LOADING SIMULATION - PASS MATCH CALCULATION

MOTIVATION

Mining companies may find that newly purchased equipment is not meeting their production goals. It is an exciting time to receive new equipment at a mining operation. It is disappointing and costly to discover that the equipment is mismatched. Mismatched equipment selection causes time and money losses from efficiency and productivity losses. Mining equipment such as trucks and loaders are typically matched using a simple pass match calculation approach. Several gaps are created with this simple calculation by variables that are not included. This could cause mines to fall short on expected payload capacities as a result of incorrect equipment selection.

The current approach to pass match calculation is a simple division using published values. Pass match value is defined as the ratio of the volume left on the dumpbody after loading is finished divided by the volume in each bucket load used for the loading. These published values are typically based on standards, such as the SAE 2:1 volume for truck dumpbodies, and heaped shape volumes with a 2:1 slope for buckets.

Loading simulation closes the gaps left by standard pass match calculation. It takes into account the critical mine application and material variables, and produces more realistic volumes for a loading tool (e.g. bucket) and dumpbody.

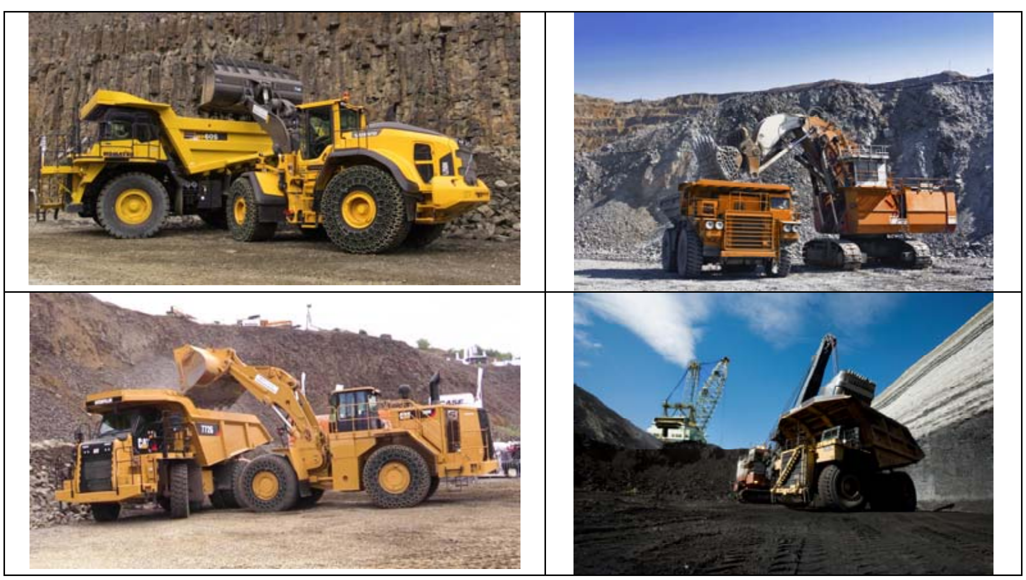

Figure 1 Truck/loader options of the same class (left) and different configurations (right)

Loading Simulation benefits for Mine Companies include:

- Improve mine operation efficiency with proper equipment selection and matches.
- Improve productivity with accurate capacity calculations for the material being loaded and hauled.
- Applicable to new and replacement dumpbodies and buckets.
- Decrease costs through discovery of solutions for existing mismatched equipment by simulation of added sideboards and/or tailgates.
- Include mine site and application factors for material loss due to grades, turns and other hauling events.

