A FRAMEWORK TO SIMPLIFY THE MANAGEMENT OF THROUGHPUT AND CONSTRAINTS

A. Cambitsis Cyest Corporation

Abstract

We show that the prioritization of business improvement and performance management decisions may be significantly improved by taking into account the systemic effects of changes made in a single process area. To do so we build a model of a mining value chain, taking into account consequential downtime that arises from downstream and upstream starvation and choking effects of each activity. Introducing the concept of internal capacity, this approach yields insight into the relative importance of key metrics such as loading and hauling rates. We suggest that a holistic view of this type should be a core component of business improvement and performance management decisions.

Introduction

Companies in the resources space increasingly need to find ways to squeeze more out of their assets, as driven by global competitive pressures for capital and the risk of commodity price downturns. Most resource companies have now established continuous improvement programmes and corresponding organizational structures that are focused on driving initiatives to maximize value within the current asset base.

In this context, while cost management and improvement are crucial to running an effective and profitable organization, the greatest gains can generally be obtained by increasing production volumes or throughput. The sensitivity analysis shown in Figure 1, which is for a relatively high margin mine, shows the impact on profit of a 10 percent change on costs *versus* a 10 percent change in production volume (taking variable costs into consideration).

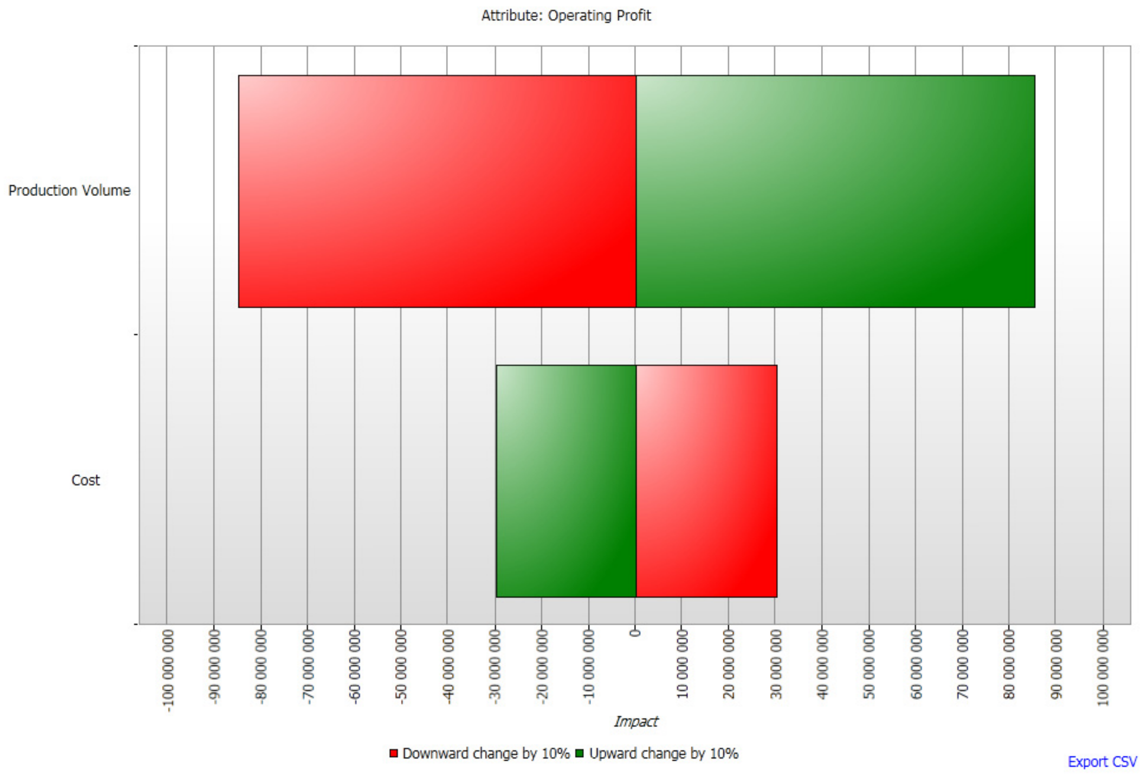

Figure 1-The relative importance of production and cost improvements (illustrative)

As can be seen, the same percentage improvement on volume has a significantly higher impact on the bottom line than that of cost. In fact, the higher the margin of the mine, the more pronounced this impact will be relative to cost. This also holds true for lower margin operations, but here the difference between the impacts is not as pronounced.

