Ore Flow Optimization – Mine to Mill

J. O. Craig Imrie, P. Eng.

Hatch

Abstract

Mine operations are being squeezed to do more with less. This is not new. But, where do mine operators turn for the next stage of improvement? Many have waged strong wars on the cost reduction front and cut back staff to the bone, yet need more improvement to remain competitive.

Leading mine operators have identified a few critical cause – effect relationships allowing rigorous optimization of a number of variables for mill feed. A few of these variables are: blasting versus crushing and grinding, SAG mill material feed size, balancing metallurgical properties in the ore feed and tracking the flow from stope to refined metal, thereby facilitating improved recovery, reduced consumable and power costs.

This paper will outline some of the findings which a few leading operators have discovered. Summaries of implemented approaches and the impact which is being felt on the bottom line will be given.

Introduction

Over the last decade or so, Mine Operators have been under heavy pressure to decrease costs as the cost of supplies and services continue on an upward trend, while commodity prices follow a downward trend. Most operators have looked at functional improvement to squeeze out the ‘fat’ and apply technology to replace staff or enhance decision making in somewhat localized areas of the operations.

A few Mine Operators are integrating the processes from geology to mill, and in particular using information technology to provide accurate ore quality information to the mineral processing operators. In this closed loop of knowledge management, they are reducing the mill feed grade variability and increasing the predictability. By taking this approach, they are focusing on increasing the quality and quantity of product produced by the operation, not just the mine or mill in isolation. They are taking a hard look at the total process and how it works together, not just the functional parts in isolation.

The results of these operations show that significant benefits can be found by taking this approach. Couched with the usual disclaimer that each mine is different, these leaders show a return of 2 to 5% recovery improvement and up to 2% concentrate grade improvement. It is also shown that mill throughput can be increased by some 5 to 10%, – perhaps as high as 15% at some operations – by managing the knowledge of rock hardness, blasting design, and grinding parameters. These are truly significant step improvements to the bottom line of operations. They result from a view point of holistic, process management versus a functional, isolated view point.

Typical Systems

The significant typical characteristics of current systems are: a collage of real time information, event or transactional data, individual systems, work group systems and enterprise systems all providing disjointed parts of the total information and technology investment. This makes it difficult to learn from operational experience. The data is too inconsistent, disjointed in storage methodologies, limited in operational scope, and difficult to assemble to be of business value.

Leading operations are now seeing significant benefits to applying a process approach on a broader scale, reaching from the Geologist to the Metallurgist. The objective of introducing Mine-to-Mill concepts is to transform the collection and use of data from being random and plagued with duplication to one of order and consistency. Also, to tie the collection and use of information to the 'metal' supply chain at critical 'hand-off' points, thus building the connection to the Customer.

In the shift from chaotic systems to Enterprise Class – Value Adding Systems , one of the first steps is to model the ore flow process or metal supply chain. This Model should detail the physical process from geology models to the customer, starting with a high level block flow diagram. Each of these blocks should be decomposed into detail models which in many cases already exist. The missing part of the model is typically the interface between the blocks. The modeling process should focus on the detailed information required to flow between the blocks in order for the downstream process to improve its operation. Further connections are required on a reverse basis to support reconciliation and feedback.

Optimization Benefits

Figure 1 graphically shows the benefits expected from the progression along the learning curve; i.e. one expects experience to give lower cost and higher productivity. When systematic information management is applied, with a process view of maintaining the context and relevance of the data, a faster progression along the learning curve is expected; thus, faster improvement to Key Performance Indicators (KPIs).

What this disciplined approach provides as well, is the foundation to make a significant step improvement. The basis for this, is that accumulated information which is maintained in a highly organized, easily accessible fashion supports the analysis and broad view of determining cause – effect relationships. It also allows the quick verification of innovative ideas which come to those close to the process – ideas which may otherwise not be acted upon.

In your operation how many ideas get quickly dismissed when you can not prove or disprove the concept? Is this because the data analysis is too onerous to even start the process of evaluation? Or is it the combination of being too onerous plus being too stressed and strained on day-to-day operations? Can you afford to lose these innovative insights?

