OPTIMIZATION OF WASTE TRANSPORTATION ANALYSIS AT HIGHLAND VALLEY COPPER

by

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Abstract

Mining operations, both in Canada and worldwide, face increasing pressures that affect mine profitability. Declining head grades, increasing strip ratios, deeper excavations and other obstacles intensify mining challenges. In addition, there are societal pressures to increase the sustainability of operations. Teck Resource Limited's Highland Valley Copper (HVC) mine is not exempt from these challenges and pressures. One challenge of increasing importance at HVC is waste transportation. Exploring opportunities to optimize the transportation of waste at HVC has the potential to bring significant economic and sustainability benefits. Using a hypothetical mine plan, this paper analyzes three options: purchasing more haul trucks, switching to larger, ultra-class haul trucks or installing an In-Pit Crushing and Conveying (IPCC) system. Teck's Sustainability Focus Areas and economic criteria are used to analyse the options. The analysis concludes that the IPCC system presents many advantages if specific criteria are met to ensure HVC maximizes its investment return.

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Keywords: Waste transportation; In-Pit Crushing and Conveying; Sustainability; Open pit mining; Haul truck

Executive Summary

Highland Valley Copper is one of the largest operations within Teck Resources Ltd. As with many other mines in BC, Canada, and the world, HVC is facing increasing costs and societal requirements to continue mining. Hence, HVC needs to continue optimizing its operations from economic, environmental and social perspectives to remain profitable.

The area of opportunity that this paper investigates is waste transportation. Initial indications from future mine plans show that waste transportation requirements will increase substantially over current requirements. Therefore, improving processes over the current status quo option of truck haulage offers the potential for considerable economic and sustainability gains.

This paper explores three options for waste transportation for a hypothetical waste plan at HVC: increase the current fleet of CAT 793 (240T) haul trucks, add ultra-class haul trucks (400T) or install an In-Pit Crushing and Conveying (IPCC) system.

The options were analysed using Teck Sustainability Focus areas and economic criteria. Teck's Sustainability Focus Areas include Water, Energy, Material Stewardship, Biodiversity, Communities and Our People.

The analysis shows that there are considerable advantages to implementing an IPCC system. The analysis also shows that there is little difference between the two truck hauling options; the option of using ultra class trucks has marginal benefits over the status quo option of increasing the existing haul truck fleet.

Significant findings for the IPCC system over the option of expanding the existing haul truck fleet include:

- $218m improvement in Net Present Value (NPV)
- 7 year payback on initial investment
- $.23/lb reduction in cost per pound of copper produced
- $96m more capital expenditure with $259m required in the first year

- Nearly 1 terra joules of energy savings and 71 kilo tonnes CO_2 effective reduction per year which meets almost all of Teck's 2015 energy targets
- Reduced annual water consumption from less road watering of over 500,000 m^3
- Decreased fugitive dust

For an IPCC system to be successful, there are a number of criteria that must be met. These include: a long mine life, large waste removal requirements involving long distances with significant elevation changes, advanced and careful mine planning and a minimal number of dump locations to minimize extended and costly downtimes required for realigning conveyors and stacker systems.

Dedication

I dedicate this paper to my late sister, Claire Elizabeth Dixon. Her perseverance, positive attitude and intelligence will forever inspire me.

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Finally, I could not have completed this paper without the endless support that my family gave throughout the long process. Thank you to my wife, Jill, for your never failing support; to my children, Rachel, Kayla and Asher for your patience; and to my parents, Mark and Susan, for all of your assistance.

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Glossary

AG Mill	An Autogenous mill is a rotating shell that uses the ore that enters the mill to reduce its size. At HVC, mills D&E are primary AG mills.
Availability	A term used to denote the percentage of time a piece of equipment is available to operate. Availability includes any downtime where the equipment is not broken down.
Bulldozer	A heavy piece of track driven equipment that uses a straight blade to move material. HVC operates Caterpillar D10 and D8 model bulldozers.
Closed Size Setting	The setting on a gyratory crusher which determines the maximum size of material that will pass through.
Conveyor	Equipment used to transfer material from one location to another. HVC primarily uses troughed rubber belt conveyors for this application.
Crusher	Equipment used to reduce the size of rock. In hard rock (rock strength greater than 150MPa) applications, gyratory crushers are primarily used.
Electrical Demand	The instantaneous power draw at any singular time. Demand is measured in Volt-Amps and includes the system power factor.
Grader	A wheeled piece of equipment with a long middle mounted blade that is primarily used to maintain roads at HVC. HVC operates CAT 16M and 24M series graders.
Gyratory Crusher	A crusher that uses a gyratory motion between its stationary surface (concaves) and its mantle. As rock enters the conical opening, the mantle forces it against the concaves until it is small enough to pass through the bottom opening.
Haul Truck	An off road vehicle used to transport material. Haul truck payloads vary in tonnage from less than 100 tons to 400 tons. The current HVC haul truck fleet is CAT 793 trucks with 240 ton payload capacity.
HVC	Highland Valley Copper is a partnership which is 97.5% owned by Teck Resources and 2.5% by Highmont Mining Company.
IPCC.	In Pit Crushing and Conveying.

Mill	Equipment used to reduce the size of rock. There are three types of mills used at HVC – Fully Autogenous, Semi Autogenous and Ball mills.
Ore	Rock which has an economically viable mineralization to process.
Overland Conveyor	A conveyor that travels long distances over land. HVC has a number of overland conveyors.
SAG Mill	A Semi Autogenous mill is a rotating shell that uses additional grinding media (typically steel balls) to reduce the size of the ore to be processed. At HVC, mills "A, B & C" are primary SAG mills.
Stacker	Mobile, extended conveyors which handle material from overland conveyors and cast the material out to create waste dumps.
Tailings	The fraction of rock that is left over after processing which is not economically viable to process.
TSF	Tailings Storage Facility –a location used to store tailings. The TSF at HVC is located in a valley with a dam at each end.
Wheel Dozer	A wheel dozer is similar to a bulldozer except that it has wheels instead of tracks for propulsion. Wheel dozers are primarily used at HVC for road maintenance and clean up.

1: Background

1.1 Highland Valley History

Highland Valley Copper (HVC) has a long and successful history of mining safely and profitably in the Highland Valley region of the interior of British Columbia. The initial low grade, open pit, porphyry mining operation in the valley was Bethlehem Copper. Bethlehem started its operations in 1962, northeast of the current HVC mine. Bethlehem operated until 1984 and was one of the first operations in the world that profitably mined low-grade copper ore (Piwek 2015).

Lornex (owned by Rio Algom) and Highmont Mines (partially owned by Teck Resources Ltd.) started in 1972 and 1978 respectively. Their pits are still in operation today. Lornex and Highmont, although separated by only a few kilometres, had completely separate infrastructure, including crushers, mills, maintenance shops and tailings storage facilities. In 1986, Highland Valley Copper (HVC) began as a joint venture between Lornex Mine (Rio Algom) and Cominco, owner of the Valley deposit. Shortly thereafter, HVC began mining the Valley pit, which is currently the largest pit in operation at HVC. In 1986, Teck bought 31% of Cominco, after which it completed the move of its Highmont Mill to join the existing HVC Mill (Piwek 2015).

1.2 Current HVC Operations

1.2.1 Current HVC Haulage Fleet

HVC operates a large haul truck fleet to transport ore to its crushers and waste to dumps. Currently, HVC has 52 CAT 793 haul trucks similar to the truck shown in Figure 1. Each truck has a maximum payload capacity of two hundred and forty (240) tons.

Figure 1 CAT 793 Haul Truck (By Author)

In past years, HVC has operated a variety of haul trucks including CAT 789 (180 ton payload), WABCO 3200B Haulpac (220 ton payload) and others (Piwek 2015).

A number of factors determine the size of the haul truck fleet. The fleet's availability, individual truck payload, distance and elevation to dumping location, truck speed, stripping ratios and mine plan all contribute to the quantity of trucks that HVC must purchase, operate and maintain. Items such as strip ratio and truck speed are beyond the control of management at HVC and, as such, the other factors must be managed as efficiently as possible. As HVC continues to mine deeper with increasing strip ratios and dumps get further from the pit, truck requirements continue to increase. Using diesel as a proxy for truck fleet size, table 1-1 shows the change in diesel consumption from 2012 (table by author, data from Teck).

Table 1-1 Historical Diesel Consumption

Year	2012	2013	2014
Diesel Consumed (Litres)	49,307,244	52,371,195	55,654,511
Percent increase from previous year	NA	6%	6%

1.2.2 **Waste Hauling**

HVC has hauled a significant amount of waste material over the course of its history. Waste material is any material from which it is uneconomical to extract copper. Waste material includes overburden (soils overlying the rock beneath) and rock with little to no mineral content.

Waste, traditionally and currently, is transported by haul trucks to a number of waste dumps that surround each pit at HVC. As mining progresses and major pit expansions commence, a number of dumps close to the pit rim have been re-excavated and the material transported further away from the rim. As HVC's active pits expand, the distance to each dump substantially increases as the dumps are located higher and further away from their point of loading.