Moreover, not only is production volume a more impactful lever, but there are often greater opportunities to realize gains in this area. The volume of ore produced and sold by a mining operation is the result of a set of activities operating in sequence to extract the ore, transport it, and beneficiate it. The rate (and often the quality) at which this is achieved is influenced by various interdependences between the activities in this value chain. Therefore to maximize throughput one needs to manage across the whole value chain, and understand the impact of these interdependencies clearly. Attempting to manage activities in isolation of the upstream and downstream dynamics, as we will show, is not a very effective way of maximizing throughput. Because organizations tend to assign responsibilities and manage in silos (i.e. per activity), in practice this leads to a sub-optimal system and a reduced potential to increase throughput on most operations.

Of course this concept is not new. Theory of constraints (TOC) and lean manufacturing address the issue of system throughput. In this paper, however, what we will show is that by building a model of the value chain, and using visually intuitive value driver trees, one can introduce a series of metrics whereby it is possible through the course of normal operational reporting to manage constraints and throughput. In other words, the lean and TOC techniques alluded to can be packaged into a *system* for managing the operations.

What is a value driver tree?

A value driver tree is a way of visualizing a model of a business in a way that links the value metric (what management or stakeholders care about) to the operational drivers (the things that can be influenced to change the value metric). In this respect a value driver tree is the visual representation of a mathematical model of a business (or a portion thereof). Most of us are familiar with spread sheet-based models of a business, often used for planning or budgeting processes. In essence all these models are nothing more than a series of mathematical relationships relating input variables to output variables. The complexity often comes in the number of the variables and relationships, how they are organized, and how transparently these are represented.

In our case we use the Carbon Modelling platform, an object-orientated modelling software technology that allows us to build complex models of a business, but still visualize the model or aspects of it in a visually accessible and intuitive value driver tree, as shown in the example in Figure 2 for a hauling activity.

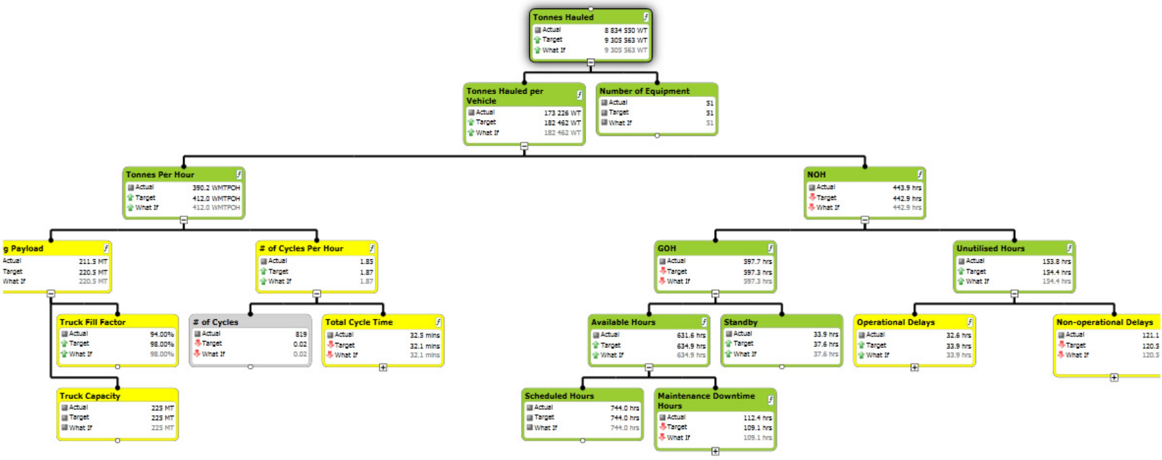

Figure 2-An example of a value driver tree

The value driver tree is useful because:

1. It is visually appealing and engaging
2. It shows how different areas of responsibility (e.g. engineering and operations) link together and affect the value metric (in the case above the tons hauled).

Modelling an activity using a value driver tree model

We start off by modelling a basic unit of production. This could be a piece of equipment such as a truck or milling line, or an activity as a whole such as drilling or crushing. In either case the output is the quantity of product (be it metres drilled or tons crushed), and this is a direct function of the amount of time the activity or equipment is operating and the rate at which it operates. This is a reasonably universal way of describing any production activity and in fact can even be applied to service activities.

The following basic equation depicts the quantity produced:

Quantity produced = production rate × net production time

Figure 3 shows this in a value driver tree format with the production output being at the apex and the drivers being beneath it. The sensitivity analysis on the right of the diagram shows the impact that a 10 percent change on each driver individually has on the quantity produced. Because of the multiplicative relationship, a 10 percent change on either driver has the same result.

