Jigsaw Advanced Mining System (JAMS)

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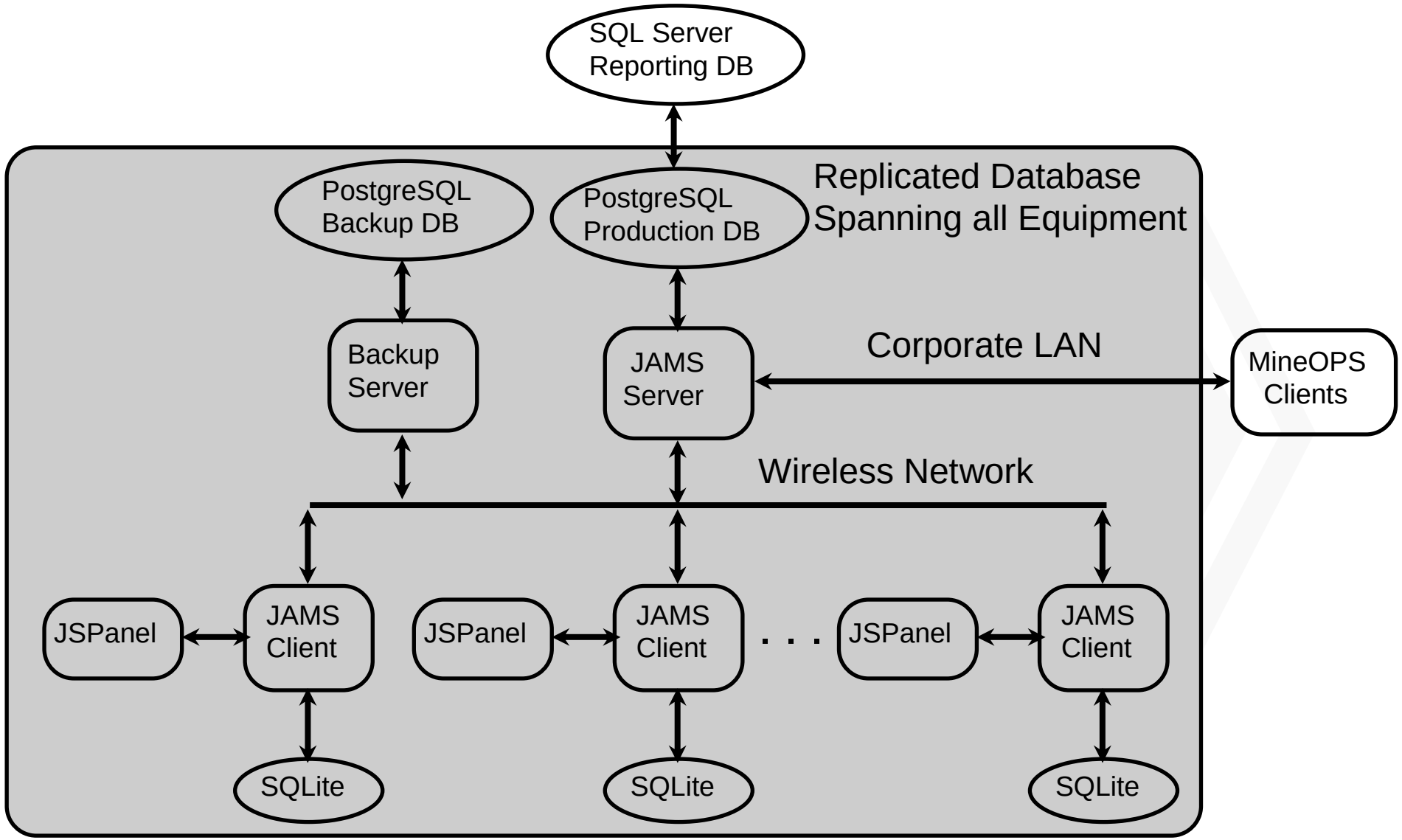
HEXAGON

Agenda

- Distributed System Architecture
- Haul Cycle Automation
- Production Optimization
- Health Monitoring
- High Precision GPS
- Extensible Reporting Database
- Projects Under Development

