Mobile crushing and conveying in quarries - a chance for better and cheaper production!

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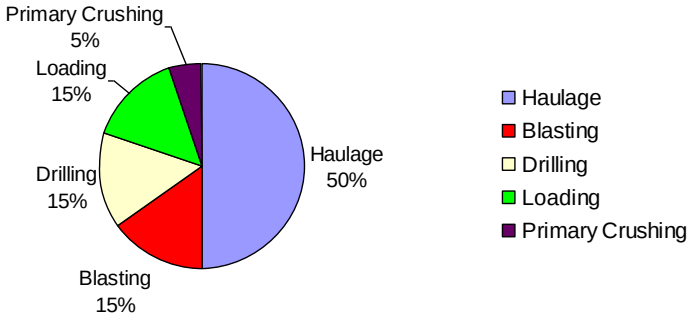
ABSTRACT: Nowadays cost reduction in every part of a production plant is a major key to surviving in global as well as in regional markets. Therefore, for quarries it is also necessary to review where money can be saved in order to increase profits and face challenging market prices. In this context, considerations regarding applications, case studies and the economic effects of fully mobile crushing and conveying systems are made.

1 INTRODUCTION

The major operation in quarries, up to and including primary crushing, can be split into drilling, blasting, loading, hauling and finally the primary crushing itself. Within these operations the blasted material is usually transported by dump trucks to the primary crushing stations, which traditionally are stationary plants. Looking back, it has become obvious that often companies have set up the plants at a more or less good starting position not thinking about the further development in the future. In a lot of cases the pit extended itself far away from the preparation plants and more and more haulage needs to be done. This is one of the most important points to be mentioned, because depending on the haulage distance and operational cost structures within the quarry, only the haulage costs themselves represent 30 to 60 percent of the whole operational costs. Therefore in countries with high fuel prices the most interested companies for mobile technology can be found.

Figure 1: Cost Structure for Hard Rock Mining



In order to lower the haulage costs, there are essentially two ways to achieve this aim. The first solution is to buy bigger dump trucks and the second might be to implement conveyor belts. If you decide for the first solution you have to check if your excavation systems, haul roads, your feed hopper and, if the feed hopper is housed, if the housing fits to the bigger dump trucks. The benefit of this decision is very simple. You can produce the same mass of raw materials with fewer employees, or on the other hand increase the production. If you decide for the second possibility then you have chosen lower operating costs for transportation and in addition to this, in pit crushing as well. In pit crushing is in fact directly linked to the conveying system, because the blasted material, concerning block size, cannot be conveyed without preparation. The key to cost reduction is an in pit crushing system (IPCS), a combination of track mounted mobile crusher, with mobile and fixed conveyor belts. In the following the authors will just refer to the IPCS, due to the fact that this is the only continuous solution known for quarries. These solutions can work as well in other fields of application, e.g. civil engineering, recycling, tunnelling and many more.

2 APPLICATION

2.1 *Quarry and Pit Design*

One major restriction using the IPCS is the pit design, which looks like a cut in the surface. This means very small and narrow high walls in combination with more than 3 mining levels, which cannot operate at the same time. These are very difficult to handle, even if the mines are planed for IPCS. It might not be the best solution in any case, if you need to move all of the equipment around the pit in order to mine another level, but there are other viable solutions.

Compared to the restrictions, the fields of possible IPCS application are huge. One great advantage is the lower stripping ratio. Normal, main haul roads need to be a minimum width of the dump trucks. In addition to this they must be "shallow" with a maximum in- or decline of about 10%. As a result the whole pit must be wider at the surface, in order to provide the trucks the safety required to navigate down to the working site. Belt conveyors need less broad roads and therefore allow for steeper pit wall angels and are then furthermore able to offer lower stripping ratios. Lower stripping ratios mean that less money has to be spent on mining overburden or waste material and transporting it around. This saves the capital of the investors at an early stage a mining operation and raises the mine profits. Furthermore, the minimization of the mine footprint will help to accelerate administrative decisions or, in the worst case, it is the only possibility to get the required permission.

2.2 *Mine Planning*

The mine planer has to consider at the initial stages, the impacts of the preferred loading method, the needs of selective mining and the number of benches that have to be worked. Another important point is the influence of haulage. For example, dump truck operations need a ramp network. But the decisive and most challenging part in mining operations is to fit the mine plan to the restrictions of the mobile conveying system. The conveying system is less flexible but also has to serve the whole mine.

