the latest operational improvement trends – the business acronym *du jour*. When it came to their TOC and Lean deployments, many organizations mentioned the criticality of communicating that they were not abandoning one methodology (Lean or TOC) in favor of the other. Rather, they each spent considerable effort and time explaining the connection of the principles and the natural progression of adding Lean to TOC or TOC to Lean. In this manner, they fought the "flavor of the month" thinking. In fact, Toyota recommends each company develop its own production system that is a guiding philosophy for operations. For example, Boeing has the Boeing Production System and General Motors has developed its Global Manufacturing System. Within these operating systems are a variety of philosophies, tools, and management approaches. Tools like kanban and TOC are just one part of a broader operating philosophy in highly successful companies.

Ease of Implementation

Most organizations reported that they had no major difficulties implementing Lean after having TOC in place. In fact, one of the organizations mentioned it actually made easier because they saw it as a logical progression.

Satisfaction with the Implementation

Not surprising given the results provided above, all of the organizations were very satisfied with their implementation efforts and the business practices that Lean and TOC provide.

Lessons from Implementing Lean First

Most of the firms interviewed had adopted some form of Lean manufacturing before TOC. The following lessons were captured from these organizations.

Advantages

Many of the organizations interviewed stated that Lean was "simpler" than TOC for their workforce to understand and apply. The techniques and concepts are considered very straightforward and their production teams picked them up and used them quickly – leading to fast, initial improvements. The obvious connection between Lean and shop floor process improvement also reduced the need for change management and increased user acceptance.

Additionally, by applying Lean before TOC, workers became familiar with the continuous improvement cycle and useful techniques to achieving improvement. Thus, when management later introduced TOC as a further refinement to the continuous improvement process, the workforce found it easier to accept.

Disadvantages

The main disadvantage identified to applying Lean before TOC is that organizations often spent continuous improvement efforts on parts of the business operations that weren't key to achieving operational growth. While they achieved successes, they were minimal or compartmentalized in nature. After bringing in TOC, they could they focus their Lean activities on true business constraints.

Lessons from Implementing TOC First

Other organization had used TOC approaches before adopting lean manufacturing. There were pros and cons to this approach as well.

Advantages

When implementing TOC first, initial effort is spent reviewing the entire business process in order to identify (and prioritize) system constraints. This holistic review provides an excellent framework for Lean process flow analysis in later efforts.

Additionally, by tackling and elevating a major constraint first (while the effort is new and has momentum), organizations identified receiving significant results on their opening try – spurring momentum and buy-in for further TOC activities and the introduction of Lean.

Disadvantages

Without functional experience using TOC in system design and implementation, organizations whose identified constraint is external to their organization will not be able to effectively address that constraint without training and mentorship from an expert in TOC.

Furthermore, while logical and seemingly simple to execute, the complexity of analyzing system interactions can be arduous and should never be underestimated.

In some cases TOC can be a broad analytic method that focuses on strategic buffers without fundamental changes in shop floor processes. When companies start with TOC they often fail to get involved in actual on-the-floor activities that can break constraints and involve employees in shop floor improvement activities.

LEVERAGING LEAN AND TOC IN THE NAVAL AIR DEPOTS

In this section, the benchmarking study departs from stating past history and findings from TOC and Lean implementations and endeavors to propose how the information gleaned from the above companies can be applied for the benefit of the Naval Air Depots.

As mentioned in the Introduction, Lean and TOC are already being deployed across two of the Naval Air Depots: Jacksonville is deploying Lean and Cherry Point is implementing TOC. This section proposes to build upon these site-level activities and provide additional focus on how they can work together to support depot operations.

Unlike the companies contacted for this study, the Naval Air Depots are not pure manufacturing organizations. In fact, the Naval Air Depots have mixed production environments: they have both intermittent and job shop production environments working side-by-side. Additionally, the Naval Air Depots have to manage project (e.g., aircraft, engines) and process (e.g., commodities, avionics, hydraulics) work types. Thus, directly applying commercial approaches to leveraging Lean and TOC to the Naval Air Depots can be viewed as complicated and inappropriate.

Regardless of the difference in business operations and which methodology has been implemented first, Lean and TOC can be combined to support Naval Air Depot operations and a robust, continuous improvement culture.

Setting the Stage

Initiatives are commenced across the Naval Air Depots only after management is convinced that they support the main objectives of the organization. In order to set the stage for how Lean and TOC can be used to support Naval Air Depot goals, the depot goals have to first be defined. The mission of the Naval Air Depots is summarized as follows:

> *To provide a full range of the highest quality services to the Fleet at a competitive price.*

Key determinants of their success in this mission are:

- The capability of the Fleet to meet Aircraft Ready for Training and Sortie (ARFT/S) requirements.
- The capability of the Naval Air Depots to induct and repair all work within customer funding and time requirements.

The following sections briefly describe how Lean and TOC can combine to support the above Naval Air Depot mission and objectives.

Capacity Transformation

The Introduction noted that the Naval Air Depots have just completed an MRP II / MRO implementation. If appropriately used in combination with the resource planning and scheduling capability of MRP II / MRO, the philosophies of lean and TOC can produce the most agile and cost-effective operating system.

MRP II / MRO works best when Master Schedulers can correctly balance supply and demand – when enough capacity and material exists to support the master production schedule. Currently, the Master Schedulers only have a rudimentary and rough understanding of depot capacity – both overall and aggregated by product family. A clearer understanding of capacity would enable the depot to create capacity-constrained master production schedules and derive the following benefits:

- Master schedules wouldn't over-state the amount of material required, reducing inventory costs.
- Inductions could be paced to match production rates, reducing WIP and shop floor confusion.
- Overtime would become an exception and not a way of life, reducing labor costs.