Distributed 3-tier Application Server Design



Advantages of Distributed System Design

- Robust architecture eliminates single point of failure
- On-board control logic functions in radio dark spots
- Accurate timing and measurement of activities and haul cycles
- Scalable architecture for data acquisition and control
- Reliable on-board storage of production and health data
- Rich operator interface including map display, KPIs, and sensor data
- Production data stored in standards based open SQL database tables

Truck Haul Cycle Automation

- Haul cycle automation combine GPS, payload, and distributed database
  - waiting at shovel - detected by GPS when truck stops within waiting_distance of active shovel.
  - spotting at shovel - detected by GPS when truck reverses direction within spotting_distance of active shovel.
  - loading at shovel - detected by GPS when spotting truck stops within loading_distance of active shovel OR when payload system indicates first dipper.
  - hauling to dump - detected by GPS when truck leaves shovel OR by shovel foot-switch OR by payload system indicating final tonnage.
  - queued at dump - detected by GPS when truck stops within a dump boundary.
  - backing at dump - detected by GPS when truck reverses direction within a dump boundary.
  - tipping at dump - detected by GPS when backing truck stops within dump boundary OR by payload system indicating bed is up or tonnage is zeroed.
  - traveling to shovel - detected by GPS when tipping truck moves more than 25 meters OR by payload system indicating bed is down.

GPS vs. payload activity indications

- Because payload systems directly measure tonnage in the truck bed, a payload system should be able to detect loading and tipping activities better than inference based on GPS heading and speed. Unfortunately, PLM systems have proved to be less than reliable and often give incorrect payload indications.
- GPS and payload normally provide redundant detection of loading and tipping activities allowing accurate load counts if either sensor is not functioning.
- Normally, JAMS accepts loading and tipping indications as reliable indicators. However the reliability of the PLM at Codelco has forced Jigsaw to treat payload as an unreliable input which must be combined with GPS to validate the payload event.
- Unreliable payload sensors require GPS and WIFI coverage to detect start of load since payload alone cannot be accepted for loading and tipping activities.
- Jigsaw currently evaluating accelerometers and ultrasonic sensors to provide reliable detection of loading and tipping events when payload systems are unreliable.

Production Optimization

- JAMS includes comprehensive LP optimization solution
  - material and haulage restrictions
  - dump blending constraints
  - truck haulage constraints
  - shovel prioritization and percent coverage
  - dump capacity constraints
  - dump blending limits
  - truck fleet restrictions
- Continuous GPS tracking and misroute detection
  - current road position and ETA updated once per second
  - immediate detection and reassignment at misroutes
  - accurate estimation of arrival times at dump and shovels
  - location detection within precise polygonal boundaries
  - dump/stockpile reassignments based on queue lengths and blend limits
  - precise intersection arrivals and accurate timing of haulage ramps

Dynamic Programming Optimizes Discrete Truck Assignments

- Dynamic programming minimizes idle times based on accurate ETAs
- Configurable travel_cost assigns higher cost for travel vs. idle.
- Assignments chosen to minimize truck idle and shovel hang time at the projected truck ETA.
- Configurable percent_coverage for each shovel allows precise tuning of shovel coverage.
- Shovel priorities help to meet production objectives with insufficient truck haulage or dumping capacity.
- Next truck assignment computed and updated continuously when truck leaves shovel. Assignment already computed and replicated to on-board database when truck requests assignment.
- DP re-evaluates assignment when truck enters road segment which ends with a reassignment call point.

