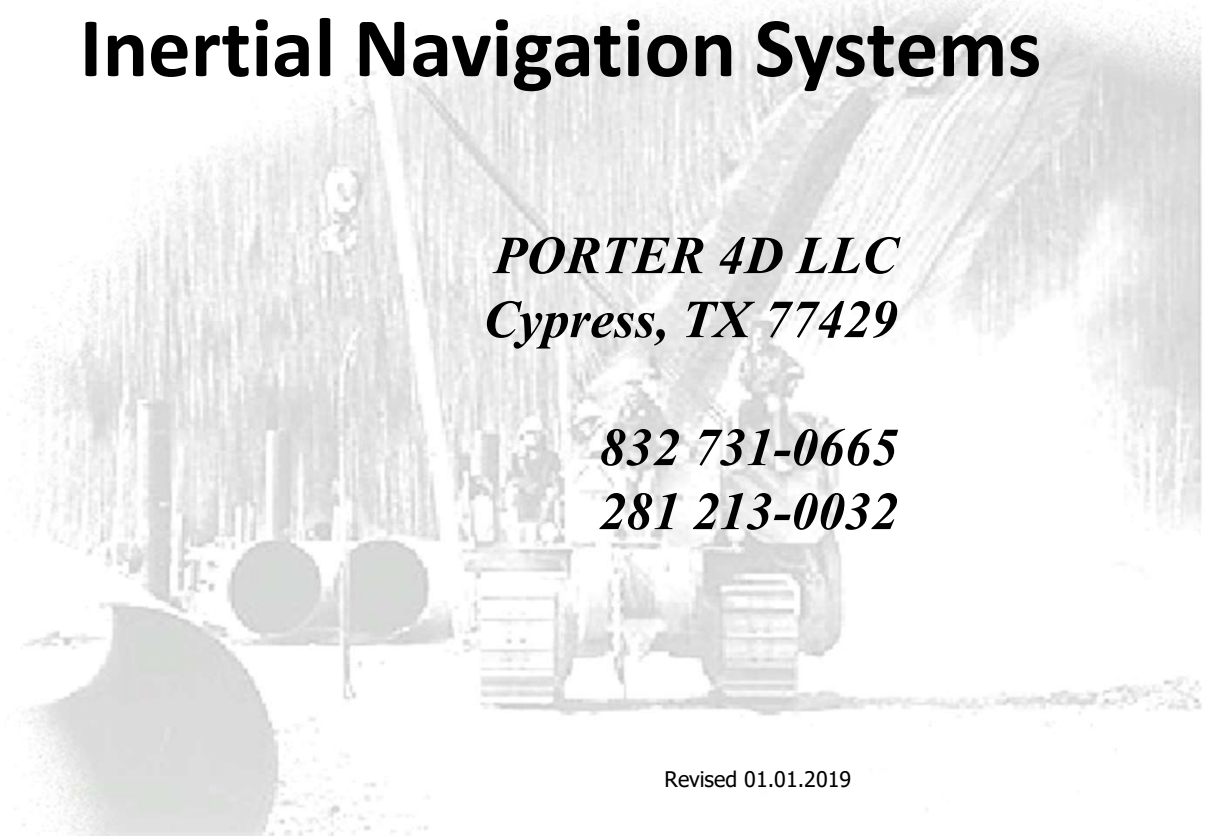
Pipeline Integrity:
Inertial Navigation Systems

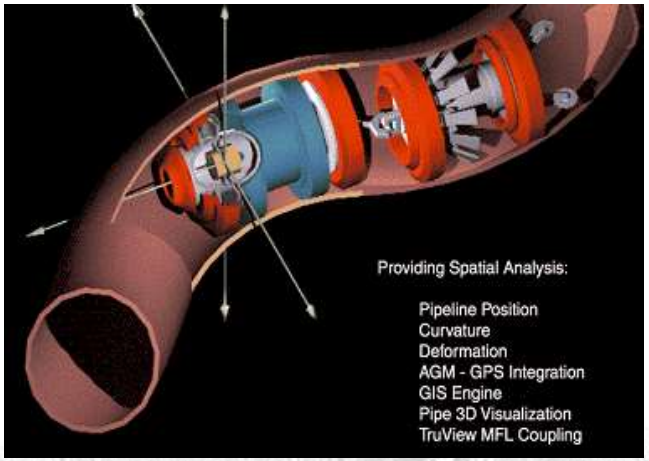


PORTER 4D LLC
Cypress, TX 77429

832 731-0665
281 213-0032

Revised 01.01.2019

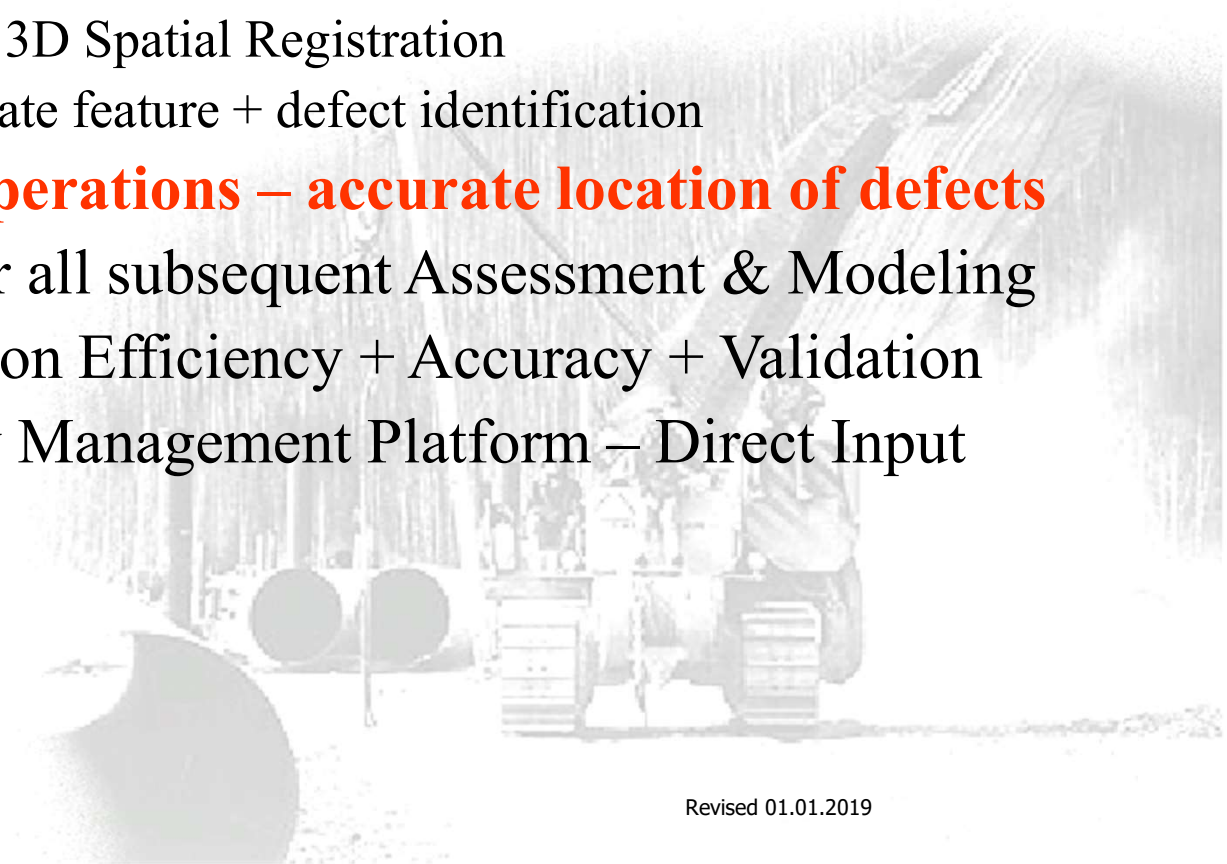
Benefits of INS



- Continuous **XYZ** pipeline position
  - accurate to +/-1m @ 1σ
  - Direct **GIS** input
  - Accurate and continuous **elevation profile**
  - Accurate spatial feature inventory via **accurate coordinates**.