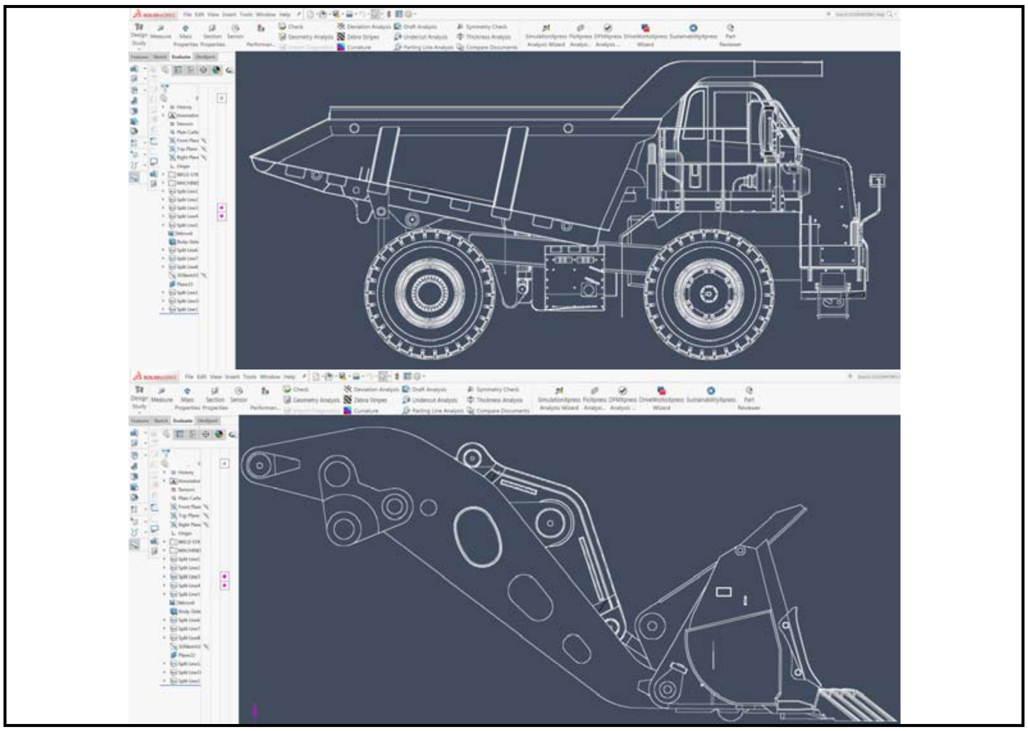

Figure 2 Design of truck body and loader bucket

Loading Simulation benefits for equipment manufacturers include:

- Application and site specific equipment design.
- Development of buckets, dumpbodies and other related equipment.

MATERIAL PROPERTIES CALIBRATION

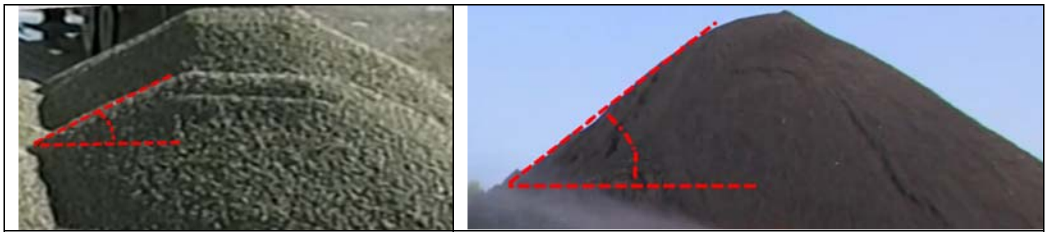

Figure 3Angle of Repose of Different Materials

Calibration of the material properties is an important part of the simulation process. Basic properties such as density and angle of repose are gathered from the material(s) to be mined. The spectrum of mined materials varies significantly and have a wide range of angle of repose that range from 15deg to 45deg. Calibrated material properties include:

- Particle size distribution.
- Bulk density.
- Angle of repose.

CASE STUDY

A comparison between standard Simple Pass Match calculation and new Loading Simulation is performed. Results documented below illustrate where significant gaps exist between the standard calculation and new simulation methods. A front wheel loader bucket and dumpbody design geometry are selected for this case study. The same geometries are used in both Simple Pass Match calculation and Loading Simulation.