According to drilling and blasting you need to consider the maximum rock size that the mobile crusher will be fed with. Furthermore, you need to take a closer look on the allowed and required safety distance while blasting. Concerning the loading and crushing equipment, q.v. the next chapter, the loader/ crusher type and size need to be considered very carefully. These are basically the same considerations that need to be done, if the equipment would be selected for normal/stationary operations. As mentioned previously, the new form of mine planning, in regards to IPCS is the most challenging part, while an existing pit is reorganized or a new pit is set up.

Dump trucks offer one greatly significant benefit, their flexibility. They are able to haul material from any part of the quarry at any time to another location within the pit. In addition to this the breakdown of one dump truck won't affect the overall production too much, because normally there are still more trucks in the fleet, which can keep up production.

IPCS can work at its best, when the need to relocate the system is reduced to an absolute minimum. This means that the mobile crusher and the linked conveying system should not be moved more often than necessary. This demand can only be satisfied if the whole operation is changed into long term planning. Furthermore IPCS in general favours a more horizontally advancing excavation. In an optimum case you don't need to mine selectively, with more than two levels and operate on wide benches which are more than 100m wide. More complicated designs are deposits or quality restrictions where selective mining or multi-bench operations are required and furthermore the benches are narrow. But even those problems can be handled. If selective mining is required and you often have to change the production benches then, if you just take one IPCS it needs to be carefully considered because relocation on the same bench of about 0.5 km takes approximately half an hour. Relocation between two or more levels will take two hours, ore even more, depending on the distance that has to be moved. A better way to face the selective mining demands is to use multiple units of IPCS. On every bench the mobile crusher is linked to a moveable and extendable field conveyor by mobile conveyors. The material flows from the crusher onto the mobile conveyor and then onto the field conveyor. The field conveyor discharges onto an uphill or downhill conveyor, which is placed along the established high wall. If the field conveyor discharges onto a downhill conveyor it should be premeditated if energy from the belt drive could be gained. As shown in figure 2 the blending of the raw crushed material could be done with stockpiles. This is possible, if the different rock/ ore qualities are available at different parts of the working face or different levels. The different qualities can be assigned to different stockpiles at the end of the quarry conveyor belt chain. By extraction in special ratios the needed quality can be produced. Therefore selective mining needs are not critical criteria for IPCS.

Figure 2: Multi Bench Operation

2.3 *Mobil Crushing*

2.3.1 *Loading and Mobility*

The most effective way to load a mobile crushing unit can be chosen according to the site conditions, and local preferences. Due to the site mobility the mobile crusher is ideally suited for being loaded by a hydraulic excavator in backhoe operation. In the typical application of the excavator, the operator is able to control the crusher with a remote radio device from his cabin. The operator of the excavator is able to perform a relocation of excavator and IPCS during production normally in less than 5 minutes. Another advantage of this type of operation is that the operator is based on a higher level than the feed hopper. Therefore he can control feed size and separate oversized material with the bucket. In addition the operator, while digging, is able to check if the correct material level is reached in the crusher and bed height on the grizzly bars is sufficient. These major advantages, in contrast to other operations, lead to the point that by using a backhoe operation the correct feed rate can be maintained during the production and therefore ensure higher productivity.

The robust construction of mobile crusher also allows for the use of conventional loading machines e.g. wheel loaders. In applications where the mobile crusher is relocated frequently and the wheel loader is chosen for loading, building an access ramp to the feed hoper is time consuming and expensive in the long run. A better way to solve this problem of building ramps and “not visible” feed hopper for the wheel loader operator is a mobile apron feeder. With this piece of equipment, loading can be done directly from ground level and furthermore the driver can clearly see if the feed Figure 2: Multi bench operation hopper is overloaded or not. This technique is used when short cycle times are necessary and the blasted material is fine and homogeneous. The moving interval of this application lies in reference to the demands within 1-5 days.

Even loading methods, which are using a dump truck or excavator with face shovel, are not excluded from feeding a mobile crusher. The face shovel is not the dedicated excavator for feeding the mobile crusher, because most of the time the operator is not able to look into feed hopper. As a consequence, experienced operators, who take care of their work, are highly recommended. Another aspect of using face shovel excavators is that the machine itself is normally a bit oversized for the mobile crusher. This is because the loading cycles would otherwise be too long. If an excavator is used, which is just able to match the requirements of height and distance at highest extended point, the boom of the excavator has to always make a very long swing from the bottom to the top of the feed hopper.

