Objectives

• Define basic Theory of Constraints concepts
• Examine the application of TOC
• Explore the linkage between TOC and LEAN
• How to gain synergy of TOC and LEAN
What is the Theory of Constraints?

A business philosophy which seeks to strive towards the global objective, or goal, of a system through an understanding of the underlying cause and effect.

Theory of Constraints, Eli Goldratt, 1990

TOC: What is the Goal?

GOAL = $

- **NET PROFIT** (Absolute)
- **RETURN ON INVESTMENT** (Relative)
- **CASH FLOW** (Survival)
- **THROUGHPUT**
- **INVENTORY**
- **OPERATING EXPENSE**
**TOC: Global Operational Measures**

*INCREASE THROUGHPUT (SALES)*

The rate at which money is generated through sales.

*DECREASE INVENTORY (INVESTMENT)*

The money invested in things intended for sale.

*DECREASE OPERATING EXPENSE (SPENDING)*

The money spent to convert inventory into throughput.

**Traditional Investment Justification**

**COMPANY:** CIRCUIT BOARD ASSEMBLY JOB SHOP  
**SALES:** $8MM PER YEAR  
**DIRECT LABOR:** 50 EMPLOYEES @ $25K/YEAR EACH  
**OPPORTUNITY:** $300K MACHINE ELIMINATES 6 EES

**FINANCIAL ANALYSIS:**

- **COST OF MACHINE:** $300,000  
- **SAVINGS (6 X $25K):** 150,000

**PAYBACK = 2 YEARS**

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TOC: Throughput Justification

BUT, WHAT IF:

LOST SALES FOR LACK OF LABOR: $2MM PER YEAR
MATERIAL COST: 30% OF SALES DOLLAR

FINANCIAL ANALYSIS:
COST OF MACHINE: $300,000
SAVINGS:
- Additional sales ($160K X 6EES) $960,000
- Less material cost ($960K X 30%) $288,000
- Additional net profit: $672,000

PAYBACK = 5 MONTHS

Traditional Headcount Reduction

COMPANY: INJECTION MOLDING SHOP
SALES: TEMPORARILY DOWN 20%
DIRECT LABOR: 15 OPERATORS ON 30 MACHINES
OPPORTUNITY: LAY OFF MATERIAL HANDLER
SAVINGS: $30K PER YEAR

WITHOUT MATERIAL HANDLER
OPERATORS MUST NOW MOVE OWN MATERIAL
**TOC: Inventory Reduction**

WITH MATERIAL HANDLER
SET UP MORE OFTEN & RUN SMALLER BATCHES

RESULTS

INVENTORY REDUCTION: $300,000
COST REDUCTION (10%): $30K PER YEAR

**TOC: What is a System?**

The total business, taken as a whole.

Not a division, cost center, or department.

The level at which financial ownership exists.
TOC: What is a Constraint?

A constraint is anything that limits a system from achieving higher performance versus its goal.

- **Logistical**: Physical, e.g. bottleneck, plant layout, long changeovers.
- **Managerial**: Policy, e.g. efficiency, utilization, allocations, absorption.
- **Behavioral**: Human, e.g. resistance to change, lack of understanding, politics.

TOC: What are the Elements of TOC?

- Global operational measures
- Five focusing steps
- Process of ongoing improvement
- Drum, buffer, rope
- Cause and effect trees
- Thinking processes
- Throughput accounting
TOC: The Five Focusing Steps

Identify the system’s constraints.
*Usually very few, but at least one*

Decide how to exploit the system’s constraints.
*Don't waste the constraint*

Subordinate everything else to the constraints.
*Non-constraints supply only what constraints need*

Elevate the system’s constraints.
*Open up the capacity of the constraints*

If a constraint has been broken, repeat the process, but avoid inertia.
*Another constraint will limit performance*

TOC: Process of Ongoing Improvement

What to change?
Diagnosis: Description of “current reality” and the core problem that will have a major impact

To what to change?
Description of “desired state” and strategy to attain it

How to change?
Detailed plans for what needs to happen in the group effort to implement the change
TOC: Drum, Buffer, Rope

