

# **Determining the Capacity Constraint Resource in an underground coal production section**

F.J. van Heerden

Department of Engineering and Technology Management, University of Pretoria

Sasol Mining, a division of Sasol Limited

## **Abstract**

The problem with the underground production section of a colliery is that the constraint of the section is unknown. The constraint for the colliery is the market because not all production of the colliery can be put into throughput. Production that is not put into throughput is inventory which account for more cost. Studies were done on a colliery previously, but this study focussed on the in-section portion of the production chain. This study focussed on the in-section part on the operations with the aim of finding the constraint for the section.

A time study was conducted on the production sections of Sasol mining to find the in section constraint. The measurements were designed to determine the capacity of the in-section equipment. Time measurements were taken on all the processes in the section and this was analyzed to determine the capacity of the relevant equipment in the section. Further analysis was done on the downtime bookings of the sections to do further analysis on the production process.

The analysis of the information showed that the three shuttle cars are the capacity constraint resource for the in-section production process. It was further found that the in-section constraint is the is the production process itself, because the production process in itself limits the production of the section and thus prevents the shuttle car from being the constraint.

*Keywords:* Theory of constraints; Capacity constraint resource.

## 1. Introduction

The problem with the mining industry is that the bottleneck or capacity constraint resources (CCR) for the in-section operations of the mine are unknown. The in-section part of the operation is the coal winning activities, which includes the cutting, loading, hauling, sizing and feeding of the coal onto the section conveyor belt. The lack of CCR knowledge makes it very difficult to manage and control the mining activities.

The planning of the operations is currently based on a seat of the pants approach and is non-scientific. The Theory of Constraints (TOC) (Goldratt 2000) states that the all non-constraints must be subordinated to the bottleneck. The bottleneck for the organisational system, which is the market, is outside the system and therefore the need arises to find the capacity constrained resource (CCR) inside the section. The bottleneck will drive the processes in the mine and if the capacity of the market changes, the number of sections will also need to change to accommodate the changing market. Logically it is easy to add more production capacity when the market demands more product volume, but to add capacity is very expensive due to the capital layout. The right decision will be to improve the existing production capacity and only when the line can not increase its throughput when it has reached its capacity, should one decide to add more production capacity. Alternatively, one will have to forfeit the opportunity to supply to the markets increased demand. The production line can only be managed to operate at optimum capacity when the capacity of the CCR and markets are known, which will then determine the potential capacity of the production system.

The capacity of the section and the CCR is unknown and therefore the optimal operating point can only be reached by guessing and can not be easily corrected once something changes. The section changes everyday and therefore the research idea for this project will be to determine the capacity critical resource and its capacity in the section.

It will be beneficial for the company if the capacity critical resource is known because the equipment can then be utilised effectively. This will bring along big cost savings because the utilisation of equipment will be more effective. The bottom line is that the production cost will decrease and the profit will increase with the effective utilisation

of the technology. A reduction in cost will benefit the company because the competition is taking place on price due to coal been a commodity.

## **2. Proposed model or conceptual method**

The hypothesis set forward by this research is that finding the capacity critical resource and managing a section in accordance with constraint management principles will lead to increased performance of the mine. The CCR in the section is currently unknown and needs to be identified through studies. The goal for the study will be therefore to determine the capacity constraint resource in the system and provide suggestions on how to subordinate all equipment to the CCR.

The capacity constrained resource can be used to control the planning process in the section. The next step will be to determine a way to subordinate the capacity constrained resource to the bottleneck. All the other non-constrained processes must be subordinated to the capacity constrained resource.

The main focus will be on finding the CCR of the underground production system because, even though the CCR is not limiting the capacity of the underground section, it is the control point between the market demand and the underground section. If the CCR is unknown the section cannot be managed to the benefit of the organisational system. The CCR will help with the planning of the underground section, because the CCR will be subordinated to the bottleneck, whilst all non-constraint equipment will be subordinated to the CCR. The work in process will decrease and the operation of the section will be more effective, because machines will only work when necessary and not to stay busy for the sake of being busy. This will help to create more capacity for the maintenance of the equipment, which will lead, to fewer breakdowns during operations.

### **3. Literature review**

#### **3.1 Basic system principles on which TOC rest**

The main idea is from the theory of constraints, Goldratt (1992; p297,303), which is that the bottleneck will determine the capacity of the production line and that everything must be subordinated to the bottleneck.

