IN-PIT CRUSHING
CONSIDERATIONS FOR CONVEYING & MATERIALS HANDLING SYSTEMS

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INTRODUCTION

Very often, materials handling systems serving mines have been designed and commissioned with due regard for the metallurgical and process requirements, but with little or no regard for the conveying systems, sometimes with disastrous effect.

For example, it is common to primary crush ore and waste in the pit to a "conveyable size" based on the belt width required, and to have all subsequent crushing done in the plant. The overburden waste will never be crushed again and as a result there is considerable conveying of large rocks, which have only been subjected to primary crushing.

This paper covers the decisions that the process engineer together with the materials handling engineer must make, which greatly affect the good design of the downstream conveying systems.

The following aspects are discussed in this regard:

- Material types v.s. crusher product
- Lump impact energy and its disastrous effects on conveyors
- The handling of dense ores
- Pre-screening and primary crushing
- Loading arrangements, capacities, lump sizes and belt widths
- Aspects unique to the handling of waste
- Types of in-pit crushers and their implications
- Conclusions to be drawn

MATERIAL TYPES V.S. CRUSHER PRODUCT

The first question to be asked is why do we need to crush rock in the first place?

Two obvious answers are: to enable us to get to the minerals inside, or to be able to transport the rock on conveyors, or both.

To the materials handling engineer, the most important aspect is to reduce the rock to conveyable size, *but all too often it is simply assumed that if the rock has been through a primary crusher or a grizzley, it is conveyable.*

The different materials that are being crushed and conveyed however, vary in their characteristics considerably, especially with regard to strength, shape and bulk density and so on. Iron, Uranium, Tin and Platinum ore for example are dense, hard and often slabby. Limestone is of medium density and is relatively soft and breaks into even lumps. Coal is not very dense at all and can be crushed by simply dropping it, as happens for example in a Bradford breaker. Waste rock can vary considerably from soft clay to hard rock, and as will be seen later on, it can pose enormous problems for other reasons.

Dealing with the easy materials first, the limestone is usually fed in large lump sizes up to around 1m^3, often over a grizzley and into an impact crusher. There the limestone is broken down with rotating hammers, and can reduce directly to tertiary product sizes, i.e. very small. The bulk density is average at 1.6t/m^3, and for the downstream conveying system this is simply ideal, and is a pleasure to handle.

Coal as well, is easy to crush, and is even less dense at around 0.9 t/m^3.

Often, it is desirable to create as little fines as possible when reducing the size of coal, and typically the Bradford Breaker or mineral sizers are selected for the duty. Both will accept large run of mine coal, and will reduce them to a uniform and consistent small lump size with relative ease. Again therefore, the downstream conveying system can easily handle such a primary crusher product.

Waste rock is typically about 1.6t/m^3 and varies in hardness and crusher requirements, whereas the tough ores for example like iron, platinum and uranium ores are heavy, and have bulk densities up to 2.6t/m^3.

In order to crush heavy ores for example Iron, Uranium, Tin and Platinum with lump size often in excess of 1m^3, large primary gyratory crushers are frequently used. Such crushers typically provide a reduction ratio of 4:1, implying a product size of minus 250mm, but which is often quite a slabby product. As a result, the downstream conveying system will invariably have great difficulty in handling such an unfriendly primary crusher product.
For example, the photograph below shows a typical sample of rock was taken off a conveyor handling the product of a primary gyratory crusher on Uranium ore:

Figure 1

This rock is quite typical of the material on the belt and measures 400mm x 250mm x 200mm and has a specific gravity of 2.9t/m^3. The mass of the rock is therefore about 57kg, (and since it was taken without deliberately waiting for extra large rocks to arrive, it follows that there are even heavier rocks to contend with.)

The current materials handling system conveying this material has an unacceptability low availability, and the belt lives on some of the conveyors involved are measured in weeks and months, and not years.