SIMPLE PASS MATCH CALCULATION

The simple pass match calculation is obtained by:

$$Pass\ Match\ Ratio = \frac{VOLUME\ of\ SAE\ 2:1\ Dumpbody}{Number\ of\ Passes \times VOLUME\ of\ Heap\ 2:1\ Bucket}$$

Published volumes often found in equipment spec-sheets are typically used in this formula, and are obtained from a standardized SAE 2:1 dumpbody pile shape. The dumpbody SAE 2:1 volume is 29.6[m^3] and the bucket SAE Heap2:1 volume is 4.268[m^3]. This results in a pass match value of 6.94. The Simple Pass Match calculation shows that 7 passes of the wheel loader bucket are needed to fill the dumpbody. This might look like a good pass match result, but the simplified calculations have often resulted in a mismatch discovered after the equipment is put in service at the mine site application. After the Loading Simulation results are shown, we will compare results and show the differences. Comparison of standard calculations to realistic loading simulation illustrates the gaps where a mismatch in equipment selection can occur.

Sources of error for this standard calculation include:

- Use of a generalized standard to define material volumes for both bucket and dumpbody.
- Typically limited to SAE 2:1 published values.
- Underfill/Overfill considerations are neglected.

PILE CREATION FOR LOADING SIMULATION

Prior to performance of Loading Simulation is the creation of one or more piles needed for use in the simulations. We have created two piles for this case study. A Heaped 2:1 Pile and a Scooped Pile. The Heaped 2:1 Pile is similar to the standard calculated pile for the bucket geometry. We will show the difference in dumpbody load capacity of the Heaped 2:1 pile relative to the standard hand calculations. The second pile is called a Scooped Pile. It is created from a simulated dig which produces a more realistic bucket load. We will also show the relative difference between the resultant dumpbody capacity loaded with the Scooped Pile.

HEAPED 2:1 PILE

A simulated Heaped2:1 pile is created for this case study to expose a gap in resultant dumpbody load where the same bucket load volume is used as input into the Simple Pass Match calculation and Loading Simulation. The Heaped2:1 pile is created by filling the bucket with material with 2:1 slope planes that shape the top of the heap to match the bucket SAE Heap 2:1 Standard published capacity. The Heaped2:1 pile is illustrated in Figure 4.

Figure 4 Bucket pile with heap 2:1 shape

SCOOPED PILE

The Scooped Pile is created by driving the bucket into a large pile of material particles. The kinematics of the loader are used to simulate the actual motion of the bucket. This motion includes bucket translation and rotation. After a dig cycle is completed and the bucket pile has settled, the resultant bucket pile is used as an input for the loading simulation. This bucket pile is a realistic volume of material that we call a Scooped Pile.

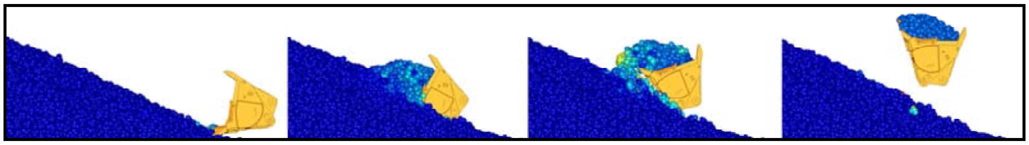

Figure 5 Bucket loading simulation

The settled Scooped Pile is shown in detail in the figure 6 below:

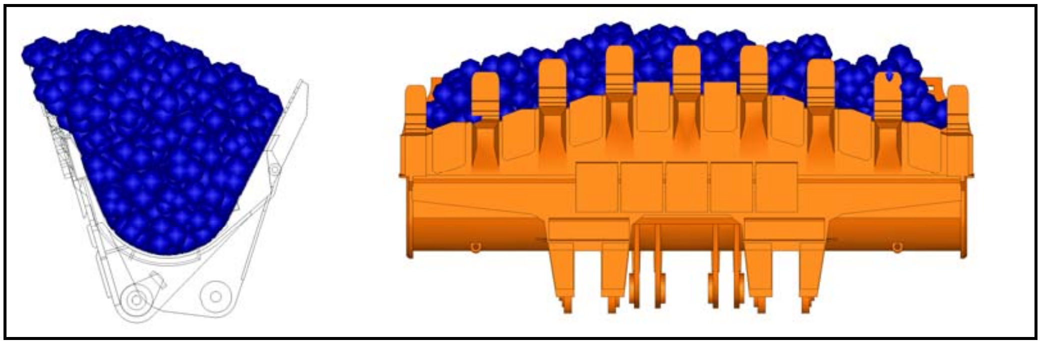

Figure 6 Scooped pile after bucket loading

Figure 7 shows a comparison of the Heaped 2:1 (yellow bucket on the left) and the Scooped Pile (orange bucket on the right). The center bucket shows each of these piles overlaid for direct comparison. The Scooped Pile has 54.9% more volume of material relative to the Heaped 2:1 pile.

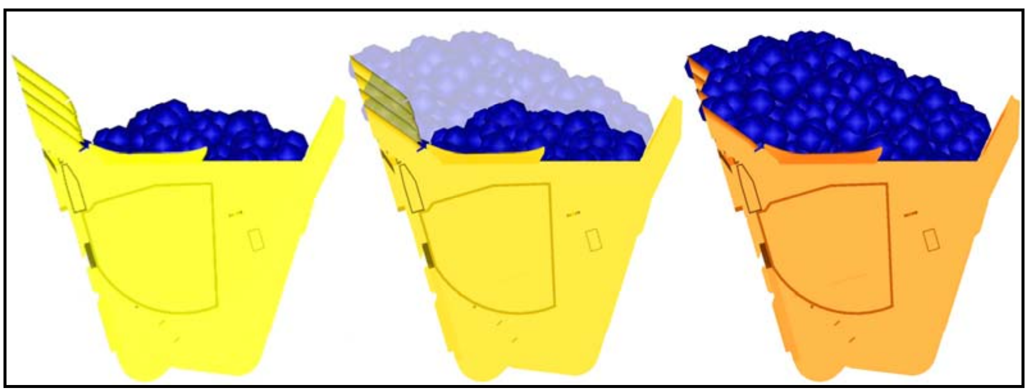

Figure 7 Comparison of Heaped 2:1 vs. scooped pile

LOADING SIMULATION

The two bucket piles are utilized as inputs for the Loading Simulations. A matrix of loading passes is set up for each pile. This is done to find realistic load volumes that settle into the dumpbody geometry for each set of passes:

- 4 Heaped 2:1 pile inputs from 6 through 9 passes of loads
- 2 Scooped Pile inputs from 5 to 6 passes of loads