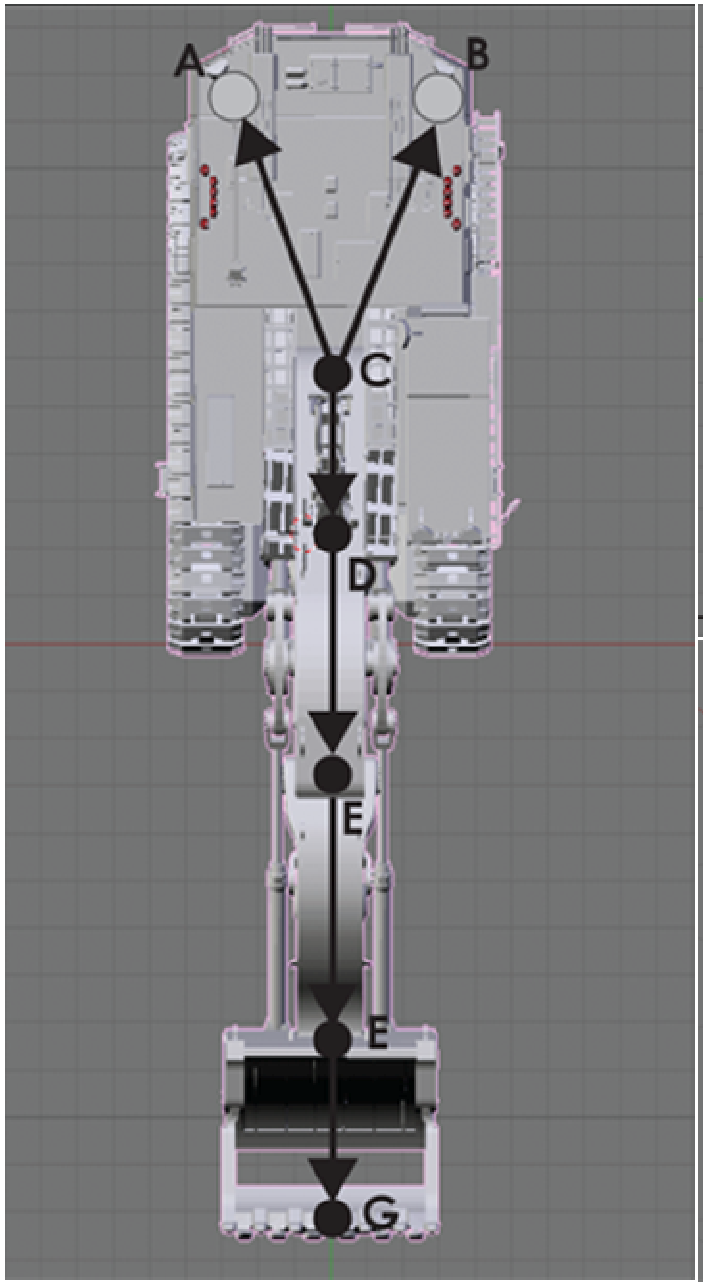
Health Monitoring

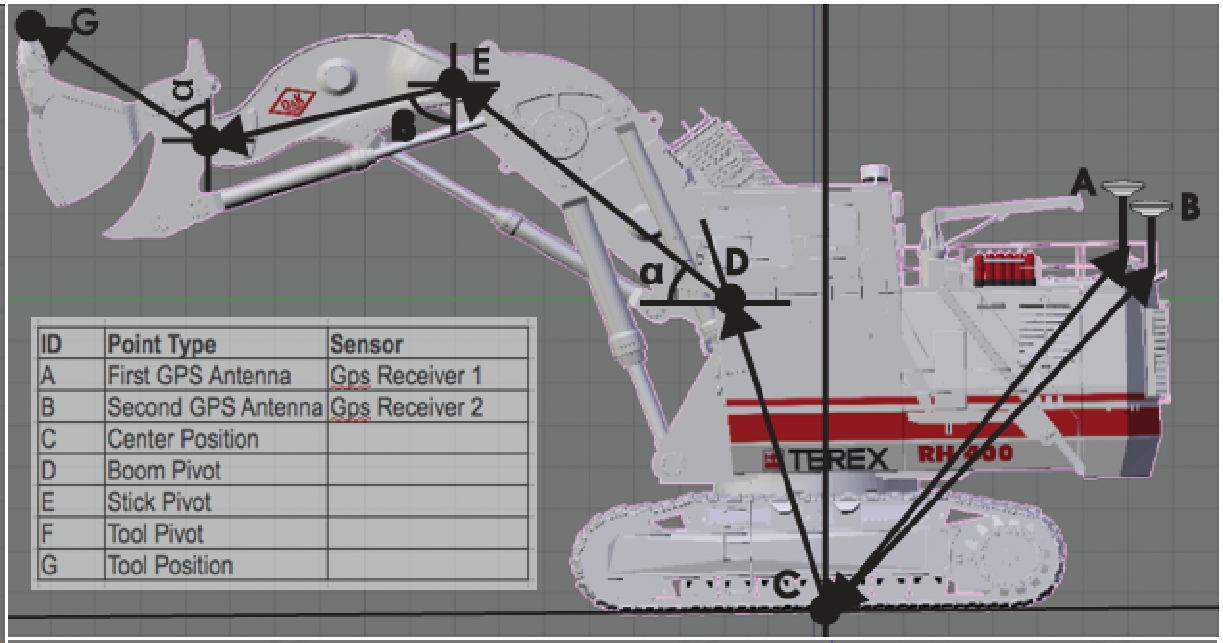
- Disparate equipment interfaces bound to a common sensor abstraction
- Sensors table updated continuously with current sensor values
- Historical measurement provides efficient storage of any defined sensor set.
- Deadbanding records changes to any sensor outside of a specified percentage
- Recording of OEM alarm events and defined min/max alarm bounds for any sensor.
- On-board averaging provides smoothed values for noisy sensors.
- Sensors allow dependencies upon other sensors being within their specified range before measurement.
- Interfaces available for VIMS, DDEC, MEMS, CENSE, CAES, STATEX, PLM, PLMII.
