Plan vs Actual: A Comparison of Electric Haulage Truck Charge Bay Locations

Abstract

The Brucejack mine in Northern British Columbia, Canada, is an underground gold mine utilizing a long-hole stoping mining method. Haulage is executed using a fleet that includes both diesel and electric haul trucks; stope haulage is exclusively electric and development rounds utilize a blended fleet.

This paper presents a case study on the design and implementation of charging infrastructure for the mine's fleet, with a particular focus on the integration of Sandvik (formerly Artisan) Z50 Electric Haul Trucks.

Initial planning relied on a simulation model that forecast charging needs and optimized fleet sizes over a ten-year period (2022-2033). However, several unforeseen challenges led to deviations from the original layout, including power availability, geotechnical constraints, and operational considerations related to battery management.

This paper highlights key factors that influenced the final design and location of each charge bay, including the misalignment between electrical plan and project requirements, unexpected geotechnical challenges, and the underestimation of necessary infrastructure. Additionally, it addresses the learning curve associated with adopting new technology at scale, including the benefits and limitations of battery electric vehicles and the support provided by Artisan before Sandvik's Site Readiness documents were established. As the project evolved, adjustments were made to accommodate additional charge bays, ensure operational efficiency, and ensure full compliance with safety standards.

These findings underscore the importance of thorough mine planning, flexibility in implementation, and continuous feedback loops in adapting new technologies in mining operations. The evolving design solutions at Brucejack illustrate the complexities of scaling electric vehicle infrastructure in an underground mining environment, with implications for future projects aiming to integrate electric haulage systems.

"**Disclaimer:** ***This paper documents project-specific challenges and solutions and is not intended as an assessment of performance or capabilities.***"

Introduction

The Brucejack mine is an underground gold mine located in Northern British Columbia, Canada. Temperatures range from -20° to +20°C on surface, and +3° to 25°C underground, with up to 20 metres of snowfall in the winter. The mine uses a long-hole stoping method, with an average of 3,000 – 4,000 tpd of ore processed. Materials are trucked from the stope location to a central tipping point at the underground crusher and then conveyed to surface.

The mine extends from 1500 masl to 960 masl with a central ramp connecting each level. A satellite zone (West Zone, WZ) is connected underground but does not yet support stoping activities. The fleet of interest includes eight Sandvik Z50 Electric Haul Trucks (Z50) – this is a

50 Tonne Battery Electric Haul Truck, and the predecessor to Sandvik's TH550B Trucks. The first truck arrived on site in October 2020, with subsequent trucks arriving approximately every 4-5 months. Charge bays were added to support the arrival of each addition to the fleet.

Planned Design and Layout

Brucejack mine conducted a simulation study to better understand the optimal layout of charging infrastructure to support implementation of a fully-electric haulage fleet. This study focused on establishing the haulage profile as per the mine plan and develop a duty cycle which would anticipate battery discharge rates. The study identified the location of charging infrastructure and optimized the fleet size to meet production demands.

An Arena model was created based on production planning from 2021 to 2033. The modelling also selected four locations for the charge bays, noting that the highest trafficked area may require more than one charge bay. The model also calculated battery swaps at each location for periods covering 2022 – 2027. Battery swapping locations were selected based on the highest travelled areas with secondary bays slightly lower in the mine to reduce the risk of running out of battery charge on lower levels. The planned layout is shown in Figure 1.