Thus, as strip ratios increase, as pits become larger and deeper and as dumps become higher and farther away, the haulage requirements increase. As shown by Table 1-2, yearly waste tonnages have increased in past years (table by author, data from Teck).

Table 1-2 Historical Waste Mined

Year	2012	2013	2014
Waste Mined (Dry Metric Tons)	54,952,347	65,670,624	74,416,694
Percent increase from previous year	NA	20%	13%

Waste dumps are limited in height and corresponding size by hauling restrictions: very tall dumps become uneconomical due to increased truck cycle times.

1.2.3 **Primary Crushing**

To feed the five primary mills within HVC's concentrator building, HVC operates three primary crushers and a number of conveyors with transfer stations. Alice Chalmers manufactured the three primary crushers that have dimensions of 60"X89" (1.52X2.26m). Crusher 1 is a fixed style crusher with a concrete and steel structure situated near the Lornex Pit. Crushers 4 and 5, commissioned in 1987, are semi-mobile. Since 1987, they have been moved five times (1992, 1996, 1998, 2007 and 2015) to meet mining requirements and minimize hauling costs. Appendix A, B and C show the historical locations including the overland conveyor system. Typically, these crushers are located in the northeast corner of the Valley Pit.

To allow for moving, the structures that support Crusher 4 and 5 are made from steel. Figure 2 shows Crusher #5's superstructure and gantry crane. Large retaining walls hold back the earth necessary for the haul trucks to dump near the top of the crusher. Crushers 4&5 also have an apron feeder to transport rock from their hopper to the crusher. While the apron feeder is another item requiring maintenance, it also lowers the total height of the crusher thereby reducing haul costs.

Figure 2 Crusher #5 Superstructure and Gantry Crane (by Author)

All three gyratory crushers reduce the size of the incoming rock. After crushing, rubber belted conveyors transport the rock to the mills. The primary and secondary mills further reduce the rock to an average of 250-450 micron size, allowing for optimal copper recovery in the flotation process.

Figure 3 shows the top components of the crusher.

Figure 3 Dump pocket and top of Crusher #1 (by Author)

The mantle moves in an eccentric path between the concaves. As the concaves and mantle trap the rock between them, the rock fractures when the stresses exceed the strength of the rock. HVC's ore is relatively hard, having a strength of approximately 180 MPa or greater, which, combined with the high desired throughputs, eliminates the ability to use many types of crushers such as double roll and sizers (Yan and Ashok 2006, p. 99, 133). Similarly, nearly all other copper mines in the world use gyratory crushers as their primary crushers (Lynch and Rowland 2005, p. 65).

The size of rock that falls through the crusher, either unimpeded or after crushing, is set by the crushers' "closed size setting". The closed size setting positions the mantle in relation to the concave. In general, a tighter setting, resulting in smaller rock falling through the crusher, is preferred. This is due to the higher process efficiency of crushing versus grinding. Primary crushing uses 3.24 KW-hr/LTON while grinding in autogenous or semi-autogenous mills requires

17.82 KW-HR/LTON (Eloranta 1997). Thus, by decreasing the closed size setting, smaller rock passes through the crusher resulting in improved efficiency due to reduced power usage by the mill.

Once the rock passes through the mantle and concaves, it lands directly on the takeaway belt (Crusher 4/5) or lands in a surge bin under the crusher (Crusher 1). The surge bin on Crusher 1 acts as a throttle to avoid overloading the apron feeder and meters the flow of rock onto the apron feeder. The takeaway belts and apron feeder then transport the rock to their connecting overland conveyors. The takeaway belts and apron feeder are 2.3m wide and can handle a maximum of 6000 tons per hour (tph).

Each crusher is expected to have an average annual production capacity of 22 million tons, which is considerably less than their nameplate capacities. Items that decrease the annual production of the crushers include breaks, scheduled downtime, unscheduled downtime and waiting for ore delivery, as shown in table 1-3 (by author).

Table 1-3 Crusher Operating Reductions

Description	**Hrs**
Hours of operation in a day	24
Lunch breaks	2
Coffee breaks	1
Shift change	1
Loss due to unscheduled downtime	2.4
Loss due to waiting/underutilization	2.6
Loss due to blockage/oversized feed	1
Total operating time at full capacity per day	**14**

1.2.4 **Overland Conveyors**

HVC has a significant number of overland conveyors that transport crushed ore to the coarse ore stockpiles for consumption by the mill. These conveyors are 1.5m wide and run at 3.9 meters per second (m/s) with a maximum capacity of 6000 tph. To increase the redundancy and flexibility of the system, there are a number of transfer stations at the end of each conveyor. These transfer stations allow for switching the ore feed from one conveyor system to another and allow for proportional blending.

Figure 4 shows the transfer station that feeds the L1B Overland Conveyor.

Figure 4 Transfer Station onto L1B Conveyor (by Author)

Figure 5 shows the conveyor belt, idlers and frame.

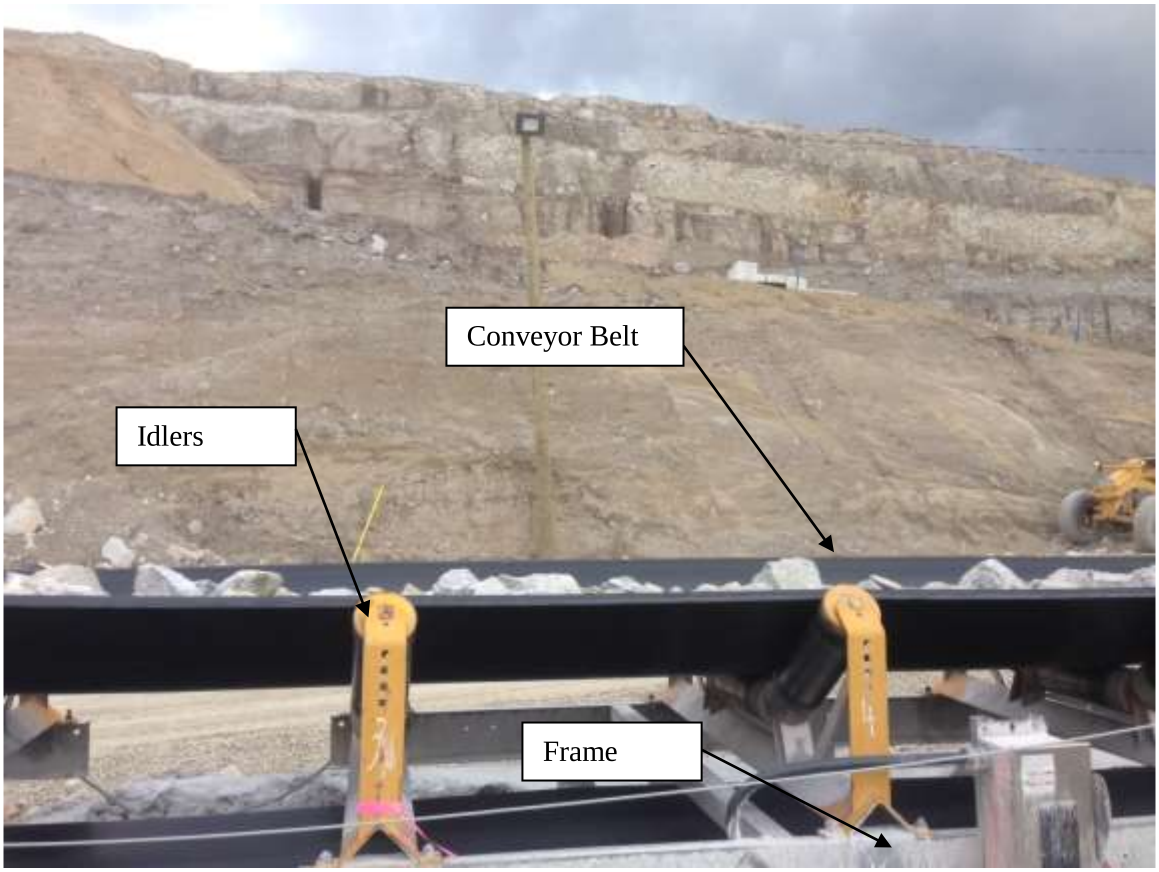


Figure 5 Conveyor Belt, idlers and frame (by Author)

Figure 6 L1B Overland Conveyor (by Author)

1.2.5 **Highland Mill**

The Highland Mill receives ore from the overland conveyor system. The mill was created by transporting Highmont's two autogenous mills to supplement the three semi-autogenous mills already present at the Lornex Mill.

Combined, the five mills have an average throughput of 133,000 tons per day. This throughput is dependent on ore hardness and other variables. Copper production is dependent on mill throughput, recovery and head grade.

1.2.6 **Tailings Storage Facilities**

Although the HVC mill produces a considerable amount of copper concentrate every year, the majority of material produced is tailings. Tailings are transported by pipelines to the Highland Tailings Storage Facility (TSF). HVC is also responsible for maintaining other non-active TSF's.

2: Current Issues

As with any mine, HVC has a number of issues that it must actively manage to ensure that it maximizes its profit to shareholders in a safe and sustainable manner. One of the largest potential opportunities is optimizing the transportation of waste material. To date, as with many other mines, haul trucks have solely transported all waste. While haul trucks offer considerable benefits and advantages in the transportation of waste, they also have many limitations.