The following table will give a short summary of the loading tools in relation to the mobile crushing unit.

Table 1: Loading Tools

	Backhoe Excavator	Face Shovel	Wheel Loader
Control of oversize	very good	good	mediocre
Feed consistency	very good	very good	mediocre
Size vs Capacity	size is selected according to the capacity requirement	oversize machine is needed to be able to reach the feed hopper	size is selected according to the capacity and the distance
Digability	very good	very good	good
move interval	2-4 hrs	2-4 hrs	1-2 weeks
Reach	5- 10m	5-10m	50- 100m
General comment	in normal blast provides the los costs per tonne	can be considered with fine blast whre beigger capacity justifies machine	provides the possibiliy to mix feed from different parts of the face

As an alternative to self-propelled crushers, semi mobile units can also be used in pit crushing. These units are suitable in fields of application, when the relocation interval varies from 0.5-2 years. In semi mobile applications the crushing unit is loaded with dump trucks. The dump trucks perform the short distance haulage, which enables selective mining. The long distance haulage is after primary crushing and is done with conveyor belts. That constellation reduces the haulage costs very efficiently. The relocation of the semi- mobile unit is assisted by a special carrier unit. The carrier unit is driven under the semi mobile crushing unit and lifts it up by help of hydraulic cylinders and carries it to the new location. Larger quarries or mines, which need several semi mobile crushing stations in different parts of the pit can use one carrier to move all units and fulfil the capacity requirements. A fully mobile crusher can also be converted into a semi mobile unit by using a skid mounted feed

hopper. This feed hopper is very large, so that dump trucks can unload the raw material directly.

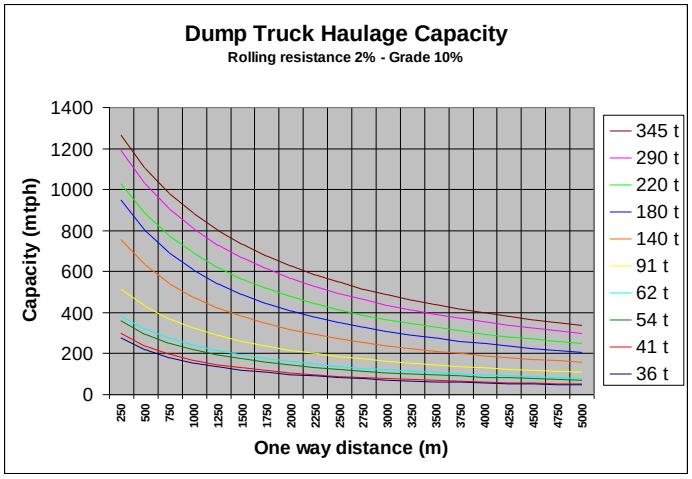
2.3.2 *Equipment and Performance*

Basically there are three different types of primary crushing units to choose from. Mobile crushers are manufactured and delivered as jaw-, impactor gyratory- crusher. The gyratory crusher at first was implemented for secondary crushing, but will be soon available for primary crushing too. Depending on the pit demands the engine can be diesel powered and reach up to 645 KW or can also be electric powered. The travel speed of the track gear is approximately 1 km/h and the mobile crushing units are able to incline 20° or 35%. The throughput for jaw crushers can range up to 1800 Mg/h depending on the feed material. The weight of mobile crushers varies from about 60 Mg to more than 200 Mg. Normally jaw crushers are equipped with a vibrating feeder, a bypass to keep small fractions away from the crushing process, the crusher itself, and a main conveyor. Depending on the manufacturer and the individual needs more equipment can be ordered. For example, screens to be placed in the bypass can be bought to scalp out waste material at an early stage of the process. Unnecessary haulage into further processes is thereby avoided. Using screens in the bypass only makes sense if there is a second discharge conveyor installed. In addition to this linking adapter for the mobile conveying system, money could be spent for such things as: dust encapsulating, magnetic separator, hydraulic hammer, driver cabin, several supporting stands, if needed. According to the needs of a mobile conveying system an electric generator must be bought too, because power supplied to the conveyor belts are normally comes from the mobile crusher units.