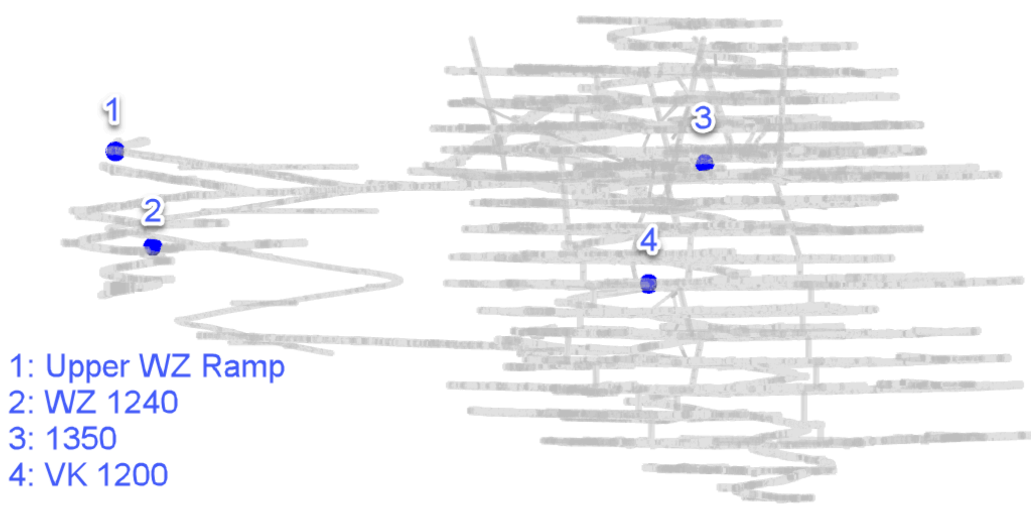

Figure 1. Cross-section of Brucejack Mine showing Planned Charge Bay locations.

The methodology proposed in the planned layout was for multiple bays in the same vicinity on the 1350L to increase the charge time available for these batteries. Charge bay designs were provided by Artisan Mining, prior to Sandvik's takeover of the company. Documentation provided at the time required 2 x 600V at 200A connections and explicitly stated that overhead cranes, concrete pads (only level ground), and ventilation ducting (for shallow configurations) were not required, while cooling cubes were not initially required. Operational experience would subsequently dictate otherwise.

Actual Layout

Decisions related to the actual charge bay location were revisited and subsequently reconsidered with each successive charge bay – based on the Z50 truck delivery schedule to site. The actual location of bays is shown in Figure 2. There were a series of unpredicted considerations that caused deviation from the initial plan, listed below.

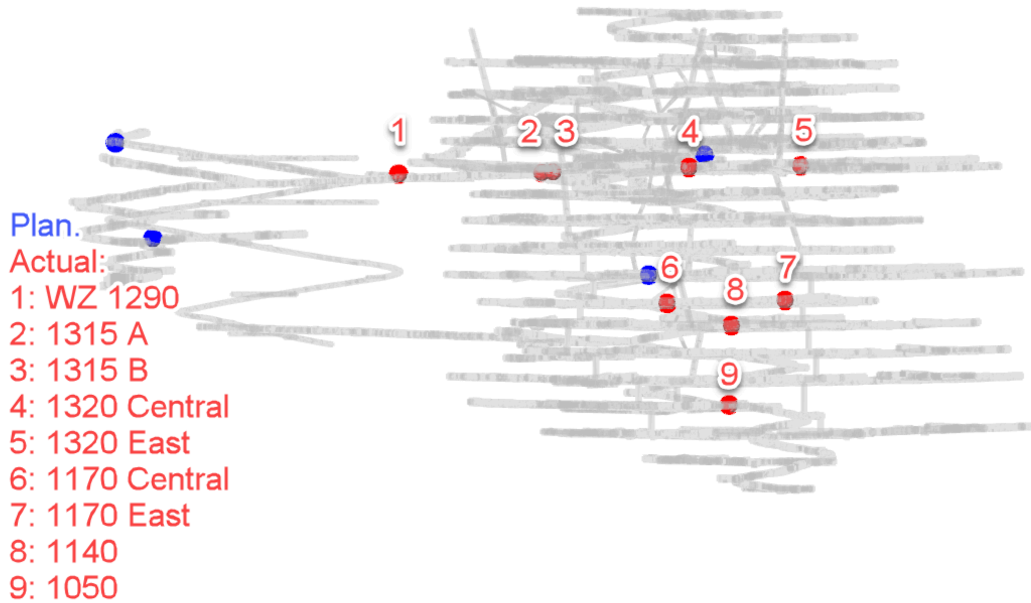

Figure 2. Cross-section of Brucejack Mine showing Actual Charge Bay locations.