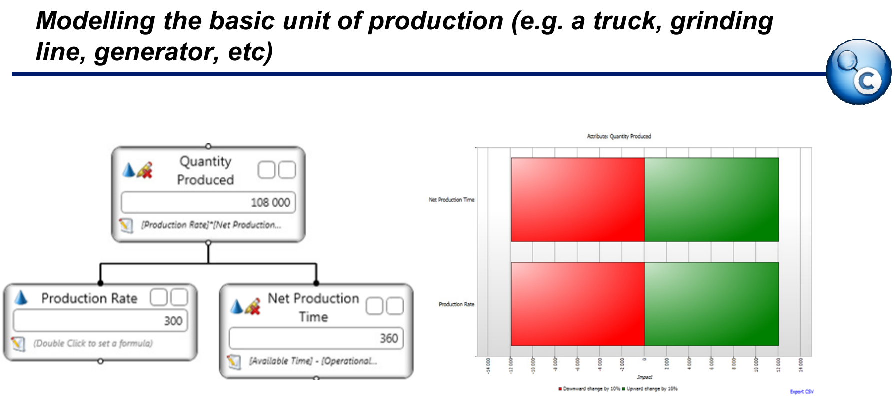

Figure 3-The fundamental equation of production

We now take this a step further, and expand the net production time into available time and operational delays. Simply put, the generally accepted definition of available time is time in which the equipment is available to work. Due to operational reasons (such as no operator, shift changes, upstream activities being down, etc.) the equipment or activity does not necessarily operate the full amount of the available time. These delays are accounted for in the operational delays variable shown in Figure 4.

Available time is often expressed as a percentage of calendar time and is thus known as availability, and the net operating hours as a percentage of the available hours is known as *use of availability* (UoA) – i.e. the percentage of available time that translates into operating hours. These definitions typically form part of what is known as a 'time model'. Most mining and production organizations have their version of the time model, and while these may vary somewhat from each other, the core principles shown here are reflected in each of them.

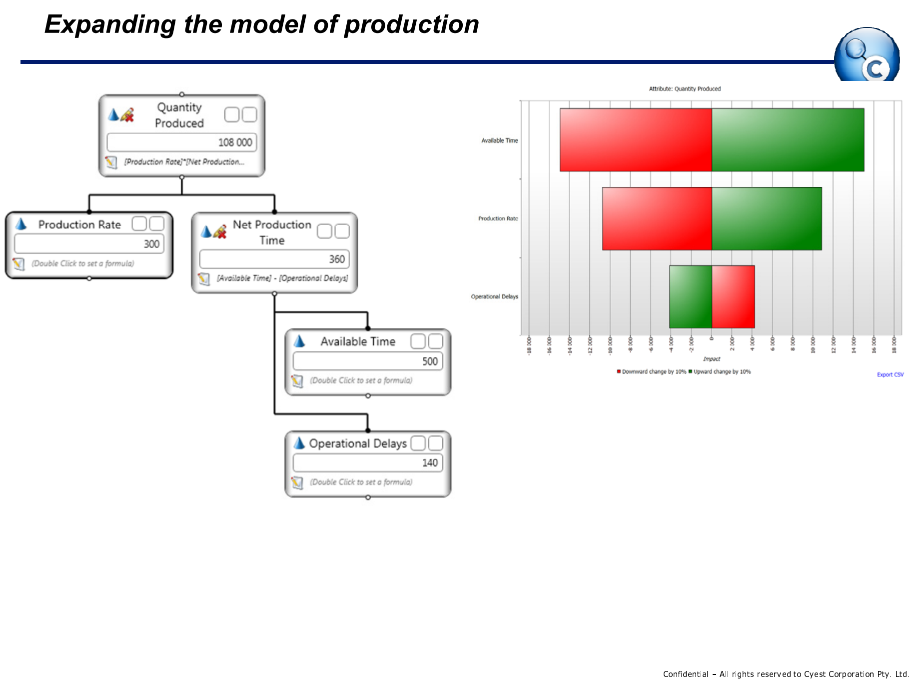

Figure 4-Decomposing net production time

Available time can be decomposed as the total calendar time available, less the time in which the equipment is not available: we broadly refer to these lost hours as maintenance downtime (Figure 5). Maintenance downtime itself can be of the planned or unplanned variety, the difference being that the latter occurs at a measurable statistical rate but is uncertain in timing.