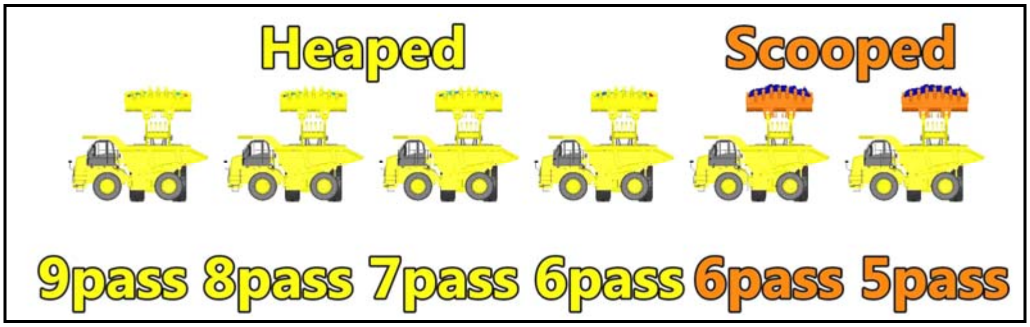

Figure 8 Configurations: 4 heaped and 2 scooped

Visualization of the Loading Simulation is performed with a software tool called RapidView. RapidView is a multi-body dynamics visualization software that provides users with the ability to obtain and communicate in-depth understanding of how their design works through visualization. RapidView software has many easy to use features developed by users that have many years of experience in the field of simulation. RapidView is available for trial and purchase from VPDS Inc. More information is available at www.vpds-inc.com

Particle color in the simulation represents the speed of the particles, it is useful to visualize areas where material slides and settles in the dumpbody to form the final material volume shape.

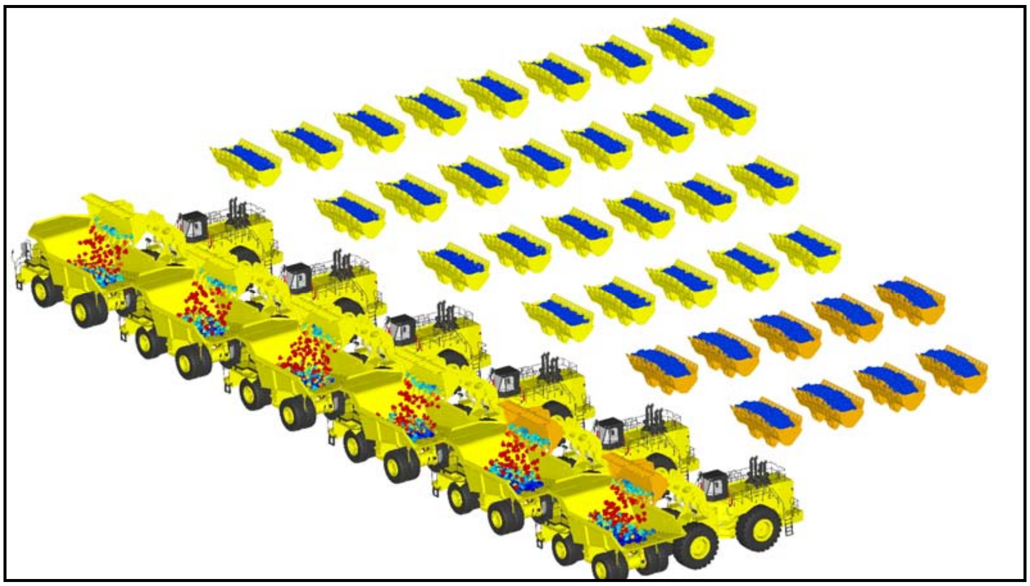

Figure 9 Loading simulation - First pass

Initial passes of material settle on the bottom of the dumpbody. After material starts to settle into each dumpbody material flows over the side walls and the tail until the final load is settled. The settled volume becomes the final realistic volume loaded into the dumpbody. The final dumpbody volume combined with the simulated bucket load volumes are used to calculate a more accurate pass match ratio.

LOADING SIMULATION RESULTS

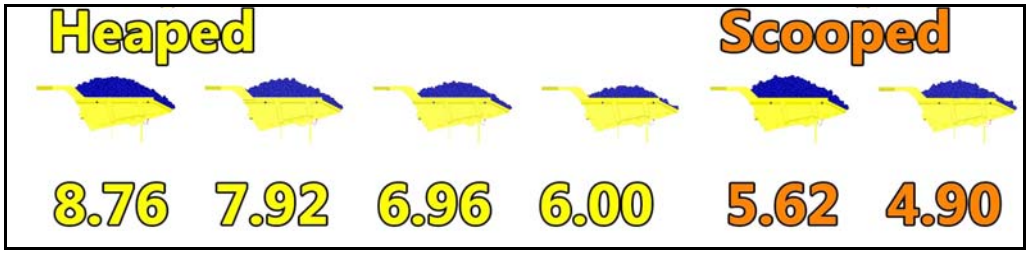

Figure 10 Settled piles after loading simulation

The pass match ratios are calculated as follows:

#Passes	9	8	7	6	5
Heaped2:1	8.76	7.92	6.96	6.00	
Scooped				5.62	4.90
Simple Calculation			6.94		

Figure 11 Pass Match Ratios

For the dumpbodies that did not underfill, the pass match values selected were:

- 8.76 (9 Heaped 2:1 passes to fill)
- 5.62 (6 Scooped passes to fill)

The first results compared are the Simple Pass Match calculation and the Heaped 2:1 Loading Simulation. The input bucket load capacity is the same for these calculations. Comparison of the pass match ratio results shows the difference between the Simple calculation and Loading Simulation.

- Simple Pass Match calculation ratio = 6.94 (7 passes to fill)
- Loading Simulation pass match ratio = 8.76 (9 passes to fill)

Though the input load piles are the same there is a difference in the dumpbody load capacities which results in a different ratio. The Loading Simulation includes the effects of material accumulation towards the front wall of the dumpbody. The standard Simple Pass Match calculation does not include this effect. The first gap identified for Simple Pass Match calculation is how the material settles in the dumpbody geometry. This material behavior is included in Loading Simulation. Though the Loading Simulation result does not include a realistic input bucket load, this comparison illustrates the significant difference in the number of passes calculated.

The more realistic bucket load input is the Scooped Pile. Now compare the pass match ratio results of the Simple Pass Match calculation with the more realistic Scooped Pile input load.

- Simple Pass Match calculation ratio = 6.94 (7 passes to fill)
- Scooped Pile Loading Simulation pass match ratio = 5.62 (6 passes to fill)

Comparison of the standard calculation method and more realistic Loading Simulation results show that one less loading pass is needed to fill the dumpbody. Anther gap identified for Simple Pass Match calculation is related to the discrepancy between the more realistic bucket Scooped Pile load input relative to the published SAE standard numbers and the effect on the resultant pass match ratio results. If the 6.94 pass match value (from the simple division calculation) was used instead of the scooped 5.62, it would lead a Mine Company to believe an extra pass was necessary to fill the dumpbody. The difference in pass match ration results could be misleading and have a negative effect on productivity and efficiency calculations.

Here are more key factors that are included within Loading Simulation that identify where more differences in results could occur when compared to the Simple Pass Match calculation:

- Relative position between the loader and truck. All 3 directions are important: fore-aft, side-side, and vertical.
- Kinematics of the loader: Includes bucket motion, height and angles.
- Material properties: Density, particle size and angle of repose.
- Material flow and settling.
- Geometry of the loader bucket: Includes all features, such as teeth that can retain or lose material.
- Geometry of the dumpbody: Includes all features, such as the front wall that can retain material.
- Features of the dumpbody geometry that may interfere or limit loader bucket position and motion such as sidewall transitions.

Differences between the standard SAE2:1 dumpbody capacity calculation of published numbers and more realistic results of settled piles with Load Simulation are shown in Figure 12. The green colored geometry is the SAE2:1 definition. Compare that with the settled material.