Drum

**Focusing step:** Identify the constraint  
**What to do:** Schedule the constraint to capacity

Buffer

**Focusing step:** Exploit the constraint  
**What to do:** Protect the constraint against Murphy

Rope

**Focusing step:** Subordinate non-constrained resources  
**What to do:** Release raw materials to drum schedule

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TOC: Cause and Effect Tree

[Diagram showing cause and effect relationships]
TOC: Cause and Effect Tree

- Shortages
  - Efficiency
  - Long setups
  - Large batches
  - Excess capacity
  - Inflexible resources
- Expediting
  - Poor on-time delivery
  - Excess inventory
  - Timely problems
  - Excess component parts
- Overtime
  - Thrusts
  - Forecast
  - Shortage to order
  - Inventory

TOC: Thinking Processes

- Current Reality Tree
  - Maps out a sequence of cause and effect from the core problem to the symptoms.
- Evaporating Cloud
  - Means of displaying and solving an apparent conflict or dilemma between two actions.
- Future Reality Tree
  - Maps out future expectations given that we will introduce something new into the reality.
- Negative Branch Reservation
  - Modification of the future reality tree that accounts for new negative outcomes.
- Pre-requisite Tree
  - The implementation plan to which timelines, responsibilities, and accountabilities can be assigned.
What is a Lean Enterprise?

A continuing agreement among all the firms sharing the value stream for a product family to correctly specify value from the standpoint of the end customer, remove wasteful actions from the value stream, and make those actions which do create value occur in continuous flow as pulled by the customer. The cooperating firms must analyze the results and start the process again through the life of the product family.

Lean Thinking, Womack and Jones, 1996

LEAN: What Is A Value Stream?

All of the activities (both value-adding and non-value-adding) required to bring a product from raw material suppliers to the customer.

The value stream includes all activities which:

- Transform the product (local solutions)
- Process information from the customer (system solutions)
**LEAN: The Five Focusing Steps**

Specify value
*What is the customer willing to pay for?*

Identify the value stream
*All of the steps, VA and NVA, from raw material to shipment.*

Establish flow
*Organize by product family to eliminate waste.*

Establish pull
*Control the non-continuous flow of material.*

Work to perfection
*Goal is perfect value with no waste.*

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**The TOC-LEAN Strategic Connection**

**TOC**
- **Business Goal = $**
- **Increase Sales**
- **Reduce Inventory**
- **Reduce Spending**

Reduce Waste (Sales + Spending↑) & Improve Flow (Sales + Inventory↑)

- **Current state VSM**
  - See the flow
- **Toyota Production System:**
  - Improve the flow
  - Changeover reduction
  - Cellular manufacturing
  - Cross-training
  - Zero defects
  - 5-S visual controls
  - Preventive maintenance
- **Pull Systems:**
  - Control the flow
- **Lean Metrics/Accounting:**
  - Measure the flow
- **Kaizen Teams:**
  - Respect for people
- **Future state VSM**

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The TOC-LEAN Tactical Connection

Business Goal = $\uparrow$

Increase Sales  Reduce Inventory  Reduce Spending

Reduce Waste ($\frac{\text{Spending}}{\text{Sales}}$) & Improve Flow ($\frac{\text{Sales}}{\text{Inventory}}$)

What to change?
Current state VSM
See the flow

What to change to?

Toyota Production System:
Improve the flow
Changeover reduction
Cellular manufacturing
Cross-training
Zero defects
5-S visual controls
Preventive maintenance
Elevate the constraint

Drum, buffer, rope
Pull Systems:
Control the flow

How to change?

Avoid inertia
Lean Metrics/Accounting:
Measure the flow

Kaizen Teams:
Respect for people

Future state VSM
What to change to?

Current State VSM (What to Change?)
The Toyota Production System

- Changeover reduction
- Cellular manufacturing
- Cross-training
- Zero defects
- 5-S visual factory
- Total productive maintenance

Changeover Details

The time required for removing the old tools, dies or fixtures; attaching new tools, dies or fixtures and running the machine until a new part, without defects, is produced.