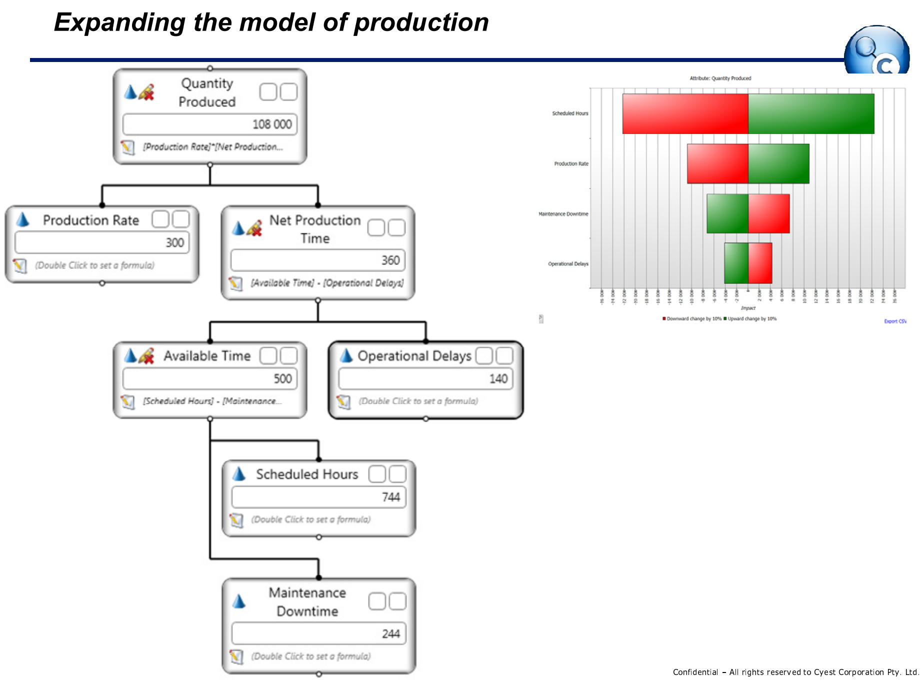

Figure 5-Decomposing available time

We further expand operational delays into three categories (Figure 6):

1. Internal delays – delays, such as a shortage of operators, that arise within the process or activity and can be influenced by management within the relevant silo
2. External delays – delays arising from external considerations such as bad weather, which directly affect the process but cannot usually be directly managed
3. Consequential delays – delays caused by a knock-on from upstream or downstream activities, in the form of 'choking' or 'starvation'. Choking refers to the activities' inability to push more product downstream because of a full stockpile or the next activity being unable to take the product. Starvation refers to the activity having no feed from the upstream activity.

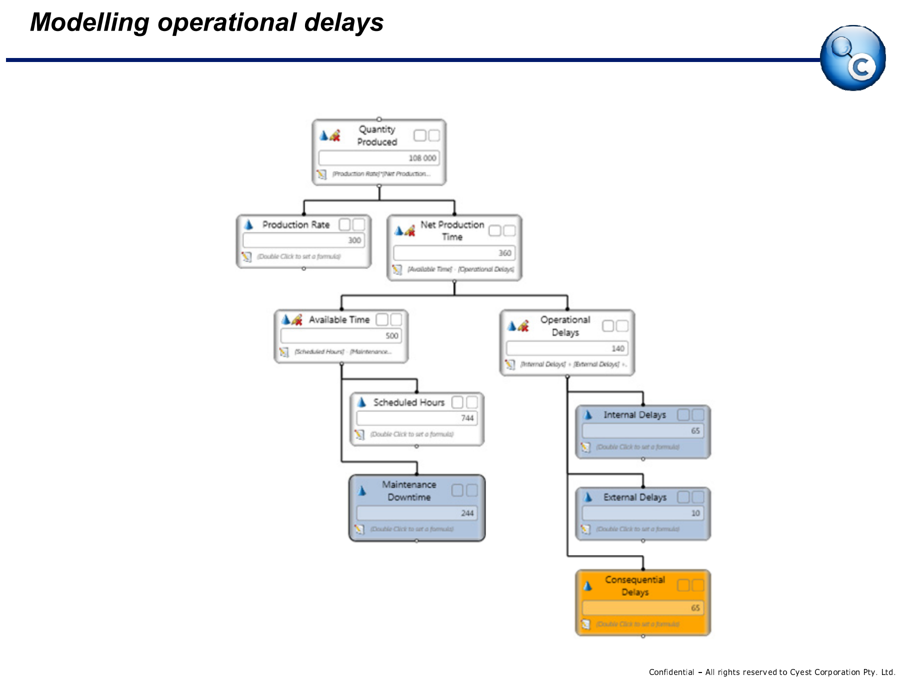

Figure 6-Decomposing operational delays

The concept of internal capacity

With the above as a basis, we can now define the concept of internal capacity for an activity. Internal capacity is defined as the quantity that the activity would produce if it were not starved or choked. In other words, if the process were able to operate in isolation, without any consequential delays, then based on figures achieved for all other internal variables this is the production that the activity would have achieved (Figure 7).