- Comprehensive dashboards currently under development.

High Precision GPS

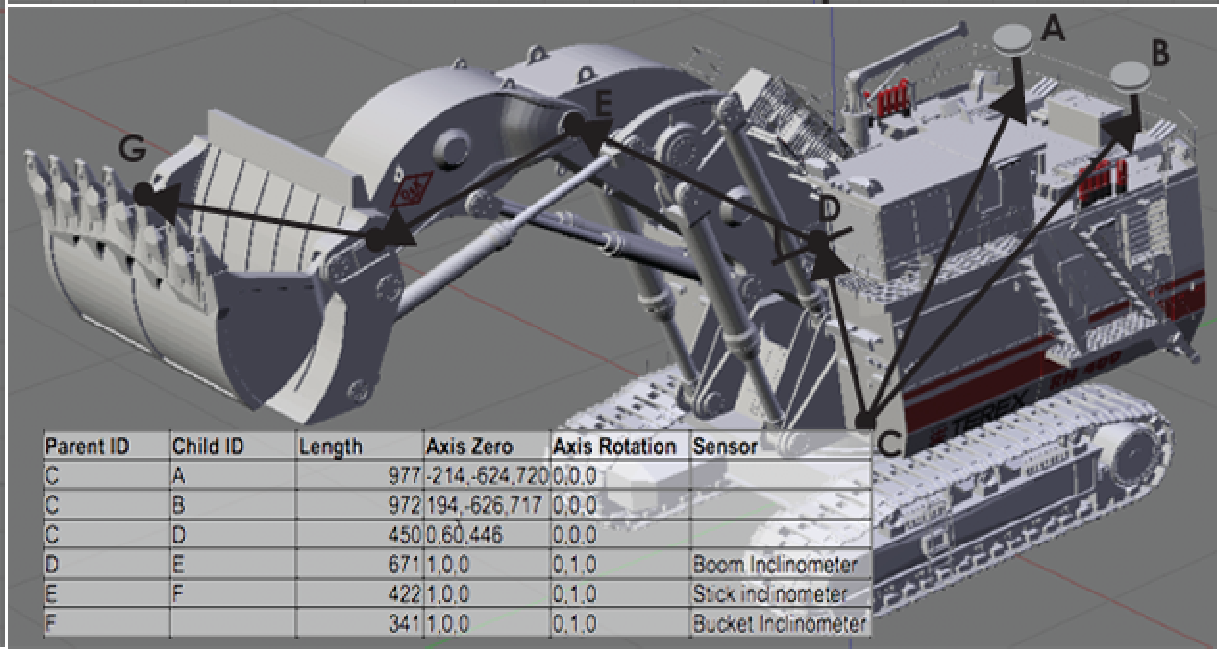
- CPU module interchangeable with low precision units. Additional high precision GPS module connects to CPU via USB
- HPGPS navigation engine combines multiple inclinometers and GPS antennas to provide 3-D orientation of equipment.
- Geometry points and segments describe equipment geometry and sensors measuring each point.
- High-level behavioral components compute dig points, drill point navigation or dozer topography, update mining contours, and compute material types
- Importers update topography and grade block database from mine planning systems