2.1 Capital Costs

HVC's truck fleet over the years has grown in capacity and numbers in order to keep up with production demands. The impact of running a larger fleet is considerable. The first impact felt by HVC is the capital cost of purchasing new trucks. Currently, a CAT 793 costs $CAD4.85 million as optioned by HVC. HVC trucks typically have a lifespan of 100,000 hours with 5,800 hours of operating time per year (Adema 2015). Thus, trucks are typically replaced every seventeen years.

2.2 Personnel Requirements

Each operating truck requires four drivers to allow for operation 24 hours a day, 365 days a year. To keep the truck in operation, specialized, heavy-duty mechanics, electricians and welders are also required at a ratio of 1.5 personnel per fleet truck (Adema 2015). Thus, direct labour requirements for each truck in the fleet equate to six full-time personnel.

2.3 Maintenance Shop Requirements

Maintenance truck shops are an important consideration for ensuring efficient truck maintenance. The industry standard for truck shop size is a five to one ratio of trucks to bays (Tsuji 2014). In 2011, HVC undertook a project to expand four support bays by twenty feet so that CAT 793 haul trucks could use these bays. At the time, the project was justified by the fact that the ratio of trucks to bays was nine to one and, hence, truck availability increased by adding more maintenance bays. This completed project cost a total of $1.85 million. Current estimates for new truck shops are approximately $17 million for a shop with four bays and $6 million for every additional two bays (Tsuji 2014).

Haul truck maintenance costs also increase over time and are rising at a greater rate than increases in total tonnage hauled. A number of factors likely cause this discrepancy, including: increased hauling distance, increasing labour costs and increasing parts' costs. Table 2-1 shows the increasing tonnages and costs, in relative terms, using the year 2012 as a baseline (table by author, data from Teck).

Table 2-1 Relative Mined Tonnages & Haul Truck Maintenance Costs

Year	2012	2013	2014
Increase in total mined tonnage %	100%	110%	124%
Increase in haul truck maintenance costs %	NA	142%	158%

2.4 Haul Road Maintenance

When calculating the operational cost of trucks, in addition to direct maintenance costs, road maintenance costs must be considered. The passage of heavily loaded trucks over the haul roads requires continual maintenance to keep the roads passable and in good condition. Increased truck maintenance will result if the roads deteriorate. On haul trucks, an increase in frame cracks and their associated repairs is a direct result of deteriorated roads. Considerable effort and associated cost is required to keep roads in good condition. Numerous support equipment are required, including bulldozers, wheel dozers and graders. At HVC, there are 21 pieces of medium sized equipment involved in road maintenance with 66 operators. In addition, the road surface is graded with sand and fresh small crushed rock at various times to ensure optimal conditions. Similar to haul truck maintenance costs, road maintenance costs are growing at a rate that is greater than the total tonnage mined. Table 2-2 shows the relative increase in road maintenance costs using 2012 as a baseline (table by author, data from Teck).

Table 2-2 Relative Mined Tonnages & Haul Road Maintenance Costs

Year	2012	2013	2014
Increase in total mined tonnage %	100%	110%	124%
Increase in haul road maintenance costs %	100%	149%	162%

Reasons for the greater rate of increase in haul road maintenance costs are likely similar to haul truck maintenance costs: increased labour, rising parts' costs and greater haul lengths.

2.4.1 **Haul Road Watering**

Another aspect of road maintenance that is greatly affected by the number of haul trucks in operation is the requirement to water haul roads. Typically, from April to October, HVC spends considerable effort and funds keeping the haul roads moist to decrease fugitive dust. HVC's existing water truck fleet consists of the following converted haul trucks - two CAT 793 and two CAT 789 trucks. During July and August, three out of four of these trucks are typically operating full time to reduce dust issues. Table 2-3 shows the number of water truck operating hours for the previous three years (table by author, data from Teck).

Table 2-3 Water Truck Historical Operating Hours

Year	2012	2013	2014
CAT 789 Total Hrs	4823	3420	2452
CAT 793 Total Hrs		289	4710
Total Hours	4823	3709	7162

Keeping the dust created by haul trucks to a minimum is beneficial for a number of reasons. Dust has the greatest impact on people working in the pit. This includes the operators of haul trucks, shovels, support equipment, drills, crushers and a variety of other personnel. Also affected are people in outlying areas beyond the mine site, some of whom have voiced concerns over the dust generated by operations at HVC. Recent improvements to dust containment on other infrastructure at HVC have left haul trucks as the biggest generators of dust on site. Thus, the generation of dust by haul trucks directly affects HVC's social license to operate.

2.5 Haul Truck Emissions

Another emerging issue with the heavy reliance on haul trucks is the potential for increased taxes or tariffs in relation to CO2 emissions. In 2008, the province of British Columbia initiated a carbon tax on all fossil fuels. As HVC consumes 55 million litres per year in diesel, any further increase in taxation of this input could have a material impact on HVC's profitability, especially when the volatility of diesel prices is considered. Furthermore, current low diesel prices are masking the true cost of using mobile equipment. HVC's effective emissions from the consumption of diesel from 2012 until 2014 are shown in table 2-4 (table by author, data from Teck).

Table 2-4 HVC's GHG Emissions

Year	2012	2013	2014
CO_2 Equivalent (tonnes)	131,305	139,464	148,208
CH_4 Equivalent (tonnes)	6.6	7.0	7.4
N_2O Equivalent (tonnes)	19.7	20.9	22.3

3: Other Mining Operations

In order to determine if HVC should change its processes given the current issues associated with the haulage of waste material, an investigation of its competitors' processes is required. A variety of other mines around the world have operating conditions similar to HVC. For this investigation, Gibraltar, Antamina, Kennecott and Fording River mines are examined. Of the four mines, only Fording River, owned by Teck, is not a copper mine. Gibraltar, Antamina and Kennecott mines were examined because they are all large-scale copper mines with similar processing methods to HVC.

3.1 Gibraltar Mine

The closest mine to HVC is Gibraltar, which is located near Williams Lake, BC. Gibraltar, seventy-five percent owned by Taseko Mines, is a copper-molybdenum mine that averages an ore throughput of 85,000 tons per day (Taseko Mines 2015). Gibraltar has a single pit rim primary crusher of the same size as HVC's for the first step of its copper production process. Gibraltar currently hauls all of its waste from its pits to waste dumps by haul trucks. Since Gibraltar's pits are much smaller and not nearly as deep, its waste hauls are, undoubtedly, not nearly as costly as HVC's.

3.2 Antamina Mine

The Antamina Project in Peru is another mine that is similar in size to HVC and is partially (22.5%) owned by Teck. Antamina has an ore throughput rate of 130,000 tons per day (Teck Resources Ltd 2015). It is able to operate with only one primary ore crusher due to a number of factors, most notably softer ore than HVC's. Antamina transports all of its waste by haul truck.

3.3 Kennecott Mine

The Kennecott mine, in Bingham County, Utah, and operated by Rio Tinto, is another comparable mine to HVC. This mine is one of the oldest and largest in the world, with a massive open pit measuring 4km wide and 1.2km deep (Steven 2002, p. 1). Kennecott operates a single 60X113 in-pit crusher with 8km of conveyors to supply 150,000 tons of ore per day to its four

SAG mills (Rio Tinto 2015). Kennecott has a fleet of 70 haul trucks and does not use waste conveyance even though, given the depth and size of its pit, there could be significant advantages in doing so.

3.4 Fording River Mine

The Fording River Coal mine (FRO), operated by Teck near Elkview, British Columbia, is one of the world's largest metallurgical coal producing mines. The mine currently has sixty-six haul trucks of 240 ton or greater payload. As with most open pit coal mines, the majority of material that it moves is waste. Recently, Fording River has begun evaluating the option of in-pit crushing and conveying for its waste material. The project would be a significant expenditure, with total capital costs over two hundred million dollars. However, the addition of this system is anticipated to reduce the future number of trucks by 35 during peak waste hauling years. Including the capital cost, the addition of this system could drop FRO's cost per ton of coal by 8.4% (Colden 2015). The project is expected to have a positive Net Present Value (NPV) (Colden 2015).

4: The Future

The future of copper mining at HVC is both promising and challenging. HVC still has considerable reserves available to mine. However, these reserves require the movement of a sizeable amount of overburden and are of lower overall grade than our existing reserves. Thus, the cost to mine each ton will be higher and HVC will extract less copper per ton. Combined, these factors will put upwards pressure on costs resulting in lower profits.

Furthermore, increasing fuel, labour and parts' costs increase costs of production and reduce the profitability of HVC. In order for HVC to maximize profits and stay in production over the long run, HVC's cost must be close to the lower quartile of copper producers. With low head grades and increasing expenditures, HVC must consider step changes in technology and processes in order to stay competitive.

4.1 Increased Strip Ratios

Similar to most mines worldwide, future HVC mining plans show increased strip ratios. HVC's preliminary future mine plans show a 66% increase in strip ratios in order to mine equivalent tonnes of ore. Without any process changes, the potential increased strip ratios will require an extra 25 haul trucks (Alikhani 2015).