Note that reaching this level of production does not necessitate any improvements in the activity *per se*; it simply requires better coordination, or isolation of the impact of upstream and downstream downtimes. The difference between the internal capacity and what was actually achieved is a crucial concept.

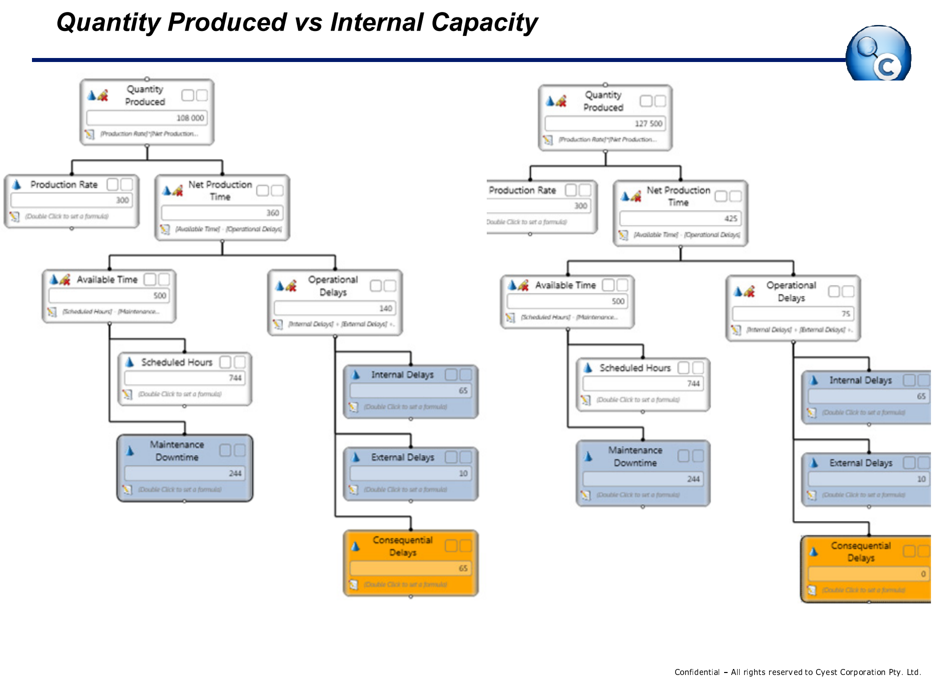

Figure 7-Comparing internal capacity to actual production

Modelling activity Interdependencies

We now proceed to use the activity value driver tree to assemble a model of a value chain and model the interdependencies between the activities, as shown in Figure 8.

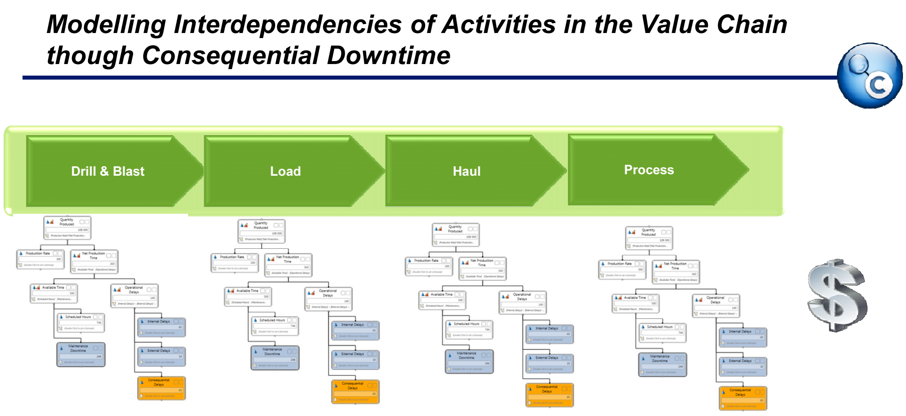

Figure 8-Linking together units of production to form a sequential process

As shown, we place the value driver trees next to each other, and the following step is modelling of the consequential downtime of each activity.