LUMP IMPACT ENERGY AND ITS DISASTROUS EFFECTS ON CONVEYORS

It has been found in practice that for fabric belts, the maximum amount of energy that a lump can be allowed to impact onto a belt is around 900 Joules. For steelcord belts we normally limit the impact per lump to 1000 Joules, and even less for the lower classes of steelcord belting. *For the 57kg lump in the above photograph in figure 1, a transfer height of only 1.6m will cause an impact energy value of 900 Joules.*

The speed of impact onto the belt for this 57kg rock must be kept to less than 5.6m/s by correct use of dead boxes in the transfers, as well as ensuring the lowest possible transfer heights.
If the lump in the above photograph were of iron ore instead of Uranium, the mass of the lump would be about 80kg, in which case a transfer height of only 1.2m will cause an impact energy value of 900 Joules.

It is therefore no wonder that belts are often destroyed soon after they are commissioned under such adverse conditions.

A typical transfer is as follows:

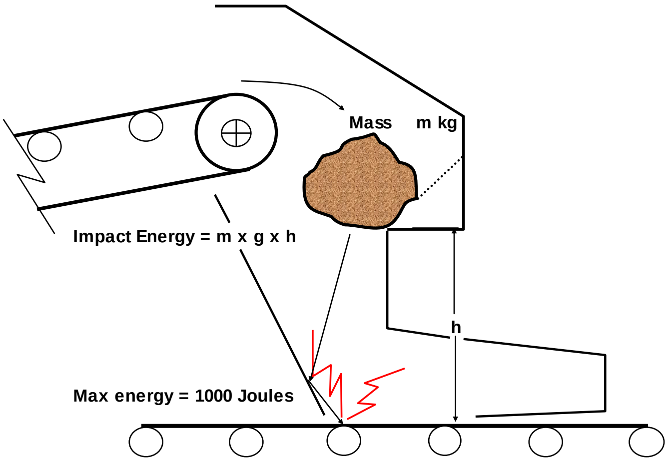
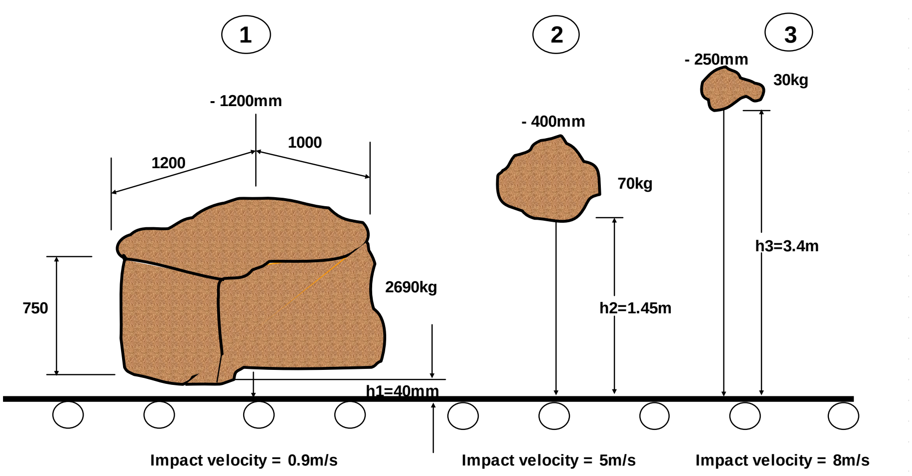


Figure 2

It therefore follows that the design of a transfer chute for primary crushed iron ore must be different from one transferring limestone or coal. In practice however, this has usually not been the case.

Compare the following lump sizes and drop heights for a typical ore with a bulk density of 1.8t/m^3, (i.e. specific gravity = 2.8t/m^3)for the same amount impact energy onto a belt:



Maximum allowable falling distance for 1000 Joules impact energy

Figure 3

It is quite normal for a conveyor transfer to be at least 3.4m, which implies that a conveyor can normally only be used to handle medium density ore, and only if it has been though a primary crusher.
The graph in figure 5 below demonstrates how extremely limited a conveyor is in practice when impact energy at the feed is taken into account.