Equipment Geometry – Hydraulic Shovel



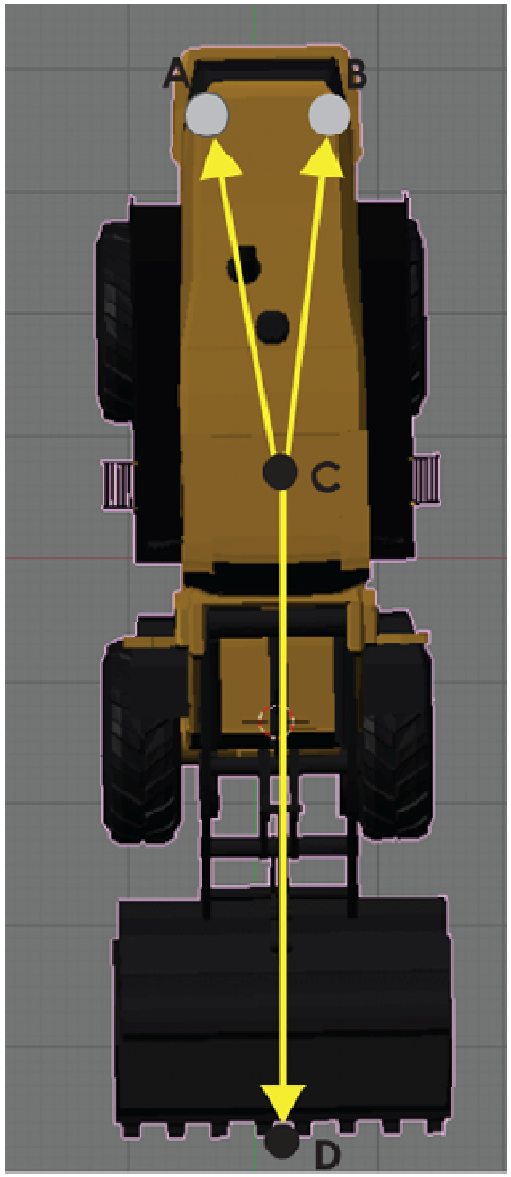


ID	Point Type	Sensor
A	First GPS Antenna	Gps Receiver 1
B	Second GPS Antenna	Gps Receiver 2
C	Center Position	
D	Boom Pivot	
E	Stick Pivot	
F	Tool Pivot	
G	Tool Position	



Parent ID	Child ID	Length	Axis Zero	Axis Rotation	Sensor
C	A	977	-214,-624,720	0,0,0	
C	B	972	194,-626,717	0,0,0	
C	D	450	0,60,446	0,0,0	
D	E	671	1,0,0	0,1,0	Boom Inclinometer
E	F	422	1,0,0	0,1,0	Stick inclinometer
F		341	1,0,0	0,1,0	Bucket Inclinometer

Equipment Geometry - Loaders



Parent Point	Child Point	Length	Axis Zero	Axis Rotation	Sensor
C	A	463	0,0,0	-105,0,451	
C	B	460	0,0,0	105,0,448	
C	D	600	0,0,0	0,600,0	