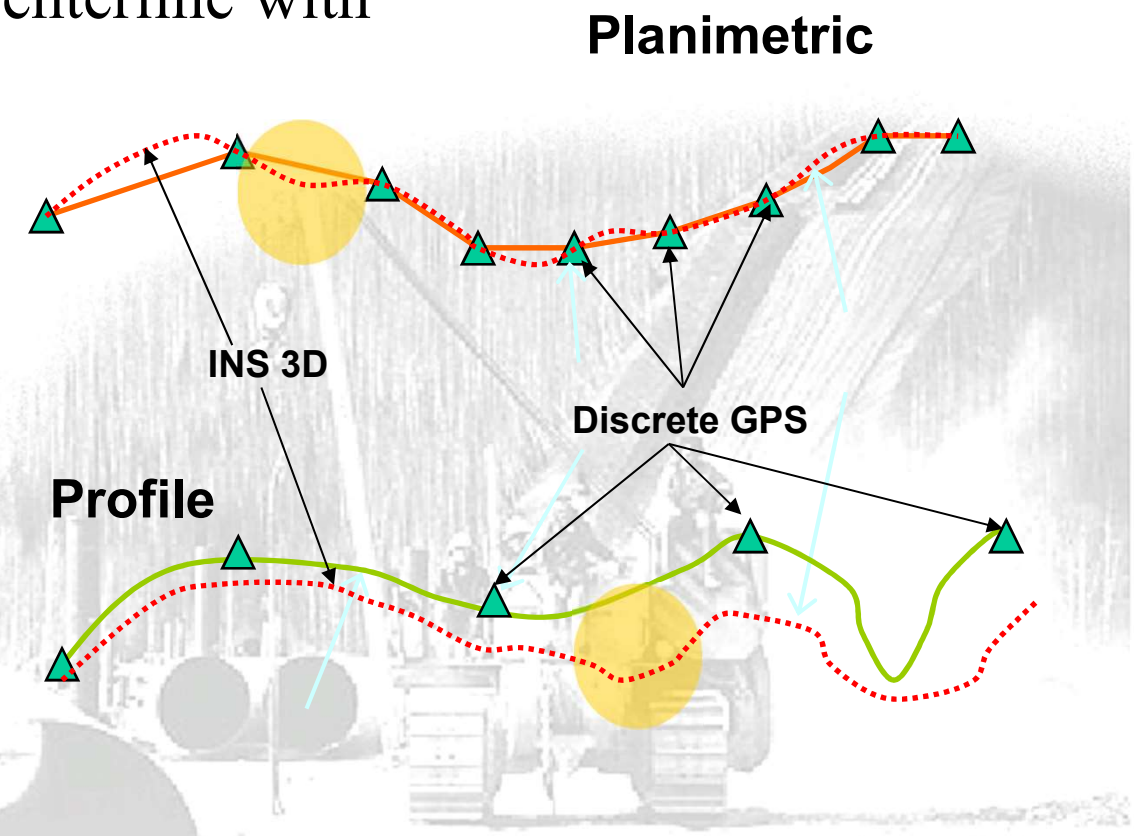
ILI-INS Baseline -> Benefits

- COMBO ILI
  - INS – 3D Spatial Registration
  - Accurate feature + defect identification
- **Field Operations – accurate location of defects**
- Basis for all subsequent Assessment & Modeling
- Integration Efficiency + Accuracy + Validation
- Integrity Management Platform – Direct Input



Spatial Registration

- Registering the pipe centerline with coordinates
- Methods
  - Digitized
  - GPS
  - INS
- Accuracy
  - Mapping Level
  - Engineering
  - RISK



Specific INS Applications

- Line, Feature Mapping
- Geotechnical unstable areas
- Frost heave / thaw settlement surveys
- Marine free-span detection
- River crossing surveys
- Dent and buckle discrimination
- Temperature / pressure profiling
- Pipe joint misalignment
- Bend detection and characterization

IMU Sensor and Electronics

Programs Using the IMU's

Air Force

- JDAM
- WCMD
- JASSM
- GAM
- Range Pods
- MMT

Navy

- JDAM
- JASSM
- ESSM
- Standard Missile
- Vandal Target
- Net Torp
- Tactical Tomahawk
- Harpoon
- JSOW Qualified

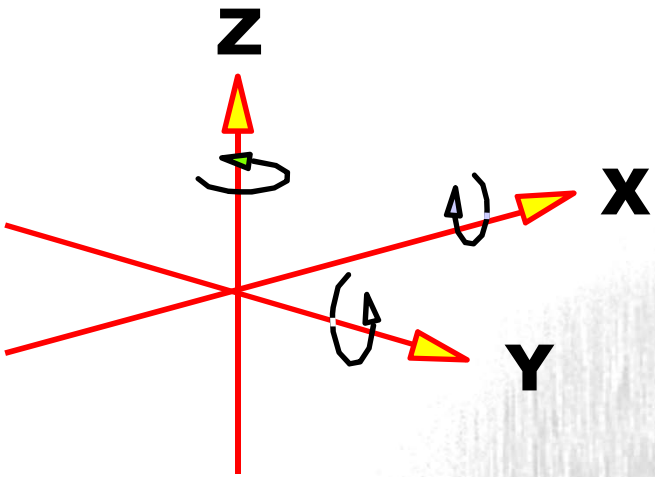
Army

- Stinger
- EFOGM
- GMLRS ATD
- LOSAT
- FMTI

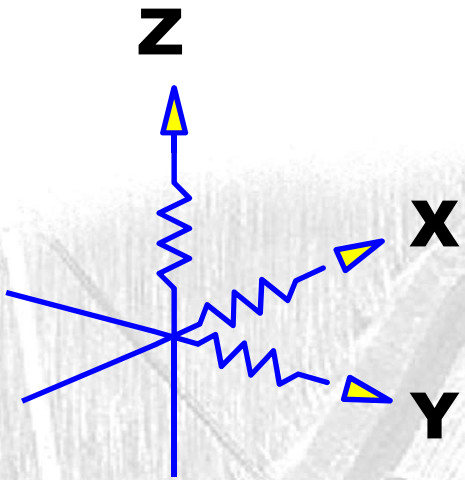
Other

- Tier 3 Minus UAV
- Cypher UAV
- Eagle Eye UAV

IMU Sensor I/O

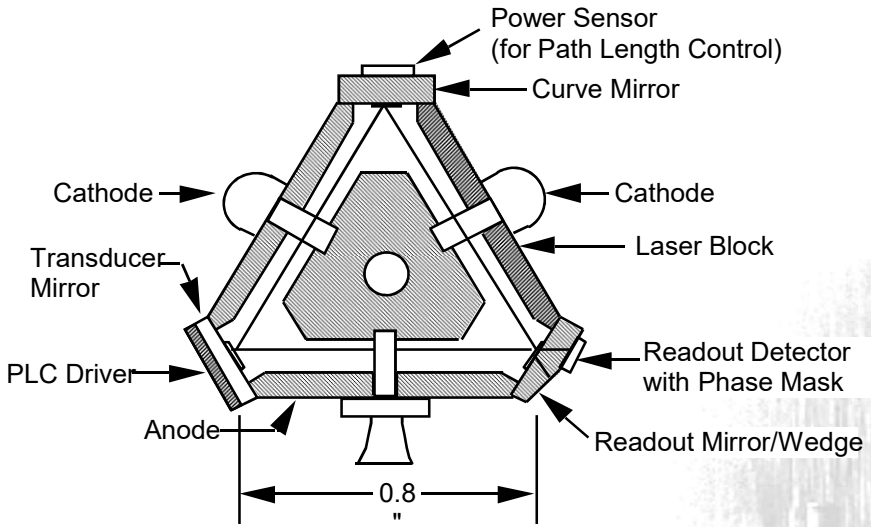


Gyro (RLG/FOG)
Angular Rate (°/sec)