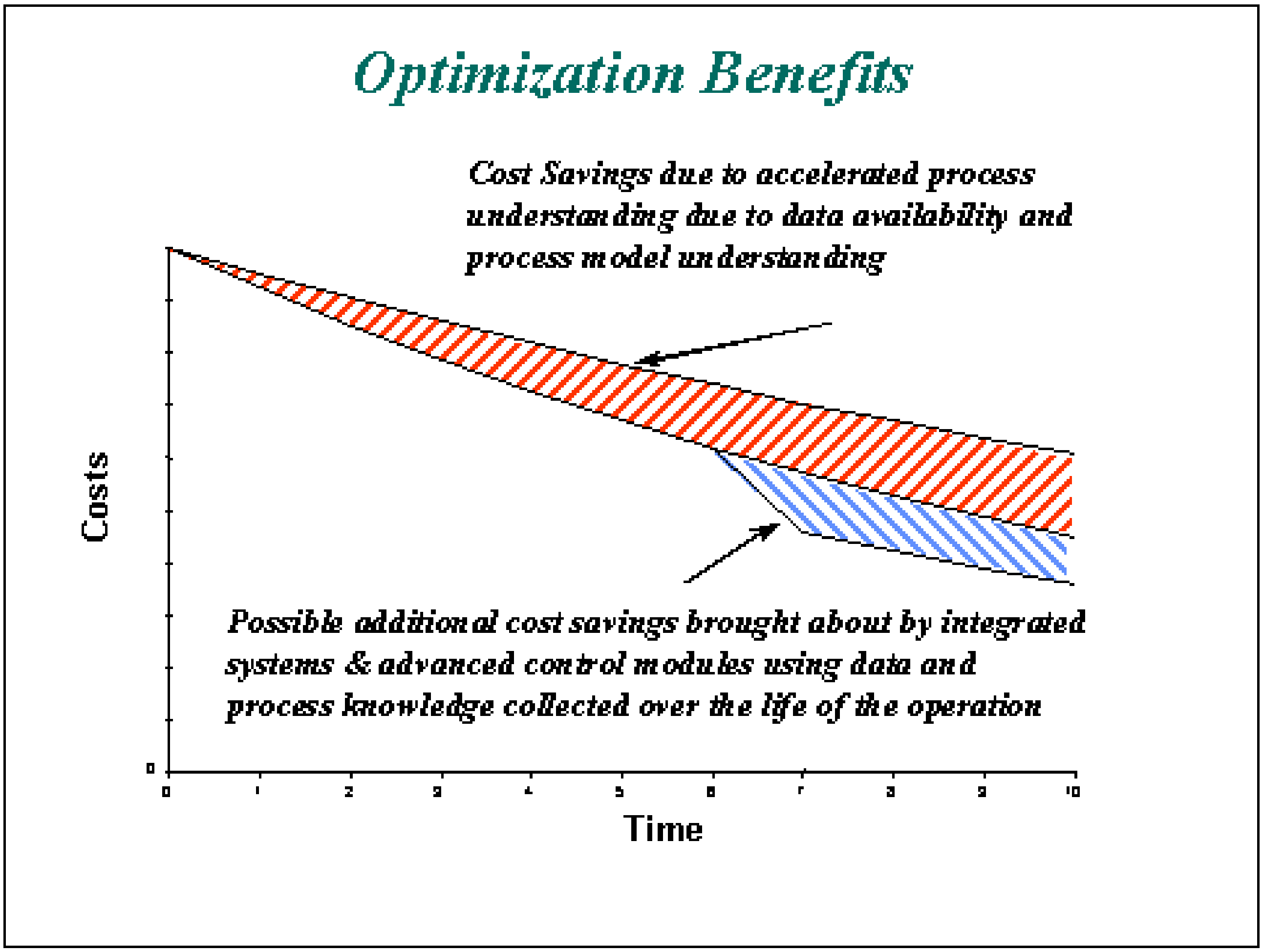

Figure 1: Optimization Step Improvement

Success Stories

The following two success stories are summaries from presentations made in 1998 with a 'Two Years Latter…' comment from the authors. These authors have provided insights and comments which are incorporated into the 'First Steps' section. In my view, these case studies represent significant steps forward in the approach to deriving more for less from mine operations.

Mount Isa Mines [Pease 1998]

Mount Isa Mines is a large base metal mining complex in Queensland Australia. This particular case study discusses lessons learnt through bringing a holistic approach to mining and milling operations at the Mount Isa and Hilton silver-lead-zinc orebodies and the lead-zinc concentrator. Application of these lessons has provided a feasible outcome in designing the George Fisher mine operation.

Situation:

Mount Isa operators demonstrate "a proud pedigree in process control." They have led the way in many applications of process control systems; yet, "the plant performance still varied widely, and the business was only surviving rather than thriving."

