SIMULATING STORAGE

Dr. Alexander A. Lebedev, Lebedev Consulting, South Africa, addresses required storage capacity and how risk profiles can spot issues and evaluate steps to reduce inefficiences.

Storage plays an important role in mining, minerals processing, and related industries. Having been involved in numerous projects both in study and operating phases, the author of this article has come across a typical perception that we need a storage capacity of X hours, shifts or days' worth of feed. Conversion of mass units applicable to storage capacity into time of feed at a given rate is a common practice. Interestingly, that kind of a human perception generally applies from one side, for example if a stockpile is required between a mine and a processing plant, the stockpile must provide feed to the plant during a specific time deemed to be adequate to resolve a problem in the mine. It therefore conveniently assumes that when a delay occurs in the mine, the stockpile is full to the top and will contain ore sufficient to feed the plant for a given time. However, the stockpile can be almost empty when the mine stops for whatever reason. Also, the plant can break down too and the stockpile must absorb feed coming from the mine and prevent unnecessary stoppage of mining activities.

Storage always works both ways, it must feed the downstream plant when there is an upstream problem and, the other way around, absorb feed from the upstream plant if there

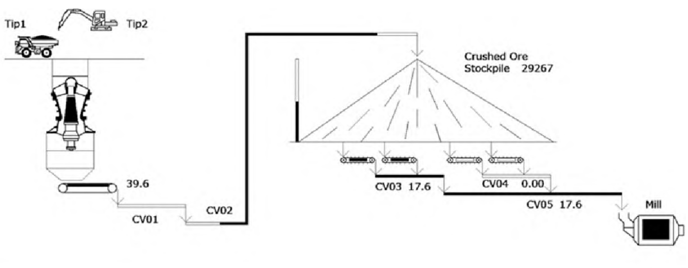


Figure 1. Animation screenshot of the stockpile simulation model.

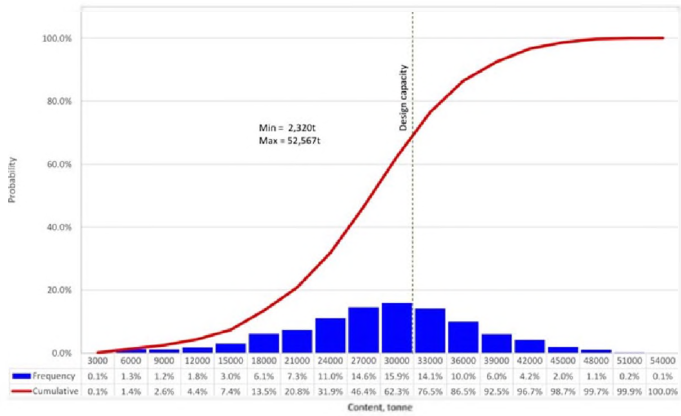


Figure 2. Crushed ore stockpile risk profile.

is a problem downstream. Ideally, a storage facility must be running half-full (or half-empty, depending on one's viewpoint) so it always has space to absorb arriving feed and also has stock available to feed further plant. Therefore, when it is said that a silo or a stockpile must have a capacity of six hours, in reality it should cater for six hours of incoming flow with closed extraction and for six hours of outgoing flow with stopped supply.

This article attempts to generalise the experience accumulated on various projects and describe a methodology that was found useful and practical for sizing bins, bunkers, silos, and stockpiles. All of these facilities will be referred to as storage, since the form in which storage is implemented is outside of this article's scope.

Why storage is required?

If incoming and outgoing flows are equal by rate and coincide in time, storage is generally not required. A pronounced requirement for storage occurs when the incoming and outgoing flowrates are not equal and do not coincide in time. Some of the examples of temporary mismatches in short and medium cycles between input and output flows are listed here:

Continuous to continuous:

- High rate incoming flow over a shorter period of time and low rate outgoing flow over a longer period of time, e.g. an underground coal mine operating two shifts a day and a coal washing plant operating three shifts a day.
- Highly variable incoming flow and constant outgoing flow albeit occurring almost at the same time, e.g. a bucket wheel reclaimer feeding a process plant.

Discrete to continuous:

- Trucks arriving from an open pit or an underground mine and feeding a continuously operated process plant.
- Trains or ships delivering coal to a power station.

Continuous to discrete:

- Process plant whose product is loaded onto trains or trucks.