Accelerometers
Linear Acceleration (m/sec^2)

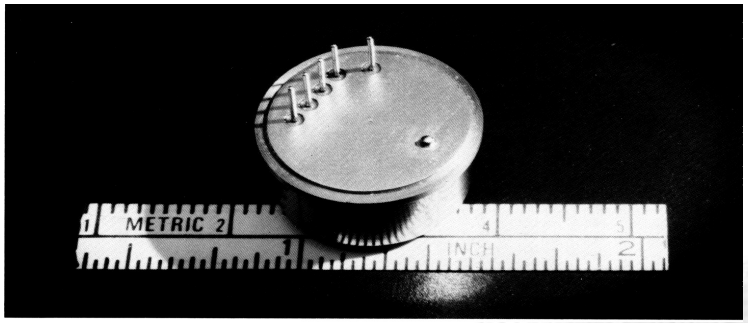
RLG Gyros

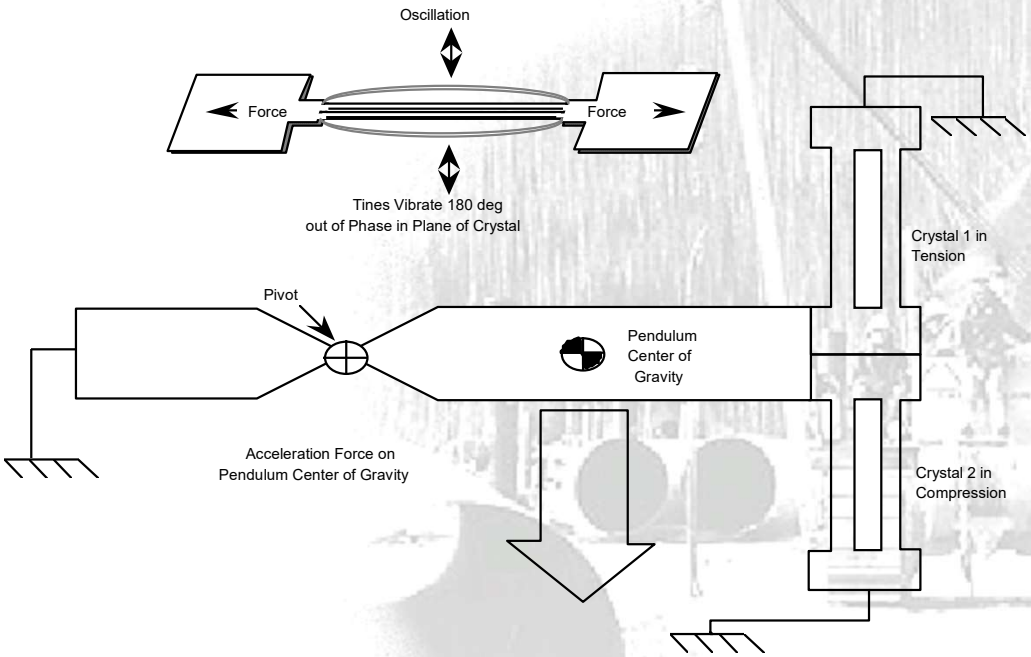


Features

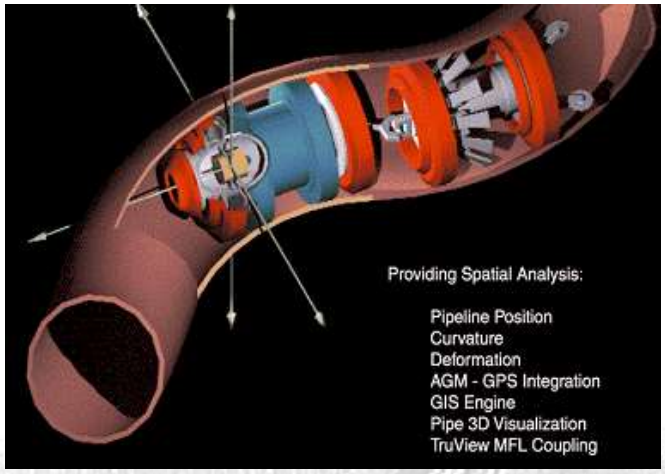
- Rugged, solid-block construction
- Short ROC curved mirror for stability
- Simplified wedge readout
- Simplified PLC transducer
- Dual cathodes for increased gas volume
- Frit seals for mirror and electrodes
- Cold weld pinch-off for high vacuum integrity
- Lapped block mirror mating surfaces