<table>
<thead>
<tr>
<th>Completion of last Good Part</th>
<th>Locate tools, dies or fixtures</th>
<th>Attach new</th>
<th>Run Part</th>
<th>Enter Offsets</th>
<th>Run Part</th>
<th>Adjust</th>
<th>Completion of first Good Part</th>
<th>1st piece inspection</th>
</tr>
</thead>
</table>

Set-up Time

Set-up time includes run time and adjustment time until a good part is produced. If a good part is produced with no adjustments, run time is part of machine process time.
Cellular Manufacturing

PROCESS FOCUS

PRODUCT FOCUS

Cross-Training Matrix
5-S Visual Factory

Make waste in the workplace visible

Sort (seiri): separate & remove unneeded items
Set in order (seiton): arrange items for easy access
Shine (seiso): clean the work area
Standardize (seiketsu): detailed plan to maintain first 3-S's
Sustain (shitsuke): ongoing commitment of workforce

Attaining Zero Defects

Define defects
Track rejects
Pareto analysis
Root cause analysis
Corrective action
Poka-yoke: error-proofing
Total Productive Maintenance (OEE)

\[ \text{A} = \text{Total Available Time} \]
\[ \text{B} = \text{Uptime} \]
\[ \text{D} = \text{Downtime} \]
\[ \text{C} = \text{Standard Output} \]
\[ \text{D} = \text{Actual Output} \]
\[ \text{E} = \text{Actual Output} \]
\[ \text{F} = \text{Good Output} \]

\[ \text{OEE} = \frac{\text{B}}{\text{A}} \times \frac{\text{D}}{\text{C}} \times \frac{\text{E}}{\text{F}} \]

The Kaizen Approach

The Kaizen Event is a focused, short-term project to improve a process.

1. Initial Analysis of Process:
   - Event area selection
   - Team selection
   - Development of a contract and a mandate

2. Kaizen Blitz Event:
   - Full day of training
   - Process analysis & baseline measurement
   - Development & implementation of new processes
   - Formal presentation of the process and accomplishment

3. Follow Up:
   - Debug the process
   - Assure timely completion of all remaining action items
   - Assure the new process is institutionalized
The Five Steps of TOC and TPS

Identify the system’s constraints (DRUM)

Level-loading and EPEI

Exploit the constraint (BUFFER)

Supermarkets, 5-S

Subordinate all else to the constraint (ROPE)

Kanban

Elevate the constraint

TPM, SMED, OEE, 6SIGMA

Repeat the process – avoid inertia

Lean metrics

Controlling Flow With Pull (or DBR?)

“The most significant source of waste is overproduction, which means producing more, sooner or faster than is required by the next process.”

Learning to See
by Mike Rother & John Shook

Moving from push to pull production has the single greatest impact on improving material flow and eliminating waste.
### ID Constraint: Level Load vs. Level Mix

<table>
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<tr>
<th>ITEM</th>
<th>MON</th>
<th>TUE</th>
<th>WED</th>
<th>THU</th>
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<td>E</td>
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</table>

**LEVEL LOAD: GOOD**

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<th>THU</th>
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<td>20</td>
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</tbody>
</table>

**LEVEL MIX: BETTER**

What is the shortest replenishment interval over which a resource can set up and make some of every part?

---

### The Replenishment Interval is . . .

. . . the shortest period (usually in days) over which a resource can make some of every product.

. . . resource-specific, not product-specific.

. . . capacity-driven, not cost-driven.

. . . also known as Every Part Every Interval (EPEI).
Setting the Replenishment Interval

Available resource time per day

Minus:
Time to cycle one day’s parts

Equals:
Daily changeover time available

Divided into:
Total changeovers on all parts

Equals:
Replenishment Interval in days

Example: A 3-Day Replenishment Interval

Available resource time per day

Time to cycle one day’s parts

Total changeovers on all parts
Example: A 3-Day Replenishment Interval

Some of every part . . .

Every three days!

Example: Acme Stamping SpotWeld 2

1 machines X 2 shifts X 460 minutes

<table>
<thead>
<tr>
<th>PART</th>
<th>W/C</th>
<th>C/O MINS</th>
<th>C/T SECS</th>
<th>DAILY DEMAND</th>
<th>DAILY CYCLE TIME MINS</th>
<th>EPEI</th>
<th>BATCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH BRACKET</td>
<td>SPOTWELD2</td>
<td>10</td>
<td>46</td>
<td>600</td>
<td>460</td>
<td>.65</td>
<td>300</td>
</tr>
<tr>
<td>RH BRACKET</td>
<td>SPOTWELD2</td>
<td>10</td>
<td>46</td>
<td>320</td>
<td>245</td>
<td>.65</td>
<td>210</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\[
EPEI = \frac{20}{3T} = .65 \text{ days}
\]
### Who Is The Constraint?

The longer the interval, the more constrained the resource!

![Diagram showing the constraint between Supplier, Processes A, B, C, and Customer with EPEI values for each step.]

