Emerging Tech Interventions in Contract Management of Road Infrastructure

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AVP- Contracts Cube Highways

Agenda

1. Industry Context & Digital Deficit
2. Blockchain & Smart-Contract Fundamentals
3. A Decentralised Contracting System
4. Computing Critical Clauses
5. Blockchain leveraged with IoT
6. Emerging Synergies and future direction

Industry Context & Digital Deficit

Construction sector's digital deficit is causing structural inefficiencies such as disputes, fragmentation and asset under-utilisation

1.1 – A Sector That Builds The World But Lags It Digitally

Construction is one of the largest sectors of the global economy — and one of the least productive.

13%

share of global GDP attributable to construction.

Ribeirinho et al., 2020

<1%

annual productivity growth over the last two decades.

Ribeirinho et al., 2020

5%

earnings before interest & tax (EBIT) margin sector-wide.

Ribeirinho et al., 2020

$15.2 T

projected global construction market size by 2030.

Oxford Economics, 2021

1.2 – Root Causes – Claims, delays and disputes

A Fragmented Value-chain Operating On Traditional, Hierarchy-based Contracts.

Misaligned contracts & siloed data

Inconsistent records and version conflicts across stakeholder organisations.

Delayed payments & weak record-keeping

In-field progress drifts from on-paper progress; payment cycles stretch.

Disputed delays & variation claims

Attribution of delay accountability is opaque, manual and contested.

Improper risk allocation

Lack of accountability and unclear digital rights across multi-party flows.

Poor visibility of physical assets

Equipment idle time, unauthorised use and breakdowns hidden behind manual logs.

1.3 – Mapping Technology To Root Causes

Five blockchain attributes mapped to five contract-management challenges.

Decentralization

Removes single-point control over records and approvals.

Immutability

Tamper-proof history of every transaction and approval.

Traceability

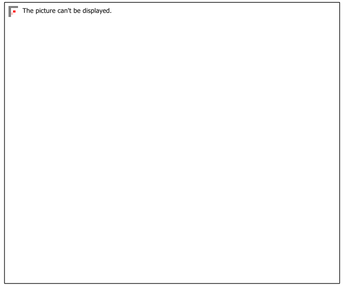
Real-time, time-stamped audit trail for all stakeholders.

Smart contracts

Self-executing clauses that automate bottleneck workflows.

Permissioned access

Role-based confidentiality calibrated to commercial sensitivity.



Blockchain & Smart-Contract Fundamentals

Use of distributed ledger, smart contracts, platform for blockchain

2.1 – Smart Contracts

A code, not a contract — but legal contracts can be automated using smart clauses (Mason 2017). A smart legal contract joins three layers: legal text · data model · execution logic.

Self-executing programs that fire when contractual conditions are met.

Verified Execution

Output validated by the network before being committed.

Conditional logic

Standard if / then rules drive deterministic outcomes.

Ledger-bound state

Reads from and writes to the underlying blockchain.

Tamper-proof & immutable

Logic cannot be altered once deployed and endorsed.

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2.2 – Distributed Ledger Technology

No central administrator; every peer holds an up-to-date copy of the ledger.

A hash-linked chain of blocks, replicated across stakeholders, validated by consensus.

Cryptographic immutability

Once information is recorded:
it cannot easily be modified,
every change leaves evidence

Prevents manipulation of:
invoices,
claims,
variation orders,
approvals,
inspection records.

Decentralized Storage

No single organization controls the database. Instead:
all authorized stakeholders share synchronized records.

Reduces dependence on one authority,

Reduces disputes over "whose version is correct."

Consensus Validation

Before a transaction is accepted: the network validates it collectively.

Example:
contractor claims work completion,
consultant validates,
client endorses,
transaction becomes official.

2.3 – Platform Of Choice

Desirable to have enterprise-grade confidentiality, channel architecture and pluggable consensus.

EXECUTE

Peers run the smart contract logic

Example:
contractor submits request,
system checks conditions.

Network
Stakeholder consortium

Includes: client, contractor, consultant, suppliers, etc.

→

ORDER

Transactions are arranged chronologically.

Ensures:
consistency, synchronization.

Channels
Private communication sub-networks.
Different stakeholders see different information.

Example: procurement channel,
payment channel,
maintenance channel.

→

VALIDATE & COMMIT

All authorized nodes:
validate transaction,
update ledger copies.

MSP (Membership Service Provider)
Identity-management system.

Controls:
who can access,
who can approve,
what permissions each participant has.