In addition to the capital required to purchase the extra haul trucks, there are many extra costs associated with increasing HVC's fleet. As mentioned in Section 2.2, each truck requires 4 drivers and 1.5 maintenance personnel to support it. Furthermore, with an addition to the fleet, either an addition to the existing maintenance shop or a new shop will need to be constructed. To keep availability high, adding additional bays to keep HVC at the industry average of five trucks per bay is important.

Other infrastructure will need upgrading to support the increase in personnel. The number of offices for the supervisory staff of the Mine Maintenance, Engineering and Operations departments will need to increase to support the extra production. The Mine Dry will need to expand to include more showers and lockers. The warehouse will need to be expanded to provide more storage for parts and support a higher passage of parts.

Furthermore, ancillary services, such as inventory and delivery of both fuel and tires, will need to increase to provide adequate support for maintenance and operations. Road maintenance and watering requirements will also increase. Table 4-1 shows the additional capital costs estimated to support an extra 25 haul trucks (table by author, data from Teck).

Table 4-1 Capital Costs for Extra Haul Trucks

Description	Capital Costs ($Cdn)
New Truck Shop	$20,000,000
Expanded Mine Operations Facility	$3,000,000
Expanded Parts Storage Building	$5,000,000
Supervisory Offices	$400,000
Total Estimated Fixed Asset Costs	$28,400,000

5: Options

As previously described, HVC is facing increasing pressures to maintain profitable operations. The optimization of the transportation of waste presents a considerable opportunity for HVC to increase its profitability and decrease its risks during market downturns. The three main options considered in this analysis include: increasing its existing haul truck fleet size, adding ultra-class sized haul trucks and introducing an In-pit Crushing and Conveying (IPCC) system for waste. The options will be described in detail in Section 5 and a detailed analysis will be completed in Section 6. There are risks associated with each of the options, including the option of carrying on with the status quo.

5.1 Option 1: Increase Existing Haulage Fleet

The status quo option is simply to increase the existing CAT 793 240 ton haul truck fleet to meet total ore and waste haulage requirements. As described in section 4.1, this option would require up to 25 extra haul trucks to ensure adequate ore supply for the mill. The issues of operating with an increased fleet are detailed in section 2 and 4. These issues include increased GHG emissions, fugitive dust, personnel requirements and capital costs.

5.2 Option 2: Add Ultra Class Haul Trucks

The second option for HVC is to add Ultra Class Haul Trucks to its fleet. Current Ultra Class trucks have a payload of 400 tons (Caterpillar 2015). As detailed in the report completed by HVC's Strategic Planning group in 2014, specific benefits with moving to larger haul trucks include increased efficiency and reduced costs. Due to stability and legacy issues within existing mining pits, HVC's haulage fleet would always include both sizes of haul trucks for the duration of the mine plan.

The introduction of larger haul trucks would result in a number of challenges. All current infrastructure is designed for the CAT 793 (240T) truck size. New or expanded infrastructure would be required, including a new maintenance shop, new crusher dump hoppers, fuel islands, water arches and haul roads.

While increased capacity trucks should decrease costs, their operation still has many of the drawbacks that the existing fleet comes with. These include, among other items, high CO_2 emissions, high personnel requirements and considerable parts' costs.

5.3 Option 3: In-pit Crushing and Conveying Waste

HVC's third option is to install an In-pit Crushing and Conveying (IPCC) system for waste. An IPCC system would include one or more crushers, overland conveyors and a stacker to deposit the waste material and construct dumps. Very similar infrastructure already exists at HVC, with the exception of the stacker. The stacker directs material from the overland conveyors to its final position by continuously moving around the dump. By using this method, no re-handling of the material is required as it's deposited into its final location.

Since HVC operates from three pits, a single IPCC system could not handle all mined waste. However, the forecast for future years is that most mine material will come from the Valley Pit. The IPCC system would decrease the reliance on haul trucks for the movement of this waste material. Conversely, an IPCC system would increase the amount of maintenance required by millwrights and electricians on the crushers and conveyor systems.

In addition, an IPCC system would decrease the redundancy of HVC's operations. Although crushers and conveyor systems have higher availabilities than haul trucks, a single waste crushing and conveying system would shut down all waste transportation when any type of maintenance event occurred. As well, haul trucks are easily scaled to increase or decrease production, whereas crushing and conveying systems have large step changes in terms of production rates once the capacity of the system is exceeded.

While the addition of crushing and conveying waste would decrease HVC's consumption of diesel, HVC's electrical power consumption would rise considerably. HVC is BC Hydro's largest single point customer and second largest customer overall. HVC's current power demand is 128 Mega Volt Amps (MVA) and its annual consumption in 2014 was 930 Giga Watt Hours (GWH), which equated to $46 million dollars (Haight 2015). A crushing and conveying system for waste will increase electrical demand at HVC by up to 25 MVA.

This demand increase, coupled with other system upgrades that HVC is considering, may push HVC over the threshold of BC Hydro's supply capacity. Therefore, to supply the total amount of power needed, HVC would require BC Hydro to upgrade their system. The specifics of this upgrade and the costs associated are outside of the scope of this paper. However, it should be noted that a significant upgrade in supply can take an extended period of time (five to ten years) and should be accounted for in mine and project planning.

In order to load waste material onto conveyors and minimize conveyor belt damage, crushing must reduce material size to a maximum of 0.3 meters (Scott, et al. 1996, p. 22). In ore processing, this step is a primary breakdown function. In waste transportation, this step is only required when using conveyors and, as such, the extra processing adds capital and operational expenses that do not exist when haul trucks are utilized.

Another significant impact that an IPCC system has is loss of flexibility in mine planning and operations. Haul trucks have the ultimate flexibility in that they can be moved from an ore route in one pit to a waste route in another pit with a simple change in assignment from the dispatch center. On the other hand, considerable planning must go into where and when an IPCC system is installed and commissioned. In addition, the stacker is limited to operating at one dump. In comparison, HVC has operated up to six waste dumps for the material coming from its three operational pits (Alikhani 2015).

Inevitably, an IPCC system would have to be moved when further stripping and pushbacks are required. If future copper prices rise to make expanded mine plans economical, additional system moves may be required. Moving this system is a significant undertaking from a cost, planning and execution perspective. HVC has considerable experience with moving its ore in-pit crushing and conveying systems, having undertaken five moves since being commissioned in 1987. In 2015, HVC moved its Crusher #4 and realigned the conveyor (L1B) where Crusher #5 discharges. The total project duration was two years with two separate thirty-day shutdowns required for the execution. The total project cost was $68.5 million. In comparison, moving Crushers #4&5 in 2008 cost $36 million dollars.

6: Options Analysis

In order to determine which of the three options is most advantageous, a thorough analysis is required. Traditionally, the option selection would primarily consider economics and the most advantageous option would have the best Net Present Value (NPV), the best cash flow, or a combination of both. However, in the changing world that Teck faces today, more and more emphasis is being placed on areas such as regulators, communities of interest and the environment. Teck is one of the few companies in the world that has tied many of these elements together into a sustainability plan and published its set targets.

Thus, this options analysis will focus on Teck's sustainability areas and economics. This analysis, while tailored to Teck specific focus areas, is similar to Triple Bottom Line analysis (Dunphy, Griffiths and Benn 2007, p. 90). While economic and sustainability items can't typically be added and subtracted, the analysis will focus on a comparative ranking based on a hypothetical waste mine plan that would require the equivalent of 25 extra 240 ton haul trucks to determine the best path forward.

6.1 Teck Sustainability Analysis

Teck has six categories included in its Sustainability Objectives: Water, Energy, Material Stewardship, Communities, Biodiversity and Our People. Each focus area is impacted to a different extent by the options described below:

6.1.1 **Water**

Water is a very important resource to Teck and its operations. HVC uses an average of 12,500 cubic meters of water per hour in its mineral extraction process. Although HVC recycles all of its water, it is still reliant on inflow water to make up the balance that is lost to evaporation and ground seepage over its considerable footprint. If HVC runs short of water, the production of copper would be limited. Thus, reducing water consumption is an important goal.

For the three options, the conveyance of waste uses significantly less water. Using haul trucks requires watering the roads at specific intervals during dry conditions to limit the amount of fugitive dust created. The majority of this water evaporates after being sprayed onto the road.

For a conveyor system, no water is required and the installation of dust collectors at transfer points would minimize dust creation.

Although the use of ultra-class haul trucks in Option II would decrease the amount of water required, due to the decreased truck hours, the water consumption of this option is still significant. The estimated average annual water consumption of each option is shown in Table 6-1 (table by author, data from Teck, calculations in Appendix D). The totals only account for the additional waste transportation and not any other waste or ore transportation watering requirements.

Table 6-1 Total Water Consumption from Waste Transport

Option	Description	Estimated Yearly Water Consumption (cubic meters)
I	Increased 793 Haul Truck Fleet	521,050
II	Mixed Fleet With UC Trucks	270,946
III	IPCC System	0

6.1.2 **Energy**

Due to the considerable amount of energy that Teck Resources Ltd. consumes, energy use is one of the six key areas of Sustainability focus. Teck's 2015/2030 goals are to reduce the energy consumed in operations by 1000/6000 terra joules and its greenhouse gas emissions by 75/450 kilo tonnes CO2 equivalent respectively (Teck n.d.). HVC operations make up a considerable portion of Teck's overall energy consumption and, therefore, any significant reductions HVC makes will have a material impact on Teck achieving these goals.