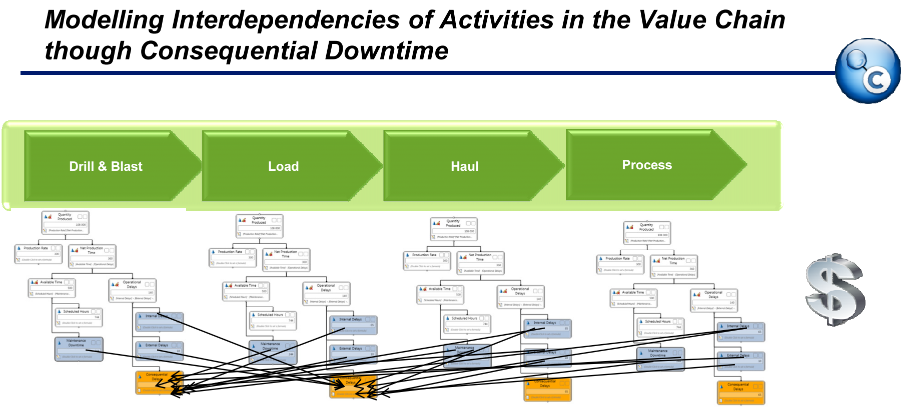

Figure 9-The process linkages due to consequential downtime

We do this by representing the percentage of internal delays of each activity that translates into consequential downtime of every other activity. This factor can be measured or derived by a detailed time simulation. Once these factors are derived, we can build a high-level model to run scenarios that will help us determine how to optimize throughput of the system as a whole (Figure 9).

The fundamental concept here is that we can now compare the dynamics of an activity in isolation to those of one that exists in the context of a value chain

In Figure 10 we have analysed the sensitivity of a hauling activity's total production to drivers **excluding those from other activities** (i.e. consequential delays). Unsurprisingly, the scheduled hours and rate of production (i.e. rate at which tons are hauled) are the most significant factors in this example.

If we were incentivized on increasing throughput on this activity in isolation, this is typically what would appear to be important based on the types of measurements that are usually recorded.