1. **Available Power, and a disconnected LOM electrical plan**

The electrical plan associated with the life of mine (LOM) plan, and Z50 adoption were not appropriately coupled. While substations were ordered in advance – as required for level development and charge bay needs – their placement and capacity were not in the Z50 project charter, and locations were not cemented into the LOMP for capital infrastructure and location designation.

Further, a misjudged assumption on charge bay design costs required plans to be enacted, which reduced capital by utilizing existing development.

Brucejack does not have a high ambient temperature (3°C to 25°C), but the batteries still require supplemental cooling. The original project charter also underestimated the capital development required for the charge bay design and additional cables required to connect the charge bays to the load center.

Geotechnical support (cable bolts) for the span were also underbudgeted.

2. **Limited Charge Bay Detailed Design Work**

In areas that were operationally ideal, faulting or general poor ground made it prohibitively expensive or potentially dangerous to excavate a wider span. When designing charge bays onsite, the spans were supported with densely spaced cable bolts, per the instructions of onsite geotechnical engineers.

Original design layout plans are shown in Figure 3, and the actual designs in Figure 4. As you can see, the design vs. actual were different.

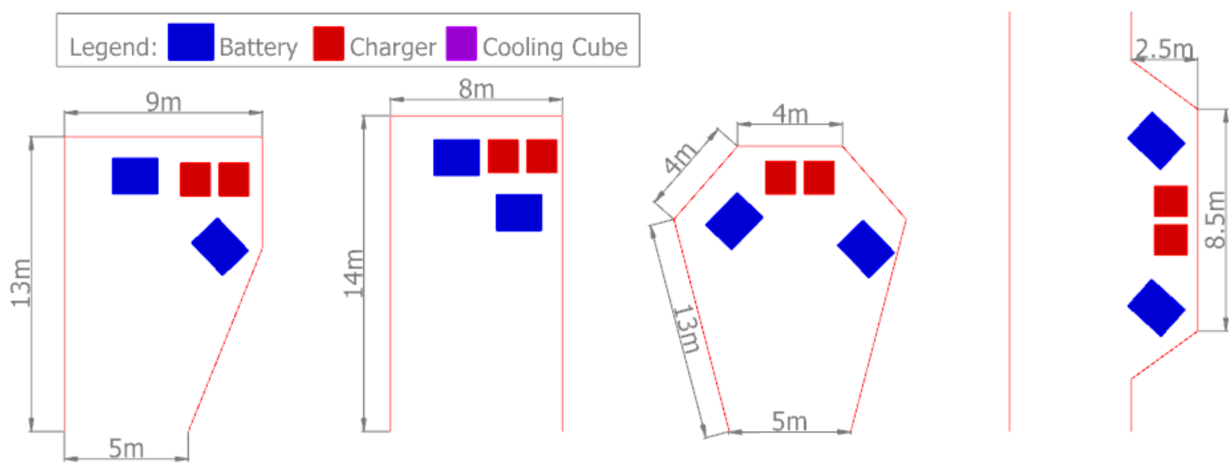

Figure 3. Initially Planned Charge Bay General Layout Arrangements (Plan View)

