The Real Cost of 'Bad Paste' to a Mining Operation

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Abstract
Paste backfill or pastefill, has become the industry standard for sustainable mine fill; minimizing surface tailings storage requirements, while maximizing resource recovery underground through improved local and regional stability. To realize all the benefits of paste backfill, a 'good' product must be produced, meeting all specified uncured and cured material properties including ingredient quantities, rheology, early strength, and final strength. When these specified properties are not met, the impact on safety, the environment, and mining production can be catastrophic.

While the immediate short-term consequences (blocked lines, paste spills, etc.) of bad paste are well known, the long-term downstream consequences and related costs are rarely totaled and reflected upon, as mine planning and operations adjust in haste after which the mining cycle continues. These long-term consequences include:

- re-working mine designs
- additional underground development requirements
- mass failure into adjacent stopes
- significant paste dilution affecting skip production and mill performance
- delay of sequences, and
- sterilization of ore.

Resulting costs stemming from bad paste are typically absorbed by multiple departments, such as engineering, mine haulage/development, mine backfill, and the processing plant. As such, the costs are rarely totalled and attributed to the bad paste incident.

The cost of the downstream flow-on effects that can be attributed to the original bad paste events have been examined. The quantification of these costs will help operations justify the upfront costs of good quality backfill engineering, construction, instrumentation, engineers, and operators that are often overlooked in attempts to reduce capital and operational expenditures.

Key words: mine backfill, pastefill, costs, consequence, dilution, quality, risk

Introduction
A key benefit of pastefill is how readily it can be engineered to behave within an operating envelope in a single system, with both its strength and flow properties being adjusted on a stope-by-stope basis. Compared to other fill types, such as hydraulic fill, cemented rock fill, or uncemented rock fill, pastefill can be modified to reflect variation in stope geometries and exposure schedules. Having the ability to change both early- and late-stage strengths allows for safe and cost-effective filling of non-exposure stopes, large exposure stopes, and undercutting of paste filled stopes. Adjustments to the rheology of the pastefill allows voids near and far to be filled safely and effectively with a single central distribution system. This added flexibility requires a substantial upfront capital investment; however, significant costs can be incurred when the paste properties deviate significantly from targets, resulting in bad paste.

Definition of 'bad Paste'

Put simply, 'bad paste' can be any pastefill that behaves or performs in a chemical, rheological, or geo-mechanical way that is not aligned with the engineered specification. The worst paste, from a process interruption and downtime point of view, is a paste or segregating material (non-paste) that cannot be cleared quickly and plugs a distribution system from top to bottom. These events are immediately apparent and quantifiable. Strength implications can be more complex, sometimes being a hidden problem, whose costs and effects on the mining cycle are felt long after the paste is placed. Although a bad paste is often associated with a lower mass concentration (wet paste), or a lower strength (weak paste), it is just as fair to say that an excessively strong paste, higher mass concentration paste, is also a bad paste when placed in scenarios that called for one lower in mass or strength.

Rheology/yield stress (flow properties)

A paste with lower than target mass concentration will exhibit a lower than expected yield stress. This results in lower friction losses in the system and the system running only partial full in areas (slack flow). Slack flow is characterised by increased velocity of the paste through the pipeline and often leads to premature damage and excessive wear in the distribution system that may result in line ruptures, broken supports, and paste spills. Furthermore, if binder content is not corrected to reflect the additional water contained in a wet paste, target strengths may not be achieved, which could have severe consequences to mine safety and production.

A higher than target mass concentration will exhibit a higher than expected yield stress. This may lead to immediate line blockage if the available gravity or pump head is insufficient to overcome the friction developed by the thicker paste in the distribution system. It may also cause higher operating pressures that exceed the system design, resulting in line ruptures. Thick paste can also create flow and angle of repose issues after the pour point, which may be undesirable if a level stope surface was intended. The reduced water in the paste will likely lead to higher cure strengths, which are typically favored by operations. In rare cases, high strength may be undesirable, such as where paste redevelopment with minimal blasting was planned.

Case Studies 1 and 2 demonstrate the long-term downstream costs of bad paste due to incorrect mass concentration.

Strength (early and final)

A lower than target paste strength (under-strength paste) is the most obvious bad paste scenario. Under-strength paste has both immediate and long-term effects, leading to increased re-entry times, delayed mining sequences, and increased paste dilution in the ore. More profound effects can include increased risk of mass paste failures, paste containment failures or "inrush" events, and potential sterilisation of ore. There is also potential to negatively influence regional ground stability, which may create a risk of liquefaction due to seismic events if the binder addition is greatly reduced or eliminated altogether.

A higher than target paste strength could often be considered good quality paste. However, if it was achieved by an overdosing of cement, either through mis-calibration of instruments or reliance on unrepresentative paste strength test work, a business may have unnecessarily spent millions of dollars on binder. Furthermore, in some circumstances a weak paste could be desired (eg, quick development re-entry, paste skin planned for fall-off). In these cases, higher strength material may cause cycle delays, extra work to remove, or pose a safety risk during production and development.

Case Studies 3 and 4 demonstrate the long-term downstream costs when an under-strength paste is delivered to underground.

Common reasons for Bad Paste

Based on the authors' experience designing, operating, and trouble shooting paste systems, the following reasons for bad paste can be considered.