In 2014, HVC consumed 930 giga-watt-hours of electricity and 55.7 million litres of diesel. The primary processes responsible for the consumption of this energy are the grinding of ore in the mill for electricity and the haulage of material in the mine for diesel. Hence, there is a significant difference between Options I, II and III in regards to the type and amount of energy consumed in primary processes.

Option III uses electricity to power all of its motors, whereas the haul trucks run on diesel fuel. In an IPCC system, the extra processing step of crushing consumes electricity. In the data presented, the efficiencies of conveying waste more than make up for the increase in consumption. Conveyance of bulk material is the most efficient method of transport; typically by a large margin (CEMA 1994, p. 15) (Gunthner, Tilke and Rakitsch n.d., p. 7). Zimmerman and Kruse state that haulage energy costs for conveyors could be 50% to 70% percent lower than those for haul truck transport (Zimmermann and Kruse 2006, p. 5).

The difference in efficiency is due to a number of factors. Most notably, haul truck transportation is discontinuous because 50% of truck travel is unloaded. Therefore, distance from loading point to dump point greatly affects haul truck capacity. Zimmerman and Kruse state that the capacity of a haul truck decreases by 50% when the haul distance increases from one to three kilometres. In comparison, distance has no effect on conveyor capacity, as they are continuous. Mines with 30 kilometre conveyors are not uncommon (Zimmermann and Kruse 2006, p. 4).

Further differences include the efficiency differences between diesel and electric motors. Diesel motors are currently limited to around 40% efficiency (Thiruvengadam, et al. 2014, p. 1) while premium efficiency electric motors have a current minimum mandated efficiency of 96% (US Department of Energy 2014).

Another significant difference is the weight of the equipment transporting the material. A CAT 793F haul truck has a payload of 227 metric tons and a gross vehicle weight of 390,089 kg (Caterpillar 2015). Thus, 42% of its energy is used to propel its own weight for any vertical distance. In comparison, the main moving component of a conveyor is the belt. An ST3500 belt weighs approximately 41.2 kilograms per meter squared (Applied Conveyor 2015). Therefore, a 1830mm wide belt of the same construction weighs 75.4 kilograms per meter. In one meter, the same belt can hold 645 kilograms of rock. Thus, only 10.5 percent of the conveyors' motor is required to propel the belt for any vertical distance (calculations by author, numbers by (Steven 2002)).

When comparing the options presented in section 5, significant differences in energy types and consumption are found. Option I consumes the most diesel with up to twenty-five extra haul trucks in operation, along with the necessary support equipment to keep the roads maintained. Option II consumes less diesel because the Ultra Class trucks will boost efficiency as they are able to haul more per load. Option III will considerably reduce diesel consumption, but electrical energy consumption will increase. However, given the efficiencies of conveyor systems in comparison to haulage trucks, the total energy consumed with Option III will still be much less. Since the majority of electricity supplied by BC Hydro comes from non-CO_2 generating sources (99.15% in 2013) (BC Hydro 2015), the shift from diesel to electricity consumption will also reduce CO_2 equivalent emissions. Table 6-2 (table by author, data from Teck) shows the differences between the options:

Table 6-2 Annual Waste Transportation Energy Consumption

Option	Description	Diesel (m liters)	CO_2 Equivalent Emissions (kt)	Electricity (GW*h)	Total Energy (GJ)	Total Energy Cost ($m)
I	Increased 793 Fleet	26.5	74	0	1,049,400	$32.2
II	Mixed Fleet With UC Trucks	23.8	66	0	942,480	$26.2
III	IPCC System	0	0.7	45.1	162,000	$2.3

Taking Option I as the "business as usual" case and comparing Option II and III, the reduction in total energy consumed is significant. The reduction in energy achieved by implementing the IPCC system would nearly equal Teck Resources Ltd's 2015 goals and account for 15% of Teck's 2030 goal. Similarly, the reduction in CO_2 equivalent emissions is substantial as the IPCC reduction is equivalent to 94% of Teck's 2015 goals and 16% of its 2030 goals.

6.1.3 **Material Stewardship**

Teck's focus area of Material Stewardship considers all aspects of Teck's production (Teck 2015). While the three options presented do not directly affect many of the Material Stewardship goals, some differences are apparent.

The most significant difference between the options is the maintenance requirements for parts replacement. Option I and, to a lesser extent, Option II include larger truck fleets which inevitably increases part replacements. On the other hand, Option III requires much lower part replacements. All of the systems' components cradle-to-cradle impacts (Lee and Bony 2009, p. 5) should be considered when analysing the difference between the three options. Therefore, Option III has a better material stewardship rating due to the reduced consumption of parts.

6.1.4 **Communities**

Teck and HVC have a considerable impact on the communities near which they operate . The communities of Logan Lake, Ashcroft, Merritt and Kamloops surround HVC and, in addition, HVC's land is within Nkala'pamux First Nation's traditional territory. The Nkala'pamux First Nation is comprised of 14 Indian Bands local to the area (British Columbia Assembly of First Nations 2015).

While HVC brings significant economic benefits to the region, members of the local Aboriginal communities have raised concerns about dust from haul truck operations and water consumption.

Although water consumption due to road watering was shown previously to have increased in recent years, fugitive dust from haul truck traffic remains a significant issue of concern. Thus, reducing the amount of truck haulage and including dust collectors at transfer points on conveyors in an IPCC system, would significantly reduce the amount of fugitive dust created.

6.1.5 **Biodiversity**

Teck's Biodiversity vision is to have a net positive impact on biodiversity by maintaining, or re-establishing, self-sustaining landscapes and ecosystems that lead to viable, diverse, long-term land uses in Teck operating areas (Teck Resources Ltd 2015). An IPCC system could potentially improve biodiversity at HVC by allowing a larger variety of plants to grow on its dumps. Typical dumps, although capped with overburden, have difficulties growing trees or shrubs. An IPCC system would create dumps with smaller particle sizes that may allow for trees and shrubs to grow more readily.

6.1.6 **Our People**

Teck's sustainability strategy for its people is to develop, retain and embed sustainability practices while decreasing the frequency and severity of safety incidents. Looking through this lens at the three options, there are considerable differences.

Option I and II include higher numbers of operating haul trucks. While safety systems and procedures will continually improve to help avoid incidents, studies have shown that 38% of fatalities in US mines and quarries are caused by powered haulage (Zimmermann and Kruse 2006). Thus, Option I, with the highest number of trucks, will have the highest risk of incident, followed by Option II and, lastly, Option III.

Similarly, due to the increased number of trucks, Option I and II will have the smallest chance of improving employees' awareness of sustainability practices. If chosen, Option III would enable HVC and Teck to celebrate the reduction in energy consumption and CO_2 equivalent production.

6.2 Economic Analysis

The economics of any project are always crucial for selection. There are a number of economic methods that can be used to analyse the options. In this analysis, I have compared and contrasted figures from such methods as Undiscounted Cash Flow (UDCF), Net Present Value (NPV), simple payback and others. All of the calculations exclude revenue, since the removal of waste material, while necessary, generates no revenue. Appendix E shows the consolidated calculations for operating, capital and total expenditures as well as the resulting NPV.

6.2.1 Undiscounted Cash Flow (UDCF)

Using today's dollars, UDCF estimates the total cash flow of each option, without including the time value of money. Table 6-3 shows the UDCF for the three options (table by author).

Table 6-3 Undiscounted Cash Flow of Options

Option	Description	UDCF ($m)
I	Increased 793 Fleet	$(1,224)
II	Mixed Fleet With UC Trucks	$(1,143)
III	IPCC System	$ (401)

The UDCF of Option III is considerably lower than the other options. This highlights the lower operational expenditures an IPCC system incurs over its lifetime.

Furthermore, the difference between the options is made even more significant by the fact that Option III has the highest asset depreciation costs, which aren't included in UDCF calculations.

6.2.2 **Net Present Value (NPV)**

The analysis of Net Present Value (NPV) is an important tool for selecting projects. NPV considers the time value of money and, thus, penalizes projects with large up-front costs or late cash flows. Table 6-4 shows the NPV for each of the options using a weighted average cost of capital (WACC) of 8% (table by author).

Table 6-4 Net Present Value (NPV) for Options

Option	Description	NPV ($m)
I	Increased 793 Fleet	$ (639)
II	Mixed Fleet With UC Trucks	$ (610)
III	IPCC System	$ (422)

Option III shows a $217m improvement in Net Present Value over Option I, in spite of its large upfront capital expenditures. The significant reduction in operating expenditures over the life of mine gives Option III the advantage over Options I and II.

In order to determine how the Weighted Average Cost of Capital (WACC) affects the difference between the three options, a sensitivity analysis was completed. Figure 7 shows the response of the options' Net Present Value to varying WACC's.