A Decentralised Contracting System

Using a permissioned blockchain network of stakeholders for construction megaprojects.

3.1 – Problem & Goal

Reform the contracting process
make it transparent, real-time and decentralised by design.

Identify challenges in current contract management	Build a conceptual model of stakeholders	Formulate a smart contract clause	Demonstrate & evaluate via prototype
Across planning, decision-making and contract execution.	A permissioned blockchain network with well-defined roles.	Automate a sample construction contract clause end-to-end.	Build, demonstrate and validate against a megaproject case.

3.2 – Method

Design Science Research — a practitioner oriented, five-step strategy.

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
IDENTIFY	**DEFINE**	**CONCEPTUALISE**	**PROTOTYPE**	**VALIDATE**
Map challenges in the current contracting system.	Set objectives; map blockchain attributes to challenges.	Build the HLF network & RACI roles; draft smart clause.	Implement on IBM Cloud Blockchain Platform.	Demonstrate to industry experts and collect feedback.

3.3 – Case Study

Dedicated Freight Corridors of India.

A representative megaproject — multi-stakeholder, multi-level decision-making, public & private finance, FIDIC contracts.

$10B	2	1,504 KM	1,861 KM
Approx. Estimated Project Cost.	Corridors — Western & Eastern.	WDFC — Dadri ↔ JNP Mumbai (JICA-funded).	EDFC — Sahnewal ↔ Dankuni (World Bank).

DFC C IL MINISTRY OF RAILWAYS J ICA WORLD BANK

3.4 – RAC I matrix – 8 Stakeholders, 16 Project Activities

Roles map directly to channel access controls and endorsement policy on the network.

Activity	MOR	JICA/WB	DFCCIL	PMC	Contractor	Designer	Supplier	Sub-Contractor
Bid Document Preparation	C	I	R / A	----	----	----	----	----
Tender & Award of contract	I	C	R / A	I	C	----	----	----
Financial Structuring	C	R	R / A	R	C	----	----	----
Design	I	I	C	A	A	R	----	----
Supply	I	I	C	A	A	----	----	R
Construction	I	I	C	A	A	----	----	R
Performance monitoring	I	I	C	R / A	R	R	R	R
Testing & Commissioning	I	I	R	R / A	R / A	----	----	----
O & M	R / A	I	R / A	----	----	----	----	----

3.8 – Outcome

Contributions & acknowledged limitations.

Contributions

- **Workable, demonstrated solution**
  First end-to-end blockchain contracting prototype for megaprojects.
- **Reusable conceptual model**
  RACI-linked permissions, channel architecture, endorsement policy.
- **Reference for future research**

Limitations & Scope

- **Economic viability untested**
  Cost–benefit varies by project scale
- **Single clause automated**
  Price variation only — broader clause coverage required.
- **Industry adoption barriers**
  Skill, regulation, organisational change.

Computable Clauses for Delay & Price Variation

Automating critical material clauses such as delay accountability, compensation and price variation through smart legal contracts.

4.1 – Why This Matters

Time overrun is chronic — and disputes over delay accountability cost more than the delay itself

CRUX Insight Report (HKA, 2022) — analysis of 1,600+ projects across 100 countries, valued > $2 trillion.

16.5 months	68.6%	$4.5T	$15.2T
Average Claimed Time Extension Across the Surveyed Projects.	Equivalent Share of the Originally Planned Project Duration.	Global Construction Market Growth, 2020 → 2030.	Projected Total Market by 2030 .

4.2 – Delay Taxonomy

A single delay event sits across two axes — criticality & accountability.

By Nature

Critical On the project critical path; impacts completion date.	**Non-critical** Float available; no extension required.
Excusable Beyond contractor's reasonable control.	**Non-excusable** Contractor's responsibility — exposes to LD.
Concurrent Independent delays overlapping in time.	**Compensable** Eligible for monetary compensation, not just EoT.

By Accountability

Employer – Attributed

Site, scope & payments
Late site handover, design changes, delayed payments. Contractor entitled to EoT and delay damages.

Contractor – Attributed

Resources & site management
Insufficient resources, poor planning. Triggers liquidated damages.

Force Majeure

Beyond either party
Pandemics, third-party events. EoT only — no compensation.

4.3 – Smart Legal Contracts

Two semantics — one machine-executable, one human-binding.

Operational	Denotational
Deterministic Logic If/then statements that automate computation. Machine-readable; ensures reproducibility.	**Legal Text** Non-operational terms preserving legal enforceability. Human-readable; binding.