It is based on ordinary "slabby" primary crushed rocks with a bulk density of 1.6t/m^3 (i.e. specific gravity=2.6t/m^3) and with a nominal width W, in the following proportions:

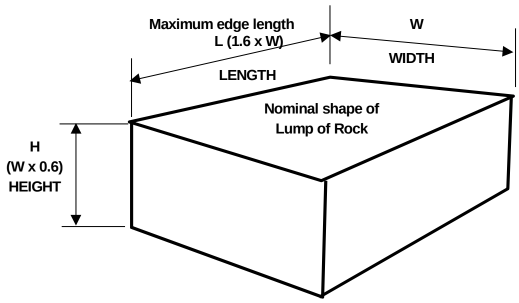


Figure 4

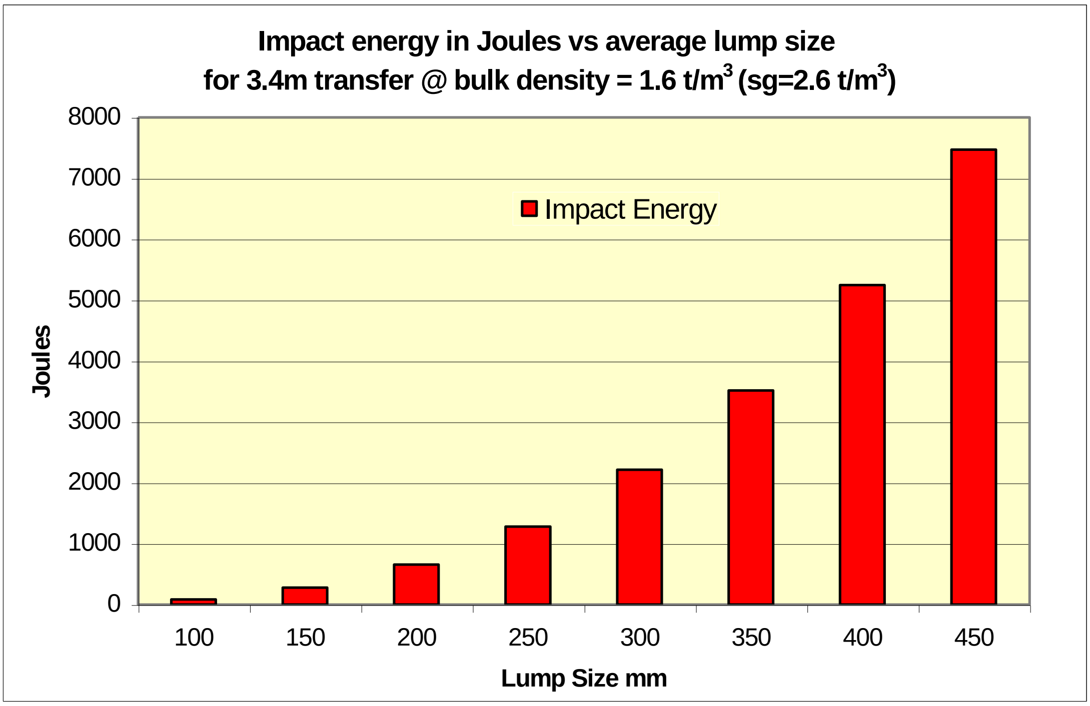


Figure 5

The implications of the above are very important, as the graph implies that you can not really convey anything heavier than normal primary crushed rock with a bulk density of 1.2t/m^3 (sg=2t/m^3) though a typical 3.4m high transfer, to limit the vertical energy to 900 Joules.

For any ore that has a bulk density greater than 1.2t/m^3, special precautions would have to be taken.
In the case of iron ore for example which has a bulk density around 2.5t/m^3, (sg=±4.5t/m^3) even the proportions of the rock from a primary crusher does not improve the impact energy. Using the dimension ratios given above for slabby material, a minus 250mm (250 x 400 x 150mm) lump of iron ore weighs 68kg, and would have a very large impact energy value of 2 268 Joules. Such a lump would be limited to a maximum transfer height of 1.34m. A lump

measuring 250 x 250 x 250mm weighs 70kg. It would have on board 2334 Joules, which would again reduce the allowable transfer height to only 1.31m.
A primary gyratory with OSS=180mm can produce iron ore slabs of 180mm x 400 x 700mm. These would have on board a massive 7 564 Joules!

THE HANDLING OF DENSE ORES

Clearly it can be seen from the above that the heavier ores, which have only been primarily crushed pose a real problem, and since such low transfer heights are usually not feasible in practice, this aspect must be addressed fully.