Young (2004; p163) wrote that the Theory of Constraints began with a simple concept about production lines, similar to the idea that a chain is only as strong as its weakest link. Later this developed into a set of thinking tools to tackle problems in business, politics and even marital breakdown. An interesting strategic perspective is that there will always be a bottleneck, the decision is where you want it. Another perspective is that anything that increases throughput at the bottleneck, almost without regard to cost, adds value to the system as long as it is safe. Away from the bottleneck, idleness of a resource cost nothing provided that resource does not become the bottleneck. The designing of a bottleneck in the system where it can be managed the best is a very powerful idea.

#### **3.2 The five focussing steps**

Goldratt (1992; p303) states that the following should be done to be able to continuously improve:

- Identify Identify the bottleneck
- Exploit Exploit the bottleneck by running it at full throughput and thus getting everything possible from it
- Subordinate Subordinate all other elements in the system to the bottleneck since the bottleneck control the throughput.
- Elevate Elevate the bottleneck if possible to get more throughput from the system.
- Prevent inertia If the constraint is broken in any of the previous steps, go back to the first step but prevent inertia from slowing down the system, revisit all previous decisions and ensure they are not slowing down the throughput.

## **4 Research design and methodology**

### **4.1 Research design**

The overall approach will be to test the theory of constraints in an underground production section of a coal mine. The test will determine the capacity constraint resource in the section and will try to evaluate the CCR by means of the five focussing steps of Goldratt (1992; p297,303) which are

- Identify the bottleneck
- Exploit the bottleneck by running it at full throughput and thus getting everything possible from it
- Subordinate all other elements in the system to the bottleneck since the bottleneck control the throughput.
- Elevate the bottleneck if possible to get more throughput from the system.
- If the constraint is broken in any of the previous steps, go back to the first step but prevent inertia from slowing down the system, revisit all previous decisions and ensure they are not slowing down the throughput.

The research will be conducted by doing time studies in several production sections of Sasol Mining. This will be the raw data gathering for the project that will be analysed later to determine the in section bottleneck. The research involved the studying of all the relevant equipment in the section. The equipment and variables that will be studied are:

- Continuous miner
- Shuttle car
- Feeder breaker
- Process time buckets

### **4.2 Research methodology**

The time studies will be done by physically measuring functional step times on the shuttle cars and on the continuous miners. The times will be measured with the aid of a stopwatch and all times will be recorded for later analysis. The shuttle car is the link between the cutting process and the conveying of the coal to the surface, it is therefore very important to keep the turn around time of the shuttle car as short as

possible. The number of loads hauled by the shuttle cars per hour will also be recorded.

The shuttle car measurements will be from 3 production sections, which will result in data for 9 shuttle cars and the continuous miner measurements will be from 15 production sections.

The time bucket system will also be evaluated and information will be gathered from this system. The time buckets are a waterfall system that groups all times in the production system into buckets or groups. The buckets are used to determine which action or process is taking up the most time during the production shift.

The data will be analysed by making use of statistical analysis to determine the bottleneck and also to find the relationship between the various factors in the productions section.

#### **4.3 Research justification**

The main drive in the research will be the theory of constraints and analysis around this. This will result in finding the CCR of the section. The data gathering as described in this chapter will be the best method to gather the information due to the fact that the information is physical measurements. This will result in quantitative results and not qualitative results because the human touch is removed from the measurement. The aim of this study will be to get results based on scientific facts and not on human feelings. The quantitative results will make the identification of the bottleneck possible by means of statistical analysis.

#### **5. Results and discussion**

The underground production section consists of a continuous miner, three shuttle cars and a feeder breaker. The function of the equipment can be summarised as follows.

- The continuous miner is the machine that mines the coal, the processes related to the continuous miner are:
  - i. Lifting of the cutter head from the stone floor to the roof.

- ii. Sumping into the coal which entails cutting into the coal face against the roof.
- iii. Shearing down from the roof to the floor and thereby cutting the coal in the face from the roof to the floor
- iv. The following, figure 4.4, is a graphical representation of the continuous miner process.