Key drivers of an activity working in isolation

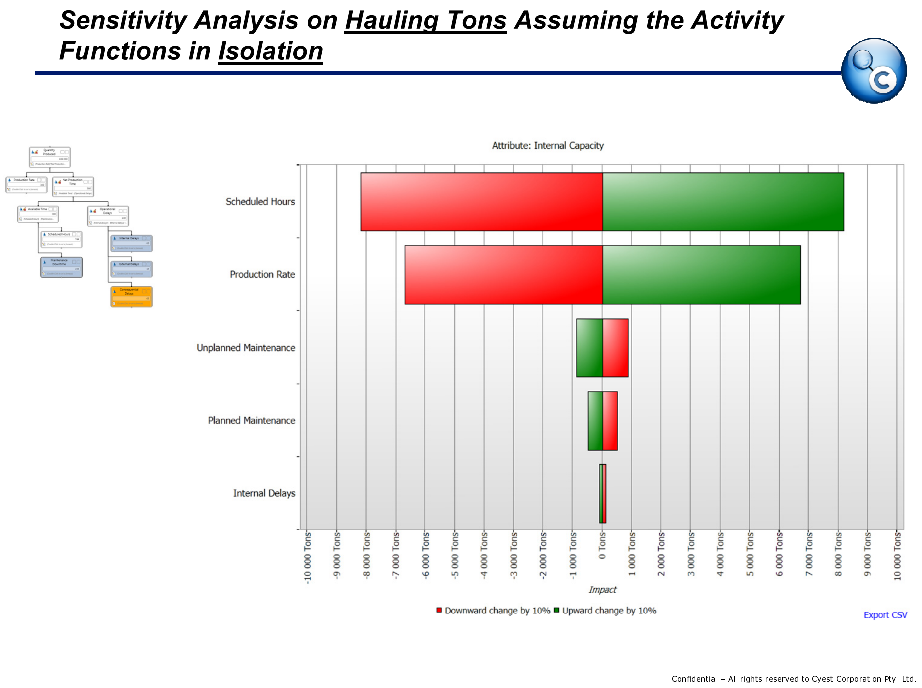

Figure 10-Sensitivity analysis of hauling tons in isolation

Key drivers of an activity in the context of a value chain

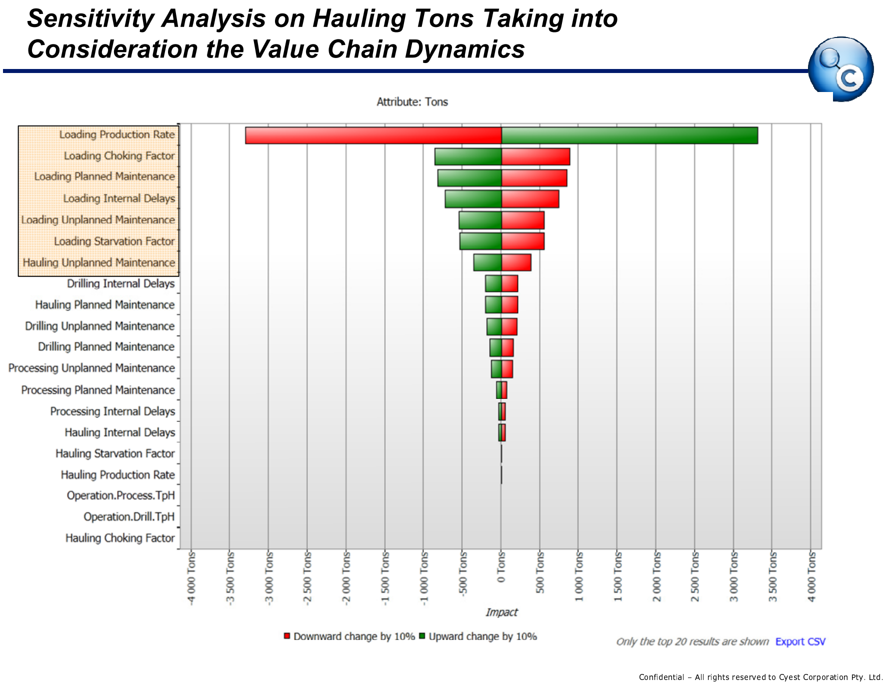

Figure 11-Sensitivity analysis on hauling tons in the context of the value chain

But what happens if we look at this activity in the context of a value chain? Our model helps us establish this by analysing the activity with the consequential downtime factored in. We see that in fact the *loading rate* (not hauling) is the factor with the biggest influence on hauling production (Figure 11). Hauling rate in fact has declined in importance to the point where it is negligible. What this indicates is that there is no point in improving the hauling process until it is de-bottlenecked by improving loading throughout.

This is the power of modelling the complete system holistically: considerations that may appear important within each silo in fact may not be significant at all in the big picture. More importantly from a management perspective, the KPIs of an individual silo owner *may not have any relationship to the performance of the whole business*, and in fact it may be counterproductive to spend money fine-tuning one area of the business when it is not involved in the systemic constraints.

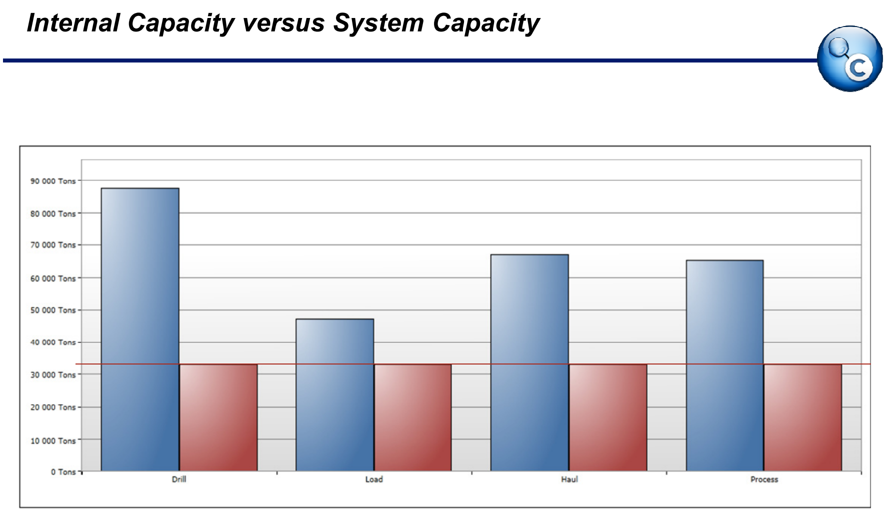

Figure 12-The key output - a capacity chart

With our ability to model the difference between internal capacity and actual performance, it becomes possible to plot a chart which helps to identify where the constraints lie. In the example in Figure 12, it is quite clear that the internal capacity of loading is the first obstacle to be overcome.

Interestingly, the actual performance of the system is *less* than the capacity of the least-capable activity. This makes sense: if it were only consequential downtime from loading that we had to worry about in this example, then the internal capacity of loading would exactly determine the throughput of the system.

However there are situations where loading itself is choked or starved, in spite of the fact that it is the bottleneck. Thus the overall capacity is less than might be initially expected.

An illustration of the magnitude of this effect can be seen in Figure 13. In our example, consequential delays in the bottleneck process were *twice as much* as the internal delays of the process. Clearly, paying attention to the inter-process effects can have a major impact on overall performance.

Advanced techniques in this area include running a Monte Carlo simulation with varying production rates, to test a more physically realistic set of throughput scenarios. Inherent process rate variability can contribute significantly to underperformance simply by virtue of its contribution to choking and starvation, and the consequent need to hold larger stockpiles than would ideally be desirable. One great thing about rate variability is that it is relatively easy to measure objectively, once operational and consequential delays are accounted for.