Test work & design

Insufficient, incorrect, or misinterpreted mine/backfill design and materials test work can set the operation up for making bad paste. This may include the design of the surface plant and underground distribution system (UDS), or design of the paste recipe itself, eg, filtration has been omitted or the hopper and surface piping limit the paste flow, bad paste in the form of low mass concentration paste may result or be required to sustain operations, leading to slack flow in the pipelines and premature pipe wear. Similarly, if the test work completed is insufficient, the paste recipe selected may not be capable of meeting the mines needs, despite the plant being capable, eg, a paste recipe developed without long-term strength testing might produce paste vulnerable to strength loss due to sulfide attack.

Ingredient quality

Pastefill ingredients that are outside of material specifications often cause bad paste. Issues may arise from incorrect particle size distribution, changes in tailings composition (mineralogy, sulfides, heavy metals), oxidised tailings, expired or hydrated binder, hydrocarbons in process water, or foreign materials in the ingredient streams.

Dosing and control

Dosing errors, either known or unknown, often result in bad paste scenarios. Known events may include untracked water addition into the process, such as hoses placed directly into the paste hopper or misguided material flow setpoints to adjust paste properties without proper engineering review. These known causes should typically be identified during the shift and corrected immediately. Unknown events may include out-of-calibration weight-o-meters and flowmeters, which may read correctly in the control system but are over- or under-dosing in the field. These are more difficult to identify and can lead to the incremental production of bad paste over a long period of time, potentially only being detected when instruments are calibrated or the problematic stopes are exposed. Preventative maintenance, QA/QC and daily checks can minimize the effect of these errors. Water infiltration into the boreholes with no casing or compromised casing can also cause a good paste to be converted into bad paste.

Operational issues

Finally, operational issues such as misinterpretation of hydraulic flow and strength models, incorrect or incomplete operational QA/QC, incorrect ingredients moisture setpoints, incorrect recipe selection by operators, overcorrection of flow properties by operators, excessive water flushing and distribution issues such as water ingress/loss etc., can ultimately result in bad paste and its downstream effects.

Difficulties in Quantifying the Real Costs

Typically, the short-term direct costs of bad paste are well known as they are directly charged to backfill related budgets shortly after the incident occurs. Expenditures may include labour, equipment, material for unblocking or replacing paste lines, or drilling replacement boreholes. Costs attributed to bad paste may also stem from operational decisions such as additional cement to make up for poor ingredient qualities, insufficient engineering, or inadequate test work. The indirect or long-term costs; however, are rarely totaled and attributed to the bad paste event. This is typically due to a variety of reasons including effects or costs that are not realised for many years, at which point: 1) mine planning adjusts to continue operations safely, working around the bad paste issue without further investigation, or 2) no data are available or personnel involved have moved on, making review and investigation of the root cause difficult.

Costs are absorbed by many departments without attributing to backfill, such as:

- Mining Haulage/Production: mucking waste paste, paste dilution of ore, cleaning paste spills instead of mucking ore
- Mine Development: additional mine development around paste failures or for adjusted stope shapes
- Mine Planning: rework of mine schedule and stope design changes, new development designs around new stope shapes, incident investigation
- Minerals Processing: poor milling performance, lower metal recoveries and additional use of reagents due to paste dilution in ore
- Entire Operation: sterilization of ore due to weak paste or paste failures.

Consequently, return-on-investment calculations used for paste design, infrastructure and resource improvements most likely underestimate the true value of these indirect costs.

The following case studies from sites with a history of successful pastefill operation are provided to quantify some of these indirect costs. They cover two common results of bad paste: line rupture or blockage and under-strength pastefill.

Line rupture and blockage case studies

Line blockage events are one of the most common serious paste related incidents and may be caused by any combination of design, ingredient, dosing, and operational issues. Although ingredient and dosing issues typically cause blockage events, it is system design and operational issues that may prevent the blockage from being cleared in a timely manner before the paste starts to cure. The following two case studies examine the aftermath of line rupture and blockage.

Case Study 1: loss of recipe control resulting in pipeline failure and blockage

In 2021, Glencore Kidd Operations (Kidd), a mine in northern Ontario, Canada, experienced a line failure and subsequent line blockage event in their paste distribution system due to upset paste plant conditions. The stope being filled at the time of incident involved the use of around 5 km of distribution piping, increasing the impacts of the blockage event. Approximately 1250 m of piping and 1250 m of internal boreholes were blocked with paste that then cured in place. The cause of the incident was traced back to recipe control issues.

Direct costs

The direct costs of line blockages are often well known, as replacement pipe order costs, site drill and operator labour costs, and contractor and equipment rental costs for cleaning and/or replacement of piping and boreholes are tracked and applied to backfill related cost centers. The direct cost estimates for this blockage event are approximately C$1.6M (Figure 1). The site opted for full replacement of the blocked pipe with new pipe as this was a quicker solution than removing cured paste from the pipes.