2.4 *Mobil Conveying*

One way to reduce the explosion of haulage costs is to use conveyor belts. The special need of a quarry operation, with a high frequency of relocating the mobile crusher, requires a mobile and flexible conveying system combined with a fixed conveying system. The mobile conveyors are assigned to haul the crushed material to the fixed system and equalize elongation between those two systems. These tracked mobile conveyors work over shorter distances than stationary ones, because they have to work as a flexible link between the track-mounted mobile crusher and the field conveying system.
The combination of mobile and fixed conveying can save up to 2/3 of the existing haulage costs.
The use of dump trucks is in fact often very inefficient. Some of the largest dump trucks use over 50 percent of the energy to move themselves in spite of hauling blasted material. To make this clearer, a dump truck is empty for half of the operational cycle. A conveyor is also empty half of the time, but it is not hard to guess which one consumes more energy. In addition to this, the haulage distance limits the transport ratio of a dump truck. The further you need to transport the material, the less efficient it is to use a dump truck. The next figure shows a general overview of dump truck haulage capacity regarding the haulage distance.

Figure 3: Dump Truck Haulage Capacity



Contrary to the reduction of the haulage capacity of dump trucks, the transport distance does not affect the capacity of conveyor belts. The capacity of conveyor belts is limited by the belt drive speed, belt width and form. As shown belt drives are much more economical than dump trucks and they are not limited by haulage distance. In opencast mines lengths of more than 30 km are not uncommon. The belt width of mobile conveyors varies up to 1600 mm and a maximum particle size of 1/3 of the belt width is suggested. Depending on the feed material and the mobile crushing unit haulage of 2000 Mg/h can be performed.

The transfer from the mobile crusher to the mobile conveyor belt is done with a direct linked system. The mobile conveying system is able to discharge onto the stationary field conveyor by a discharge hopper on rails or on a skid. The hopper is mostly equipped with a conical adapter for easier positioning and a vibrating feeder to protect the belt. The radial wheel set of the mobile belt, always mounted between two belts, is steered hydraulically by a remote device. The maximum number of mobile conveyor belts, which are directly linked to a mobile crushing unit and which can be controlled by a single operator is three. Moreover there are conveying solutions with self propelled-, track mounted transfer conveyors, stackers and truck loading hoppers available for each special demand.

2.4.1 *Cost Savings*

Belt conveyors save a lot of money in comparison to dump truck haulage. Belt conveyors are much cheaper to maintain, because they contain far fewer parts and they also don't use as many spare parts, e.g. tires, as dump trucks. In addition the excavator can be downsized to fit the capacity which is needed for the crusher. Usually the amount of haulage affects the required size of dump trucks and the design of the truck itself directly influences the choice of the excavator. By using IPCS the excavator only needs to match the demands of the mobile crusher processing potential. As explained previously, the best way to feed the mobile crusher is an excavator in backhoe operation. Therefore it is obvious that a smaller excavator in combination with IPCS can be as productive as an excavator with linked dump truck haulage. If the haulage is done by a conveying system, which is controlled by the excavator operator, there is no longer a demand for dump trucks and operators for them. Therefore labour costs could be saved and the quarry roads don't need to be built elaborately and kept well maintained, which could be expensive in the long term. In different internal studies it has been proved that the haulage energy costs could be 50 percent to 70 percent lower in comparison with dump truck transport.

Table 2: Comparison between Dump Truck and Conveyor

	Dump Truck	Belt Conveyor
Gradeability	10%	30%
Payload %	50 to 60	90 to 95
No of Operators	1	0
Power Draw	0,5- 1,0 kW/ Mg*km	0,1- 0,15kW/ Mg*km
Cost / Mg	0,30- 0,5 $ / Mg* km	0,10- 0,15 $ / Mg* km
Max Particle Size	no practical limit	30% con. width

Cost saving with IPCS in removing overburden or waste material is not excluded.