### Exploit Constraint: Supermarkets

A strategically-placed inventory of an item, which:

- Triggers replenishment based on consumption of the item
- Protects the flow of material through the value stream
- Links the flow among value streams and loops
- Focuses additional lean improvements
Sizing Supermarkets

All driven by the daily rate!

Sizing Supermarkets

All driven by the daily rate!
**Subordinate Non-Constraints: Kanban**

No one goes faster than the slowest step in the system (constraint).

**Logistical Pull Techniques (Ropes)**

- *Kanban*: Card which signals consumption has taken place
- *Order point*: Replenish fixed quantity when inventory reaches this level
- *Min/max*: Replenish to max when inventory reaches min
- *Two-bin*: Fill one container while working out of the other
- *Reorder report*: Triggers replenishment based on perpetual inventory records
- *Breadman*: Refill depleted shelf inventory
- *Vendor managed*: Outside supplier replenishes inventory
- *Trigger board*: Accumulates kanbans at supplier
- *Virtual kanban*: Electronic version of trigger boards
- *FIFO lane*: Visual control of first-in-first-out at secondary operations
- *Heijunka box*: Visual load-leveling technique
- *Mixed-model*: Smoothing of production volume & mix
- *Kanban post*: Accumulates kanbans in the order received
Pull Systems (DBR) Account For...

Demand constraints
Demand rates and variability
Competitive lead times and service levels

Supply constraints
Supplier lead times and reliability
Resource uptimes, changeover times and cycle times
Quality yield rates and startup scrap
Material logistics, containers, storage

How LEAN Addresses Cause/Effect

- SMED
  - Long Setups
  - Process Inefficiency
- Cells
  - Large Batches
  - Wandering Bottlenecks
- Six Sigma
  - Excess Capacity
  - High Utilization
- XTraining
  - Inflexible Resources
- Lean Metrics
  - Operating Expense
  - Audit
- Pull/Kanban
### A TOC/Lean Translator

<table>
<thead>
<tr>
<th>TOC</th>
<th>LEAN</th>
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<tbody>
<tr>
<td>Optimize system</td>
<td>Lean value stream</td>
</tr>
<tr>
<td>T, I, OE</td>
<td>Flow and waste</td>
</tr>
<tr>
<td>Identify constraint</td>
<td>Level-loading and EPEI</td>
</tr>
<tr>
<td>Exploit constraint</td>
<td>Supermarkets, 5-S</td>
</tr>
<tr>
<td>Subordinate to constraint</td>
<td>Kanban</td>
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<tr>
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<td>TPM, SMED, OEE, 6SIGMA</td>
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<tr>
<td>Repeat – avoid inertia</td>
<td>Lean metrics</td>
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<tr>
<td>What to change?</td>
<td>Current state VSM</td>
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<tr>
<td>To what to change?</td>
<td>Future state VSM</td>
</tr>
<tr>
<td>How to change?</td>
<td>TPS AND Kaizen</td>
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<tr>
<td>Drum-buffer-rope</td>
<td>Pull/Kanban</td>
</tr>
<tr>
<td>Effect-cause-effect</td>
<td>5-whys</td>
</tr>
</tbody>
</table>

### Words of Caution

**Theory of constraints:**

- A system is the total business, taken as a whole. The level at which financial ownership exists.

**Lean manufacturing:**

- A value stream is all of the activities required to bring a product from raw material suppliers to the customer.

Value stream waste is not reduced unless total system spending decreases!
Continuous Improvement: Cost Accounting?

EFFICIENCIES
Amortize changeover costs
Encourages large batches

HIGH UTILIZATION
Over-activates non-bottleneck resources
Builds inventory ahead of constraints

OVERHEAD ALLOCATION
Assumes all costs are variable
Ignores fixed cost

OVERHEAD ABSORPTION
Encourages inventory build
Ignores impact of fixed costs

EARNED HOURS
Credit for partial completion
Encourages input – not output

Continuous Improvement: Throughput Accounting?

• Sales dollars per person
• On-time shipments to customer
• Dock-to-dock lead time
• First pass yield
• Target cost performance
• Average cost per unit shipped
• OEE at bottlenecks
• Average cross-training per person
Why Marry TOC with Lean?

- Global business strategy
- Sync value streams with each other
- Quantify constraints to better flow/less waste
- Springboard to continuous improvement
- Evolve the TOC/lean mindset - not cost reduction
- Crush the competition!