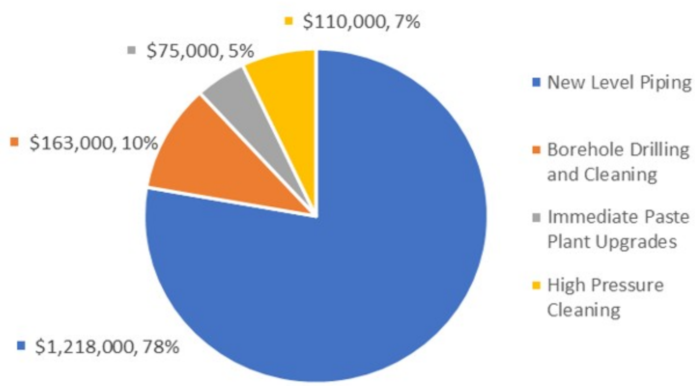

Figure 1. Direct cost breakdown for line blockage event.

Indirect costs

With mine plans constantly adapting to achieve production targets, the exact changes to the mine plan as a result of a bad paste event are difficult to determine retroactively. The Kidd UDS system has redundancy, enabling filling in other areas while the affected zones were being unblocked. However, after the blockage event and due to the inability to fill key sequence stopes for a 6 month period, paste and ore production were 23 and 17% below production targets, respectively. It was estimated that this event resulted in 20–C$30M equivalent amount of ore being pushed from the 2021 budget into the following years. The forecast and actual ore and paste production metrics are shown in Figure 2.

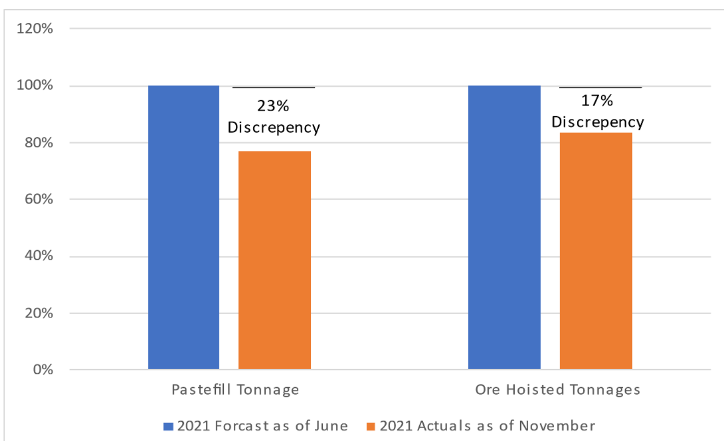

Figure 2. Ore and paste production 2021 forecast prior to paste incident versus year-end

Redundancy in the paste UDS and an extensive mining footprint allowed the operation to pastefill in the upper zone and through the UDS cascade system while the mainline boreholes were being cleaned and drilled further down in the mine (Figure 3). Stopes were rescheduled to bring ahead those that were accessible during the blockage recovery phase.

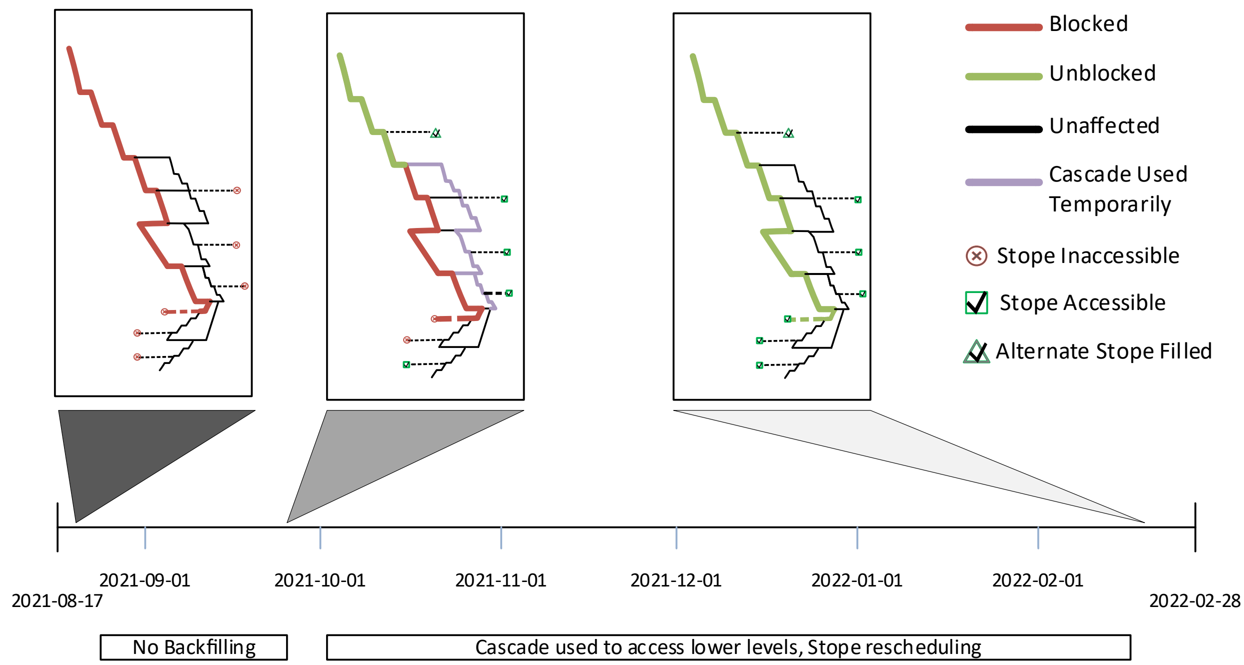

Figure 3. Schematic of blockage incident timeline showing use of cascade system.

