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pinpointer.

Digital environmental control to improve traceability and sustainable management of soil and rock materials

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1. Introduction

Excavated soil and rock constitute one of the largest material flows in the Nordic countries. In Sweden, an estimated 60–200 million tonnes arise annually, and resource-efficient handling of these masses was the subject of a government assignment reported by the Swedish EPA in May 2026 [1]. How masses are investigated, classified, transported and received determines both the environmental risk associated with contaminated materials and the potential for reuse.

Despite the volumes involved, documentation of mass transports remains largely analogue. Transport documents are paper-based, information is re-entered manually by each actor, and the chain of custody is fragmented across property owners, environmental consultants, contractors, hauliers and receiving facilities. As a consequence, basic questions, such as how much mass a project has moved, where it went, in which contamination classes, and how complete the documentation is, cannot be answered systematically after the fact.

Electronic reporting has been mandatory for hazardous waste in Sweden since 2020 [5], but the substantially larger flows of excavated soil and rock are not covered by equivalent digital traceability requirements. Regulatory development now points in that direction: the EU Soil Monitoring and Resilience Directive (EU) 2025/2360, in force since December 2025, requires member states to monitor soil health, to establish registers of potentially contaminated sites, and to address emerging contaminants including PFAS [6].

2. Aim

The aim of this work is to characterise, through a descriptive analysis of operational data, what a digital environmental control system for excavated soil and rock delivers in ordinary production use, with respect to (i) load-level traceability across the actor chain, (ii) completeness of documentation, (iii) the ability to characterise mass flows by contamination class, and (iv) the conditions created for sustainable mass management, including transport-work quantification and regional mass balance.