ID	Point Type	Sensor Type
A	First GPS Antenna	Gps Receiver 1
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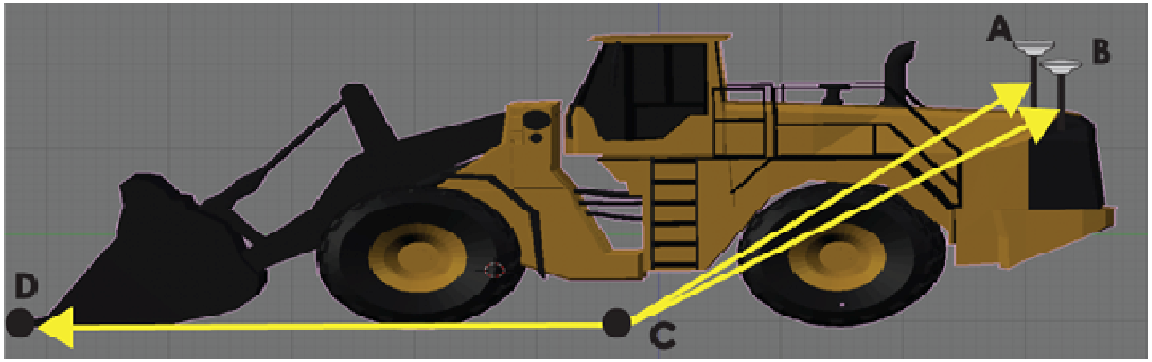
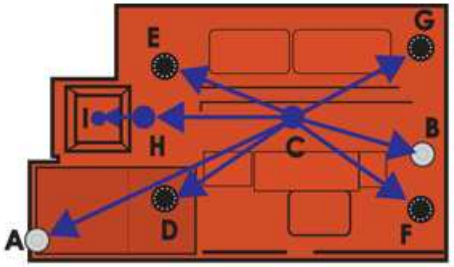
C	Center Position	
D	Tool Position	