While system redundancy helped the mine continue producing during the blockage recovery phase, long periods of using the cascade system resulted in increased wear in piping that was not expected to handle that volume of paste flow. There was concern that this extra use may have resulted in borehole and piping changeout requirements in areas that were expected to be good for the life-of-mine.

To rectify the issues, paste crews were diverted from regular system expansion to support the cleaning effort and replacement of pipe. A dedicated project crew, made up of highly experienced personnel from both surface and underground, was also established to focus on the system repairs and complete other major paste work to efficiently address recommendations resulting from this blockage incident. This focus incurred other costs and inefficiencies as it pulled experienced workers away from other mining processes.

Solutions

Conscious of the direct costs and large stope sequence delays experienced downstream of this blockage, Kidd invested into their paste system post-incident. These investments included improvements to their tailings live bottom feeder, weigh scales, and plant water addition system to increase the control of material and the mixing process. The cost of these upgrades was estimated at C$500K, which seems justifiable when compared to the cost of downtime related to the incident that totalled > C$10M.

The site also investigated the development of a flushing system underground to allow areas below line breaks or blockages to be flushed successfully. This would be beneficial in a large distribution system, where there may be a significant length of unblocked piping downstream of a blockage that cannot be flushed from surface.

Case Study 2: high paste concentration resulting in pipeline failure and blockage

A mine in Northern Quebec experienced a blockage incident in their UDS. The pressures in the pipeline increased due to thicker paste being produced, which caused a weak point in the piping to fail. This incident resulted in a two-week downtime to clean up the paste, repair piping, and unblock eight levels of boreholes and pipelines (900 m of pipe).

The mine provided details on a second incident, in 2023, which led to a similar expanse of UDS blockage. In this case, the site experienced a blockage incident after an emergency shutdown was initiated due to a power outage, in which the plant was not able to execute the emergency flush procedure properly. While this UDS blockage was due to an operational issue not directly related to bad paste, the repercussions of this event were similar to those blockages caused by bad paste and thus would cause similar costs and damages.

The lack of efficient flushing resulted in the blockage of 11 levels of pastefill piping and boreholes, a total of 200 m of horizontal piping and 1500 m of boreholes. The UDS was unusable for nine days and only fully serviceable after 1.5 months. The pastefill system at this site branches into two parallel systems, allowing access to different parts of the mine. In some cases, stopes can be accessed by both systems. The mine focussed on clearing the common distribution network first, which allowed filling through the unaffected branch of the UDS. The progression of the system clean-up is shown in the long section schematics in Figure 4.

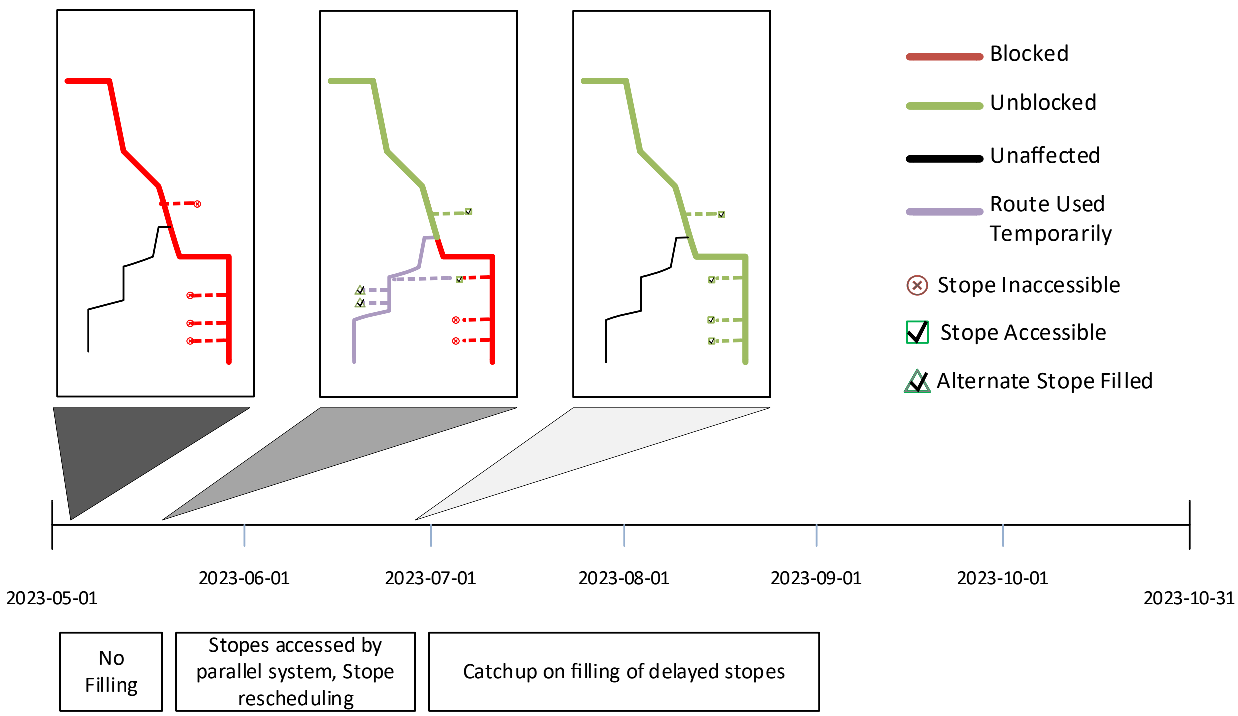

Figure 4. Schematic of blockage incident timeline showing use of temporary routing.

