SURFACE MINING AND subsurface mining requires expensive machinery and equipment. A 12-ton front-end loader and 35-ton haul truck, for example, can cost $1.2 million and $350,000, respectively. A single site can use several pieces of equipment, with additional capital needed for the plant’s fixed machinery, pushing the up-front investment into the tens of millions of dollars.

In 50 Words Or Less
- The 6TOC improvement method employs elements of Six Sigma, lean and the theory of constraints (TOC) to zero in on process bottlenecks and eliminate waste and variation.
- A 10-step implementation plan based on Eliyahu Goldratt’s chain project management process and Joseph M. Juran’s management principles can help any industry implement 6TOC.

Combining lean, Six Sigma and theory of constraints creates a process improvement powerhouse by Todd Creasy
These capital investments can prevent entry into the industry and complicate efforts to grow or improve productivity. Because money is the language of senior management, site managers are careful about unnecessary capital expenses, and often try to focus on controlling expenses while improving worker and equipment productivity.

The aim to improve operational results while reducing inputs or keeping the same is what led one organization to embark on a multiyear quest resulting in a method called 6TOC (pronounced “six tock”) and results worthy of examination.

6TOC is the unique combination of Six Sigma, lean and the theory of constraints (TOC). Its principles and deployment steps are shown in Table 1.

Although this approach to process and productivity improvement is presented here in its application to a mid-southern U.S. mining organization with more than 50 sites, 6TOC can apply to a broad spectrum of industries.

A hybrid combination, 6TOC has elements of Six Sigma, lean and TOC. Six Sigma focuses on quality improvement and reducing production variation, while lean focuses on eliminating waste in all of its seven forms. When these two philosophies are combined with TOC and its focus on bottlenecks, it makes a potent combination, particularly if there is managerial support to improve productivity. Using TOC’s five steps, bottlenecks are exploited and elevated with Six Sigma and lean tools.

Begin 6TOC by identifying the capstone metric. All organizations have financial or operational ratios that predict success or profitability. In this collection of ratios or metrics, one has a higher correlation relationship to profitability than all the others. As part of 6TOC, teams are charged with identifying bottlenecks in the mining industry, there are several rate-specific and contemporaneous measurements to consider, such as tons produced per hour, total costs as a percentage of sales, cost per ton and overtime expense per ton. Table 2 shows examples of site-specific metrics.

After studying 14 months of operational metrics and month-end results for more than 50 locations (n = 700), the metric most positively correlated to profitability was determined to be tons per man-hour (TPMH), which became the capstone metric.

Similar practices have been conducted at large organizations to determine a single most-important metric. The focus on Southwest Airlines’ gate turnaround time and Walgreens’ revenue per customer visit, for example, produced positive results for both organizations.

When demand exceeds capacity

The next step in 6TOC deployment is to determine the scope of the value-creation process flow or chain. In some industries, this may begin with overseeing component manufacturers, raw material suppliers or an in-house receiving department.

In the mining industry, it begins with the stone that has been blasted from the stone face. The process continues with the stone-truck (a large front-end loader, several haul trucks and a primary crusher) to be used.

Step 7: Use lean Six Sigma tools to exploit or eliminate bottlenecks in process.

Step 8: Repeat step 7 working through the next most critical bottleneck.

Step 9: Develop a metrics pyramid for your organization identifying pertinent metrics at each level (corporate, division and location).

Step 10: Develop a communication system using the metrics pyramid for pertinent levels in the organization; consider using scorecards and scoreboards.

6TOC = A method that combines lean, Six Sigma and theory of constraints.

### Site specific metrics / TABLE 2

<table>
<thead>
<tr>
<th>Production</th>
<th>Maintenance</th>
<th>Costs</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tons per hour</td>
<td>Plant availability</td>
<td>Cost per ton</td>
<td>Days since last incident</td>
</tr>
<tr>
<td>Tons per man-hour</td>
<td>Rolling stock availability</td>
<td>Labor cost per ton</td>
<td>Number of near misses year to date</td>
</tr>
</tbody>
</table>

### Critical process flowchart for mining operation

<table>
<thead>
<tr>
<th>Phase</th>
<th>Figure 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Coarse rock to primary crusher</td>
</tr>
<tr>
<td>Phase II</td>
<td>Conveyed to secondary crusher and then to stockpiles</td>
</tr>
<tr>
<td>Phase III</td>
<td>Loaded on trucks then weighed and ticketed</td>
</tr>
</tbody>
</table>