The following graph in figure 6 illustrates the point further and shows to what lump size the ore must be crushed in practice for a normal transfer to not destroy the belt and the loading point below.

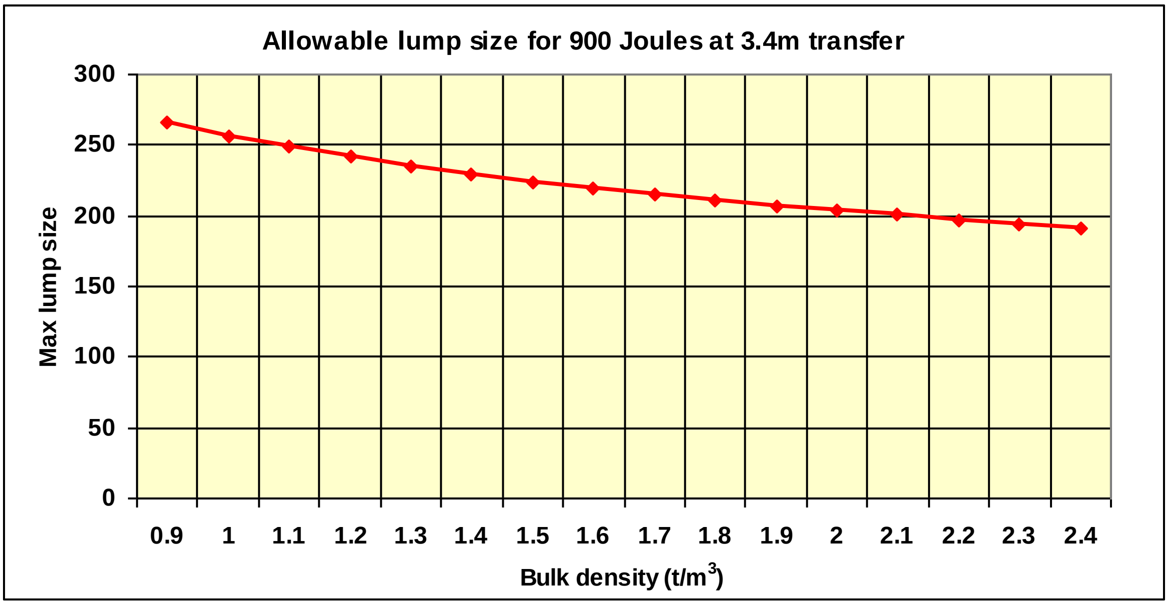


Figure 6

If it is not possible to meet the requirements of the above graph with only a primary crusher, then other avenues to cater for dense ores have to be followed, for example:

- Crush the rock further with a secondary crusher
- Design transfer chutes that enable the dead material inside them to absorb the excess energy
- Improve the primary crusher reduction ratio by using pre-screening

Attempting to cater for the high impact at the loading point is not a real option, as hopefully the following sketch in figure 7 will hammer this point home.

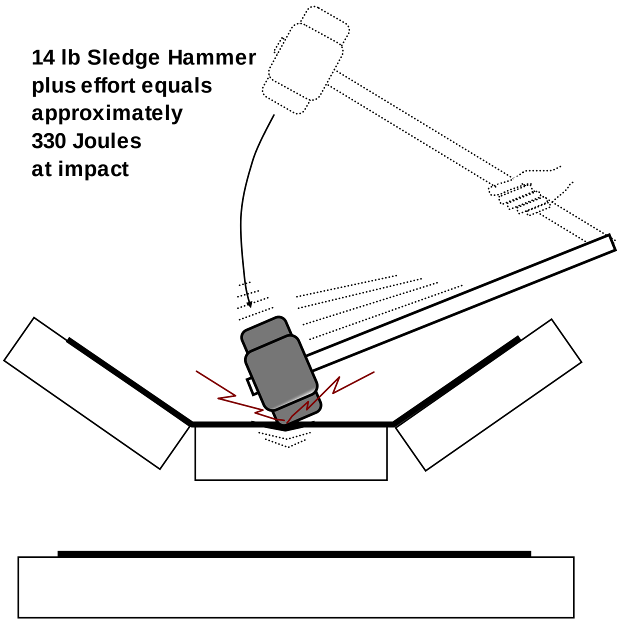


Figure 7

For the receiving belt to cater for the 2 300 Joule impact potential from a 250mm lump of iron ore in a typical 3.4m transfer, is therefore about seven times worse than being smashed with a 14 lb sledge hammer, and this possibility should never be entertained.