Direct costs
Initial response to the UDS blockage was to mobilise the sites' high pressure wash crews for around the clock pipeline cleaning. These crews were supplemented by an external high pressure wash crew initially, when the most success in cleaning could be achieved. Emergency response to this incident was recorded as C$277K, including the cost of the internal crews used to clean the pipe.

Indirect costs
The incident happened mid-year and the mine reported that they were able to catch up on the stope filling and subsequent mining before year-end. The stope mining sequencing was changed to focus on stopes in the non-affected areas of the mine. In total, there were only nine days of stope production delay due to this incident. The mine estimates a production opportunity loss of 20% of one month's worth of production. Production during the month of the event decreased by 18%. They compensated for this the following month by increasing production by 21%. The missed opportunity was that, if both production months had gone as planned, they may have still been able to obtain higher production rates in the second month.

Thus, indirect cost of this line blockage could have been potentially 2% of the annual production. It is acknowledged that it would have been much higher without the flexibility of the system, an established emergency response plan, and the fast reaction of the pastefill team to unblock the pipeline. Recovery time was also sped up by the use of a production drill to clean out the pipes without taking them down from the back. However, this solution diverted the drill from production, which was also an indirect cost to the mine.

Solutions
Learning from previous incidents had allowed the site to justify the purchase of their own high-pressure washer and training of two crews on its use. This incident showed that the underground response time was decreased by having the two pressure washers available (one in-house, one hired) in the early stages after the blockage, which allowed them to get the main system operational in just over a week. This case also highlights the benefits of having redundancy in the UDS. Redundancy allowed the mine schedule some flexibility to bring in stopes from different zones earlier, which were not impacted by the UDS blockage.

Based on this incident, the site was able to justify and implement improvements to their preventive maintenance practices to include regular borehole and pipeline inspections to proactively replace worn pipes. They also initiated scheduled cleaning of the pipelines to minimize buildup of paste which can lead to high pressure incidents and blockages.

Under-strength paste case studies
Under-strength paste events are another serious type of paste-related incident. They are also typically caused by design, ingredient, or dosing issues. These incidents typically have repercussions that are seen years later in the mine life when affected stopes are exposed. The following two case studies examine the aftermath of under-strength paste.

Case Study 3: cement underdosing by design
In 2020, MBCC's Jabal Sayid mine (Jabal) in Saudi Arabia had a paste underdosing event, where understrength pastefill was placed into seven stopes over a four-month period. During this event, the pastefill was dosed correctly according to recently updated design rules implemented to reduce cement usage on the site. However, through potentially misinterpreted test work results, the updated design rules led to lower paste strengths than were required for the stope geometry and exposure sequence. This discrepancy was caught after four months of use and the design rules were adjusted. Figure 5 shows the difference between the erroneous cement dosage used in the stopes and the revised cement dosage after the correction.

The first of the under-dosed stope was exposed in March 2022, at which time the impact of those four-months of underdosing was realised. Paste from one of the bad paste stopes ran into the adjacent stope and out the draw point when it was vertically exposed during the adjacent stope blasting, as shown in Figure 6.

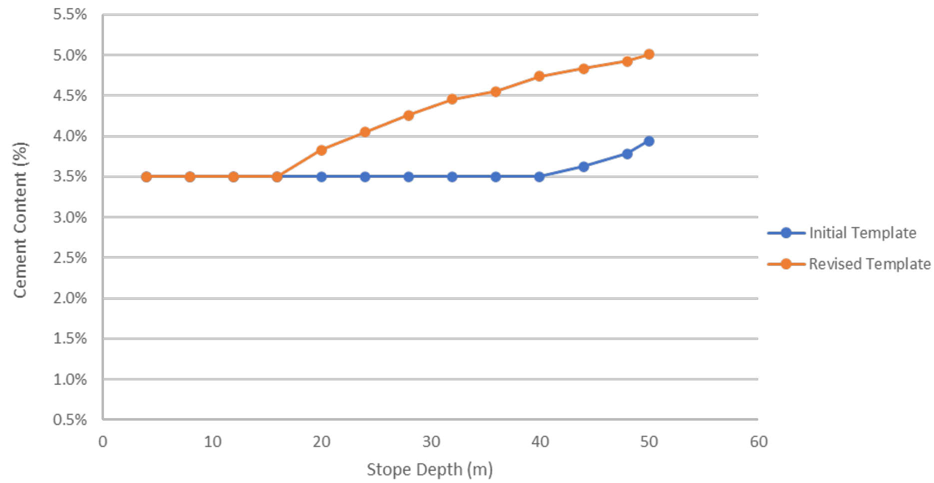

Figure 5: Cement content added to stope by depth (initial calculation vs revised calculation).

Figure 6: Under-strength paste remobilised into the draw point of adjacent stope after vertical exposure.