2.5 *Further Advantages*

Besides the cost savings, there are still other advantages of an IPCS that should be mentioned. By the use of conveyor haulage the impact to the environment is also significantly reduced. The elimination of dump trucks reduces noise and emissions of exhaust gas. Moreover fast driving dump trucks are always a risk for operators and the technical surrounding. Studies indicate that vehicle movement is one of the most dangerous operations in quarries. In 1997 almost 38 percent of all US mines and quarry fatalities were caused by powered haulage. Besides increased safety, less traffic also means that less dust is produced. Therefore the watering of haul roads can also be reduced. As an example a Texas based mining operator reports that his new 2-mile-long conveyor eliminates more than 140.000 cycles, which means 570.000 vehicle miles on an annual basis are no longer needed. As a matter of fact, this does not only reduce fuel consumption and labour costs but also reduces estimated production of PM- 10 emissions by mobile haulage from 95 kg/d to 3 kg /d. Under very special conditions regarding dust emissions the whole conveying chain could be equipped with dust encapsulation. Furthermore, IPCS offers high resale values if mining activities are stopped at a site. Normally only some parts of a former primary stationary crushing plant can be sold and moved, e.g. crusher and feeder. But the concrete will remain and the steel has only scrap value. By using IPCS everything could be moved easily to another mine or operation, because there is a growing world market for second hand mobile crushers. Even if mine prospecting went wrong and the primary crusher is set up on the best part of the deposit, there would be no need to worry, if an IPCS was chosen. A fast, easy and cheap relocation will grant access to this part too.

2.6 *Case Studies*

2.6.1 *Cost Comparison Example*

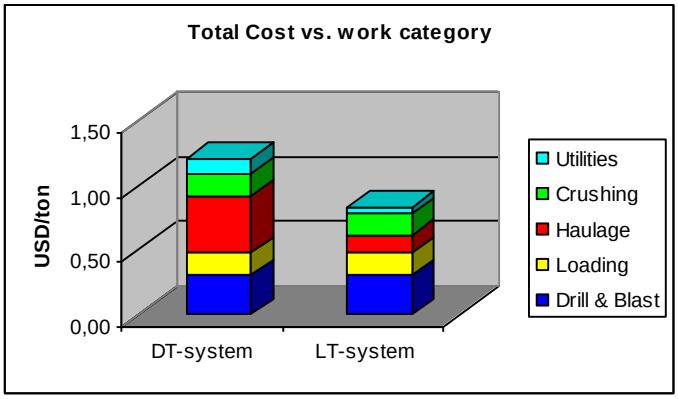
In the following, a cost comparison example between Metso Minerals Lokotrack & Lokolink (LT) and a dump truck (DT) system are presented.

Table 3: Key Data Cost Comparison

	LT System	DT System
Annual Production	1,4 Mio. Mg / a	1,4 Mio. Mg / a
Excavator	4 m³	4 m³
Dump Truck 55 Mg	0	3
Average Crusher Capacity	700 Mg / h	701 Mg / h
Field Conveyor	1500 m	0 m
Mobil Conveyor	LL 12	0
Annual Working Hours	2000	2000
Mine Life	20 a	20 a
Interest Rate	7%	7%
Depreciation Time	5 a	5 a
Hourly Wages + Social	35 USD	35 USD
Fuel Price	0,5 USD / l	0,5 USD / l
Electricity Price	0,05 USD / kWh	0,05 USD / kWh

In addition to the data above the LT system requires a crane to do the maintenance for some hours per year and the DT system needs a grader for haul road maintenance. The next figure shows a comparison between the total costs vs. work category.

Figure 4: Cost Comparison DT vs. LT System



As shown in figure 4 the main part in cost saving structures are the haulage and utility costs. The special costs of drilling & blasting, as well as the loading costs are not affected by changing the operation system. Even the crushing costs remain nearly the same. As a result it could be stated, that the LT system, in this simple example, saves 0.37 USD/ Mg. To underline this fact 0.37 USD/ Mg means that approximately 525.000 USD/ a or 10.5 Mio. USD in 20 years could be saved, by changing the operating system. With the yearly rising fuel prices it is not exaggerated that cost savings could very well be much bigger in future.

2.6.2 *Case Study Canada*

The quarry in question produces 1.2 Mio.Mg/ year, of very hard granite. The work index (BOND) is at maximum at 26.5 kWh/Mg and at the average is 14.5 kWh/ Mg. The abrasiveness of the granite is medium. Until 2001 a dump truck fleet and an old Nordberg stationary primary gyratory crusher were installed. The dump truck fleet was aging and the gyratory crusher had high maintenance costs. In addition to this labour costs should be reduced and the working safety should be improved. Beside these technical and economical problems the company got more and more pressure by a suburban neighbourhood to reduce noise and dust emissions. The main goal of the mine was to significantly save money in total operating costs, and fulfil the other demands. Within this area of conflict the only solution to be considered was to switch from discontinuous to continuous mining by using IPCS. The IPCS consists of:

- Excavator CAT 365L,
- Primary crusher on tracks, Nordberg LT 140,
- Moveable conveyor system, Nordberg LL 12,
- 4 conveyors, approximately 55 m long and 1,2 m wide and
- two operators.