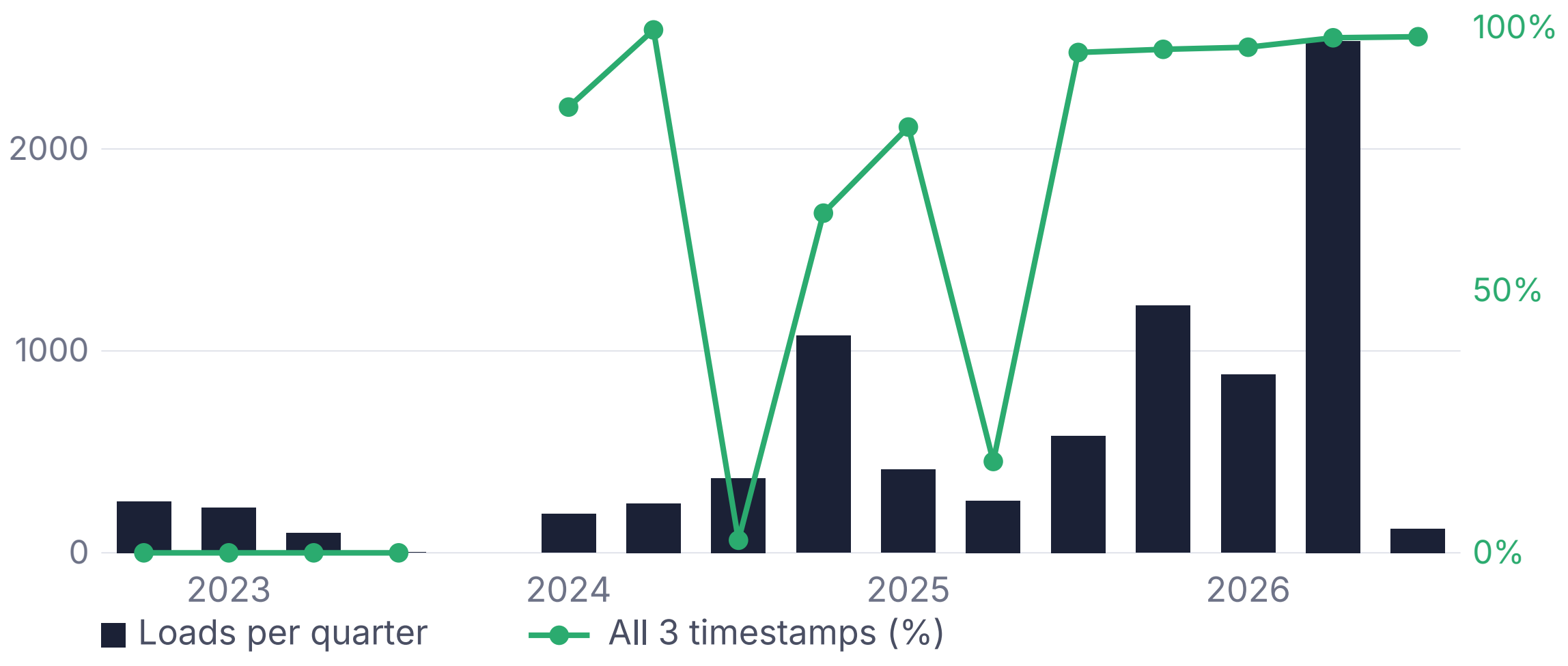

Figure 1. Documented loads per quarter (bars, left axis) and share of loads with all three field-captured timestamps (line, right axis), Oct 2022 – Jul 2026. Field timestamps occur in the data from 2024 onward; variation until mid-2025 reflects differences between concurrent projects, and from Q3 2025 the share stabilises at 95–98 %.

3. Materials and method

3.1 System description

A digital chain-of-custody model has been in operational use in Swedish construction and remediation projects since 2022. Each load is assigned a unique delivery record linking origin, material, contamination class, transport and receiving facility (Fig. 2).

Classification is supported by decision support based on Swedish generic guideline values [2] and established in situ classification methodology [4]; the final classification decision is always made by a qualified environmental consultant, and the assigned class follows each load. Timestamps are captured when loading starts, when the load is accepted and when it is delivered, together with vehicle, quantity and transport distance.

STEP 1
Investigation and classification
Decision support based on national guideline values; final decision by the environmental consultant.
Data: contamination class per load

STEP 2
Digital load identity
Order, material, class and designated receiving facility fixed before the load leaves the site.
Data: unique delivery ID

STEP 3
Transport
Digital delivery record replaces the paper transport document.
Data: vehicle, timestamps, distance

STEP 4
Receiving
Delivery registered at the designated facility with quantity per load.
Data: facility, quantity, time delivered

STEP 5
Verified receipt
Receipt archived; the complete event history per load is available to the parties.
Data: audit trail

Figure 2. The digital chain-of-custody model as evaluated. Verification data are captured at each step and follow the load through the chain.

3.2 Data and analysis

Receipt-level data were extracted from the platform in July 2026 for all projects with a complete receipt-level export available at the time of extraction (convenience sample): eight Swedish construction and remediation projects, one record per load (n = 8 471; Fig. 1). Environmental investigation and classification in the included projects were performed by qualified environmental consultants; in one of the eight projects by Jordnära (co-author). Metrics comprised volume and logistics (mass, transport distance, transport work), documentation completeness per data element, separated into system-enforced and field-captured elements, completeness of a full core record (delivery ID, date, material type, receiving facility, quantity and all three timestamps), and the distribution of contamination classes by number of loads and by mass. Two records (0.02 %) with quantities exceeding any legal vehicle payload (>100 t) were treated as input errors and excluded from mass calculations.

4. Results

System data are summarised in Table 1. The eight projects span remediation and urban construction, 22 receiving facilities and 264 vehicles over almost four years of operation.

PARAMETER	VALUE
Evaluation period	Oct 2022 – Jul 2026[a]
Projects	8
Receiving facilities	22
Vehicles	264
Load records	8 471
Documented mass	249 700 t[b]
Mean load	29.5 t
Transport distance, mean / median	39.8 / 29.8 km
Transport work[c]	10.8 M tonne-km
Complete core record	78.7 %
Contamination class assigned	68.9 %

Table 1. System data from operational use. [a] Three projects ongoing at data extraction. [b] Two records (0.02 %) excluded as input errors. [c] One-way loaded distance; return trips excluded.