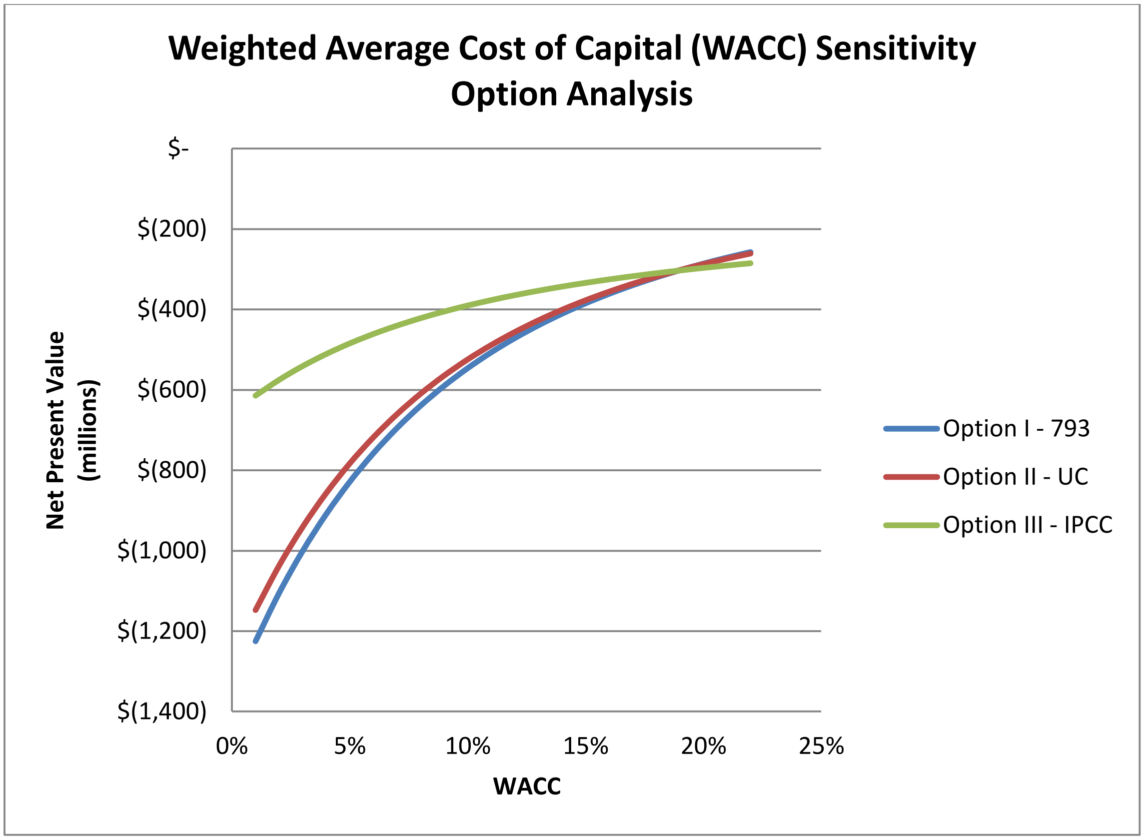


Figure 7 Weighted Average Cost of Capital Sensitivity Analysis (by Author)

As the chart shows, at a WACC of approximately 19%, the different options have nearly the same Net Present Value. After nineteen percent WACC, Options I & II continue to show a better NPV than Option III.

6.2.3 **Cost of Production**

The cost of production is a significant number for HVC and other mines. While it is inherently included within the other calculations, showing the differences between the options is important. Decreasing the cost of production allows the mine to operate profitably in times of low copper prices.

For the purposes of this calculation, the following table (table by author) shows the change in cost per pound of copper between Options I, II and III. The costs include operational expenditures and no capital or depreciation costs. As well, no costs from any other part of production are included. HVC's 2014 copper production of 121,000 tonnes (Teck Resources Ltd

2015) is used as a denominator and, therefore, future variances in copper production could positively or negatively affect these numbers.

Table 6-5 Options' additional cost to production

Option	Description	Min $/lb	Max $/lb
I	Increased 793 Fleet	$0.03	$0.25
II	Mixed Fleet With UC Trucks	$0.04	$0.23
III	IPCC System	$0.03	$0.03

Table 6-5 shows large differences in the minimum and maximum costs of the different options. Option I and II's costs increase with a mine plan that involves purchasing more trucks. Near the end of such a plan, the costs decrease again as waste hauling decreases and fewer trucks are required.

Option III's costs were assumed to stay constant throughout the mine plan. Although there will be variation in the early and late years of Option III due to the use of less power and fewer moving costs , this variation was disregarded for simplicity and contingency reasons. Consequently, full waste production has been calculated throughout the mine plan for this option.

It is significant that Option III offers a $0.22/lb cost reduction over Option I. Furthermore, Option III's costs are much less likely to rise as a result of increasing wages or diesel fuel prices.

6.2.4 **Capital Cost**

Capital costs of any project are always an important consideration. Deploying capital where it will bring the most value is the goal of corporations worldwide. Since Teck has numerous operations that all vie for capital, there is a limited amount that can be spent at any one operation. The total estimated capital costs for each option are shown in the table below (table by author).

Table 6-6 Capital Costs of Options

Option	Description	Capital Cost ($million)
I	Increased 793 Fleet	$ 169
II	Mixed Fleet With UC Trucks	$ 151
III	IPCC System	$ 265

As shown, there is a considerable difference between the options for total capital cost. Option III costs 57% more than Option I and the vast majority of capital expenditure for Option III comes at the start of the mine plan. In comparison, Options I and II spread their cash flows out as additional trucks are purchased to meet waste hauling requirements. However, Option II also includes earlier costs as a new shop and wash bay would have to be built immediately to service and clean the larger trucks as they will not fit in the existing facilities.

However, it is noteworthy that Option III's early and large capital expenditures will be a significant determinate in the selection process.

6.2.5 **Other Economic Criteria**

Other economic criteria that are of use in comparing the different options include simple payback and internal rate of return (IRR). Options I and II are similar enough that a comparative analysis between the two would be meaningless. Therefore, Table 6-7 shows the results from subtracting total cash flows of Option I against Option III (table by author).

Table 6-7 Comparative Analysis between Option III & I

Criteria	Amount
Payback	7 years
Internal Rate of Return	19%

The non-discounted payback of seven years compares well to a hypothetical study, done much earlier, regarding HVC, which showed a payback of four years (Radlowski 1988). Radlowski's analysis did not include the extra costs associated with crushers and stacker systems since his IPCC system only processed and transported ore.

7: Conclusion

The path to profitability for any mining operation is a challenging one. The pressures exerted on operations are continually changing and mining corporations need to adapt in order to continue mining profitably and providing maximum value to their shareholders.

Teck Resources Ltd., and its Highland Valley Copper operation, are not exempt from these challenges. Since large scale mining at Highland Valley first started in 1962, there have been enormous changes in the processes of mining and the perceptions and expectations of local communities towards mining.

In order to continue mining profitably, HVC must continue to look for ways to optimize and improve its operations. HVC must continue to build upon Teck's reputation as one of the most sustainable companies in North America and the world (Morrow 2014).

A process at HVC which has seen little optimization over the years is waste material transportation. Improvements to this process have been limited to larger electric rope shovels and haul trucks that have incrementally improved efficiency. By investigating and potentially adopting new strategies and processes for transporting waste, HVC would be one of the first operations in the world to adopt a different strategy than the standard shovel and truck.

However, a complete analysis must be done to determine whether change should occur and what form it should take. Since HVC is subject to different pressures and restrictions than other mines around the world, the optimal solution at another mine may not be the best one for HVC. Thus, the analysis must be tailored to HVC's unique set of operating conditions.

Through its history, HVC has moved a significant amount of waste. Future mine plans show that waste transportation requirements will increase which will negatively impact profits. Considering the fact that haulage costs are typically fifty percent of a mines' overall cost (Zimmermann and Kruse 2006), there is a clear incentive to improve current processes.

In order to analyze HVC's options, a hypothetical twenty year mine plan was created that required up to an additional equivalent of 25 of HVC's existing CAT 793 haul trucks. This option formed the base case of "Option I – Increased 793 Fleet". The second option analyzed was the addition of 13 Ultra Class (400 ton) trucks and was named "Option II – Mixed Fleet with

UC Trucks”. Lastly, the option of In-pit Crushing and Conveying (IPCC) was analyzed and was named “Option III – IPCC System.

Each option was comparatively analyzed using a number of sustainable and economic criteria. The sustainable items were based on Teck’s Sustainability Focus Areas: Energy, Water, Material Stewardship, Communities, Biodiversity and Our People. Economic criteria for analysis included: Undiscounted Cash Flow, Net Present Value, cost of production and capital costs.

Table 7-1 summarizes a comparative analysis of the options on the sustainability focus areas. On a scale of one to five, lower numbers indicate a poorer comparative score, while higher numbers indicate a better score(table by author).