In 1995, a new general manager initiated the intervention in thinking required to initiate "out-of-the-box" solutions. His manufacturing background provided the experience and insight to declare the plant "totally out of control" after a brief tour. What this new perspective provided, was the impetus to challenge the variability in ore feed, versus blindly accepting it as a given.

Adopted lessons from manufacturing and paradigm changes:

Traditionally, metallurgical studies are conducted on composite ore samples taken for bulk testing. The underlying premise is that "average" conditions will prevail in the operation, and that milling operations will react to swings in actual conditions with satisfactory results. The reality is that average conditions rarely prevail and that any operation which is operated in reactionary mode will lag reality and be sub-optimal.

The manufacturer's approach showed there are only two ways of shifting from this sub-optimal position. First, is to reduce the input variability, thus reducing the magnitude of reactionary adjustment required at any given time; and second, is to increase the degree of predictability, especially trends, thus ensuring adjustments are appropriately buffered.

The first step needed, was to understand the highly variable ore characteristics in the mill feed. The geologists and metallurgist cooperated in correlation studies of drill core sample tests to actual mill results. The correlation was high. This led to the development of an integrated team from the geologists, mine engineers, mine operators, metallurgists and accountants to reduce mill feed variability, increase predictability and ensure economic considerations were met.

Results:

The first significant result was the realization that particular zones were in fact uneconomic. The premise that operating based on average parameters would work had led to subsidised mining of some 35% of the mill feed at the time. The review removed these uneconomic sources from the schedule, and focussed future schedules only on clearly economic sources. The paradigm was changed from "the mill must be kept full at all times" to "we should mine only profitable ore, and as much of it as possible".

Challenging this assumption led to the approach of sizing the mill operations to what the mine production schedule would yield, versus demanding the mine deliver to the mill capacity. It also led to the insight that bigger is not always better – being selective has strong merit.

Implementation of this lesson in conducting the feasibility of the George Fisher deposit **shifted the feasibility of the George Fisher ore body to being profitable at 2.5Mt/yr.** Studies of operating at 4 Mt/yr had been unsatisfactory; therefore, following tradition a study at 6 Mt/yr was carried out. This was even worse. When a study was conducted at 2.5 Mt/yr applying selective mine development and scheduling, the result was a viable, robust operating plan. The mine is currently under development.

The improvement in milling operations which supported the feasibility study were impressive, to say the least. In summary they are:

- Tonnes mined & treated dropped 35%
- Pb bullion increased 10%, Pb recovery increased 5%, Pb concentrate grade increased 2%
- Ag production increased 6.5%, Ag recovery increased 5%
- Zn concentrate production dropped 28%, Zn recovery increased 2%

Two Years Latter… [Pease 99]

" Two years later the benefits of the integrated business approach were more than we would have dared predict. This is perhaps usual – the early approach can quantify identifiable gains, but once the approach is in place continuous improvement dwarfs these gains. Early success meant that the logic of the Mine-to-Mill approach was quickly accepted by people working at all levels in the operation, and those people found new areas to improve. Once scientific people understand a truth, they can only be reasoned out of it with better logic - once you know the earth is round, no-one will convince you again it is flat. Organisation structures and KPI's at Mt Isa do not mirror the Mine-to-Mill approach, but this is not important if it is the way people think and work.

"To introduce a new approach, people have challenged the orthodox. Once the new approach is in place, it becomes the orthodoxy and will itself be challenged by thinking people. This is essential. If proved right, it strengthens the new approach. Generally there are improvements to be made, or assumptions that have changed. For example, at Mt Isa, the new approach was so successful in improving the lead zinc business and extending its life that some of the ore sources originally deemed to be uneconomic have become economic. To the outsider it may appear that we have gone though a pointless full circle; in fact, it has been a highly valuable revolution."

Highland Valley Copper [Simkus 1998]

Highland Valley Copper is a large open pit porphyry copper operation located in south western British Columbia, Canada. Ore comes from two open pits – Valley and Lornex – via three in pit crushers and a conveying system to the mill stockpiles. Grinding comprises three SAG mills and two AG mills in parallel. HVC use the Modular Mining System Inc. - Dispatch™ system to locate shovels and drills in the pit and to facilitate the tracking of ore properties from the open pits to the mill.

Situation:

Since 1977 HVC have been measuring rock hardness and classifying this characteristic against SAG mill throughput. As technology advanced they implemented the Aquila system on the production drills to aid in measuring rock hardness during the drilling process. This data was modeled by geology with rock hardness contour maps being generated. The Dispatch™ system was used to track ore properties and facilitate blending of ore for mill feed on the basis of hardness.