Built on the Accord Project codebase using Concerto (data model) and Ergo (execution logic).

Legal text	Data model Concerto	Logic · Ergo
Human-readable	**Machine-readable**	**Machine-executable**

4.4 – Clauses Automated

Two FIDIC Yellow Book clauses lifted into computable form.

FIDIC SUB-CLAUSE 8.7

Delay damages.
Compensation paid by the contractor when delay is attributable to the contractor.

$LC = K \times P$ $K = (DC / DT) + (DC / DT - 0.5) \times (DT / S)$

P = qualitative factor
DC = contractor-attributed delay
DT = total delay
S = stipulated duration.

FIDIC SUB-CLAUSE 13.8

Adjustment for changes in cost.
Price variation calculated against base & current government indices for labour, cement, steel, copper, electrical wires & fuel.

Adjustment $M(a, b, c, L_n, L_0, M_n, M_0)$ a = 0.20 (fixed)
b = 0.10 (labour)
c = 0.05 (cement)

Indices retrieved via blockchain oracles from official feeds (Labour Bureau · MoCI).

4.5 – Execution & Testing

The clause executed across three input cases — outputs aligned with manual calculation.

Case 01

Contractor-heavy delay

S=120 DT=60 DC=45 P=3

2.625%

Levy of compensation as % of tendered value.

Case 02

Employer-heavy delay

S=120 DT=120 DC=30

0%

Code emits an error obligation: "employer not liable to receive delay damages."

Case 03

Mixed Accountability

S=100 DT=150 DC=75 P=3

1.5%

K = 0.5 → LC = 1.5% of tendered value.

4.6 - Case Study

A 175-km design–build single-line railway corridor.

Contract signed 30 Sep 2020, contract value $88.6 M, time for completion 900 days. Project suffered land unavailability, delayed access, heavy rainfall and COVID-19 lockdowns.

CONTRACT VALUE

$88.6 M

Tender Value, Original Work

EoT REQUEST

537 Days

Extension claimed by contractor.

PRICE VARIATION

$114.18 M

Computed Actual Cost After Adjustment

CAP APPLIED

$93.0 3 M

When 5% cap above contract value enforced.

4.7 – Outcome

Contributions & acknowledged limitations.

Contributions

- **Computable FIDIC clauses**
  Operational + denotational semantics for delay damages and price variation.
- **Tested execution logic**
  Validated across three input cases plus a real megaproject.
- **Globally applicable**
  Formulae and oracles generalise across FIDIC-based contracts.

Limitations & Scope

- **Two clauses only**
  Broader clause coverage required (variations, EOT trigger conditions, claims).
- **Oracle Dependence**
  Index integrity hinges on trusted external data feeds.
- **Legal & jurisdictional fit**
  Smart legal contract enforceability varies by jurisdiction

Blockchain-of-Things

IoT-integrated, Hyperledger Fabric-based system for transparent, real-time Asset management.

5.1 – Problem Framing

HIA
Highways Investor Association

Assets are the backbone of infrastructure, whether during construction or during O&M phase

Maintainability, Serviceability, theft, breakdowns and manual record-keeping compound across multi-site programmes.

During Construction Phase, how the construction equipment fair?

36%

share of overall project costs attributed to equipment-related issues.

Prasertrungruang & Hadikusumo, 2009

30-50%

share of operational time during which construction equipment remains idle.

Ushadevi et al., 2022

~20%

budget loss attributable to inadequate maintenance.

Shash & Ghazi, 2003

40%

downtime reduction potential from predictive maintenance.

Industry literature

5.2 – Challenge Identification

What practitioners actually struggle with — in their own words.

Project managers, deputy PMs, project directors, planning engineers across multiple construction firms.

TOP CHALLENGES

Real-time tracking deficiencies	**30.32%**
Lack of trained operators	**21.31%**
Long lead times for spare parts	**20.49%**
Decision-making delays	**13.11%**
Weather conditions	**8.19%**
High maintenance costs	**6.55%**

EQUIPMENT IDLE TIME ON SITE

10–25% idle	63.30%
25–50% idle	18.40%
< 10% idle	10.20%
> 50% idle	8.20%

Over 81% of respondents report that more than 10% of their equipment sits idle on site.

5.3 – Tech Adoption Gap

Practitioners want IoT data — but most still rely on manual oversight.

A clear gap between aspiration (IoT priorities) and practice (manual logs and on-site supervisors).