Table 7-1 Comparative Sustainability Option Ranking

Sustainability Area 1=much lower 5= much higher	I – Increased 793 Fleet	II – Mixed Fleet With UC trucks	III – IPCC system
Water	1	2	5
Energy	1	1	5
Material Stewardship	2	3	4
Communities	3	3	4
Biodiversity	3	3	3
Our People	3	3	3

Option III is clearly superior in regards to Water and Energy, while leading by smaller margins in Material Stewardship and Communities. Significant advantages offered by Option III include: close to one terra joule per year of energy savings, seventy one kilo tonnes less CO_2 equivalent emission and four million cubic meters of water savings at peak production. If implemented, Option III would singlehandedly meet nearly all of Teck’s 2015 energy and GHG targets. Option III was ranked slightly higher in material stewardship as less replacement parts are required. Option III is also slightly better in the Communities area because it would reduce fugitive dust and water consumption, both of which are significant concerns of the community.

Biodiversity and Our People rank very similarly. Option I would include higher employment numbers but the resulting increase in haul truck traffic would increase risks of haul truck interactions thus potentially reducing overall site safety. Option II, with less haul trucks, would have lower employment numbers than Option I but would be slightly safer given the lower risk of haul truck interactions. Option III would include the lowest number of employees but, with no additional haul trucks, would be the safest.

Table 7-2 ranks the different economic criteria in a similar manner to table 7-1 (table by author).

Table 7-2 Comparative Economic Option Ranking

Economic Criteria 1=much lower 5= much higher	I – Increased 793 Fleet	II – Mixed Fleet With UC trucks	III – IPCC system
Undiscounted Cash Flow	1	1	4
Net Present Value	3	3	4
Cost of Production	2	3	5
Capital Expenditure	3	4	2

Option III performs significantly better in Undiscounted Cash Flow and Cost of Production criteria than the other options. However, Option III's capital expenditure ranks lower. Net Present Value is closer but, again, Option III ranks better than Options I and II.

There are a number of other factors that need to be considered when analyzing the available options. Option III significantly reduces mine planning flexibility by limiting where and when waste transportation is feasible. Mine planning around infrastructure that isn't fully mobile creates extra challenges (Independent Mining Consultants, Inc. 1985). Option III would also have no redundancy, whereas Options I and II can operate at a reduced rate if one or more haul trucks have unscheduled downtime.

While Option III is at greater risk of project cost overruns, Options I and II have considerably more component, labor and fuel escalation risks. Another unknown risk for Options I and II is future increases to British Columbia's carbon tax, or any another carbon pricing scheme that is enacted.

Considering all of these rankings, risks and potential issues, Option III is clearly the best choice. It has significant sustainability and economic advantages over Options I and II. However, there are a number of criteria that must be met to ensure that Option III is the best course of action for HVC.

First and foremost, Teck must have the available capital funds to invest in this project. While supplier or third party financing may be an option, it would likely have a negative impact on the project's economics.

Secondly, a number of mining parameters must be met. The mine plan must be long enough to ensure that the returns outweigh the risk of an earlier closure. Option III would likely not be feasible with a mine plan of less than twelve years.

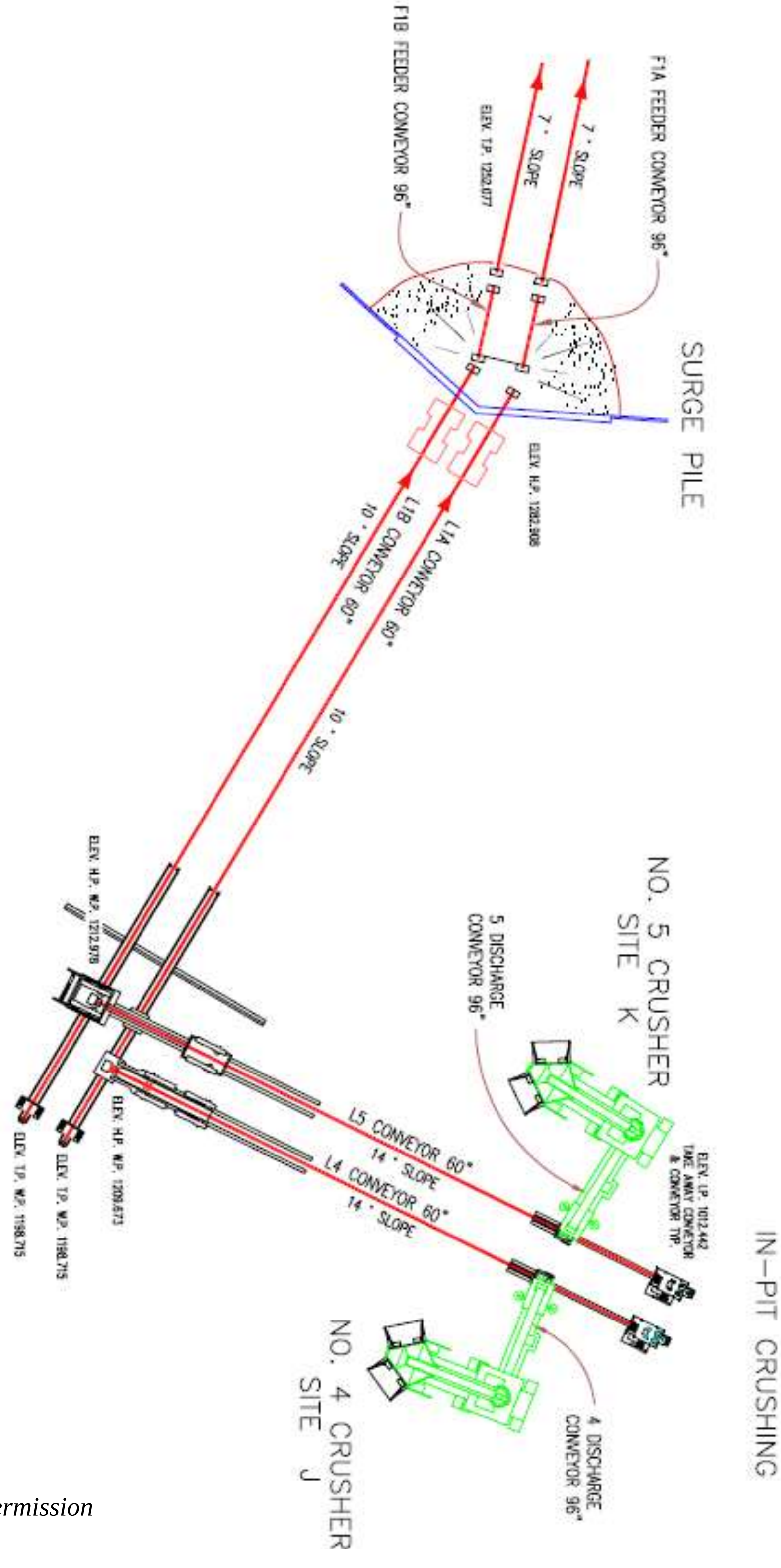
Thirdly, it would be preferable that the mine plan allow all waste to go to one dump so as to limit extended downtime associated with costly moves.

Finally, the haul distance must be of reasonable length and include elevation gain to reap the efficiency gains of the use of conveyors versus haul trucks (Radlowski 1988).

In conclusion, the advantage of using an IPCC system for waste transportation at Highland Valley Copper presents significant benefits and its implementation should be given serious consideration.

