Enabling larger-scale onshore seismic with nodes

Introduction

The use of modern, low-cost, lightweight, nodes is enabling faster, safer and denser land seismic acquisition when compared to cabled recording, even with significantly smaller crew sizes (e.g. Ourabah and Chatenay, 2022). In terms of channel count, the largest nodal crews (~165,000 channels) are approaching parity with the largest cabled crews (~200,000 channels; Al-Deen et al., 2014) and, given the trend for ever-denser and larger surveys, nodal crews will soon overtake their cabled peers.

Seismic production on typical vibroseis crews is limited by receiver roll-rates, especially as high-productivity single-source and simultaneous sweeping techniques are increasingly employed. While the operational and geophysical benefits of nodal acquisition have led to rapid adoption in most markets, nodes are not yet routinely used for large-scale surveys in desert environments, typically requiring 50,000 or more channels. To understand what factors may be limiting the uptake of nodes for large-scale seismic surveys, we examine how different nodal system architectures affect receiver throughput and crew resourcing requirements. We use a realistic scenario of a crew rolling 10,000 nodes per day to assess the feasibility of various nodal system designs for land seismic production at scale.

Constraints on Land Seismic Production

Seismic production, as the name suggests, can be likened to a manufacturing process where the raw materials are the source and receiver systems (equipment and personnel), and the finished goods are the seismic deliverables to the processing centre. The theory of constraints (Goldratt and Cox, 1984) is commonly used to analyse and improve manufacturing processes by isolating and addressing the most significant bottleneck in a system so that, when applied iteratively, overall system throughput is maximized.

For vibroseis operations, receiver-side productivity constraints must be addressed to improve overall production. It should be noted that receiver and source productivity are not independent, as the choice of receiver equipment itself impacts vibroseis operational speed. For example, higher source productivity can be achieved using fully-buried nodal recorders that allow unconstrained vibrator navigation when compared to unburied nodes or cabled receivers.

At a high level, all nodal systems follow a similar operational procedure (Figure 1). Nodes are prepared in camp and laid out in the field to listen during source acquisition. Once acquisition is complete, nodes are retrieved and returned to camp so that the recorded seismic data and metadata can be offloaded, quality checked and transcribed for delivery to processing. The cycle then restarts, with nodes prepared again for deployment as the spread rolls across the survey area. Nodal system operation can thus be separated into camp procedures, such as battery charging and data download, and field procedures, such as node planting, activation and retrieval. The efficiency of each can be analysed separately to assess overall constraints on system throughput and opportunities for improvement.