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Current Equipment-Management Approach

Traditional / manual methods	**51.0 %**
Considering IoT & AI	**28.6 %**
Use IoT sensors	**12.0 %**
Use IoT + AI optimization	**8.2 %**

Most-Valued IoT Data Types

Real-Time Location Tracking	**25.5 %**
Usage Hours & Operational Efficiency	**25.5 %**
Idle-Time Tracking	**23.4 %**
Maintenance Records	**11.72 %**
Load/Performance Monitoring	**13.79 %**

5.5 – CONCEPTUAL MODEL

Thirteen stakeholders interacting across three permissioned channels.

Equipment request & allocation

Project Managers and Planning Engineers raise requests via the Web-Based Application. Smart Contract S1 validates; Ledger L1 records.

Pm · Planning Engr · Scm · Store Mgr · Supplier

Maintenance & scheduling

Smart Contract S2 automates scheduling. Ledger L2 stores maintenance and equipment-health data.

PM · SITE ENGR · SAFETY ENGR · P&M MGR

Inventory & procurement

Smart Contract S3 manages procurement and stock updates. Ledger L3 records supply records and management decisions.

PURCHASE · P&M DEPT · MGMT TEAM · SUPPLIER

5.7 – Outcome

Contributions & acknowledged limitations.

Contributions

- **Consortium network with channels**
  Distinct channels for allocation, monitoring and procurement.
- **Role-based access control**
  Maps blockchain permissions onto real organisational roles.
- **Asset tokenisation**
  Equipment and users as digital tokens — atomic transfers.
- **Workflow automation**
  Filtering, validation, ownership transfer + GraphQL fallback.
- **User-centric application layer**
  Web dashboard abstracts blockchain complexity from end users.

Limitations & Scope

- **Simulated IoT integration**
  Live sensor feed not yet deployed at scale.
- **Single device, single use case**
  PoC scoped to one IoT device due to time/cost.
- **Survey size moderate**
  49 respondents — generalisability is bounded.
- **Adoption headwinds**
  Workforce training, ERP interoperability, ROI evaluation.

Emerging Directions

From contracting governance, to computable clauses, to physical asset operations.

6.1 – Contracting → Computable Clauses → Operational Asset Management

Decentralised contracting		Computable clauses		BoTEMS · IoT-integrated
Network of stakeholders. RACI & channels. SCOPE: governance.	→	FIDIC 8.7 & 13.8 automated. Operational + denotational semantics. SCOPE: contract logic.	→	BoT-enabled equipment management. Tokenised assets, real-time data. SCOPE: physical operations.
FOUNDATION LAYER		LOGIC LAYER		OPERATIONS LAYER

6.2 – Combined Contribution

An end-to-end blueprint: from how parties contract, to how clauses execute, to how assets are tracked.

Hyperledger Fabric

SHARED CHASSIS

Permissioned consortium, channel architecture, MSP-based identity — across all three studies.

Roles → Permissions

SHARED PRINCIPLE

RACI in P1, endorsement policy in P2, role-based access in P3.

Smart Contracts

SHARED MECHANISM

From price variation, to delay damages, to ownership transfer of physical assets.

Trust by Design

SHARED OUTCOME

Transparency, traceability and accountability without a central administrator.

6.3 – Future Directions

Interoperability Cross-chain & ERP interoperability — bridging consortium ledgers with enterprise systems.	**BIM & digital twins** Anchor BIM models & twin states on-chain for trustworthy lifecycle data.	**Predictive maintenance** Couple IoT streams with ML to schedule interventions before breakdown.
AI integration Clause drafting, claim classification and dispute risk scoring on validated data.	**Scalability** Off-chain storage (IPFS), throughput tuning, hybrid networks for high-volume IoT.	**Real-time oracles** Trusted feeds for indices, weather, regulatory data feeding contract logic.
Legal robustness Cross-jurisdiction enforceability of smart legal contracts.	**Cost–benefit at scale** ROI modelling and adoption thresholds across project sizes.	**Workforce & governance** Skill development, regulatory frameworks, organisational change management.

Where the next decade of work sits — across legal, technical & operational frontiers.

6.4 – Conclusion

Blockchain & smart contracts can institute reform across the construction value chain, when matched to a calibrated technical & legal stack.

Governance reformed by permissioned, decentralised contracting networks.	Disputes contained by computable clauses with deterministic outcomes.	Operations made auditable through IoT + blockchain of things asset tracking.	Adoption still constrained by legal, scalability & ROI considerations.

6.5 – CREDITS and PRIMARY REFERENCES

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Thank You.