Direct costs

During the first exposure of an affected stope, a paste failure occurred leading to cured paste falling and flowing out of the adjacent stope draw point. This incident was considered a near miss event; the direct cost may have been more significant in different circumstances. Instead, the only direct costs were the removal of enough of the fallen paste to allow for re-barricading and filling of the adjacent stope. The site noted the fallen paste had reconsolidated, hindering removal, and most of the fallen paste was left in place to be included as dilution when the stope below was mined.

Indirect costs
The indirect costs of this paste underdosing event were seen through many departments. Upfront, there were engineering and management time spent investigating the cause, as well as identifying the location of poor paste, re-assessing engineering analysis for new strength relationships, and creating a plan to safely expose the remaining seven stopes affected by under-strength paste. It is estimated that one month of equivalent engineering and management time was spent identifying, investigating, and re-engineering affected paste stopes.

For the first affected stope, fall-off was such that it exited the draw point of the empty adjacent stope. The fall-off resulted in additional mucking tonnages with the associated lost opportunity of mucking other ore instead of paste. The stope immediately below the first impacted stope also had the additional failed paste as dilution which was taken with the ore in that stope. For the remaining six affected stopes, high risk stope plans were developed for their exposures. This plan included placing stopes on tele-remotes earlier, prior to the brow opening, and modified drill and blast procedures to provide additional standoff to the lower strength paste. As tele-remote mucking is less efficient than conventional mucking, these additional tele-remote tonnages added more time to the stope sequences in the interest of mining safely.

Depending on severity of the underdosing, this situation could have been much worse. Even lower strength paste would have required more significant stope shape changes, which could have potentially cost the operation millions, delaying stope sequences or even sterilising ore.

Solutions
The site identified the underdosing issues after exposure of the first affected stope and was able to adjust their designs and procedures accordingly to minimise impacts. As the understrength paste was *in situ*, the site developed the high-risk stope plans and were still able to mine the adjacent stopes without major mine planning adjustments. The site then re-assessed the paste test work and updated the recipe requirements to ensure sufficient strengths were achieved in all stopes being exposed in the future, which was the root cause of the event.

Ultimately events like this can be avoided with thorough engineering design. When adjusting critical design parameters, such as paste strength requirements, it is recommended that the engineering design/assumptions are received and confirmed in house, or by external experts.

Case Study 4: paste quality variability resulting in under-strength paste
A mine in Northern Quebec reported repeatedly having to modify the design of secondary stope development because of low long-term paste strength. The under-strength paste was attributed to variability in the paste production and quality control, and not sulfide attack.

Direct Costs
In this case, it was noted that there were no direct short-term costs associated with the low-quality paste. Paste was successfully placed in the stopes without issue, and the strength development was sufficient for blasting of adjacent stopes. This is often the case with under-strength paste scenarios, with filling being completed without issue, and the under-strength results only being identified after QA/QC results are received, the paste mass is exposed, or paste re-development commences.

Indirect Costs
The mine is currently still managing the long-term effects of these historical bad paste stopes as they develop through the paste in the older backfilled zones. The mine reports development cycle time

increases in these areas due to the lower strength paste, requiring slower development blasting and increased ground support to ensure operator safety. This increased cycle time leads to the development costing more per meter, with there also being an opportunity cost of the development drills and operators not being at other critical development headings to access production sites.

Paste redevelopment, both short-term to allow for production drill clearances when drilling out adjacent stopes, and long-term to re-access mining areas through filled stopes, is common in stoping operations. Poor quality fill can severely impact paste re-development, as experienced by this site, with the potential need for re-routing of development around affected stopes costing operations immensely.

Solutions
The site recognised the negative impact of variability and lack of control in the paste plant, which was resulting in unpredictable, low paste strengths, and made improvements to their pastefill management strategy. Increased QA/QC and close monitoring of the pastefill operation has eliminated these bad paste events in the last 2–3 yrs.

Case Study Analysis
The case studies presented show the ripple effect that a single bad paste incident can have on mine safety and production. While there are many causes of bad paste, two common results are line blockages and under-strength paste. Digging deeper into these case studies, a portrait of the potential impact that these types of events have on the mine emerges (Figure 7; Figure 8).