Accelerometers





IMU Integration

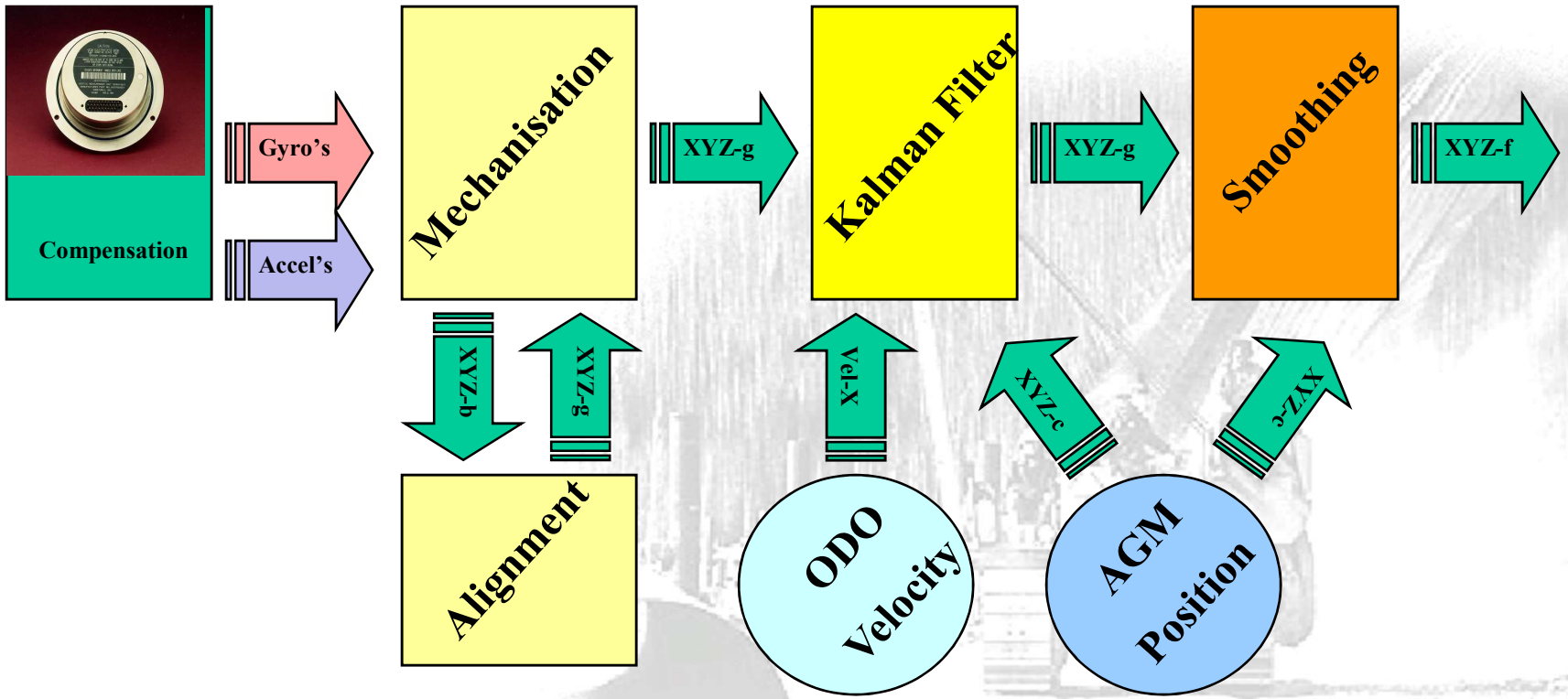


- Combo Tool Add-in
- Independent Time Based Recorder
- Requires Accurate Odometer data -> velocity
- Requires Accurate AGM timing / positions
- Continuous **XYZ** pipeline position
  - accurate to better than 1m
  - Direct **GIS** input
  - Accurate and continuous **elevation profile**
  - Accurate spatial feature inventory via **accurate coordinates**.

IMU Operation

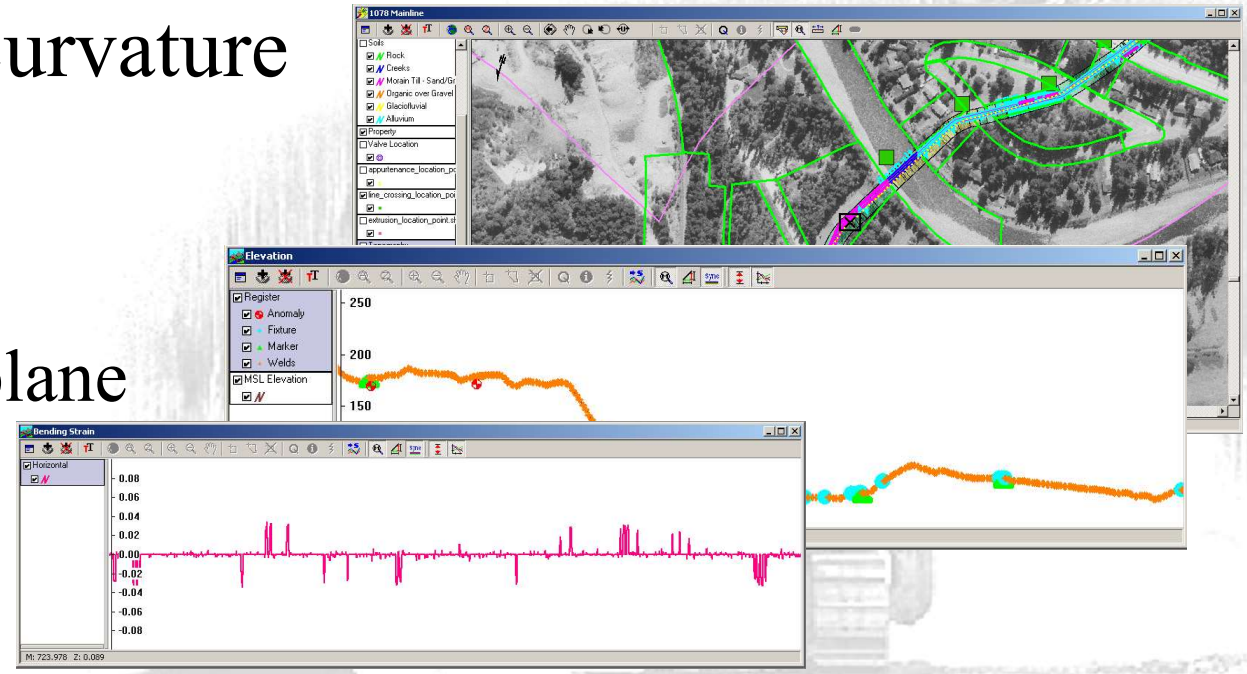
- GO / No GO indication
- Launch calibration
  - Sensor calibration
  - Launch barrel alignment
  - Stationary period
- Trap verification
  - Stationary period
  - ScanIMU – raw data integrity
- AGM time extraction

IMU Data Processing



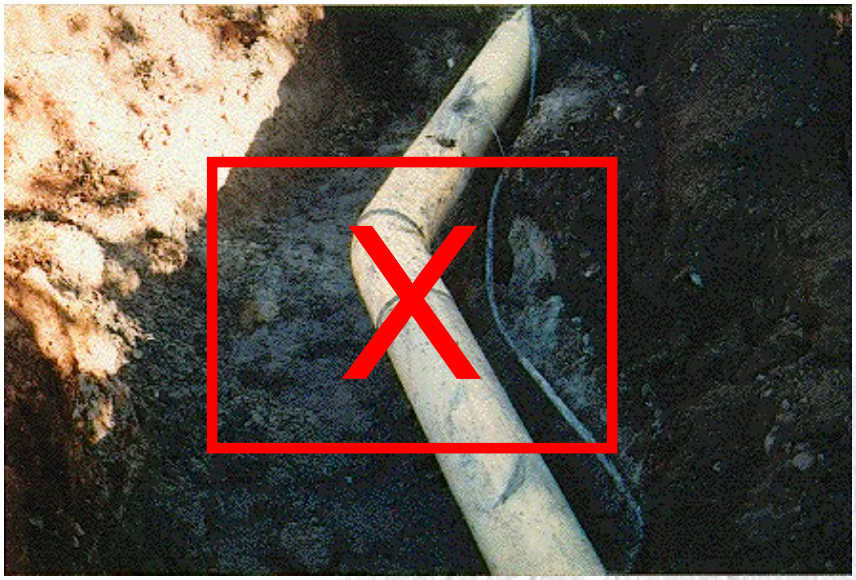
IMU – INS Results

- Continuous Normalized XYZ file
- Continuous Curvature
  - Horizontal
  - Vertical
  - Max out of plane



Integrity Management – INS-GPS Concepts

Dig Smart!