In 1996 drill hole diameter was increased in order to reduce drilling and blasting costs. This changed the fragmentation size distribution; which, subsequently lead to a slow but steady decline in mill throughput. The Mine and Mill were operating as separate business functions.

The cause of the slow decline in throughput was not readily apparent at the time, yet the impact of losing some 10% grinding capacity was very significant to the operation.

Action:

In 1997, HVC integrated the management functions for ore handling. This created an environment to support the studying of ore properties from geology to milling. WipFrag image analysis technology for scanning ore fragmentation size and distribution was implemented at key transfer points, i.e. primary crusher discharge and AG mill feed conveyors. Although the scanner results did not correlate easily to actual screen analysis, they did provide repeatable results which could be calibrated to meaningful size groupings, i.e. fine (-50mm), medium (50 – 125mm) and coarse (+125mm), which approximated the screening parameters for mill feed.

With the combination of the WipFrag scanning system, Aquila ore hardness measuring system on the drills, and the Dispatch™ system to track the ore properties through the ore handling systems, enough data was captured to allow studying the correlation of these factors to mill throughput.

Results

Some of the results were counter intuitive, i.e. the AG mills preferred a finer feed then was previously believed and that physically identical AG mills had different specific feed requirements to deliver optimal results. Further, that operating the primary crusher in choke mode would generate the preferred size distribution for grinding.

The knowledge gained through this evolutionary process allowed the mine to regain the 10% grinding throughput loss plus an additional 7.5% gain. Also, they discovered a cost benefit multiplier of 5 - 10 times between blasting cost & SAG/AG cost, allowing an overall optimization of rock sizing practices.

Two Years Latter… [Dance]

As part of the continuous improvement process and seizing opportunities as they were presented, HVC shifted the organisation structure to more closely align with the Mine-to-Mill concepts. They changed from a mine manager and mill manager to an operations manager and a maintenance manager – each responsible for mine and mill.

Technology wise, the Wipfrag results have continued to give excellent results in gathering effective information in a timely manner. As the quality and quantity of information grew along with the understanding of what the cause and effect relationships were, HVC staff have managed to coax more improvements out of the operation. In a specific quote from Adrian Dance:-

“An added point is that by separately measuring the mill feed hardness and particle size we could isolate their effects on mill throughput. It turned out for Highland Valley that - perhaps uniquely - hardness had very little effect on mill tonnage. Mill throughput changes could be accounted for purely with feed size. The historical relationship between mineralogy and tonnage was not due to “hard” and “soft” ore but rather, varying fragmentation size distributions.

“I also would like to add that the project is ongoing and we are still refining the process. I would not be surprised if we can “squeeze” out a further 5 to 10% more tonnage through improved (and

CONSISTENT) blasting and crushing practices."

Case Summary & Benefits

The examples set out by Mount Isa Mines and Highland Valley Copper represent a change in management approach to **consider the whole operation as one process.** High quality functional systems are supporting integrated process systems allowing the benefits to be driven out. In both cases, these benefits have been counter-intuitive, much bigger then expected and extended the mine life by driving down costs and increasing throughput and recovery.

First Steps to Implementation

Typical first questions asked by other companies are: *"What does it mean to my operation?" or "Where should I start?"*

From what I have seen so far, it entails detailing the 'metal' supply chain from geology to concentrate (or to customer). I am focusing the supply chain on the prime metals of the mine versus the supplies and consumable materials which go to support the process. I feel this is the first step, as one needs to know the fundamental process of transforming ore from geologic models to saleable product. Then identify and layer in the information exchange details to know where improved technology, management organization and information access can help. It will serve as a baseline to observe changes to the process.

Making a further extension of the comment by Pease, "Once scientific people understand a truth,…" the steps in scientific or engineering processes – which follow a disciplined process in itself – are: model the context of the problem, state an hypothesis, design an experiment to test the hypothesis, measure the result, conduct analysis, draw conclusions and repeat the process.

How many operators can truthfully say they follow these steps? Is now the time to extend the 'context' boundaries?

As outlined by Pease, "first you need a detailed flowchart of the whole process - and it must be detailed enough to catch even apparently minor technical aspects, so you need members from all technical and commmercial interests working on it. For example - a flowsheet of Mt Isa or Highland Valley would have missed mineralogical variation or ore sizing if there wasn't an obstinate metallurgist there insisting that it was important. **The facilitator of the flowsheet must make no assumptions about where the breakthrough will come,** only to demonstrate faith that someone on site will recognize and believe in it (i.e. unfortunately, most people don't believe in it), and, that it (the breakthrough idea) isn't being managed now.