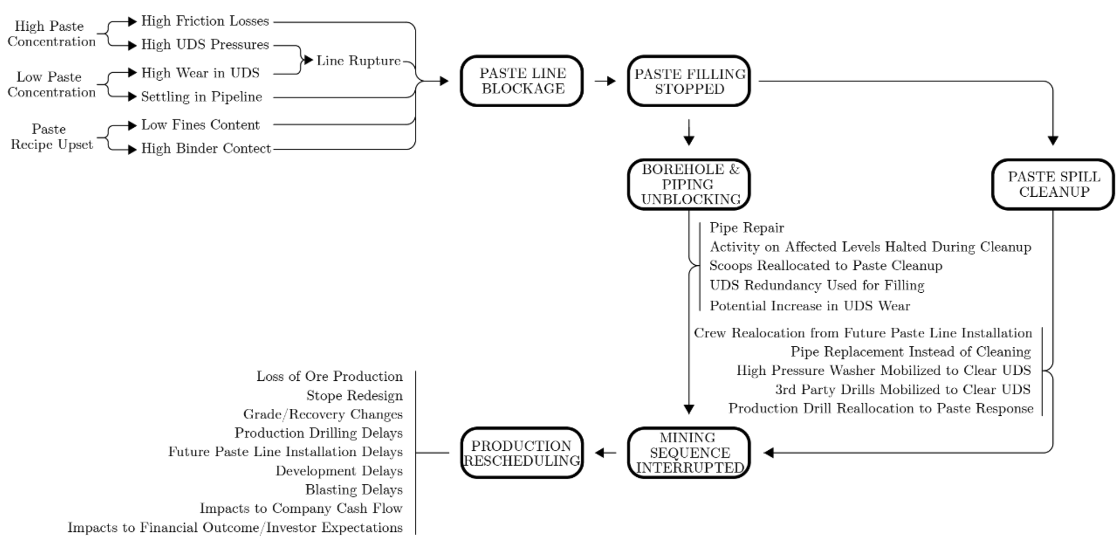

Figure 7: Ripple profile of line blockage.

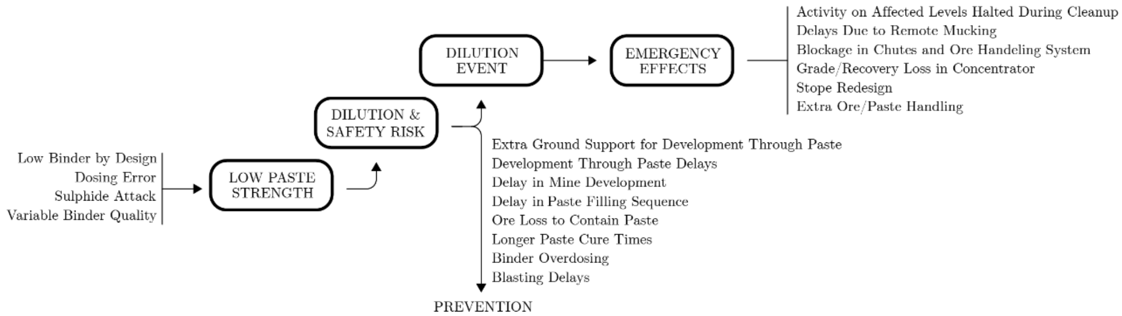

Figure 8: Ripple profile of under-strength paste.

The reader can benefit from experiences at these sites to evaluate the potential effect and cost of a bad paste incident. Cost considerations for these two common scenarios are outlined in Table 1.

Avoiding These Costs

Investigations into these incidents commonly include recommendations that are associated with backfill management strategies, including:

- **People resourcing:** providing dedicated plant and underground operators, supervision and technical oversight
- **Data collection and analysis**: reporting and follow up with operations to identity issues early
- **QA/QC**: controlling feed products, material dosing, water control, particle size control
- **Training**: provide training on emergency response, paste stope design, QA/QC, backfill theory and operation
- **Emergency response**: preparing procedures, readiness plans, communication strategies
- **Keep an operational focus**: timely QA/QC, monitoring, backfill management practices
- **System reliability**: proactive maintenance, wear monitoring, timely repairs
- **Use of technology**: valves, instrumentation, cameras, real time monitoring (underground and plant).

The common thread of most of these recommendations is that they are based on monitoring and prevention. It is important that test equipment, instrumentation, and personnel are available at all times during paste production to verify ingredient parameters are within suitable ranges. When outside these ranges, correct ingredients may be sourced, adjustments may be made by engineering, or paste production may be halted until the issues are rectified. Readiness plans are key in minimising the effect of system upsets.

Fundamental system changes may also help prevent bad paste. These are ideally captured earlier in the design stage of the project, including:

- Built-in redundancy in UDS
- Catchup capability in the plant
- Proper water balance for paste recipe control
- Material characterisation and recipe development

Table 1: Example cost estimates for common effects of bad paste

Line Blockage	**Paste Dilution Risk**
Ore production loss In smaller or newer mines with less flexibility, the option to reschedule may not be available and new development may be required to access alternate stopes, resulting in a temporary lack of production stopes during the event cleanup. One-week equivalent irrecuperable loss of ore production potentially represents 2% of annual revenue lost (simply put, 1/52 weeks).	*Ore loss* Leaving a 2 m offset on the side of a 20m stope to contain low strength paste to avoid dilution is effectively a loss of 10% ore per stope and the forfeit counteracts one of paste's greatest benefits; to remove the need for pillars in the mining plan. At a copper grade of 2%, this 2 m skin of ore may reflect a loss of > C$200k at current copper prices.
Emergency response One month of a 4-person crew diverted from production or contracted to support backfill clean up and/or repair. 1/12 of an annual UG salary of four people is estimated at C$50k[1].	*Binder overdosing* An increase of 0.5% binder to avoid dilution in a 20kt paste stope at a cost of C$315/t binder is equivalent to C$24,500 extra per stope. Doing this systematically for a year, can easily cost an operation over C$2M.
Equipment Diversion Diverting a development or production drill to unblock pipes and boreholes. One week of equipment use with an operator estimated at C$22k[4] per week. Other costs include lost opportunity and potential delays in development and stope drilling due to low drill availability.	*Delays in development through low strength paste* If secondary stopes mined in low strength paste require 10m of extra ground control, the indirect costs can be estimated at C$28k per stope. If the mine drives ten such stopes a year, the cost could be over C$250k / year.[2]
External Support Acceleration of cleaning efforts in early days of incident by bringing in external support for pipeline and borehole clearing, including high pressure washer & crew for horizontal pipe clearing and Cubex drill & crew to ream out paste borehole. One week of equipment use with an operator estimated at C$22k[4] per week.	*Delays paste strength development* If each stope cycle takes longer to develop the required strength, the mine will experience a loss to production if scheduling/mine geometry doesn't permit opening up more stopes at once. Based on the Case 1 experience, an equivalent of one month loss of backfilling could result in a 3% decrease in ore production and equivalent revenue.
Rescheduling Emergency rescheduling of mine plan and redesign of stopes using two planners for one week, estimated at C$10k[1]/week with the opportunity cost of delaying their planned work.	*Extra handling to deal with dilution* 20% dilution of paste[3] into ore in a 15000m^3 stope results in 3000m^3 of paste to be mucked and hauled; at 8m^3 per truck, that is 375 additional trips hauling waste paste.
Downgrade of ore Loss of ore grade due to stope rescheduling and inefficient mine sequencing. Site specific.	*Delays due to remote mucking procedures* Remote mucking may be required if an adjacent paste stope is identified as at risk of sloughing. This usually results in longer mucking sequences which can delay the stope cycle.