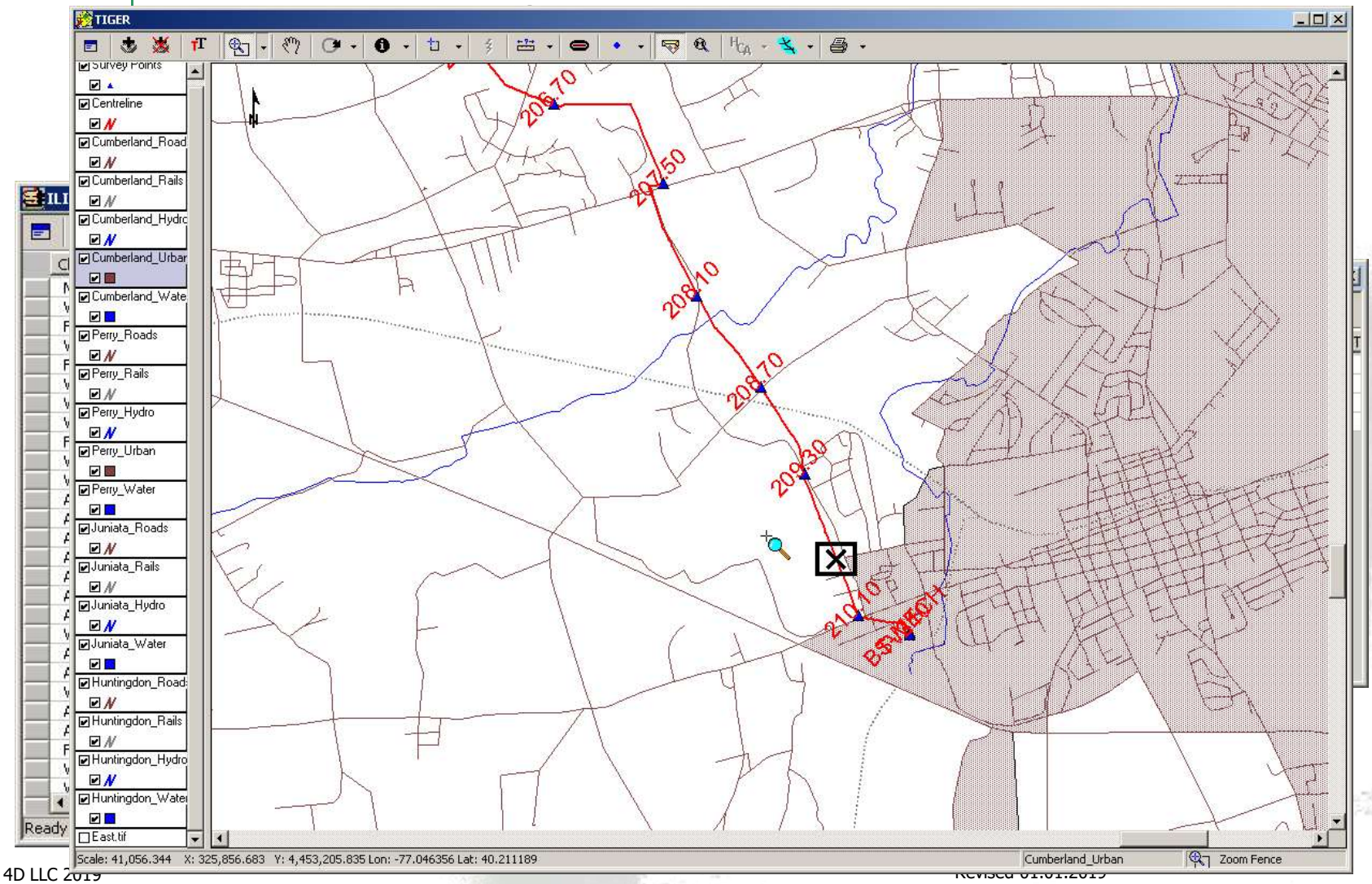


Save $

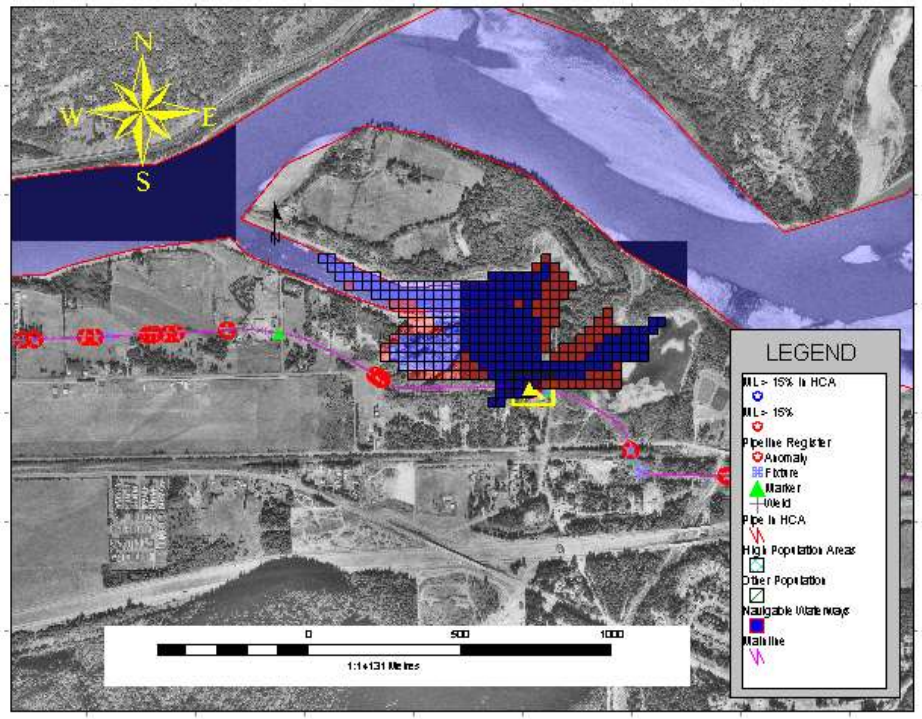
Integrity Management – INS-GPS Concepts

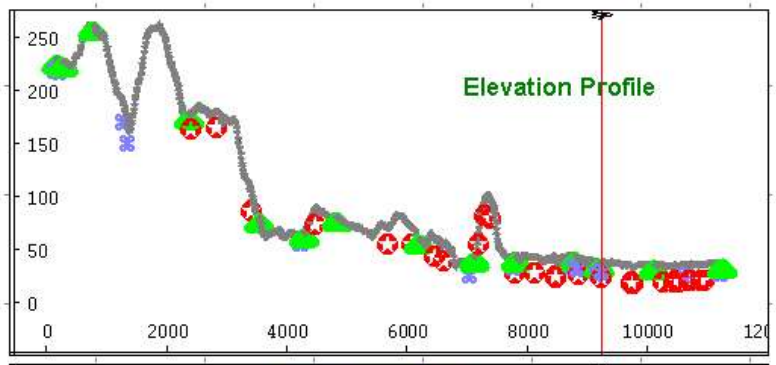
Tactical - Be Here Now!

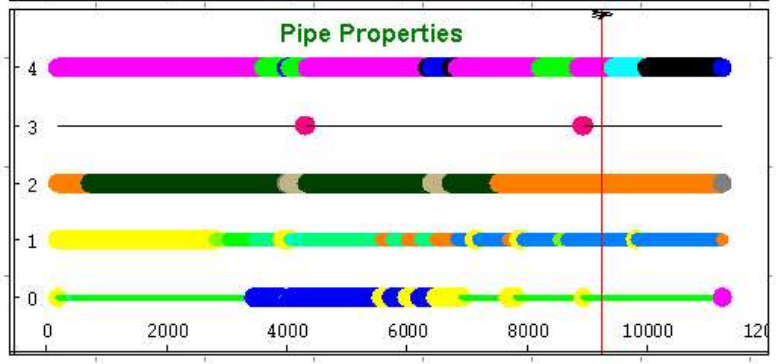
Integrity Management – INS-GPS Concepts



Integrity Management – INS-GPS Concepts

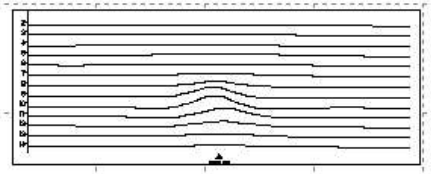


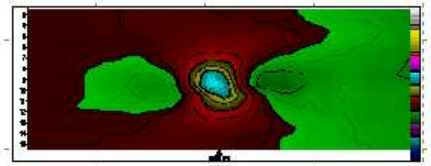


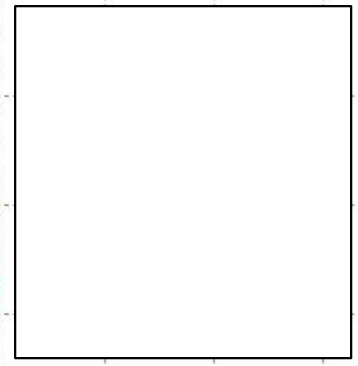


Pipeline Register (Anomalies > 15%)