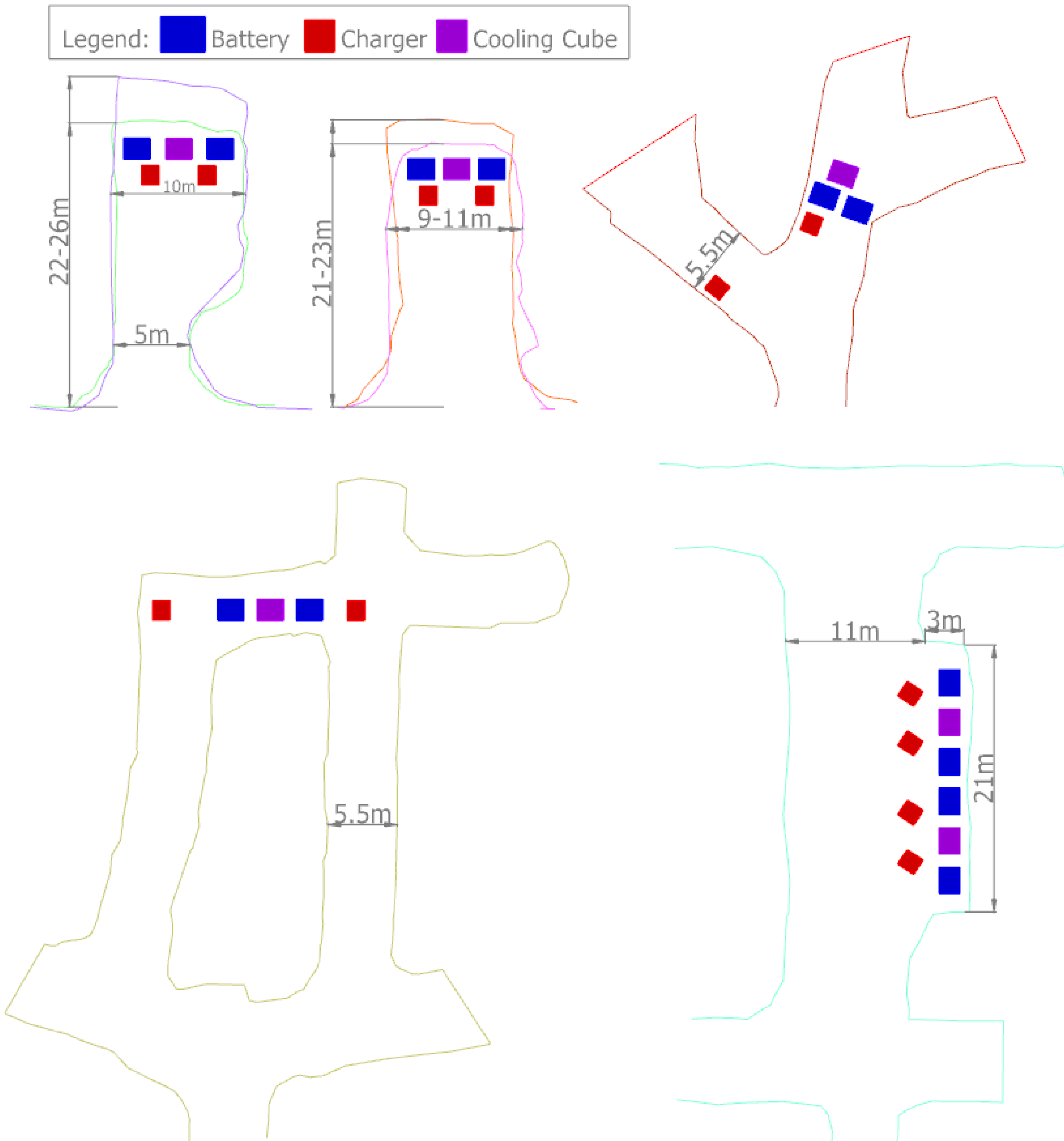

Figure 4. Actual Charge Bay Design Layouts (Plan View)

3. **Adding Charging Bays in the lower part of the Brucejack Mine**

The original plan called for a single charging bay to provide a back-up for operators on 1200 Level who did not have sufficient battery life to make a loaded trip from the bottom of the mine to the tipple.