[1] The 2021/2022 median Ontario/Quebec hourly wage for people working as "miner" was reported to be CAD$36.03 to 53.7/hr, excluding bonus (ref Canadian Job Bank). The hourly wage for people working as "mining engineer" were reported to be CAD$47.6 to 75.24/hr. Converting these hourly wages to an annual salary based on a 40-hour work week and 1.4 multiplier for business cost benefits, this equates to between CAD$105 to 157k/year and between CAD$$137 to 219k/year, for miners and mining engineers, respectively. (Canada Job 2022)

[2] A benchmarking study of mining operations documented very poor ground control costing 2 times the cost of typical 5mx5m headings, which cost CAD$6000/m on average to develop in 2016 (Poxleitner 2016).

[3] Paste dilution values can vary by stope size, paste strength and blasting practices, with 5 to 10% dilution being common and usually due to the removal of confining rock and blasting interference while over 10% will be seen when there is a lack of fill integrity (Veenstra 2015).

[4] A cost analysis study of mine roadways [development] by drilling and blasting methods (Su and Akkas 2019).

Ounce of prevention; pound of cure

The high price tag associated with bad paste events justifies the cost of implementing quality control practices, dedicated backfill teams, and plant improvements, as reported by the mines in the case studies presented. In the face of > C$5M production loss, > C$1M in clean up costs or C$250K in development delays, the cost of additional instrumentation, upgrading control sequences, and other system upgrades seem relatively insignificant. Table 2 compares estimates of these improvements to cost of mitigation and repair of a bad paste incident.

Similarly, providing pastefill training to operators, supervisors and the engineering team is a low-cost activity which can help avoid high-cost incidents by providing backfill awareness and troubleshooting skills to these key employees. Even on-going costs such as dedicated operators, underground crews, pastefill technicians and engineers are justifiable if those people succeed in avoiding or minimising one or two bad paste incidents each year. The challenge for mining operations is to recognise this fact and act proactively to put these strategies in place rather than waiting for a list of recommendations from an incident investigation to initiate the changes.

Table 2: Cost of site improvements versus mitigation and repair of bad paste incidents

Site Improvements	**Mitigation or Repair of Bad Paste**
Paste strength and rheology test work < C$200k	2% ore loss from annual forecast > C$2M
Key lab equipment for QA/QC < C$200k	Paste development delays > C$25k per stope
UDS Instrumentation Pressure gauges, Valves < C$150k (excluding communication system)	Clean up of blockage > C$250k per incident, potentially much higher
Detail engineering of system improvements < C$500k	Systematic binder overdosing > C$1M per year
Training < C$100k	Emergency response by others > C$150k per incident
One extra paste employee < C$150k per year	Emergency rescheduling > C$25k per incident

Conclusion

Even from this small snapshot of bad paste events, it is clear that the repercussions of poor-quality control and operational upsets ripple throughout the whole mining cycle. Sites rarely have the time and effort required to track all the direct and indirect costs of paste incidents. Their focus, naturally, is to get back into operation as quickly as possible. Scheduling is a fluid process as stopes are pulled ahead and production zones switched to target accessible stopes during the recovery period. These case studies show that if sites could track the main indirect costs, they would likely find that they dwarf the direct costs of the bad paste incident, and would further justify implementing preventive measures.

Operations are encouraged to use the bad paste ripple profile outlined in this paper as a starting point for incident analysis at their site. By adding site specific costs, it can be used to support efforts to hone the quality control, operational controls, and training in their backfill operations, resulting in immense cost avoidance for the whole mine for years to come. New or future operations can also learn from these findings and plan for best practice backfill system design, effective quality control, and oversight of the backfill system from the start.

In short, it is more cost effective to act proactively rather than implementing best practice backfill operations and management on the heels of an incident.

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Acronyms

QA/QC	Quality Assurance and Quality Control
UDS	Underground Distribution System