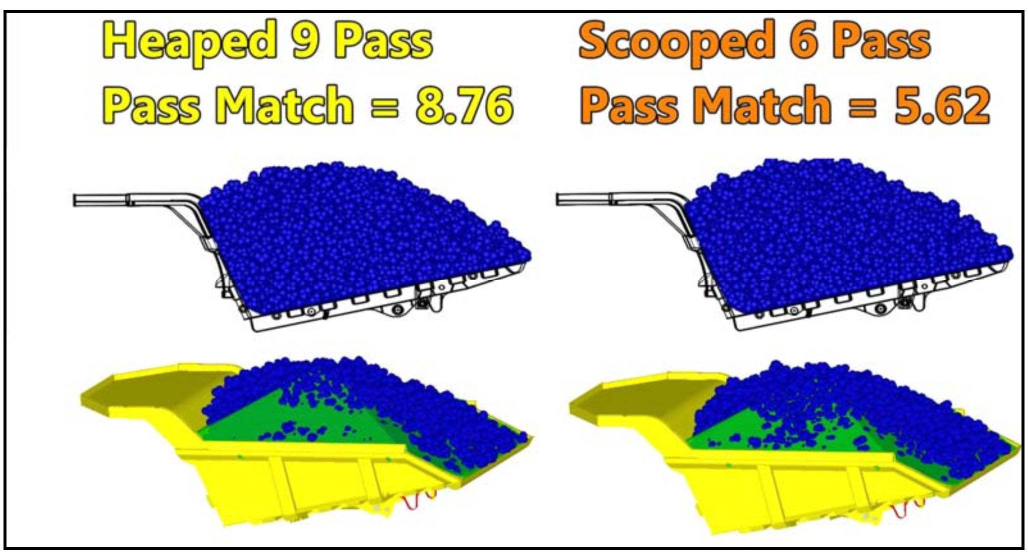

Figure 12 Settled piles compared to SAE 2:1 standard pile

We also want to include comments about the sensitivity of other factors that come into play when comparing current standard calculation methods with Loading Simulation:

- We elected to use an angle of repose for the case study material which is calibrated to a 2:1 slope. If a different angle of repose is needed for a particular mined material, the difference between the Simple Pass Match calculations and Loading Simulation would be even more significant.
- Settle material in the dumpbody result in a more "conical" pile shape. Comparison of the more realistic settled material to the SAE2:1 pile geometry (ref: green geometry in Figure 12) illustrates the corners of the SAE2:1 geometry are not filled with material. Changes in angle of repose would have even more magnification of these differences.
- Simulated piles retain material towards the front wall. The SAE2:1 standard does not include this volumetric region, and is another source of error in pass match ratio results.

LOADING CONFIGURATIONS

Mine Companies may be interested in simulation of other equipment strategies. Loading simulation can be used to compare different equipment loading and hauling configurations. Figure 13 illustrates another possibility to compare pass match performance of a wheel loader side loading a truck compared to that of an excavator elevated on a bank backloading a truck. Any loading or hauling equipment geometry can be simulated to support Mine Companies with better equipment selections and maximize mining productivity to meet business financial goals.

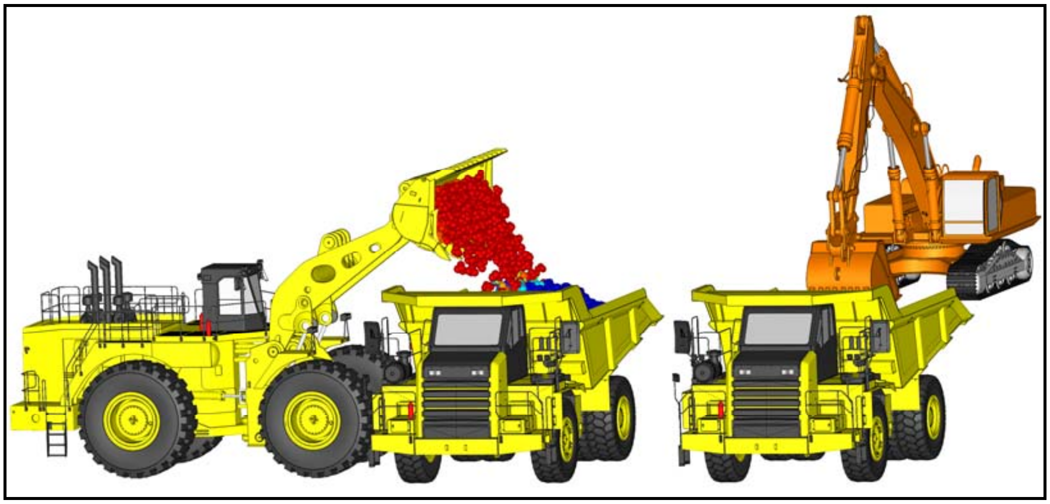

Figure 13 Loading Configurations - Loader/Truck (Left) and Excavator/Truck(Right)