DISTANCE	DESCRIPTION	Cat_Descrip	COMMENT	WALL_LOSS	Anmly_Loc	DEPTH	ORIENTATIO
30315.2167	Anomaly	General Corr...	External	80	External		80
29001.475	Anomaly	Circumferenti...	External	29	External		180
33723.8	Anomaly	General Corr...	External	26	External		115
25598.6167	Anomaly	Circumferenti...	External	25	External		25
31961.775	Anomaly	Pitting	External	24	External		165
21277.9083	Anomaly	General Corr...	External	24	External		25
26724.2833	Anomaly	Pitting	External	23	External		185
34505.6083	Anomaly	General Corr...	External	22	External		275
34268.2333	Anomaly	Axial Groove	External	22	External		225
27810.0417	Anomaly	General Corr...	External	22	External		210
27809.675	Anomaly	General Corr...	External	22	External		185
31963.95	Anomaly	General Corr...	External	21	External		185
27811.2083	Anomaly	General Corr...	External	21	External		195
27822.0833	Anomaly	General Corr...	External	19	External		295
27810.7917	Anomaly	General Corr...	External	19	External		120
19941.8083	Anomaly	General Corr...	External	19	External		65
34497.2833	Anomaly	General Corr...	External	18	External		270

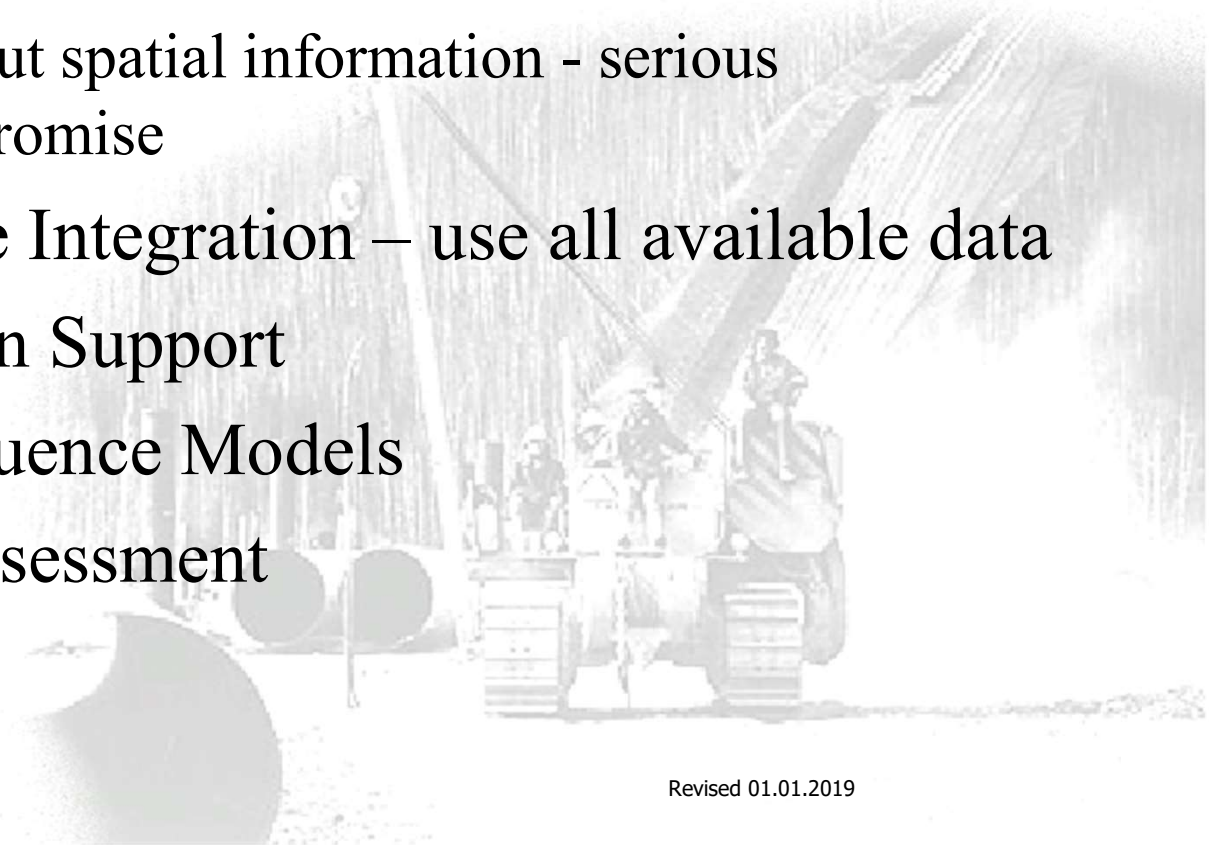






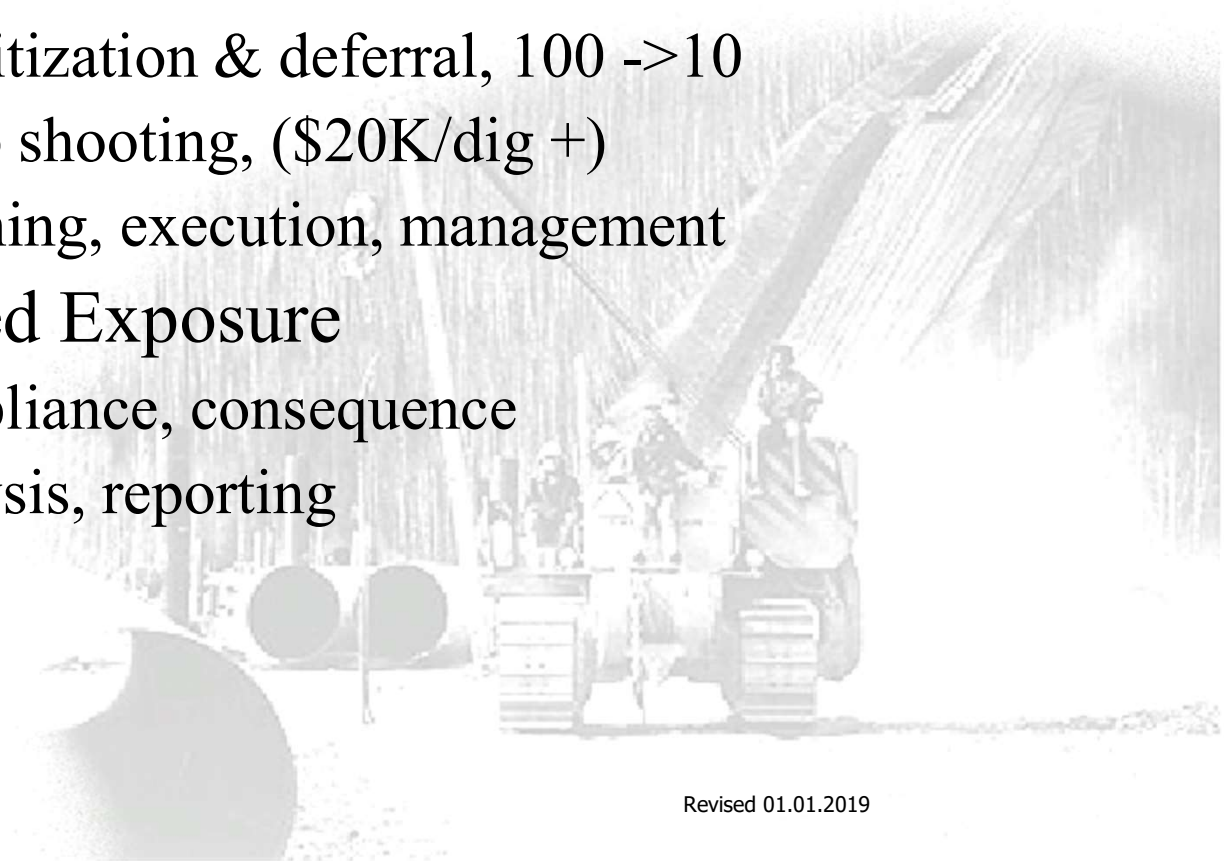
More Informed Decisions

- Leverage Combo Tool Technology (+INS)
  - without spatial information - serious compromise
- Flexible Integration – use all available data
- Decision Support
- Consequence Models
- Risk Assessment