Discrete to discrete, normally associated with smaller parcels arriving more frequently whose content is then transhipped into larger parcels arriving less frequently, or vice versa:

- Trains delivering ore to a port for loading on ships.
- Large ships delivering bulk materials for further distribution by barges (coastal) or trains (inland).

All of those can be reduced to a fundamental principle according to which any storage facility functions, which is described by a mass balance:

$$\int_0^T R_{in}(t)dt + M_1 = \int_0^T R_{out}(t)dt + M_2$$

Where:

- T is the length of time t.
- $R_{in}(t)$ is the function describing the rate of incoming flow.
- M_1 is an opening material inventory/balance in the beginning of a cycle.
- $R_{out}(t)$ is the function describing the rate of outgoing flow.
- M_2 is a closing material inventory/balance in the end of a cycle.

The difference between M_1 and M_2 is exactly what storage should compensate for.

A simple case study

To illustrate the point, consider the following:

- A mine needs to produce 7 million tpy of ore.
- ROM ore is delivered to a primary crusher by 100 t trucks, hauling 16 hr/d, six days per week, with uneven distribution of time between three shifts. On the seventh day, due to maintenance activities and operating delays in a pit truck, hauling time is reduced to only four hours. In total, ore hauling time per week is 100 hours.
- Ore is crushed and stacked onto a stockpile which feeds the mills.

- The mills operate continuously with the exception of breakdowns and a planned maintenance shutdown every fortnight for seven hours. In order to minimise the impact of the mills' planned maintenance shutdown, it is scheduled to take place during the same time as the stoppage in the pit.
- Plant availability due to breakdowns was incorporated based on surveyed data.

The case study is characterised as follows:

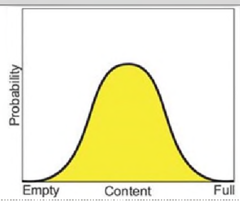
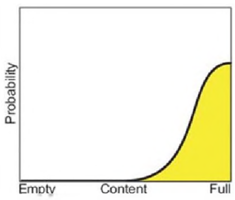
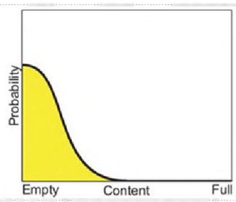
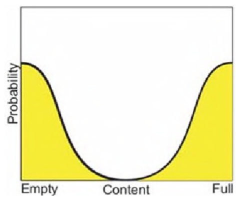
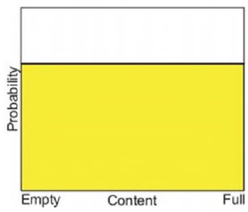
- Discrete input (trucks) to continuous output (the mills).
- Scheduled delivery time is 200 hours per fortnight vs 329 hours milling time, including breakdowns.
- ROM ore incoming rate is higher than feed rate into the mills.
- Breakdowns affect both the front end (from the primary crusher to the stockpile) and the back end from the stockpile to the mills.

Designers allowed for a 30 000 t crushed ore stockpile, however they wanted to check whether it would be sufficient.

A dynamic simulation model was subsequently built with Witness simulation software, which apart from discrete events can also model continuous processes – a feature only available in a few simulation packages, though useful specifically for modelling metallurgical and other processing plants (Figure 1).

The model considered random occurrence of events and applied distributions obtained in similar real operations.