### Truck cycle time actual vs. capable / FIGURE 3

<table>
<thead>
<tr>
<th>Cycle time actual</th>
<th>Cycle time capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.07</td>
<td>3.35</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
<th>Step 5</th>
<th>Step 6</th>
<th>Step 7</th>
<th>Step 8</th>
<th>Step 9</th>
<th>Step 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify and validate operational metrics.</td>
<td>Identify capstone metric through correlation analysis.</td>
<td>Identify value-creating, primary process flow.</td>
<td>Divide primary process flow into three or four logical and measurable segments.</td>
<td>Identify bottlenecks or constraints in each segment.</td>
<td>Begin with the segment with the most restrictive bottleneck.</td>
<td>Develop a communication system using the metrics pyramid for pertinent levels in the organization; consider using scoreboards and scorecards.</td>
<td>Use lean Six Sigma tools to exploit or eliminate bottlenecks in process.</td>
<td>Repeat step 7 working through the next most critical bottleneck.</td>
<td>Develop a metrics pyramid for your organization identifying pertinent metrics at each level (corporate, division and location).</td>
<td>Develop a communication system using the metrics pyramid for pertinent levels in the organization; consider using scorecards and scoreboards.</td>
</tr>
</tbody>
</table>
In the mining case study, attempts were made to exploit the haul truck bottleneck by getting as much out of the constraint as possible. We began using lean to determine how much time would elapse during a typical haul truck cycle. It begins with the truck being loaded with coarse rock, it travels to the primary crusher, it dumps the rock into the crusher and it travels back for another load. The distance from rock loading to rock dumping can range from several hundred feet to two miles.

The time lapse between each load of rock being dumped into the primary crusher was measured using a proximity switch attached to each haul truck. The proximity switch fed information to an on-board GPS unit linked to a mobile phone and uploaded daily cycle times into the cloud and database.

We tested each haul truck to see what its cycle time capability was compared to its actual production time. Several trials were conducted. Example results are shown in Figure 6, p. 47. A lower cycle time equates to greater production levels, thus exploiting the bottleneck.

**People, process and machinery**

The capability time was one minute and 30 seconds. With a five-minute cycle time, each truck will deliver 96 loads a day (12 loads an hour x eight hours). With a three-minute cycle time, each haul truck will deliver 136 loads a day (17 loads an hour x eight hours). These theoretical additional 40 loads x 35 tons x three trucks equate to 4,200 tons a day in improved production with the same equipment, the same equipment operating hours and no additional overtime. Let’s explore the people, process and machinery factors that led to this constraint exploitation.

**People.** The haul truck operators were not aggressively driving their trucks to achieve maximum production. They took their time. The drivers were not positioning their haul trucks correctly near the loader prior to being loaded. The loader operator was not loading the truck efficiently, using techniques that consumed more time.

Cycle times were not communicated to drivers so they did not know how they were performing. This failure to adhere to Joseph M. Juran’s principle of “placing employees in a state of control” was rectified, resulting in a healthy competition between drivers for the lowest cycle time. Times were posted daily reflecting the previous day’s results. See Figure 4 for an example.

**Process.** Other vehicles on the route often would clog the passageway, slowing the cycle time. The haul roads were not wide enough in some areas for two trucks to safely oppose one another in their transport.

In the mining case study, attempts were made to exploit the haul truck bottleneck by getting as much out of the constraint as possible. We began using lean to determine how much time would elapse during a typical haul truck cycle. It begins with the truck being loaded with coarse rock, it travels to the primary crusher, it dumps the rock into the crusher and it travels back for another load. The distance from rock loading to rock dumping can range from several hundred feet to two miles.

The time lapse between each load of rock being dumped into the primary crusher was measured using a proximity switch attached to each haul truck. The proximity switch fed information to an on-board GPS unit linked to a mobile phone and uploaded daily cycle times into the cloud and database.

We tested each haul truck to see what its cycle time capability was compared to its actual production time. Several trials were conducted. Example results are shown in Figure 6, p. 47. A lower cycle time equates to greater production levels, thus exploiting the bottleneck.

**People, process and machinery**

The capability time was one minute and 30 seconds. With a five-minute cycle time, each truck will deliver 96 loads a day (12 loads an hour x eight hours). With a three-minute cycle time, each haul truck will deliver 136 loads a day (17 loads an hour x eight hours). These theoretical additional 40 loads x 35 tons x three trucks equate to 4,200 tons a day in improved production with the same equipment, the same equipment operating hours and no additional overtime. Let’s explore the people, process and machinery factors that led to this constraint exploitation.

**People.** The haul truck operators were not aggressively driving their trucks to achieve maximum production. They took their time. The drivers were not positioning their haul trucks correctly near the loader prior to being loaded. The loader operator was not loading the truck efficiently, using techniques that consumed more time.