SPILLAGE

Spillage due to grades, turns, hard shifting, and terrain obstacles can also be simulated after the loading simulation pile has settled (see Figure 14).

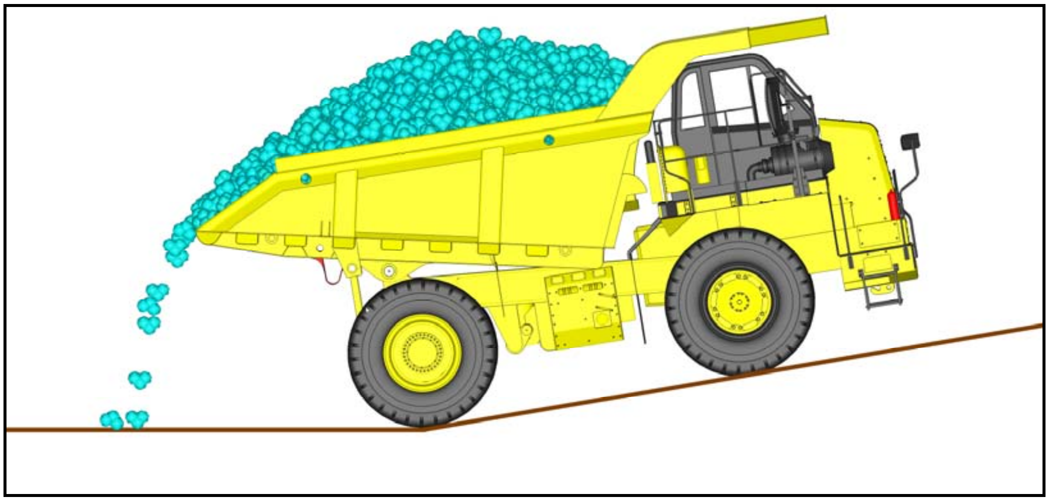

Figure 14 Spillage on truck due to change in grade

By understanding the sensitivities of payload lost due to driving conditions, Loading Simulation can be used to adjust the volume of material loaded into a dumpbody. This reduces or eliminates spillage and increases overall productivity of a mining operation by only loading the necessary volume onto the truck. Tailgates and side boards can also be included in simulation to study and understand the effectiveness and potential for increased productivity as a result of these features added to a truck dumpbody.

TIRE LOAD AND WEAR CONSIDERATIONS

The final shape of a pile settled into a dumpbody can shift the Center of Gravity location of the truck. Unequal tire loads could result and increase uneven tire wear. Loading Simulation can be used to find an optimal loading point to locate the pile Center of Gravity that would result in even tire load distribution. Equalized tire loads help ensure even tire wear which saves money on operating costs.

CONCLUSIONS

Loading Simulation services may be employed by Mining Companies that are considering purchase of new equipment or replacement loading tools and/or dumpbodies. Upgrades of existing dumpbodies with tailgates and/or sideboards can be analyzed with Loading Simulation to calculate improvements in productivity. It is used to make knowledgeable selections and purchases of equipment, avoid losses from mismatched equipment and maximize productivity.

OEM and aftermarket manufactures can leverage Loading Simulation to develop application specific design configurations that maximize value of their products and increase productivity of their mining customers.

The VPDS team has many years of experience with development of mining equipment products. VPDS loading simulation expertise and service may be employed to provide customers with purchase decision confidence in their equipment selection process. VPDS can also support companies with efficient mining product development services.