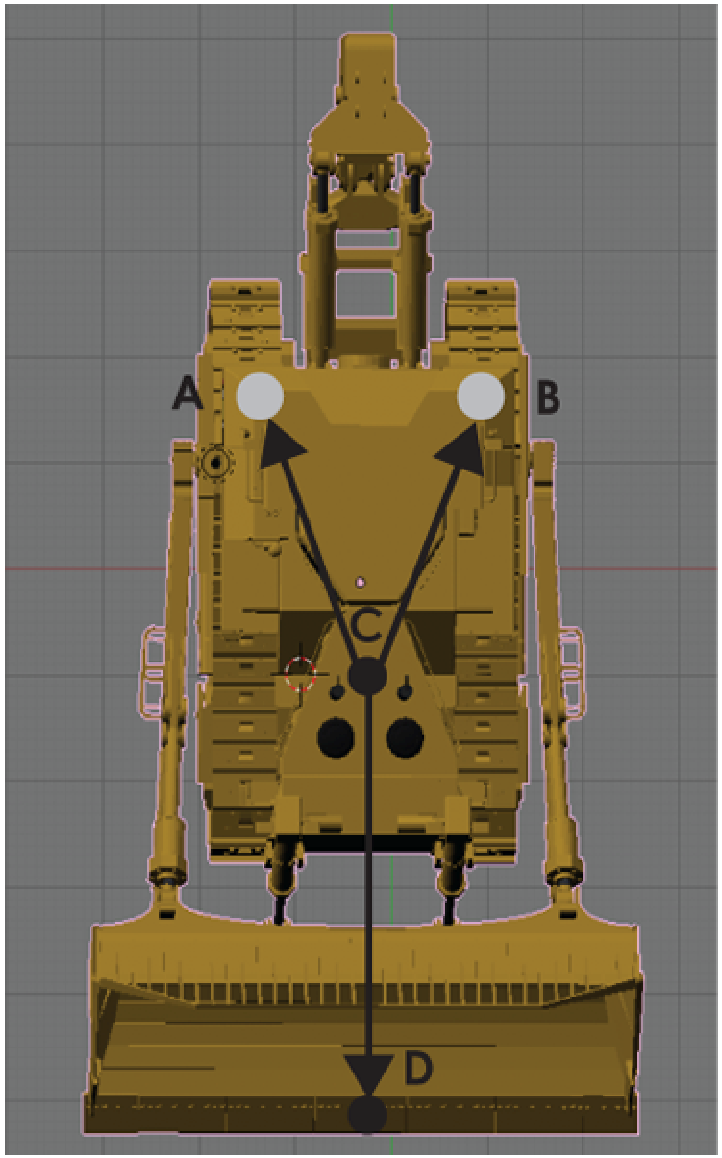
Equipment Geometry - Drills

Parent Point	Child Point	Length	Axis Zero	Axis Rotation	Sensor
C	A	44	40,20,0		
C	B	44	40,20,0		
C	D	44	40,20,0		
C	E	44	40,20,0		
C	F	44	40,20,0		
C	G	44	40,20,0		
C	H	36	30,20,0		
H	I	0	0,0,0	1,0,0	Mast Pitch Inclinometer

ID	Point Type	Sensor
A	First GPS Antenna	Gps Receiver 1
B	Second GPS Antenna	Gps Receiver 2
C	Center Position	
D	First Jack	
E	Second Jack	
F	Third Jack	
G	Fourth Jack	
H	Mast Pivot	
I	Tool Position	



Equipment Geometry – Dozer



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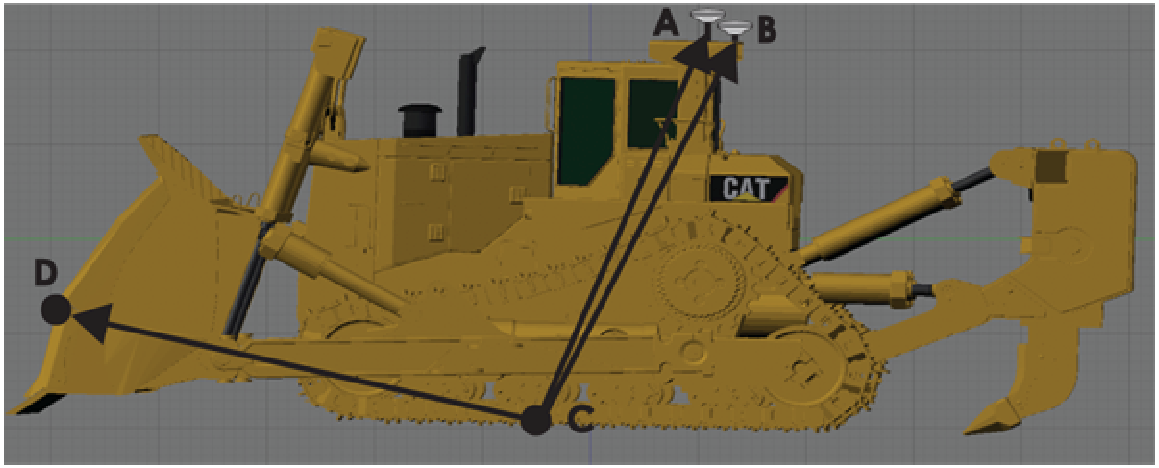

Extensible Reporting Database

- The reporting database contains a set of de-normalized summary tables computed from the normalized transactional data set generated by JAMS. These tables greatly speed up report generation and produce a consistent set of reports requiring only minimal computations in the report itself.
- All reporting database tables are defined by a single summaries table which describes the table to be created, the time granularity of the summary, the grouping of the summary, and the aggregate functions to compute.
- New summaries are easy to create by adding a single row to the summaries table.
- The Summarizer tool updates all summary tables every 5 minutes to provide up to date information for all reports.
- The Summarizer tool automatically recomputes any summarized data when the dependent data changes.
- Summary tables can aggregate by hour, shift, day, week, or month.

Projects Under Development

- Additional sensors for reliable detection of loading and tipping activities
- Analysis tools and dashboards for health monitoring system
- Peer-to-peer connectivity between trucks and HPGPS shovels
- HTML5 web based replacement for MineOPS and JSPanel
- Additional OEM equipment interfaces
- Flexible web based dashboard and charting tools
- Automated road network maintenance