Elements enforced at record creation were complete for all records by design. Field-captured timestamps reached 80–84 % overall (Fig. 3). No field timestamps occur in the data before 2024; per-project shares varied between 40 and 99 %, and projects initiated from September 2025 onward reached 93–99 % (Fig. 1). In individual projects the remaining gap could be attributed to a single capture step. The two excluded quantity errors were directly identifiable in the digital format.

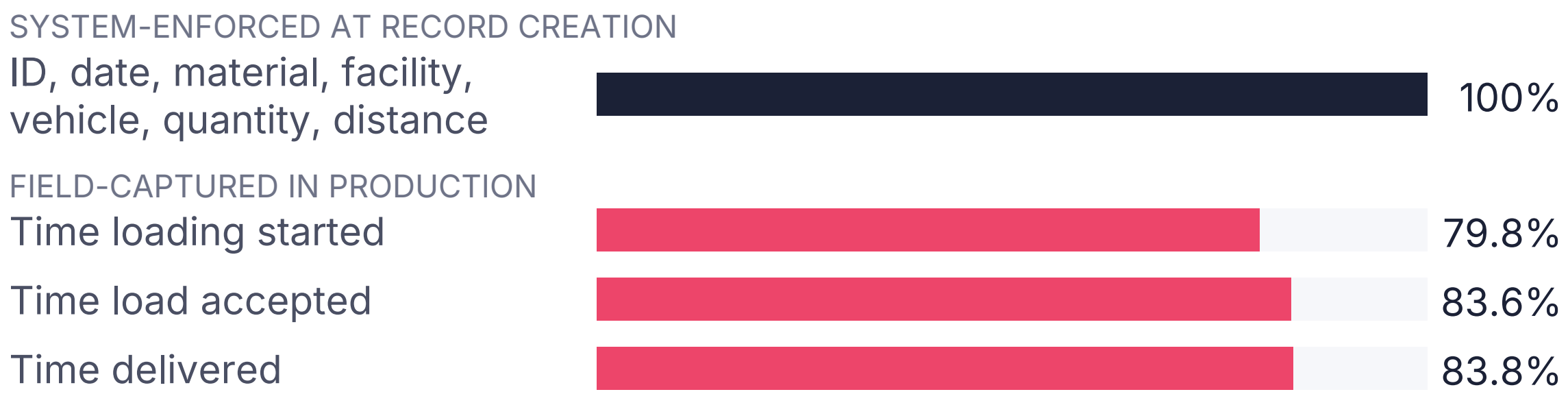

Figure 3. Documentation completeness, n = 8 471 load records, grouped by capture mechanism. System-enforced completeness follows from the data model; field-captured completeness reflects production routines.

A contamination class was assigned for 68.9 % of loads. By mass, classified materials were dominated by the KM–MKM and MKM–FA intervals (Fig. 4); hazardous masses (>FA) made up 1.3 %. Unclassified loads consisted mainly of rock and inert materials.