By itself, MRP II/MRO will not make shop floor practices efficient, create flow, and involve people in continuous improvement. In fact, MRP II/MRO only provides tools that can support an efficient and effective process and organization. TOC can be used to identify places to work to get maximum benefit and the lean philosophy and tools can be used to straighten out product flows and involve people in continuous improvement. The Naval Air Depots could utilize TOC (and the Advanced Planning and Scheduling application) to identify the constraints for the depot and each product family. Since constraints determine the pace of production, and thus define capacity, master schedulers can use this information to balance workload.

And much like their commercial counterparts, the Naval Air Depots could utilize Lean techniques to exploit and elevate the depot constraints – increasing their capacity to perform more work each year. Through an iterative, continuous application of TOC and Lean, the Naval Air Depots could transform their available capacity and significantly impact Fleet readiness.

Workforce Transformation

Studies performed by NAVAIR show that by 2008 over 50% of the workforce at the Naval Air Depots will be retirement eligible. The potentially high turnover of skilled workers needs to be addressed years before it occurs to allow for sufficient knowledge transfer. However, the replacement of retirement-eligible workers needs to be performed intelligently. The Naval Air Depots need to identify the skills that need to be replaced and those skills where they could afford manpower reductions. Lean and TOC could be utilized in this effort.

TOC can be used to model current business processes and identify the skills and resources required to maintain specific capacity levels at each process step. Through value stream mapping a "future state model" can be developed that shows capacity and throughput given the predicted retirement of specific workers. Based upon their impact on depot capability, capacity and throughput, the Naval Air Depot could identify which skills need to be replaced and which should go unfilled.

The Naval Air Depots could take this process one step further and use TOC and Lean for real workforce transformation. They could use the TOC and Lean models and techniques to begin *planning* which work centers, product flows and operations to change (e.g., collapse, break-out, modernize, outsource) to meet future manpower reduction requirements.

Production Transformation

Lastly, the Naval Air Depots could use TOC and Lean to transform their production capabilities. Currently, Naval Air Depot Cherry Point is using TOC in conjunction with MRP II / MRO to plan the release of work to the shop floor. Using TOC, the Naval Air Depot determines the pace of production and where buffers need to be placed to protect the constraint. This information is translated into the MRP II / MRO production schedules and work is planned and released at the pace established by TOC.

At the Naval Air Depot Jacksonville, Lean is being utilized to remove waste from shop floor activities. MRP II / MRO is used for the management of all workload, but 5S is utilized to keep the shop floor clean, organized and confusion-free. More sophisticated lean methods beyond 5S can be used to streamline processes through flow methods to reduce waste and speed up the pace of repairs.

With very few modifications, the Naval Air Depots could share their TOC and Lean practices with each other to enhance their production transformation activities. The integration would closely resemble the use of TOC and Lean across the companies previously identified in this study: TOC would identify production rates and constraints and Lean would be used to exploit and elevate constraints. MRP II / MRO would continue to form the foundation of resource planning and shop floor execution, but TOC and Lean would round out the production toolbox the depots need to effectively run their intermittent/job-shop production environments.

SUMMARY

The Naval Air Depots continue to pursue new methodologies to meet their mission for the Fleet. Over the past few years, they have focused on establishing MRP II / MRO as the foundation for further improvements. While MRP II / MRO provides an information backbone for rationally planning and scheduling work, further effort is needed to fundamentally transform operations to meet the increasing demands for speed and efficiency of the customer. So, the Naval Air Depots have begun to add Lean or TOC to their management toolboxes to help them “take that next step.”

TOC emphasizes identifying constraints, eliminating these constraints and scheduling resources and tasks to maximize the system throughput. By applying TOC analysis, the depots can identify the specific target areas that impede the total system flow. To manage the day-to-day workload flow through the depot system, the TOC buffer management techniques can be applied to effectively manage and prioritize the depot’s work.

Radical improvements to the depot’s constraints will result from the structured waste elimination methods of Lean Manufacturing. By applying Value Stream Mapping and then “leaning” these high impact areas, the Naval Air Depots will realize significant benefits for the entire business system – both “above” and on the shop floor. In “above the shop floor” processes, Lean techniques are key to improving fast cycle times for processes that are viewed as “non-value added but required.”

This benchmarking study has been conducted to support the TOC and Lean efforts in two ways: first, to create a baseline against which the Naval Air Depots can evaluate the success of their TOC and Lean deployment efforts; and second, to determine how TOC and Lean can be used together for greater effect.

Based upon a limited sample of firms who have Lean and/or TOC experience, the firms describe Lean and TOC as mutually supportive and natural extensions of each other. While the production environment of the Naval Air Depots differ from the firms interviewed in this study, a judicial application of Lean and TOC could help transform depot capacity, workforce and production characteristics. Both Lean and TOC methodically analyze the entire business system Value Stream to improve the flow of the system.

Iteratively applying this approach will enable continuous improvements throughout the Naval Air Depots business system and support the current efforts to reduce the depot's non-value added elements, reduce cycle times, and improve the workload throughput.

Finally, we want to emphasize that streamlining repair and overhaul operations ultimately depends on people using creativity to solve problems and continually improve processes. Tools are tools and will not solve any problems by themselves. What Toyota and other excellent private sector companies have taught us is the need for a clear and consistent management philosophy focusing on empowering the workforce and providing tools on the shop floor for problem solving and continuous improvement. Thus, any "tool kit" must be part of a broader management philosophy focusing on delivering maximum value to customers.