The IPCS had to replace the following existing technical equipment:

- 3x 50 Mg dump trucks International,
- Wheel loader, Komatsu WA 700
- Primary gyratory crusher, Nordberg and
- Five operators.

The indicative capital value of the new equipment, which the quarry needed to reduce cost rising, is shown in the next table.

Table 4: Indicative Value of new Equipment

Before	Costs	Now	Costs
3 Dump Trucks	1.590.000	Excavator	750.000
Wheel Loader	900.000	Nordberg LT 140	1.240.000
Primary Gyratory	1.000.000	Nordberg LL 12	505.000
		Conveyors	800.000
	3.490.000		**3.295.000**

The table shows that there is not a great difference regarding investment between dump truck operation and an IPCS.

The reorganisation of the quarry reduced the costs from 870.000 USD per year to now 388.000 USD per year. This is a significant decrease of more than 50 percent in operating costs.

Figure 5: Quarry Overview

The excavator is equipped with a high cabin. This offers the opportunity to watch the feed hopper from an elevated point while operating, which makes the operation safer and steadies the material flow. In addition to the IPCS three stationary conveyors had to be installed. They transport the crushed material to a stockpile with a tunnel feeder, which is in turn feeding the stationary preparation plant. With further developments of the working face more conveyor sections will be added. Regarding the cost categories; maintenance, labour and energy incur the most saving.

2.7 *Advanced Quarry Operation*

Within the most advanced quarry operations transport between the crushing and screening stages could be eliminated completely, by installing a fully mobile crushing plant. These plants consist of different stages of crushing and screening, each on a mobile unit. With this constellation the end products can be directly sold from stockpiles inside the quarry. With the crushing and preparation units placed in the quarry, it also means that there are no visible buildings disturbing the environment. If the production routines should be changed in order to produce other products, the whole assembly could be easily reorganized and new processing could be started within some hours. This is a great advantage if the raw material qualities are changing from time to time and therefore the demands of products can not be fulfilled. A change in the processing chain can improve the end product qualities, even if bad raw materials are being fed. In regard to the quality restrictions of the end products; one, two or three step mobile preparation plants can be installed. Every reasonable combination of mobile crushing and mobile screening units can be combined. As an example, a three-step preparation plant is described. At first a mobile crusher should be used, whereas different crusher types could be chosen. The mobile crusher feeds a secondary crushing unit, in which a first screening and secondary crushing are carried out. This generates a first product and material to be further processed in a tertiary crushing unit. This unit is only used, if there are high quality demands to be matched. After the tertiary unit the output material is fed onto a mobile screening unit, which defines the end product qualities.

The fully mobile preparation plant offers assets and drawbacks at the same time. One of he biggest advantages is that no housing for the preparation plants is needed. This might be the biggest disadvantage, because products for asphalt and concrete application require special moisture contents, which within a region with high precipitation cannot always be ensured. A wet stockpile can be an elimination criterion for the application of the stockpiled products. Therefore silos have to be built, which are not easy to feed with wheel loaders. As a matter of fact, wheel loaders are the most suitable machines for mobile plants. They are able to feed the crusher as well as load the products quickly onto trucks. Another necessity is that the products must be removed at several different points at the plant. The high mobility of the wheel loader makes it possible, that trucks are loaded, material is stockpiled and the conveyors of the mobile units get not in touch with the discharged products. In total one excavator feeding the crusher, one wheel loader loading trucks, two operators and, depending on the quality demands, up to four mobile units can completely substitute a stationary preparation plant, within some defined restrictions.

3 CONCLUSION

The application of IPCS has gained wide popularity in aggregate operations. In mining applications the reduction of operational costs plays a major role in toady's mine planning. Adapting the IPCS to a mining operation provides considerable advantages. The reduction of

- Labour costs,
- Haulage costs,
- Fuel Consumption and
- Pollution (Dust and Noise),

is mirrored by an increase of health and safety. Nowadays the application of IPCS is only avoided through special quarry design. And even for the most challenging conditions, such as a small and tiny working face, solutions may be found and considered. In several case solutions the manufacturers of IPCS have proved their competence and knowledge in planning and construction. In the future, an offer of higher productivity and lower costs per Mg product will more and more convincing to companies in order to change the operating system from dump truck to mobile crushing and conveying, or mobile plants.

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