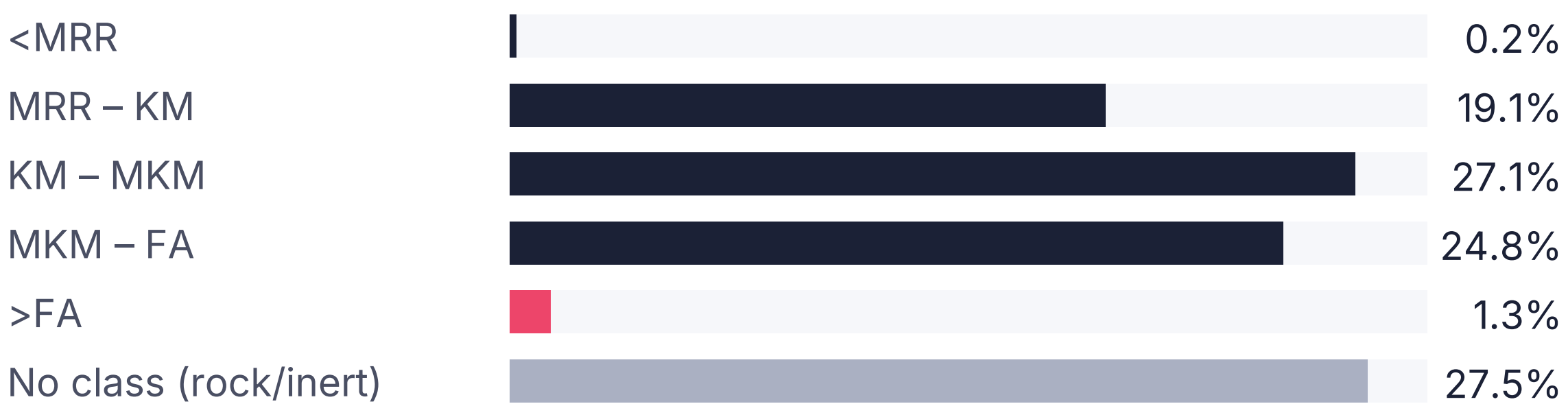

Figure 4. Distribution of documented mass by assigned contamination class. MRR per [3]; KM / MKM per generic guideline values [2]; FA per waste classification under [5]. Assigned class reflects the responsible consultant's decision.

For the corresponding paper-based process, none of the metrics in Table 1 or Figs. 3–4 can be produced retrospectively, as the underlying information does not exist in analyzable form.

> “With verified data per load, supervision can move from after-the-fact document review to proactive follow-up.”
>
> Johan Sörén, Arboga municipality

5. Discussion and outlook

The results indicate that full load-level traceability is practically achievable in ordinary Swedish construction and remediation production, not only in pilot settings. The central difference from analogue routines is that documentation quality becomes measurable: field-captured completeness rose from zero during the introduction years to a stable 95–98 % from Q3 2025, and remaining gaps could be localised to specific capture steps and projects, and addressed. In a paper-based process, neither the level nor the location of missing information can be established. From the environmental consultant’s perspective, load-level class assignment ties the classification decision to each physical transport, closing the documentation gap between the investigation report and the executed removal.

Load-level mass, distance and class data further allow direct quantification of transport work (10.8 M tonne-km one way in this dataset), a prerequisite for assessing the climate impact of mass logistics, and provide the granularity needed for regional mass balance and reuse planning, in line with the data needs following from Directive (EU) 2025/2360 [6].

Limitations: the analysis is descriptive, based on operational data from one platform and a convenience sample of eight projects under Swedish conditions. System data cannot by themselves verify that every physical transport was recorded; coverage verification would require reconciliation against independent sources such as weighbridge registers. The correctness of assigned contamination classes was not independently verified, and the classification module is decision support that does not replace expert judgement.

Outlook. The findings motivate three development directions, currently being implemented in the next system generation: (i) enforced or assisted field capture, including GPS-verified loading and delivery positions, closing the remaining timestamp gap and adding positional verification that each load was collected and delivered at the intended locations; (ii) automated matching of each load against facility-specific acceptance criteria, including PFAS parameters, addressing the fact that class conformity is not independently verified at receipt today; and (iii) standardised data exchange per BEAst Supply 4.0 [7] together with weighbridge reconciliation, enabling coverage verification and the aggregated reporting foreseen by Directive (EU) 2025/2360 [6].

6. Conclusions

- Digital chain-of-custody documentation of 8 471 loads and approximately 250 000 tonnes across eight projects indicates that load-level traceability of soil and rock is practically achievable at production scale.
- Documentation quality becomes measurable and improvable: the share of loads with complete field timestamps rose from zero at introduction to a stable 95–98 % from Q3 2025, a property analogue routines cannot offer.
- Class- and mass-resolved data enable transport-work quantification and regional mass balance, core prerequisites for sustainable land management and increased reuse.
- Automated receiving criteria, including PFAS parameters, and standardised data exchange are the natural next step toward the monitoring and register requirements of the EU Soil Monitoring and Resilience Directive (2025/2360).

References

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Disclosure. J. Klintred is founder and CEO of Pinpointer AB, the developer of the evaluated system. V. Lundborg represents Jordnära, which served as environmental consultant in one of the included projects. **Acknowledgements.** The authors thank the participating contractors, receiving facilities and Arboga municipality. **Data.** Receipt-level export from the Pinpointer platform, July 2026, eight projects; results reported in aggregate only, no personal data.

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