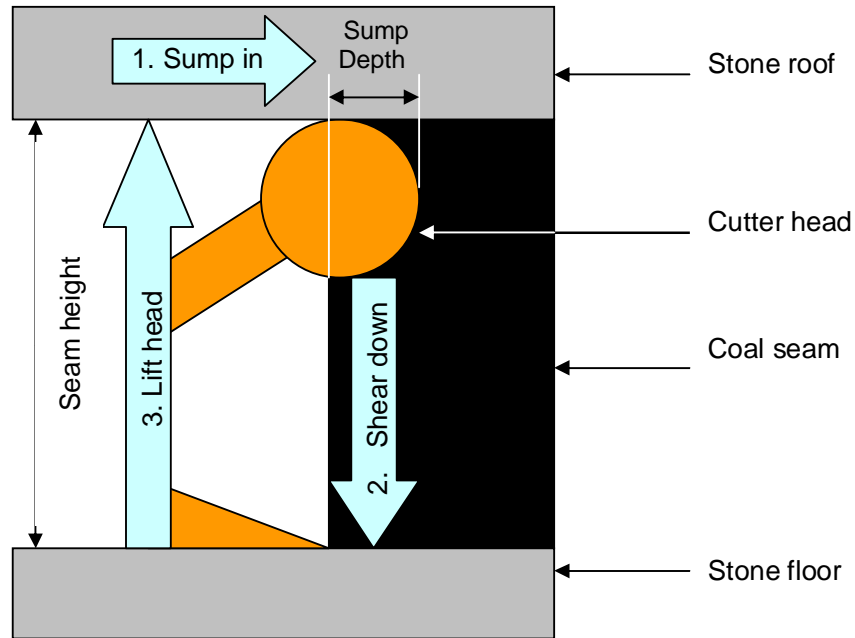


Figure 5.1 Cross sectional layout of cutting cycle

- The shuttle car is utilised to haul the coal from the face to the feeder breaker, the processes related to the shuttle car are:
  - i. The shuttle car gets loaded by the continuous miner in the coal face.
  - ii. The shuttle car hauls the coal form the continuous miner in the coal face to the feeder breaker at the conveyor belt tail end. The shuttle car is electrically driven via a trammig cable and can therefore only travel on a predetermined route.
  - iii. The shuttle car dumps the coal into the feeder breaker.
- The feeder breaker is stationary at the conveyor belt. The processes related to the feeder breaker are.
  - i. The feeder breaker gets loaded by the shuttle cars and feeds the coal to the crusher drum of the feeder breaker.
  - ii. The feeder breaker sizes the coal before the coal is fed onto the production section conveyor belt.

The underground production section process is displayed in chart 4.1. The continuous miner, three shuttle cars and feeder breaker interactions is presented in the chart. It should be noted that only one shuttle car can be loaded by the continuous miner at any time and that up to three cars can tip into the feeder breaker together.

Production process sequence						
Machine	Process					
Continuous Miner	Lift head					
		Sump				
			Shear			
	Load					
Shuttle Car	Load					
				Haul		
					Dump	
Feeder Breaker					Feed	
					Sizing	

Chart 5.1 Production sequence

A time study was done on all the steps of the production process. The time study was very comprehensive, but only a summary of the results will be presented in this paper. A summary of the times recorded in the production section is presented in table 5.1.

Machine	Process	Minimum	Maximum	Average	Geo Mean
Continuous Miner	Shear	34	103	61	55
	Lift head	12	63	29	28
	Sump in	13	59	27	27
	Total	59	225	117	109
Shuttle car	Load	39	280	80	72
	Haul	28	3272	351	437
	Dump	37	261	96	84
	Total	107	3397	591	434
Feeder Breaker	Feed + Size	37	261	96	84

Table 5.1 Summary of time measurements in seconds

The average is the sum of all samples divided by the number of samples, also known as the arithmetic mean. The geometric mean can be calculated by the  $n^{\text{th}}$  root of the product of all the samples. The following formulae represent the average and geometric mean mathematically.

$$\text{Geometric mean} = \sqrt[n]{\prod_{i=1}^n X_i} \quad (1)$$

$$\text{Arithmetic mean} = \left( \sum_{i=1}^n X_i \right) / n \quad (2)$$

The capacity of all of the equipment can be determined by analysing the summarised data in table 4.1. The geometric mean cycle time of the continuous miner where found to be 109s. The hauling capacity of the shuttle car is 16 tons and therefore the batch size of the system is the hauling capacity of the shuttle car. The batch size is not a statement regarding the capacity of the continuous miner, but rather about the production process. The shift capacity of the continuous miner is found with the following calculation.