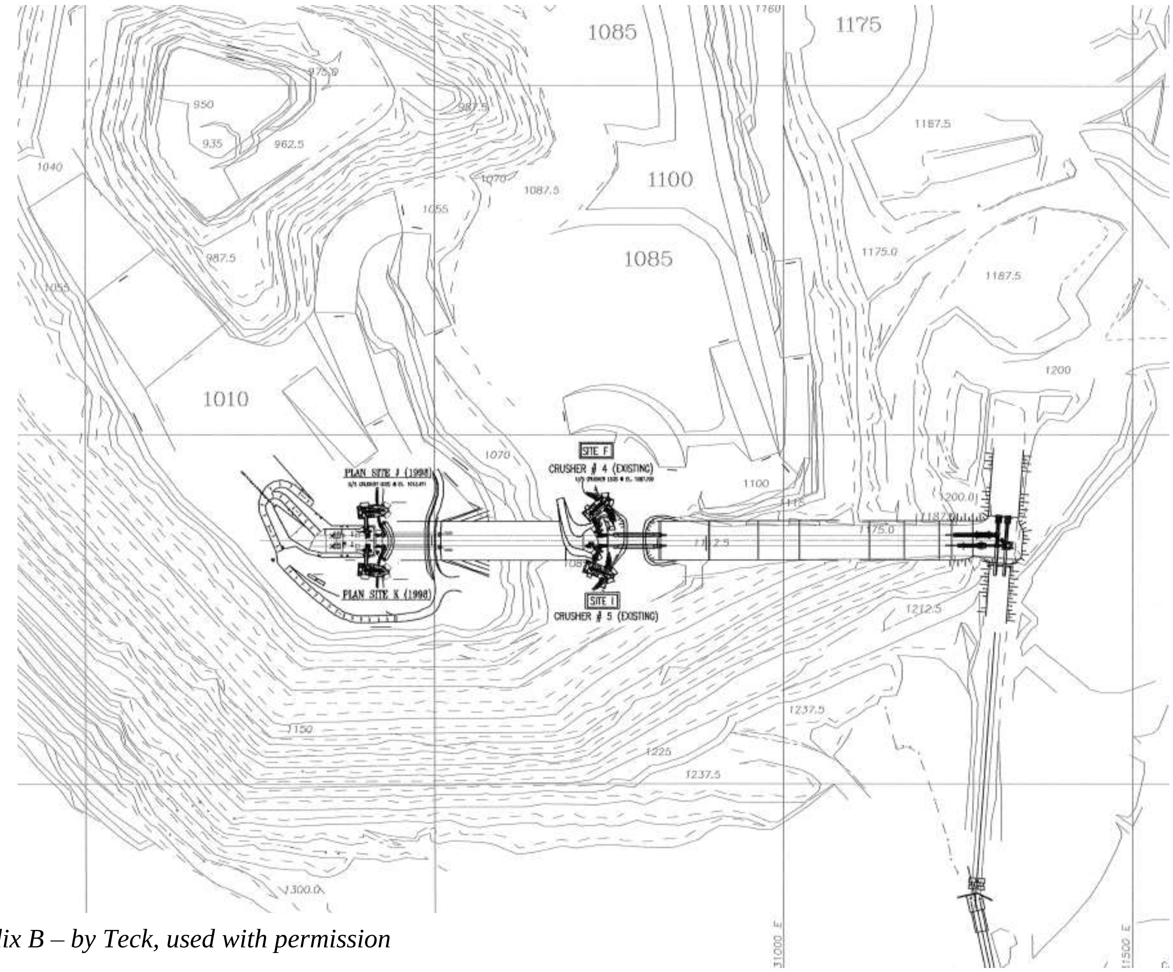
Appendices

Appendix A Crusher 4 & 5 and Conveyor Belt Layout – 1992



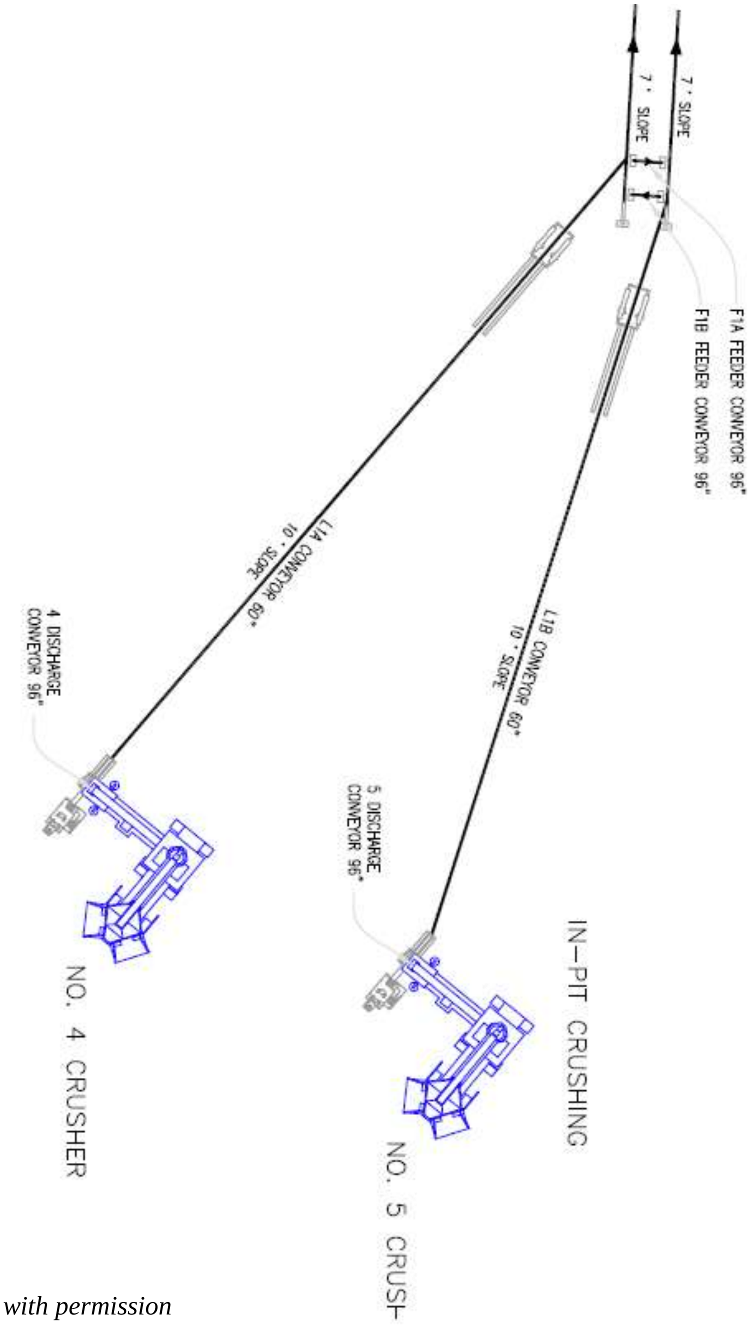
Appendix A – by Teck, used with permission

Appendix B Crusher 4 & 5 Moves - 1998



Appendix B – by Teck, used with permission

Appendix C Crusher 4 & 5 and Conveyor Belt Layout - 2015



Appendix C – by Teck, used with permission

Appendix D Water Consumption from Haul Truck Road Watering

	CAT 789	**CAT 793**	**Total**
Water truck hours per year (2014)	2,452	4,710	**7,162**
Hourly water consumption (m3/hr)	100	133	
Yearly water consumption (m3)	245,200	626,430	**871,630**
Consumption associated with waste (m3)			**521,050**
Ultra Class truck estimated consumption (m3)			**270,946**

Appendix E Economic Analysis

Year	0	1	2	3	4	5	6	7	8	9	10
793 Trucks	3	6	9	12	15	20	25	25	25	25	25
Total OpEx	$ 8,109,231	$ 16,218,462	$ 24,327,692	$ 32,436,923	$ 40,546,154	$ 54,061,538	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 67,576,923
Total CapEx	$ 15,400,000	$ 17,800,000	$ 44,400,000	$ 14,400,000	$ 17,400,000	$ 25,000,000	$ 24,000,000	$ 3,000,000	$ -	$ -	$ 4,000,000
Total Cashflow	$ 23,509,231	$ 34,738,462	$ 70,167,692	$ 51,092,511	$ 62,921,742	$ 85,132,127	$ 98,847,511	$ 78,826,923	$ 76,201,923	$ 76,201,923	$ 80,201,923
NPV (@8%)	$ (639,441,904)										
Ultra Class Trucks	2	4	5	7	9	12	13	13	13	13	13
Total OpEx	$ 9,358,546	$ 18,717,091	$ 23,396,364	$ 32,754,909	$ 42,113,455	$ 56,151,273	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 60,830,546
Total CapEx	$ 55,200,000	$ 17,400,000	$ 7,000,000	$ 14,000,000	$ 17,000,000	$ 22,000,000	$ 7,000,000	$ 3,000,000	$ -	$ -	$ 4,000,000
Total Cashflow	$ 64,558,546	$ 56,592,091	$ 41,350,311	$ 65,058,857	$ 81,117,402	$ 106,230,221	$ 81,959,493	$ 74,309,493	$ 68,684,493	$ 68,059,493	$ 76,059,493
NPV (@8%)	$ (674,584,219)										
IPCC System											
Total OpEx	$ -	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400
Total CapEx	$ 258,461,000	$ -	$ -	$ -	$ -	$ 2,000,000	$ -	$ -	$ -	$ -	$ 2,000,000
Total Cashflow	$ 258,461,000	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 21,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 21,759,450
NPV (@8%)	$ (421,648,361)										

Year	11	12	13	14	15	16	17	18	19	20
793 Trucks	25	25	25	25	25	25	20	15	10	5
Total OpEx	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 67,576,923	$ 54,061,538	$ 40,546,154	$ 27,030,769	$ 13,515,385
Total CapEx	$ -	$ -	$ 3,000,000	$ -	$ 1,000,000	$ -	$ -	$ -	$ -	$ -
Total Cashflow	$ 75,951,923	$ 75,951,923	$ 78,576,923	$ 75,951,923	$ 76,951,923	$ 75,576,923	$ 62,061,538	$ 48,546,154	$ 34,655,769	$ 21,140,385
NPV (@8%)										
Ultra Class Trucks	13	13	13	13	13	13	12	9	6	3
Total OpEx	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 60,830,546	$ 56,151,273	$ 42,113,455	$ 28,075,637	$ 14,037,818
Total CapEx	$ -	$ -	$ 3,000,000	$ -	$ 1,000,000	$ -	$ -	$ -	$ -	$ -
Total Cashflow	$ 68,434,493	$ 68,434,493	$ 74,059,493	$ 68,434,493	$ 70,434,493	$ 68,059,493	$ 63,380,221	$ 49,342,402	$ 34,929,584	$ 20,891,766
NPV (@8%)										
IPCC System										
Total OpEx	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400	$ 6,836,400
Total CapEx	$ -	$ -	$ -	$ -	$ 2,000,000	$ -	$ -	$ -	$ -	$ -
Total Cashflow	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 21,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450	$ 19,759,450
NPV (@8%)										

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