Table 1. Types of storage risk profiles and their interpretations

Risk profile	Interpretation
	Well balanced bell-shaped profile. An ideally sized storage that runs neither empty nor full, hence always has capacity to accommodate incoming flow should there be a downstream problem, and always feeds the downstream plant if the incoming flow is interrupted. Well balanced supply and demand, Push = Pull. Chokes neither upstream nor downstream plant. This is the most desirable storage performance and risk profile. No change in storage capacity is required.
	Skewed to high values profile. There are a few scenarios where such profile is observed: •Mainly a poorly balanced scenario, where supply exceeds demand, i.e. supply to storage exceeds demand from it, Push > Pull. •Downstream bottleneck restricting extraction from a stockpile by either rate or time, but more likely a combination of both. This is undesirable due to choking upstream plant, however, some engineers prefer to have storage to run like this due to a sensitive plant behind it, for example a diamond DMS plant. An increase in storage capacity will unlikely improve the profile and will just push it further to the right.
	Skewed to low values profile. Similar to the above, there are a few scenarios where such profile is observed: •Mainly a poorly balanced scenario, where demand exceeds supply, i.e. extraction from storage exceeds feed into it, Push < Pull. •Upstream bottleneck restricting supply into storage by either rate or time, but more likely a combination of both. This is an undesirable scenario, the stockpile chokes a downstream plant. A reduction of capacity can be considered.
	Inverted bell profile. This is a totally inadequate storage which predominantly runs either full or empty, i.e. chokes both the upstream and downstream plants. While the supply and demand can be actually balanced medium to long-term, due to a small size of the storage it fills up quickly when supply exceeds demand over a short time, and to the contrary, quickly drains down when extraction exceeds stacking over a short time. In other words, short misalignment in incoming and outgoing flows fills up or empties down the storage. This must be avoided at all cost. Storage capacity must be increased.
	Flat profile. As a rule, this storage is used on an alternative and staggered basis, i.e. either filling or discharging, it is first filled up to the top and then drained down to the bottom, and so it replicates in cycles. Typical layout is a stockpile with two beds, of which one is stacking and another one is reclaiming, and then the machines swap around. Frequently used for blending/homogenising. A change in storage capacity will influence material residence time and frequency of filling/extraction changeovers.

Running the first iteration of the model revealed that the stockpile, sized at the design 30 000 t capacity, filled up to the top and remained full for a long time, missing the ROM target due to choking of the primary crusher. The second iteration was executed with the stockpile oversized to 60 000 t to quantify both the minimum and maximum ore levels. It was then established that the peak stockpile content does not exceed 53 000 t.

The final simulation was run at 53 000 t and produced the risk profile depicted in Figure 2. The interpretation of the risk profile is outlined here:

- The stockpile content scale (X-axis) was set at 54 000 t.
- The entire range of 0 - 54 000 t was then divided into 18 virtual 'pockets', the first responsible for the values from 0 - 3000 t, the second one for the 3000 - 6000 t range, and so on, with the last one covering the 51 000 - 54 000 t range.
- Every hour the model polled the ore content on the stockpile and placed an observation into the appropriate pocket, for example if the ore content on the stockpile was 10 000 t, the model would add an observation to the fourth pocket.
- Vertical bars therefore indicate a fraction of time during which the stockpile had a specific ore content.

The solid red line in Figure 2 shows the cumulative probability of the content ending at 100% as it covered the entire range of all possible stockpile loading scenarios, and as such the red line constitutes the risk profile. The crushed ore risk profile inter alia advises the following:

- The stockpile design capacity of 30 000 t only covers 62.3% of the stockpile loading, i.e. the stockpile overflow risk is 37.7%.
- Should the stockpile cover 100% of risk, its capacity should be set at 53 000 t.
- Should the stockpile cover 95% of risk, for example, its capacity must be 40 000 t at the least (95% value belongs to the 39 000 - 42 000 t pocket, perhaps a midpoint would be a safe estimate but this is immaterial in practice as the cost of the stockpile will be much the same).

A second check was then performed whereby the stockpile capacity was capped at 30 000 t and the loss in annual production was approximately 400 000 tpy.

If the stockpile is capped at 40 000 t capacity, the loss in production is only 20 000 t, which in real life can be recovered for example by running the trucks for a short extra time or perhaps an extra truck in a fleet.

The risk profile is therefore a useful tool that can help take informed decisions for sizing storage facilities.

Types of storage risk profiles

Working on multiple studies for the mines and analysing different operating scenarios and storage performance, the types (or classes) of risk profiles can be generalised as indicated in Table 1. 'Push' and 'Pull' terms are applied to indicate quantities to be injected into and drawn from, a storage facility, generally over medium to long-term.

Conclusions and recommendations

A storage risk profile quantifies cumulative probability of content in a storage facility in the entire range from empty to full, and allows for an accurate evaluation of the minimum practical capacity required to achieve the production target. The risk profile can recommend a significant reduction in the storage capacity by taking a relatively small risk of storage overflow or running empty.

Storage risk profile also identifies bottlenecks in a supply chain as well as points at poorly balanced material flow, which in turn may prompt to remedial action.

Types of risk profiles are generalised, which help understand the root of the problem, if any, and a course of action. In some applications where the flow of material is not balanced over long-term, storage will not necessarily solve the problem and instead a reexamination of supply and demand may be required, or perhaps an analysis of the bottlenecks in the entire supply chain needs to be undertaken. DB