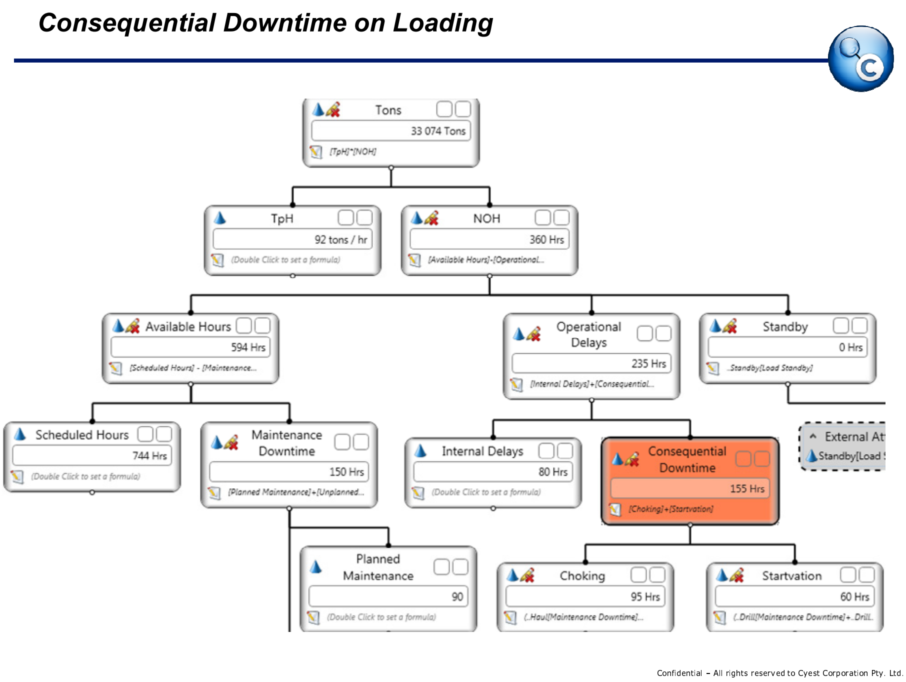

Figure 13-Measuring the consequential downtime on the bottleneck activity

Benefits of this approach

Using this holistic process modelling approach, we can derive the following benefits:

1. We can determine which activity has the least capacity and therefore is the potential bottleneck
2. We can show how much production was lost at each activity due to upstream or downstream constraints

3. We can see the cumulative effect of choking and starvation beyond the capacity limitations of the bottleneck activity.

These insights can be communicated to the heads of each activity. In this way they can begin to understand how their actions lead to increased downtime both downstream and upstream of their own process. Additionally, the information can be used to prioritize focus on improvement in particular silos.

Conclusion

Focusing on increasing throughput of a mining company is usually a very effective way of increasing value because:

1. A certain percentage change in volumes (throughput) *drives more value* than the same percentage change in costs
2. There is generally unrealized throughput potential in the existing asset base due to the interdependent nature of ore flow through a value chain.

By building a model of the value chain using visual value driver tree principles, and paying respect to the interdependencies between activities, we can demonstrate how managing an activity in isolation (and incentivizing management as such) does not help increase overall system throughput.

The model, however, allows us to understand which activity is constraining throughput, and how system throughput is further diminished by starving or choking the constrained activity. A model of this nature contains metrics that can assist management to understand the true potential of the value chain, and which areas to focus on in order to maximize flow through it. Such models can be built for mining operations and introduced into daily performance management activities, helping management realize maximum value from the installed asset base.

Acknowledgements

The author would like to thank his team members and clients who have over the years developed models of increasing sophistication that led to the insights reflected in this paper, and for their commitment to finding ways of improving how businesses can be run using more scientific decision-making tools.

References

Cambitsis A. 2012. Using Equation Based Modelling to Modell Value Chain Throughput. *Internal White Paper*, Cyest Corporation.

Goldratt E. 1992. The Goal: A Process of Ongoing Improvement. *2nd Rev edition, ISBN 0-88427-061-0*

Sye G.L.. 2009. Process Mastery with Lean Six Sigma. a practitioners guide to the utilisation of modern day Lean Six Sigma methodology, *ISBN 978-1-920875-11-4*

The Author

Andreas Cambitsis, Cyest Corporation

Andreas Cambitsis has a B.Eng. in Aerospace Systems Engineering and a Masters Degree in Operations Research from the University of Cambridge, UK. Prior to joining Cyest, Andreas worked for three and a half years as a Strategy Consultant for Monitor Company.

During that period he acquired experience in several industries including, mining, retail banking and logistics, whilst working on projects in South Africa, the US, Canada, and Europe. At Monitor Andreas led several engagements where he specialised in the application of analytic technology for, amongst other things, competitor simulation techniques incorporating game theory. Over time Andreas has developed niche skills in his primary passion, namely - addressing strategic business issues by developing analytical tools using cutting edge technology.