“This means 20 blind alleys for every real gain, because there will always be people who are passionately interested in technical issues that only have a minor impact to the business (eg. the geos will talk about the extra drilling they need, or the new ore reserves software, the miners will talk about a new mine communication system and better mobile equipment, the metallurgists will insist they need a better measuring instrument and the latest flotation cell). But, all of these groups get a fair hearing on these issues with their boss, who is probably an expert in the field too, and can evaluate cost/benefit.

“So, I propose an additional filter - once you have the process flowchart, then superimpose the management structure. If the issue raised is wholly under one manager’s control, then ignore it. Only consider it if it falls between two managers, or in the “white space” on the organisation chart. There is now a chance that it is a major issue that hasn’t been managed because of the organisation dynamics. This would capture the examples at Mt Isa and HVC. This approach makes the reasonable assumption that technical people and managers are reasonably intelligent, and can generally manage their own areas well. If they can’t you are in trouble anyway. But, organizations traditionally have their difficulty across groups - people naturally form themselves into teams, then they begin to worry only about their own team’s performance, not the whole group, then they start competing against other teams .....”

Taking these comments and synthesizing with personal experience, I present Figure 2 as an example of what this type of high level, block flow diagram might look like. This model has been based on a direct shipping iron mine, and generalized to show the concepts. The block flow model describes the prime functions in the process loop, while the underlying zones represent the ‘zone of ownership’ of the processes i.e. the organization chart. Obviously, one will have drill down models with increasing detail. What this allows is identification of key information which must cross the boundaries transparently.

In order to construct the ‘meat’ of this model, i.e. the detailed attributes which impact down-stream and up-stream processes and decisions, a series of multidiscipline workshops must be conducted. One should start with the known and brainstorm into the unknown. Then with the rigors of scientific methods, i.e. data capture and analysis, changes are made and benefits derived. It is also a process where an outside perspective can add significant value through validation, questioning and articulating the ‘obvious’ to those too close to see it.

It is interesting to note that in most business cases the supply chain is modeled as an open-ended line. In this case it is a closed loop with groups typically feeling the greatest separation actually being inter-linked partners.

A dimension or layer which is missing from this model is plant maintenance and administrative support. These elements are also critical to achieving reliably high levels of effectiveness and efficiency; however, beyond the scope of this paper.