Better Economic Decisions

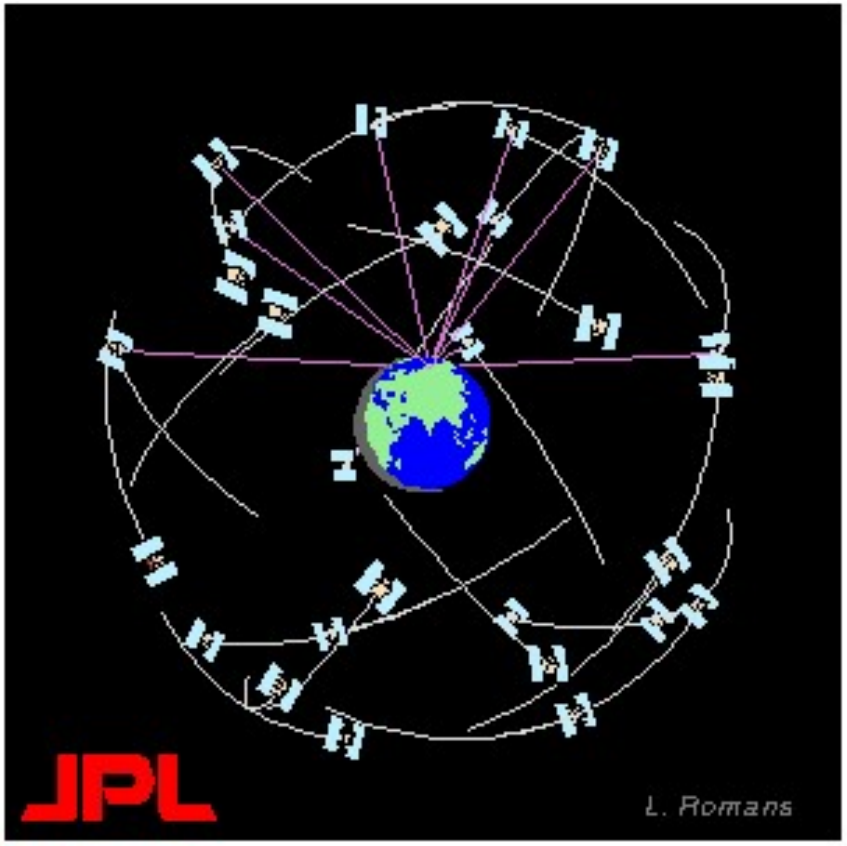
- Reduced Remediation Costs
  - prioritization & deferral, 100 ->10
  - sharp shooting, ($20K/dig +)
  - planning, execution, management
- Reduced Exposure
  - compliance, consequence
  - analysis, reporting



Rapid Solutions

- Turn-around
  - Quicker, more accurate, more reliable
- Integrated
  - Utilization of all corporate data
- Reporting / Dissemination
  - Intranet, WEB, Regulatory Agencies

GPS Overview



- 24 SV's @ 20,000 km orbit
- 12 hour orbit, 55 deg-incline
- 5-11 SV's visible
- GPS Modes
  - GPS (GARMIN, 3-5m)
  - DGPS (ProXRS 1-2m)
  - FSS (Precise, 0.005-0.05m)

INS, AGM & GPS

- INS provides relative position between survey points
- AGM's provide detection & tracking, and coordinate control for the INS
- GPS provides precise coordinates of appurtenances & AGM's
  - Absolute reference for X, Y & Z
  - Centimeter GPS accuracy
- Sub-meter system accuracy.