When making the decision on subsequent bays, additional charging bays were installed to ensure that operators had numerous options to recharge in the lower mine. Detailed battery management planning for trucks was largely an unknown at the time of design, and on-site operator concerns centred around trucks hauling from the lowest parts of the mine - requiring additional charging bays. The prudence of this concern is difficult to measure because operators rarely to never run-out of battery power.

For battery management planning, trucks are assigned to a dedicated charge bay. This is handled on a shift-by-shift basis by utilizing trucks associated with charge bays nearest to the area the truck will be working. However, given the spread of the mine and the charge bays, there are instances whereby a truck will have to make an empty trip to charge batteries. This encouraged spacing bays throughout the mine to function as regional chargers for those stopes but the use of 2-4 trucks per stope results in trucks travelling farther to change batteries, adding to the cycle time. This problem is addressed through a program to hot-swap batteries by way of a dispatcher, who can direct trucks to the nearest fully charged battery and obtain additional rigour and oversight on the process to drive efficiency.

The addition of charge bays in the lower mine was also driven by a lack of available areas in the center to place them. Part of this is due to the density of stopes in this area, while part is restricted by a lack of high-density orebody definition at a granular level. Additional definition drilling is required to confirm an area is uneconomic to mine before fixed infrastructure is installed. Drilling focus focuses on expanding the resource in high potential areas. This added to charge bay placement locations because it is limited to areas that are confirmed to be uneconomical.

The 1350 level was excavated prior to the Z50 plan, and charge bay locations were not excavated at the same time as the original development. Part of this was the result of definition drilling demand limiting the opportunity to drill “condemnation holes” in planned charge bay locations.

Another issue was the favourable results of these drill holes. This reconciled itself in creative solutions, such as drilling service holes between levels connecting planned substations that had capacity, with the charge bays on other levels.

Matching charge rates to battery draw rates have proven inconclusive as it is primarily dependent on external factors such as: delays along trucking route, positioning of charge bay vs stope vs distance to dump point, and payload variability.

Typical shifts average two battery swaps per truck per 10-hour shift.

4. **Revising Existing Mine Designs to Incorporate Charge Bays and Larger Trucks.**

Original charge bay designs were situated near the footwall drive, however positive ore results brought stoping to the intersection in most areas. Therefore, charge bays were situated farther into levels, increasing the time needed for battery swaps.

The Z50 adoption also required an expansion in drift widths, from 4.5m x 4.5m to 5.5m x 5.5m averages, while retaining the smaller AD30s for historical areas. Truck load-out height also increased to 6.5m. These challenges are associated with the upgrade in any equipment and have caused minimal issues during transition.

The most challenging operational and design issue present involves truck dumping locations, which requires a 7m high back to safely accommodate the 6.52m bed height. Ore-surge remucks at the crusher were expanded by benching, without water flooding issues. On-level remucks have proven more difficult to plan because the location needed for underground waste dumped from trucks is often sporadic. This has reduced the efficiency of underground waste deposition but not halted it.

5. Project Management

In order for the charge bay design implementation to be successful , a structured project management approach is required:

- **A dedicated Projects Manager** to oversee planning, funding allocation, and long-term infrastructure development.
- **Comprehensive feasibility studies** and pilot implementations before full-scale deployment.
- **A clear governance structure** to ensure that all technical, financial, and operational considerations were addressed in advance.
- **Proactive stakeholder engagement** to align engineering, operations, and finance teams from the start.
- **Robust training and knowledge transfer programs** to ensure that personnel understood system capabilities and limitations.

6. Early Adopters of a Pioneering Technology.

As an early adopter of this technology, Brucejack served as an initial location for the Z50 development. The known and unknowns contributed to the challenge of adopting trucks and charge bays into the mine plan. This manifested itself in an under-estimated capital budget for the charge bays; resulting in increased scrutiny of infrastructure in each charge bay; resulting in necessary cuts or cheaper alternatives to adhere to the wider operational budget.