It is therefore considerably better to crush further to at least say minus 100mm, and reduce the impact potential to only 150 Joules per lump in a 3.4m transfer.

Failing this, the belt must be protected from direct impact from a falling or sliding rock in the transfer. It is a common misconception that if a rock is transferred in a chute fitted with rock-boxes, the dead material will absorb most of the kinetic energy in the rock. This is because of the tendency of rocks to roll and bounce in much the same way as if the chute were simply made of lined steel plate. If however there is a full range of size distribution, this rolling and bouncing effect is reduced, as the fall of the large rocks is dampened by the fines.
The writer has achieved reasonably good results by replacing troublesome high transfer chutes which inherently had nothing to reduce impact, with ones fitted with adjustable cascade rock boxes.
One such chute had an eleven metre transfer height and served large lumps of platinum ore. The calculated impact energy was 18 000 Joules or twenty times the allowable 900 Joules, which is equivalent to being simultaneously smashed by 54 sledge hammers! It was no wonder that the belt below was totally destroyed within two weeks.
The adjustable cascade rock boxes reduced the magnitude the impact from 18 000 Joules to less than 2 000, which although not ideal, was at least a vast improvement.

PRE-SCREENING AND PRIMARY CRUSHING

Quite often, a crusher is selected for the maximum size of lump that it can accept, and not for its capacity. A large primary crusher produces a large product, for which a wide conveyor belt is selected. As a result, transfer chutes tend to be wide, and run virtually empty. This causes the lumps to rattle around in the chutes, as there is too little mass flow to control the lumps. In such cases, the impact damage of individual lumps on the receiving belt tends to be greater.
(Therefore, by installing a secondary crusher, a narrower conveyor belt can be installed, with far less impact damage all round.)

However, when a crusher is selected for the maximum size of lump that it can accept, and not for its capacity, the open side setting can in fact be tightened up to improve the size reduction ratio. The same applies when higher through-puts are to be handled, if the ore is pre-screened such that only the oversize is crushed.

By installing an upstream grizzley cutting at say 150mm, a smaller size of crusher product can be achieved. This therefore will make for a much more conveyable size distribution of material.

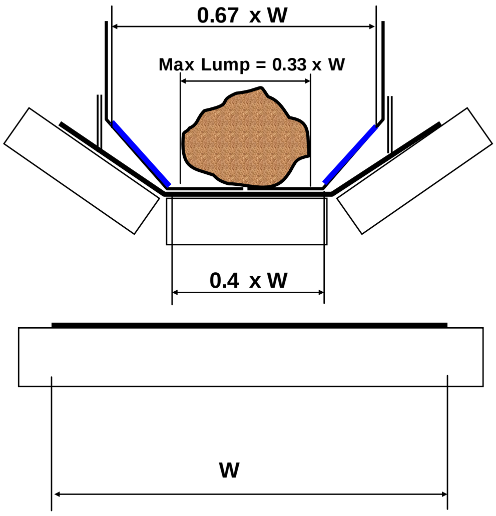
In real life however, things tend to be completely different. This is due to the following reasons:

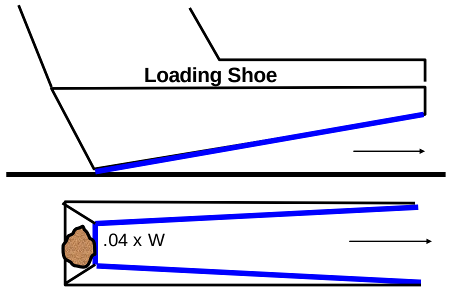
- Semi-mobile and especially mobile crushing plants would be severely compromised by the inclusion of a grizzley
- Primary gyratory crushers are usually (and conveniently) choke fed by direct tipping
- In practice, the bigger the open side setting, the greater the throughput, and most mines seem to capitalize on this. The example of the lump of primary crushed Uranium ore in the photograph (fig. 1) is a classic example of this.