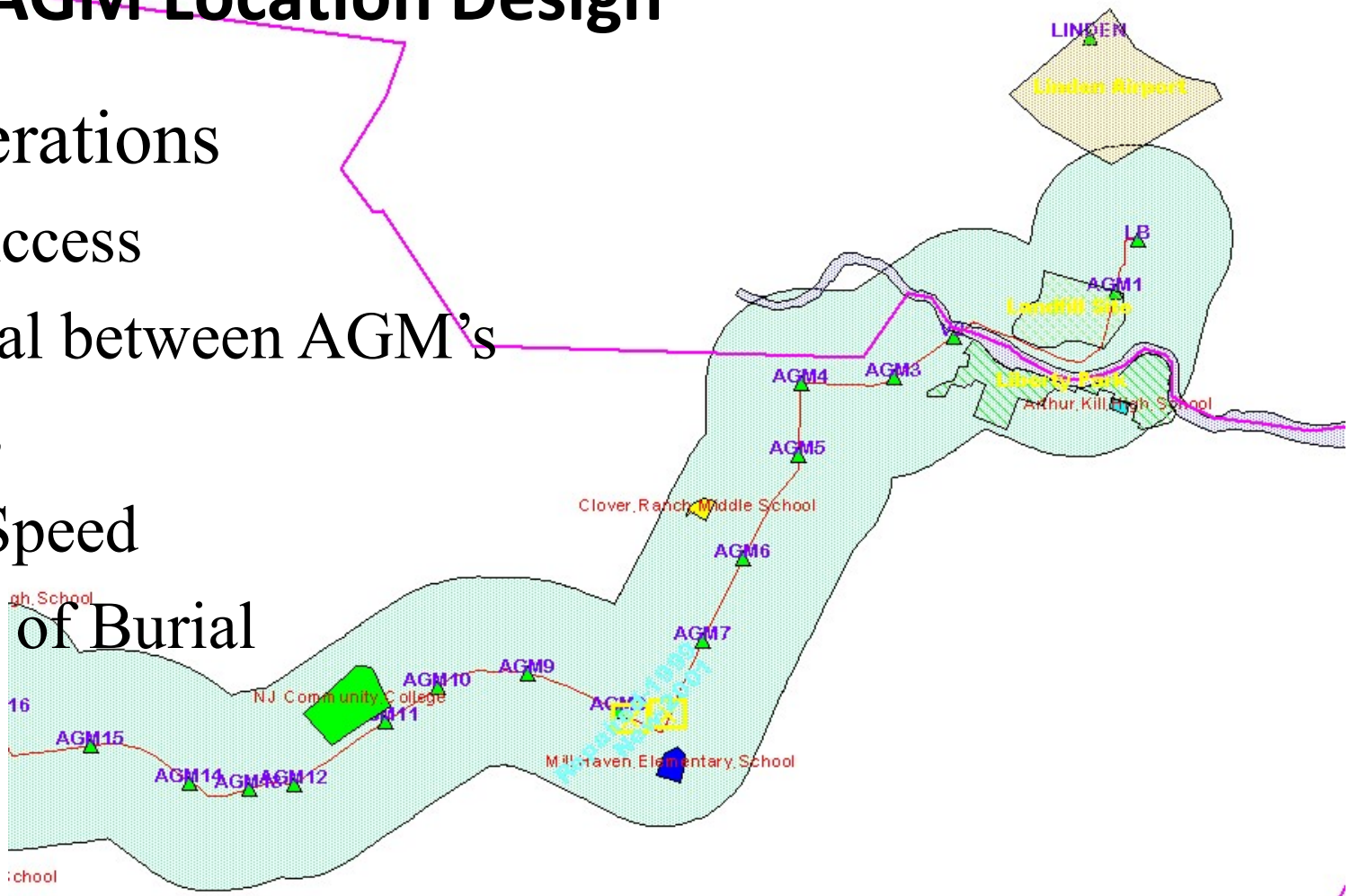
Integrity Management – INS-GPS Concepts

ERROR TYPE	DESCRIPTION	Min. (m)
INS	General inherent error	0.10
Line Location	AGM box locations are staked with line location units. The accuracy of detecting "top center" of the pipeline depends on line diameter, depth of burial, and skill of the operator. This error must be considered.	0.10
AGM - Placement	AGM boxes must be placed exactly over the surveyed marker. Any error in placement will go undetected, and add directly to the final position error.	0.10
AGM - Missed	Generally 1:1000 relative accuracy can be expected, so with each missed AGM, an additional 1 meter can be added.	0.00
AGM - Timing	AGM trigger times must be very accurate. This is used for position updates of the INS. Any error in timing multiplied by the tool speed, will contribute to the along track error.	0.25
Tool Speed	Tool speed must be within the standard requirements for MFL/DEF surveys. For INS, slow speed actually degrades accuracy because it becomes difficult to compute accurate velocity, and drift errors become large. Therefore fast is best.	0.00
Speed Variation	Large speed excursions can be accomodated, only if the odometers remain in contact and within accuracy specifications. The best results todate however, have been in +/-15% average speed variation situations.	0.15
Time Interval	One of the most critical parameters for an INS run, is the time between AGM events. As noted, INS errors accumulate with time, and after 20 minutes become non-linear and difficult to reduce. Therefore, <20 minute intervals are required.	0.25
Trajectory - Bends	The INS has an inherent heading sensitivity, meaning that @ horizontal bends, the biases change, and it become difficult to control errors. Therefore, we try to design the AGM layout to capture most large bends	0.25
TOTAL		**1.20**

Revised 01.01.2019

AGM Location Design

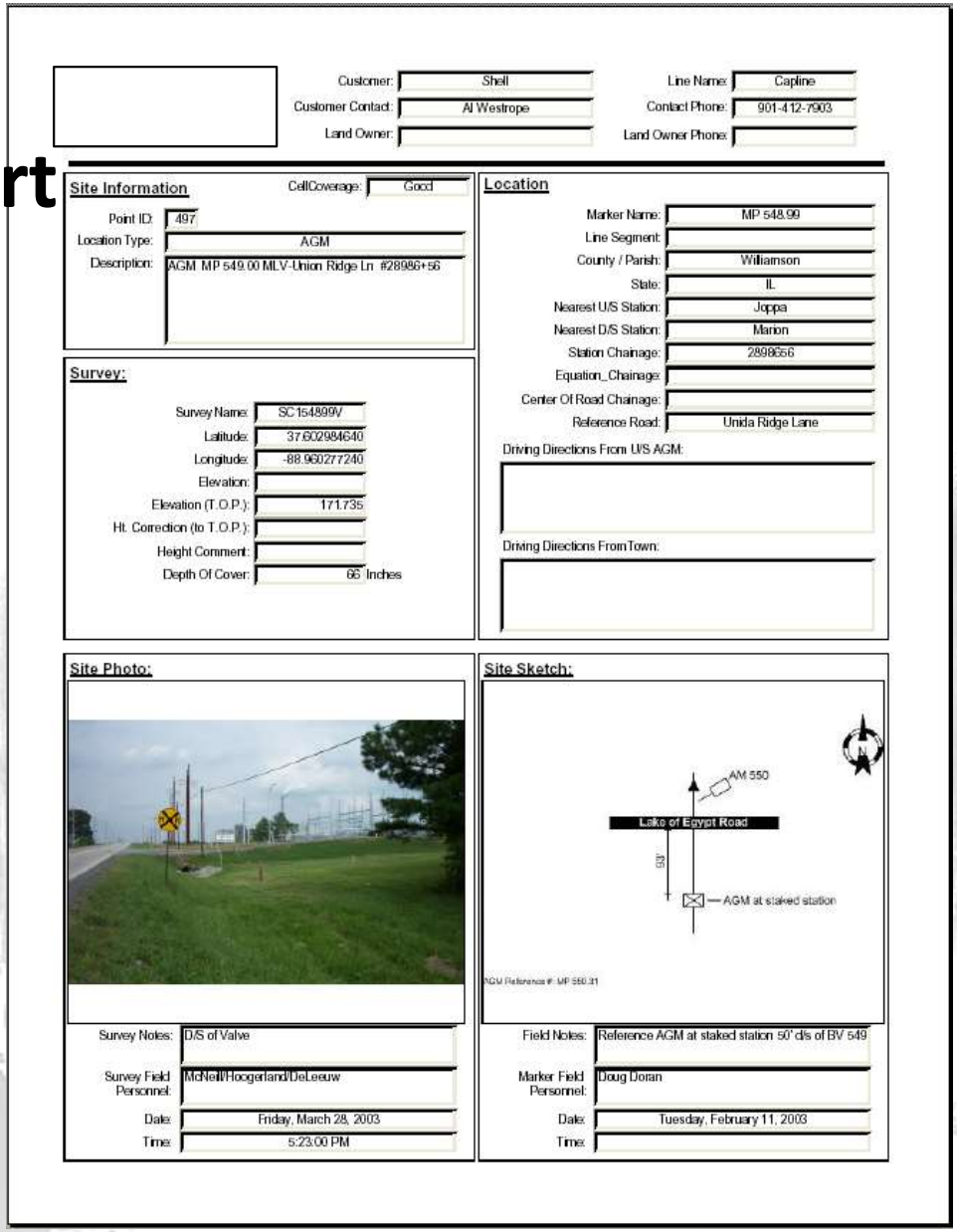
- Considerations
  - Site Access
  - Interval between AGM's
  - Bends
  - Line Speed
  - Depth of Burial



Integrity Management – INS-GPS Concepts

AGM Site Report

- Line Information
- Location
- Survey Summary
- Site Photo
- Site Sketch (recovery)



Customer: Shell
Customer Contact: Al Westrope
Land Owner:
Line Name: Capline
Contact Phone: 901-412-7903
Land Owner Phone:

Site Information
CellCoverage: Good
Point ID: 497
Location Type: AGM
Description: AGM MP 549.00 MLV-Union Ridge Ln #28986+56

Survey:
Survey Name: SC154899V
Latitude: 37.602984640
Longitude: -88.960277240
Elevation:
Elevation (T.O.P.): 171.735
Ht. Correction (to T.O.P.):
Height Comment:
Depth Of Cover: 66 Inches

Location
Marker Name: MP 548.99
Line Segment:
County / Parish: Williamson
State: IL
Nearest U/S Station: Joppa
Nearest D/S Station: Marion
Station Chainage: 2898656
Equation_Chainage:
Center Of Road Chainage:
Reference Road: Unida Ridge Lane
Driving Directions From U/S AGM:
Driving Directions FromTown:

Site Photo:

Site Sketch:
AM 550
Lake of Egypt Road
549
AGM at staked station

Survey Notes: D/S of Valve
Survey Field Personnel: McNeil/Hoogerland/DeLeeuw
Date: Friday, March 28, 2003
Time: 5:23:00 PM

Field Notes: Reference AGM at staked station 50' d/s of BV 549
Marker Field Personnel: Doug Doran
Date: Tuesday, February 11, 2003
Time:

GPS Surveys

- Planning
- Coordination
- Select / Staking / Demarcation
- Reporting
- Coordinate with AGM Layout crew
- MAKE SURE IT'S DONE RIGHT!