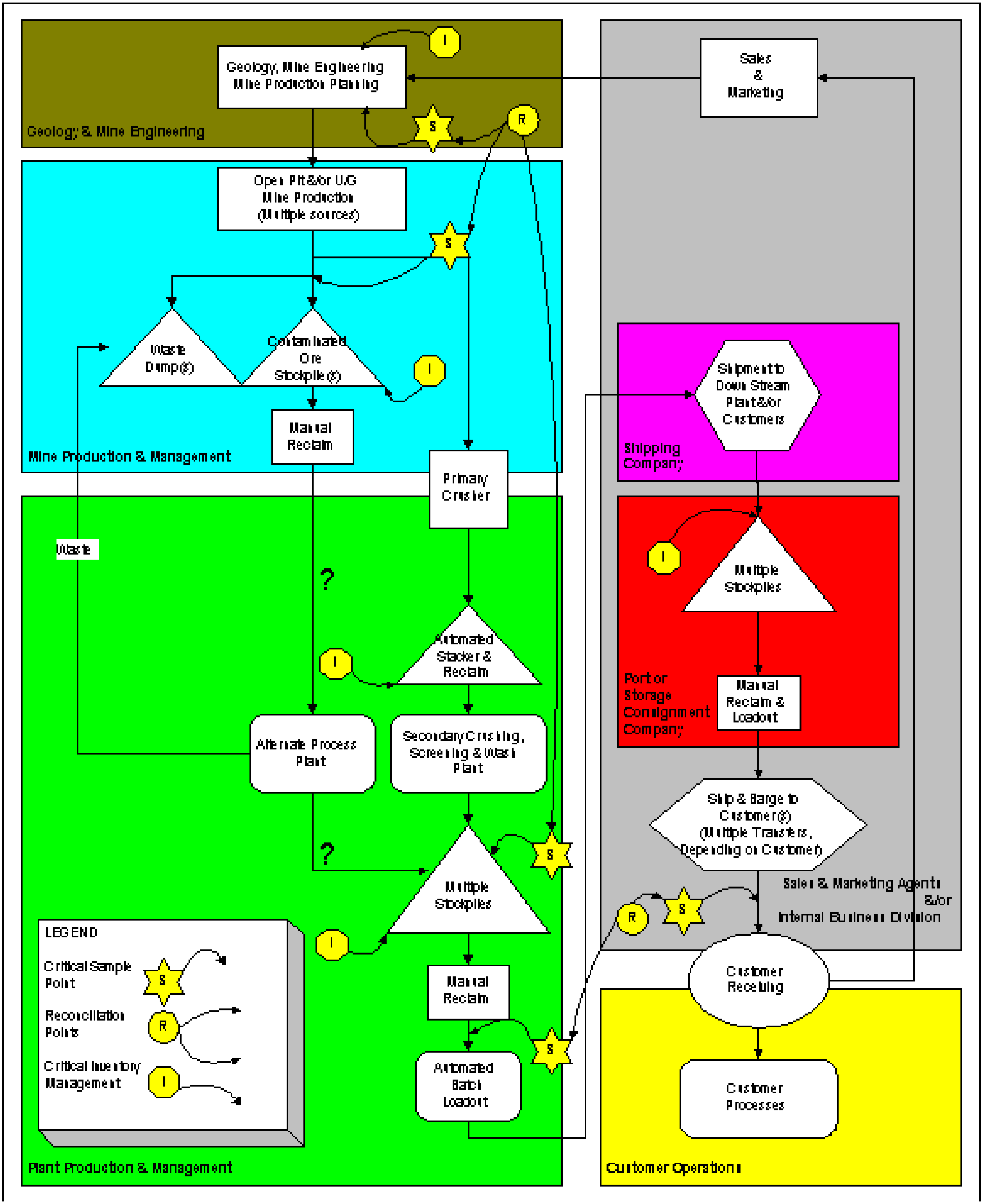
Geology, Mine Engineering
Mine Production Planning
Geology & Mine Engineering
Sales & Marketing
Open Pit &/or U/G Mine Production (Multiple sources)
Waste Dump(s)
Contaminated Ore Stockpile(s)
Manual Reclaim
Mine Production & Management
Primary Crusher
Shipment to Down Stream Plant &/or Customers
Shipping Company
Waste
Multiple Stockpiles
?
Automated Stacker & Reclaim
Alternate Process Plant
Secondary Crushing, Screening & Wash Plant
Port or Storage Consignment Company
Manual Reclaim & Loadout
Ship & Barge to Customer(s) (Multiple Transfers, Depending on Customer)
?
Multiple Stockpiles
Sales & Marketing Agents &/or Internal Business Division
LEGEND
Critical Sample Point
Reconciliation Points
Critical Inventory Management
Manual Reclaim
Automated Batch Loadout
Customer Receiving
Customer Processes
Plant Production & Management
Customer Operations

Figure 2: Generalized 'Metal' Supply Chain

Recommendations

It is easy to become lost in the sea of data and information available to management these days. By **focus**ing **on the single critical purpose of the operation** – production of high quality, low cost product – one can determine the correct information to support proactive action initiated on quality knowledge of the physical processes.

The benefits these operators have found are significant. Experience shows that when focus is brought on an opportunity, ways and means will be found to overcome technical challenges or current road blocks. Building on the lessons of the operators, and acknowledging the fact that each ore body has different ore variability characteristics, you should undertake a serious review of what is feasible for your particular situation. There is often more capability within your operations than what first or second impressions may indicate. Do some digging. The benefits are there.

Acknowledgments

I would like to thank Joe Pease, Adrian Dance, Hatch and numerous supporters for contributing ideas, providing feedback and providing me the opportunity to write and present this paper.

References

DANCE, A. 1999

Personal conversations and email correspondence.

PEASE, J. D.; YOUNG, M. F.; JOHNSON, M.; CLARK, A.; AND TUCKER G. OCTOBER 11-14, 1998

Lessons from Manufacturing – Integrating Mining and Milling for a Complex Orebody. Mine to Mill Conference, Brisbane.

PEASE, J. D. 1999

Personal conversations and email correspondence.

SIMKUS, R.; DANCE, A. OCTOBER 11 – 14, 1998

Tracking Hardness and Size: Measuring and Monitoring ROM Ore Properties at Highland Valley Copper. Mine to Mill Conference, Brisbane.