Battery performance in-field also remained an area that required large-scale onsite testing that only full deployment could achieve. An example of this is early trucks driving loops on a level to dissipate newly charged batteries before they could proceed down-ramp, ultimately solved by identifying which bays would need to under-charge their batteries to allow for regeneration on downhill travel.

Another unexpected challenge is the lack of external monitoring of battery charge percentages. Occasionally, operators would fail to properly connect batteries, or internal faults would trip the charger and stop battery charging. When operators returned to swap batteries, they would need to re-plug the battery, before waiting hours for the tripped battery to charge. Currently, external monitoring from a control room is unavailable but Sandvik is working with clients on providing a solution to provide better visibility on battery metrics.

The performance of trucks were estimated for the initial justification to adopt the technology but these were theoretical and supported by environmental, government grant incentives, and health and safety improvements. When the outgoing fleet of Caterpillar AD30 trucks were compared to the incoming fleet of Z50's, Brucejack realized a 64% t*km increase. This efficiency gain has reaffirmed the decision to upgrade the fleet to electric options.

Actual Design Requirements

The first bays were designed based on the input and advice of the original equipment manufacturer, Artisan with minimum accessories. In the three years since Sandvik's acquisition of Artisan, the suggested requirements have increased to include:

- Ventilation – preferably in a return airway in case of unlikely battery cell-venting
- Relatively dry and dust free areas
- Cable covers or festoons – alongside cranes for cable and operator safety
- Concrete floors for reduced maintenance and improved operator safety
- Drift dimensions 2m wider than previously recommended (10m vs 8m)
- Shotcrete charging area back over entire charging area
-

The additional accessories have merit as the alternatives have actualized damage and incidents.

There have been limited reports of operator strain due to cable management without the mechanical advantage of a crane or festoon to move cables between batteries. Improper cable management has also lead to batteries being lowered onto cables. The uneven ground of crushed rock, in lieu of concrete floors, have caused damage to the battery lifting arms. The presence of water, deflected by tarps, have not caused measurable damage to the charging units but a dry area is preferable. No incidents related to battery cell-venting have occurred on site but given the magnitude of this risk, it is understandable to incorporate ventilation planning in charge bay design.

The design-build-review cycle of charge bays at Brucejack has evolved, and now the bays reflect the design requirements detailed by Sandvik, which were developed based on the learnings at Brucejack.

The layout differences of each bay also come with positives and negatives - there are opportunities to improve safety, cost, maintenance, and productivity in the current designs. In retrospect, a centralized charging area with all batteries - save for a singular low-mine backup - would be more operationally effective. Looking forward, the site is evaluating mobile charge bays to improve flexibility and adaptability to a changing mine plan.

Conclusion

The integration of electric haul trucks at the mine has proven to be both a challenging and rewarding process, underscoring the complexities of implementing new technologies in underground mining operations.

The initial charging infrastructure design, based on a predictive model and assumptions made early in the project, encountered several unexpected obstacles, including misaligned electrical planning, unforeseen geotechnical constraints, and a lack of detailed manufacturer specifications. These challenges led to deviations from the original plan, requiring adaptive strategies and ongoing design modifications.

Despite these setbacks, the project has provided valuable insights into requirements and limitations of electric vehicle infrastructure in the mining sector. The addition of multiple charging bays, the reassessment of battery management protocols, and the continuous refinement of design criteria have resulted in a more resilient and efficient charging system. Importantly, the lessons learned highlight the need for close collaboration between equipment manufacturers, mine planners, and project managers to ensure that infrastructure requirements are fully understood and integrated from the outset.

The Brucejack experience serves as a case study for future underground mining projects adopting electric haulage systems, emphasizing the importance of thorough planning, flexibility in execution, and ongoing project management to address the evolving challenges of ambitious technological transitions. As the mining industry continues to move toward sustainable, electrified solutions, the insights gained at Brucejack will be invaluable in shaping the future of underground electric vehicle infrastructure.