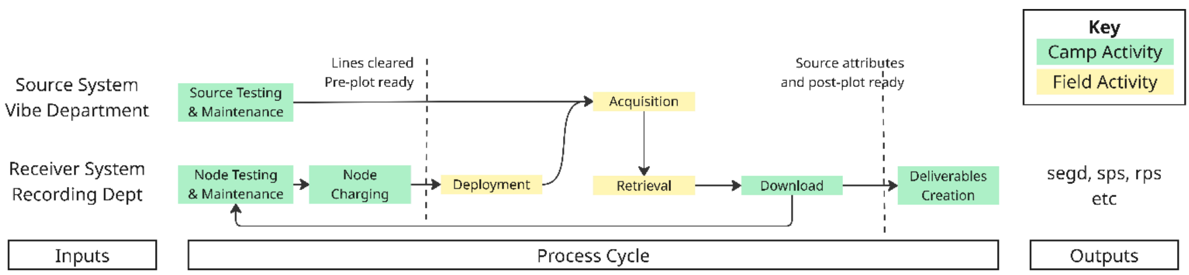

Figure 1: *a simplified model of the land seismic production process*

Field Operational Efficiency

The primary determinant of field operational efficiency of land nodal systems is in-field logistics. The weight and volume of equipment to be transported to the line controls the number and type of vehicles and field personnel required to deploy each receiver station. The node weight and form factor also have a strong influence on the time taken to deploy each station. Small, lightweight nodes with tapered (rather than boxy) form factors are preferred as they are easier to transport and faster to bury. A compact form factor that allows easy burial is also advantageous geophysically: wind noise is common in many areas where large-scale land seismic datasets are acquired, and shallow burial of sensors provides at least 3 dB of wind noise attenuation (Muijzert, 2022). For data quality reasons we should thus prefer a node that can be buried quickly and easily. A further advantage of burial is reduced risk of theft, damage or other interference with equipment by humans or nature. Consequently, a primary focus of instrument manufacturers has been node miniaturization.

Node autonomy also impacts field operations efficiency, HSE risk exposure and crew size, with long autonomy preferred to minimize or, ideally, eliminate any need for battery management on the active spread. 50 days is increasingly requested as the node autonomy specification by seismic contractors, and miniaturization must not come at an undue cost to autonomy.

All other things being equal, sensor choice fundamentally controls node weight and power consumption (Goujon et al., 2021). The average node weight has trended down over recent years (Figure 2a) due to growing acceptance of nodes with limited or no remote QC which require fewer battery cells to achieve an acceptable recording autonomy. Three sensor types (geophones, MEMS and piezoelectric accelerometers) are represented in the current generation of nodal receivers MEMS sensors are extremely small and light but have higher power requirements, paradoxically making MEMS nodes similar in size and weight to nodes containing larger and heavier, but less power-hungry, geophone sensors. Further improvement in the weight of MEMS and geophone-based nodes will be challenging to achieve without sacrificing autonomy. Piezo nodes are in a class of their own in terms of weight while still achieving 50 days autonomy (Figure 2b).

The time to deploy each receiver station is also critical for the viability of large-scale land seismic acquisition, and contractors must balance deployment time with quality. Building a seismic vault at each station is clearly not feasible, but nodes with compact and streamlined form factors can be quickly buried to mitigate the most important receiver-related signal perturbations by ensuring good coupling and verticality combined with surface noise attenuation. In contrast, nodes designed to sit on the ground surface rely on friction for coupling, are easily tilted, directly pick up wind noise and are unshielded from surface noise such as wind. A further benefit of burial is unobstructed source operations with minimized risk of node theft, damage or disruption. Table 1 shows typical deployment cycle times achieved using lightweight nodes in various terrain conditions commonly encountered in large-scale land seismic operations.

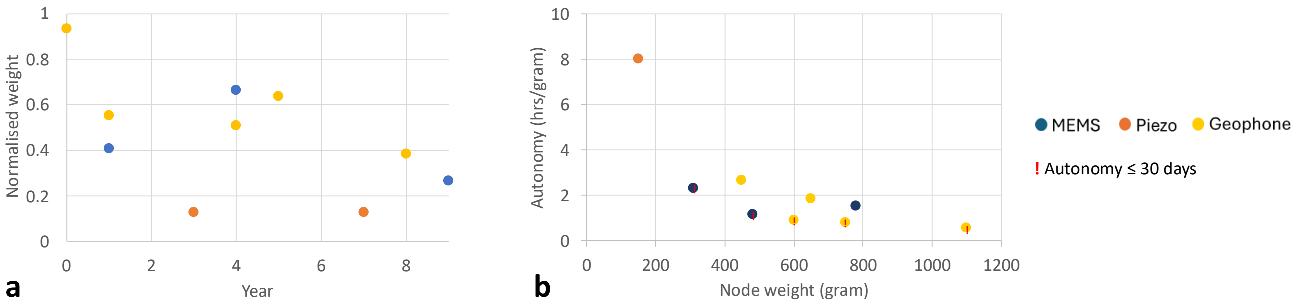

Figure 2: ***(a)*** *Node weight vs year of release. Nodes have become lighter over time.* ***(b)*** *Comparison of node weight and autonomy for various sensor types. Trade-offs between sensor weight and power consumption control the overall weight of MEMS and geophone nodes.*