It is actually rare to come across a conveyor handling primary feedstock where the lump size actually meets the design criteria.
"Tombstones" are a fact of life.

LOADING ARRANGEMENTS, CAPACITIES, LUMP SIZES AND BELT WIDTHS

For conveyors with heavy duty loading points, the Langlaagte tapering feed shoe arrangement is normally selected. The width of the upstream part of the Langlaagte is normally taken as one third of the belt width, and tapers out to two thirds of the belt width at the discharge end. This limits things for primary crusher product, as the rule of thumb for selecting belt width is that it should be equal to or greater than three times the maximum lump size.
In such a case, the lump size therefore approximates to the width of the Langlaagte at the narrow end, which can lead to blockages.
With higher belt speeds and greater capacities, the width of the upstream part of the Langlaagte is now normally taken as 0.4 times the belt width. This also improves the lump size scenario, but only to a degree, and the lump size must in practice be less than 0.33 times the belt width as shown below.





W (mm)	0.4 x W	0.33 x W
750	300	248
900	360	297
1050	420	347
1200	480	396
1350	540	446
1500	600	495
1350	540	446
1800	720	594
2100	840	693
2200	880	726

Figure 8

In our example for slabby 250mm primary crusher product typically with a maximum edge length of 400mm, the minimum practical belt width is 1200mm. Conversely, for any belt width over 1200mm wide, the maximum lump size is still 250mm with a maximum edge length of 400mm due to the impact energy limitations.

ASPECTS UNIQUE TO THE HANDLING OF WASTE

The following aspects relate specifically to the conveying and handling of waste:

- It can be hard dense slabby material which normally contains nothing of any value, and therefore does not warrant the expense of any crushing except to reduce it to a "handleable" size.
- It must either be transported to a waste dump, or to a position where it can be used as backfill (often a long way away).
- It must normally negotiate many transfer points, and ultimately be spread via a moveable/mobile dump top system.
- A waste handling system can have an unacceptably low practical availability because of the above.

Compare the following:

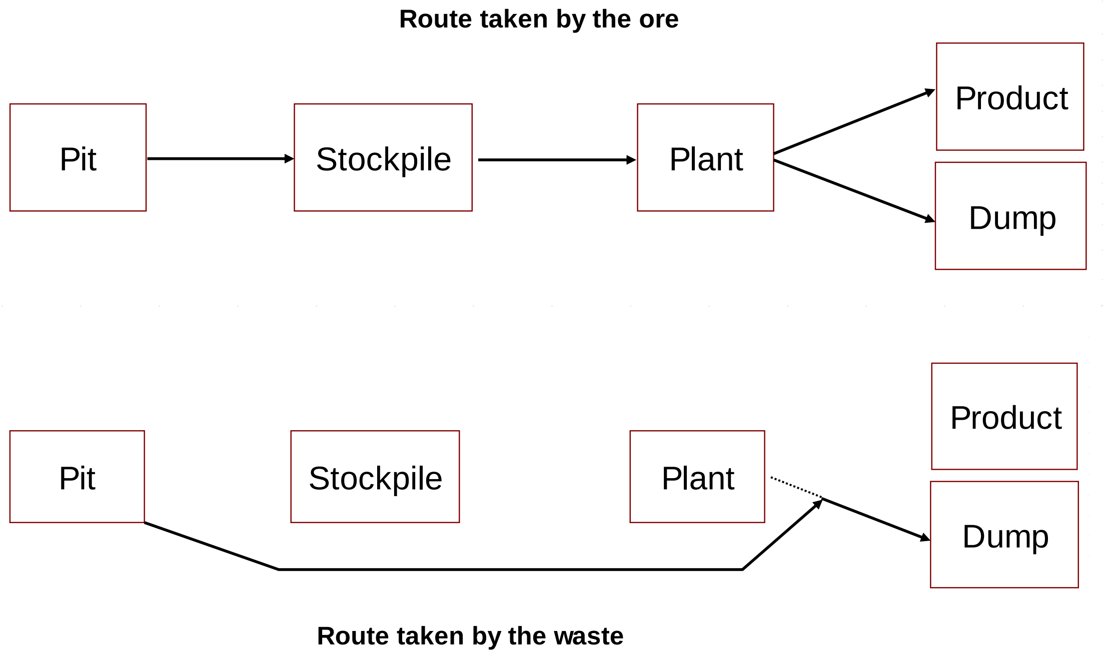


Figure 9

For the ore, there can be primary through to tertiary or possibly quartinary crushing plants, and as can be seen from the above graphs, it is often necessary to put the secondary crusher adjacent to the primary to ensure that the ore is in a conveyable state.

There are unfortunately many examples of systems where the engineer has neglected to consider secondary crushing directly after primary crushing, and which stockpile the ore that has only been subjected to primary crushing. This not only means that more of the conveyors must be of width suitable for the lump size, but also that the conveyors and transfers must endure the worst and most arduous duties.

Also, mobile in-pit crusher systems are normally only the primary crushing stage, and again the worst materials handling scenario occurs.

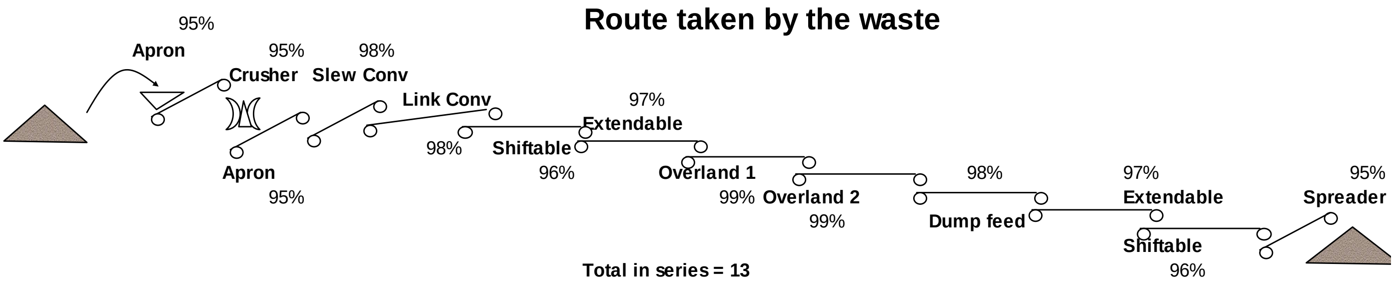
To put this into some kind of perspective, consider the conveyor to be a 4 x 4 which runs on a road made of the ore. I certainly would not like to drive my vehicle for any distance regularly over a road of coarse, minus 250mm material for any length of time.

But what about the waste handling system? As mentioned above, waste normally does not contain anything of value, and what client would entertain the idea of spending money to crush rock that will simply be thrown away?
In the above diagram (figure 9), it can be seen that for the waste, a long and arduous route can apply, without further crushing and often without a stockpile. Because of this, a poorly thought out waste handling system can lead to serious problems, and consequently has to be thoroughly analyzed before being entertained.

By way of example, consider a waste handling system that was put in at a coal mine.
In order to convey the blasted inter-burden from the pit to the waste dump, the following items were installed in series:

1. A mobile crusher station with a gyratory crusher on board
2. One crawler mounted link conveyor
3. A shiftable conveyor
4. An extendable conveyor
5. A couple of overland conveyors
6. One steep dump feed conveyor
7. A dump top extendable conveyor
8. A radial shiftable conveyor
9. One dump top spreader

The availability of the system was dictated by the number of items in series as well as the availability of each item. The availability was low due to the large lump size of the primary crushed waste.
The schematic of the system (figure 10), including the calculation of the best case availabilities using the normal calculation procedure, are as follows:



$$\eta_s = \frac{1}{\left(\frac{1}{0.95}\right)+\left(\frac{1}{0.95}\right)+\left(\frac{1}{0.95}\right)+\left(\frac{1}{0.98}\right)+\left(\frac{1}{0.98}\right)+\left(\frac{1}{0.96}\right)+\left(\frac{1}{0.97}\right)+\left(\frac{1}{0.99}\right)+\left(\frac{1}{0.99}\right)+\left(\frac{1}{0.98}\right)+\left(\frac{1}{0.97}\right)+\left(\frac{1}{0.96}\right)+\left(\frac{1}{0.95}\right)-\left(13-1\right)} \times 100\%$$