Cycle times were not communicated to drivers so they did not know how they were performing. This failure to adhere to Joseph M. Juran’s principle of “placing employees in a state of control” was rectified, resulting in a healthy competition between drivers for the lowest cycle time. Times were posted daily reflecting the previous day’s results. See Figure 4 for an example.

**Process.** Other vehicles on the route often would clog the passageway, slowing the cycle time. The haul roads were not wide enough in some areas for two trucks to safely oppose one another in their transport.
One truck would have to stop and wait for the other to pass, causing cycle delays.

**Machinery.** The roads on the haul route were not smooth. The rough rides caused bodily discomfort during transport and slowed cycle times. Different brands and models of trucks with different maximum operating speeds were being used, which complicated team synergy and produced lower cycle times. Preventive maintenance was not being performed as required, which slowed production during downtime events.

**Communication strategy**
The process of exploiting or elevating bottlenecks occurred throughout the site’s entire production flow process. These findings were replicated to other sites. With the capstone metric firmly established, each level of the organization (corporate, strategic business units and site locations) had metrics that were directly or indirectly tied to the capstone metric. The establishment of these associated metrics enabled the organization to align toward a common direction.

Figure 5 on p. 48 is an example of the metrics pyramid. This pyramid has three sections. The top portion represents the metrics of primary interest to senior management, which includes the capstone metric. The second tier represents middle metrics and is of primary interest to divisional management. The third section has foundational metrics used by location-specific personnel.

The last stage of implementing 6TOC is the management and employee communication system. To keep employees in a state of control, Juran said they must understand the goal, understand their performance and have the autonomy to meet the goal if performance lags.18

Using lean, a series of communication systems was established based on the metrics identified as important for each level of the organization. Senior management received communication monthly through standard financial reviews and reports on the capstone metric and other pertinent metric values.

Regional or divisional management received performance information weekly that compared locations. Location-level managers and personnel often required information that is posted daily and populated with data from the previous day’s activities. See Figure 6 on p. 49 for a schematic of 6TOC’s communication system and Figure 7 for the communication system’s example of a scoreboard and scorecard.

**Doing more with less**
6TOC enabled the mining organization to go against the operating paradigms and traditional thinking prevalent in the industry. This hybrid of Six Sigma, lean and TOC proved you can do more with less and don’t need to reach for the checkbook to improve productivity.

Because production goals were generally met before an eight-hour shift was completed, preventive maintenance activities, which were normally conducted during overtime hours, were conducted during normal shift hours. Also, because of the aggressive preventive maintenance schedules, plant and equipment availability climbed into the mid-90% range from the upper 70 to mid-80% level.

In most locations, little capital was expended to achieve these results. Most long-time employees previously believed new equipment or refurbished machinery would have to be purchased to improve equipment availability and productivity.

Equipment expenses dropped because the desired tonnage was being produced in fewer hours. Inventory accuracy improved because of the increase in measurements along the throughput process, which prevented financial surprises at the end of an accounting period.

For a comparison of mean tons per hour, month-over-month production comparisons by location (represented in box plots), refer to Figure 8.

Practitioners of continuous improvement constantly search for tools to help lead teams and organizations toward successful outcomes. The marriage of lean and Six Sigma illustrates the complementary strengths each method offers for delivering on organizational or project needs.

The addition of TOC creates a potent combination for quickly finding root causes and producing solutions with a direct bottom-line impact. Regardless of industry, 6TOC can save time, effort and money when dealing with process constraints and productivity improvement goals, and enable organizations to better serve all stakeholders, including customers, suppliers, team members and managers.19

---

**REFERENCES**
8. Goldratt, Critical Chain, see references 7 and 8.
10. Ibid.

**TODD CREADY** is an associate professor at Western Carolina University in Cullowhee, NC, and a consultant at Bridgepoint LLC in Asheville, NC. He holds a doctorate in Management from Case Western Reserve University in Cleveland. An ASQ-certified Six Sigma Black Belt.

---

**Scorecard of divisional or regional metrics**

<table>
<thead>
<tr>
<th>Site location</th>
<th>Margin per ton compared to group average</th>
<th>Cost per ton compared to group average</th>
<th>Plant availability compared to group average</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Scoreboard of site or location-level metrics**

![Scoreboard](image)

**Monthly performance**

- **Location A tons per hour**
  - Baseline = 675 tons
  - Improvement: 36%

- **Location B tons per hour**
  - Baseline = 625 tons
  - Improvement: 23%

- **Location C tons per hour**
  - Baseline = 500 tons
  - Improvement: 23%

---

**Monthly performance**

![Graph](image)