$$\begin{aligned} \text{Tons per shift} &= (\text{Cycles per shift}) \times (\text{Tons per cycle}) \\ &= [ (\text{Shift time}) / (\text{Cycle time}) ] \times (\text{Tons per Cycle}) \\ &= [ (8.75\text{hr} \times 60\text{min} \times 60 \text{ s}) / (109 \text{ s}) ] \times (16 \text{ ton}) \\ &= [ (31500 \text{ s}) / (109 \text{ s}) ] \times (16 \text{ ton}) \\ &= 289 \times 16 \text{ ton} \\ &= 4624 \text{ ton per shift} \quad (3) \end{aligned}$$

The capacity of the shuttle cars and feeder breaker can also be determined with (3). The cycle time for the shuttle car is 144s, because 3 shuttle cars are used in the section and therefore the cycle time for a shuttle car in the system is a third of the 434s for a single shuttle car. The times for the shuttle car and feeder breaker were calculated the same as for the continuous miner and the results are presented in table 4.2.

Machine	Continuous miner	3 x Shuttle car	Feeder breaker
Capacity (ton/shift)	4624	3484	6000

Table 5.2 Machine capacity

The calculation showed that the three shuttle cars have the lowest capacity and therefore it can be concluded that the shuttle car must be the capacity critical resource (CCR).

Summary of section time buckets	
Infrastructure	7.2%
Essentials	5.6%
Start and end of shift	8.4%
Statutory	1.2%
Geology	0%
Operating	11.6%
Planned downtime	0.9%
Breakdowns	9.7%
None measurable	27.6%
Cutting time	27.8%

Table 5.3 Summary of section time buckets

#### **5.4.1 The capacity constraint resource**

The Drum, Buffer, Rope (Cox 1998) is a scheduling technique for the theory of constraints. The scheduling process takes on the following format.

**a) Identify the constraint resource.**

The shuttle cars were identified as the capacity critical resource with a capacity of 3484 ton / shift.

**b) The cycle time of the constraint resource determines the throughput for the entire system, this is the drum**

The cycle time of a shuttle car is found to be 434 s, but the system utilises 3 shuttle cars which brings the cycle time down to 144 s. The essence of the 144 s is that the production section can put a batch of 16 tons of coal through every 144s.

**c) Create the master schedule based on the drum's available capacity**

The shuttle car is the CCR which tells us that the schedule should revolve around the shuttle car. The shuttle cars must be reliable as this is the CCR. The continuous miner and feeder breaker are single path equipment, meaning all the coal must pass through these two machines, but both the continuous miner and feeder breaker can run at lower capacities before they become the CCR. A breakdown on the continuous miner and feeder breaker will stop the section and is therefore also important equipment. A decrease in any of the three shuttle cars will have an immediate reduction in throughput of the section.

**d) Create buffers, buffers may dispel any apprehension the scheduler may feel.**

- i) The first buffer is placed in the shipping area. This is the time offset from the constraint schedule to the promised ship date.
- ii) The next buffer to be created is an assembly buffer.
  - 1) It protects the shipping schedule against external and internal disruptions.
  - 2) The second use of the assembly buffer is to protect the assembly line from variability within the factory.
- iii) The next buffer to be implemented is at the constraint resources or CCR.

The reality surrounding the coal production section is that there is no opportunity for any buffers. The process and equipment are designed that the coal must be passed from one machine to the next. A piece of equipment can not store the coal and start to process another batch before the next piece of equipment take delivery of the batch.

**e) The last step is the creation of the rope. The function of the rope is to create a communication method to ensure that the release of material into the plant is sufficient to always support the constraints operation.**

The rope is a communication process to support the CCR. The rope must ensure that the shuttle cars are transferring. The cars must not wait for coal when it gets to the coal face, the continuous miner must be ready to load the cars when it reaches the coal face. The feeder breaker must also be available to take the coal from the shuttle cars when it reaches the tip, the shuttle cars must not wait for the feeder breaker. The throughput of the section reduces when the shuttle cars waits for anything.