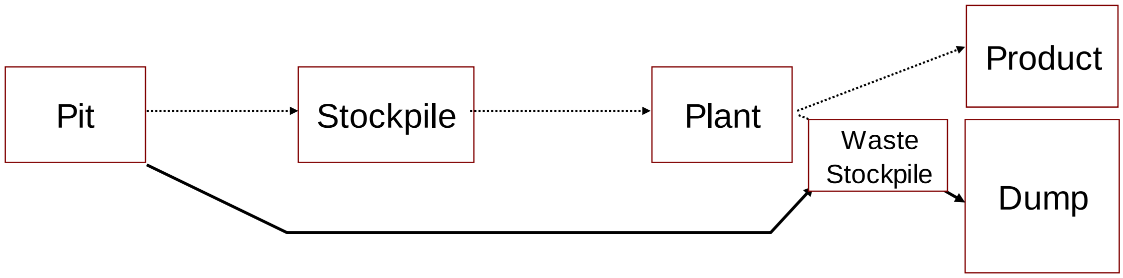
$$\eta_s = 69.6\ \%$$

Figure 10

The low calculated availability of 69.6% is in fact artificially high in this case, as the system contained two areas relying on shiftable equipment. Not only is shifting a relatively slow process which also puts the system out of action, but having two shiftable systems in series compounds the problems severely.

In practice, it was not possible to operate the system, and as a result, a waste stockpile was found to be mandatory.

The diagram below indicates the revised waste handling system.



Route taken by the waste
Figure 11

Now even more items are put in series, and all of them have to operate with primary crushed arduous waste. In our example, all the waste passed un-screened through the large primary gyratory crusher at 2600 tons per hour, with no potential to tighten up the closed side setting. As a result, there were over ten transfer points, each above the 900 Joule impact limit. This, together with the added complication of blockages due to the presence of clay, resulted in the system being abandoned.

Serious thought must therefore be given to whether it would not actually be better to simply pay the premium and truck the waste in haulers, as happened in the case in our example above. In fact in our example, the client eventually ended up having to pay for both the extremely expensive waste crushing and conveying system, as well as eventually using the trucks instead.

TYPES OF IN-PIT CRUSHERS AND THEIR IMPLICATIONS

By now it should be clear that the selection of type and number of stages for in-pit crushing systems is very important for the well being of the downstream conveying and handling systems.
For an indicative selection of various materials normally encountered, the following table is typical of which type of crusher is normally selected, as well as the typical state of the conveyability of the crusher product:

	Iron	**Tin**	**Plat**	**Uranium**	**Copper**	**Limestone**	**Coal**	**Waste**
Gyratory	Yes	Yes	Yes	Yes	Yes			Yes
Conveyable	Bad	Risk	Risk	Risk	Risk			Risk
Jaw		Yes	Yes	Yes	Yes			Yes
Conveyable		Risk	Risk	Risk	Risk			Risk
Min Sizer						Yes	Yes	Yes
Conveyable						OK	Yes	Risk
Impact						Yes		
Conveyable						Yes		
Bradford							Yes	
Conveyable							Yes	

Figure 12

CONCLUSIONS TO BE DRAWN

1) Primary Crusher products differ considerably and affect their conveyability.
2) For hard ore, seriously consider secondary crushing in the pit as well as primary.
3) Pre-screening can be beneficial to the downstream conveyors.
4) For waste, use minimum number of materials handling items in series.
5) Consider the use of trucks going to separate dump close to pit for waste.
6) Or use short conveyor system going to separate dump close to pit for waste.
7) *Always* calculate the expected mass of typical lumps and their impact energy.
8) Design chutes and transfers *and the system* to give maximum of 900 to 1000 Joules (fabric and steelcord respectively).
9) Take serious note of possible clay with the rocks in ore and waste systems.
10) Trucking vs conveying is not only cost comparison, take a serious look at the practicalities of conveying and handling primary crushed materials too.