Terrain	RP Increment	Cycle Time	RP per hour
Flat desert	8.33 m	11 s	327
Flat desert	12.5 m	13 s	276
Rocky desert w offsets	7.5 m	15 s	240
Flat, hard, gravel	25 m	16 s	225
Dunes	25 m	25 s	144

Table 1: *typical deployment cycle times when using lightweight, compact, nodes*

Camp Operations Efficiency

Node battery charging is slower than data offload, hence is the rate-limiting step when preparing nodes in camp. Today's nodal systems can be separated into three types based on their approach to battery charging: i) batch handling of units of 90 nodes using a motorized lifting aid with combined charging and data download hardware (Figure 3); ii) individual or small-batch handling of nodes with combined charging and data download hardware; iii) individual handling of nodes with separate charging and download hardware.

Battery technology is similar across nodal receiver systems, hence charging time is comparable for most nodal systems. Charging rack capacity and loading/unloading efficiency therefore controls overall throughput and camp crew resourcing requirements. Table 2 summarises charging and download hardware and manual handling requirements when rolling 10,000 nodes per day using the three types of nodal recording system described above. High-capacity charging/download racks that can be loaded in bulk are fundamental for enabling large-scale nodal seismic acquisition with nodes.

Various other aspects of recording system design also become increasing important as channel counts and roll-rate increase including: reliability of charging technology (e.g., wired vs wireless), reliability and scalability of data download (e.g., radio vs wired vs optical), and node testing methodology (manual vs automated).

System hardware and software must also be architected to be modular, composable and performant so that receiver systems can be sized appropriately to the project requirements without need for costly customization or bespoke solutions. Fundamental hardware and software design choices control the ability of a system to support high channel-counts and it is extremely difficult to retrofit a system for scalability. The system architecture also closely controls its resiliency to hardware failures, which will always occur on large-scale, long-running, operations. We should prefer a receiver system designed from the outset for the purpose of high-channel-count seismic, architected to prevent isolated failures cascading into a situation that results in system shutdown and crew downtime.

Figure 3: *mechanized loading of modular, high-capacity, charge/download racks (left) and automated high-capacity node tester (right) enable scalable camp operations*

Handling Method	Charging & Download	Rack Capacity & Throughput	Racks	Handling Operations
Batch, motorized	Combined	540 nodes 3,240 nodes/day	4 racks 3 linear m	223
Individual, manual	Combined	36–108 nodes 144–432 nodes/day	35–70 racks 14–42 linear m	20,000
Individual, manual	Separate	32–48 nodes 220–355 nodes/day	56–90 racks 70–120 linear m	40,000

Table 2: *Charging/download rack and manual handling requirements for three types of nodal recording system rolling 10,000 nodes per day*

Conclusions

The technical and operational scalability of nodal receiver systems is a function of inter-related choices between node and charging/download hardware design. As such, systems must be designed holistically with high-channel-count seismic in mind, rather than evolved from existing systems that were not conceived for such applications. Applying the theory of constraints to onshore seismic production with nodes, we find that approaches focussed solely on improving field operational efficiency bottlenecks, such as miniaturisation of recording equipment, shift the constraint on overall seismic production rate onto the process of node preparation in camp and do not, by themselves, make the overall system more suitable or cost-effective for large-scale nodal seismic operations.

Receiver system architectures that rely entirely on manual handling of individual nodes in camp inherently require recording department headcount to increase in proportion to channel count and roll-rate, making them impractical and uneconomic for large-scale seismic operations, as evidenced by the lack of large-scale deployments (50,000+ channels) using such systems. In contrast, systems built from the ground up with scalability in mind, incorporating motorized batch handling and high-capacity charging and download racks, have already been proven at very large scale (165,000 channels, 10,000+ daily roll) with minimal camp recording crew. True scalability is not theoretical but is achievable in practice, opening the door for wider adoption of nodes for large-scale land seismic acquisition.

References

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