## **6. Conclusions and recommendations**

The assumption was made that the market is the bottle neck and this was the reason to find and optimise the in section CCR.

The main conclusion that was found in the study is that the processes in the section are not subordinated to the capacity constraint resource of the section, which is the shuttle car. It is also concluded that there is no schedule to support the CCR. The schedule process for the theory of constraints states that the drum, buffer and rope need to be addressed in the schedule.

The shuttle car is the drum, which is supposed to control the process. The production is not scheduled according to the CCR, but to the market constraint. The section however, should be scheduled according to the schedule of the CCR, after the CCR schedule has been determined by the market demand.

The rope is not visible and the conclusion is reached that the rope does not exist. The rope is the communication channel and needs to be built to ensure that all processes are subordinated to the CCR and ultimately the bottleneck. No buffers exist in the production section system. If physical buffers are not possible, then the buffer must exist in the protective capacity of the resources.

Given a set of alternative allocations and a set of individuals, a movement from one alternative allocation to another that can make at least one individual better off, without making any other individual worse off is called a Pareto improvement or Pareto optimization.

The capacity constraint resource must be used as the drum in the underground section during scheduling. All other resources in the section must be subordinated to the CCR.

Pareto stated the 80-20 rule and this will be a good place to start. The 20% that will give the 80% improvement must be identified and utilised. The vital few are identified because these are the causes with the biggest time as.

- Non measurable time
- Breakdown time
- Start and end of shift time

The above times account for 45.5% of the shift time or can also be seen as lost production or lost utilisation. The CCR utilisation is at present only 44.19%, the utilisation of the system will be increased to 73.4 % if the three time groups or

buckets can be changed from downtime to uptime. The utilisation of the CCR does not increase to 89.69%, because a portion of the non-measure time will not increase the utilisation of the shuttle car as is discussed in chapter 4. The latter two times can easily be addressed with a proper maintenance plan and with a hot seat change system. The non measurable times will need more effort to address.

## References

1. Goldratt E, Cox J. The Goal, 2000, 2<sup>nd</sup> ed. Aldershot: Gower.
2. Schmenner, Roger W., Swink, Morgan L., 1998, On theory in operations management, Journal of operations management
3. Lawrence, S.R, Buss, A.H., 1995, "Economic Analysis of Production Bottlenecks," Mathematical Problems in Engineering,
4. H. Schneider, International Journal of Technology Management 1997 - Vol. 14, No.1 pp. 29-38
5. Goldratt E.M, Fox R.E ,1986, The Race, Aldershot Gower
6. Terry Young, Using industrial processes to improve patient care, BMJ 2004;328:162-164 (17 January)
7. The Theory of Constraints Center (TOCC),The Five-Step Process, Available from <http://www.tocc.com>
8. The Theory of Constraints Center (TOCC),The Theory of Constraints Performance Improvement Process, Available from <http://www.tocc.com>
9. 10.James F. Cox , Michael S. Spencer,1998, The constraints management handbook, CRC Press LLC.
11. [http://en.wikipedia.org/wiki/Pareto\\_principle](http://en.wikipedia.org/wiki/Pareto_principle)
12. Lockamy III A, Industrial Management & Data Systems, October 2003, vol. 103, no. 8, pp. 591-599(9) , Emerald Group Publishing Limited
13. Mahesh C. Gupta , Sidney J. Baxendale , P. S. Raju, Integrating ABM/TOC approaches for performance improvement: a framework and application, 1988
14. Jayson, Susan, "Goldratt & Fox: Revolutionizing the Factory Floor", Management Accounting, May 1987, pp 18-22

17. Driscoll, J. & Hurley, S. 1991, "The development of a generic bottleneck scheduler", Production Research: Approaching the 21st Century, Pridham, Mark & O'brien, Christopher, Taylor & Francis, Inc.
18. Gardiner, Stanley C, Blackstone Jr, John H., & Gardiner, Lorraine R., "Drum-Buffer-Rope and buffer Management: Impact on Production Management Study and Practices", International Journal of Operations & Production Management, Vol. 13 No. 6, 1993, pp. 68-78
19. Goldratt, Eliahu, & Cox, Jeff ,1987, The Goal: A Process of Ongoing Improvement, revised edition, North River Press, Croton-on- Hudson, NY
20. <http://www.joy.com>
21. <http://www.icon.co.za>