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The supply chain gets smarter

Autonomous supply chains at the nexus of IoT, AI, and blockchain

Supply chains are evolving into more network-like, collaborative ecosystems – with implications for all the parties involved; and opportunities to leverage new technologies to augment traditional supply chain management practices.

In this paper we look at how IoT, AI, and blockchain (in combination; and when integrated with more traditional business systems and business network practices) can give form to the notion of a smarter, more 'autonomous' supply chain; how these components fit together, and how they each add value generally; and use some examples (around tracking, traceability and asset provenance; digital twinning and whole-life lifecycle management; and end-to-end insurance, global payments, and logistics admin) to illustrate the affordances specifically (as well as look at the benefits and risks in deployment).

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Executive summary

The first point to bear in mind before attempting to embark on any 'more sophisticated' autonomous supply chain endeavour, is that modern supply ecosystems need to run on a 'digital backbone' that enables all these other technological advances to bear fruit. Unless you have a fully-connected digital supply chain network in the first place, then it's very unlikely that you'll be able to realise the benefits that an infusion of IoT, AI, and blockchain promises to bring.

However, once that foundation is in place, whilst each of the three technologies this paper looks at (i.e. IoT, AI, and blockchain) *can* add value to supply chain management in isolation; it's *in combination* that they present the opportunity to be deployed in some well-defined use case scenarios in order to deliver a smarter, more intelligent, more autonomous supply chain operation – especially as supply chains evolve into networks and ecosystems; and with expectations of achieving efficiency gains whilst delivering more highly granular services at scale (and autonomously).

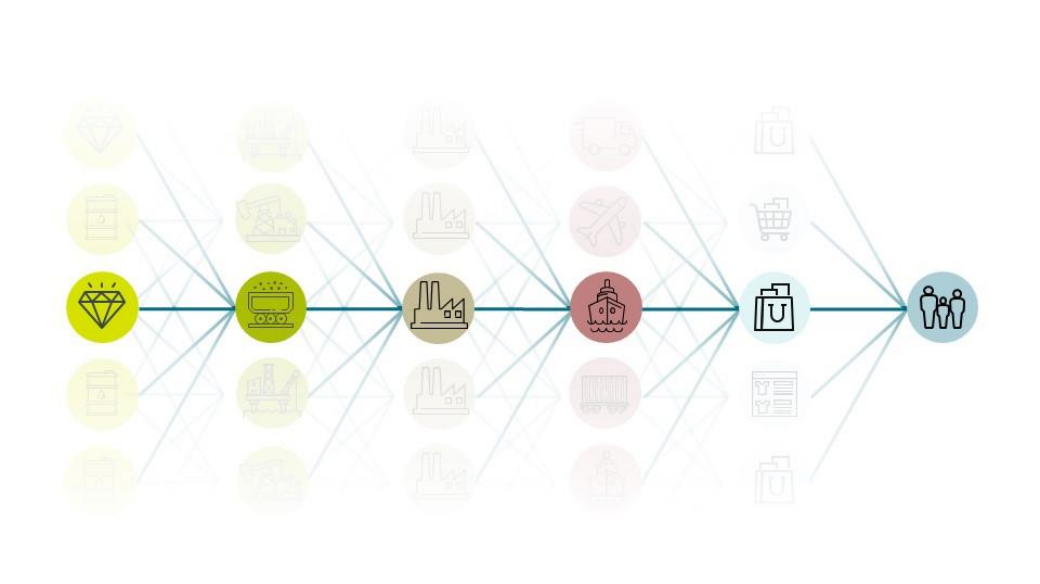
The evolving supply chain network

In order to show how IoT, AI and blockchain technologies might add value as use cases evolve, we first need to look at some of the challenges that organisations face when transacting business with each other across disparate and elongated supply chains.

We can think of all the parties involved as being part of a business system; whose component parts all communicate, and exchange assets and value, with each another as part of a supply 'network'. In 'pre-digital' times, these systems were complicated, expensive and time-consuming to set up and (re)configure – so they tended to be relatively static, linear (and 'chain-like').

Figure 1 (below) illustrates this type of arrangement, with raw materials (on the left-hand side) being supplied to factories where they're made into goods, which are then shipped out to retail points, and ultimately sold to consumers (on the right-hand side).

Figure 1 Simple supply chains

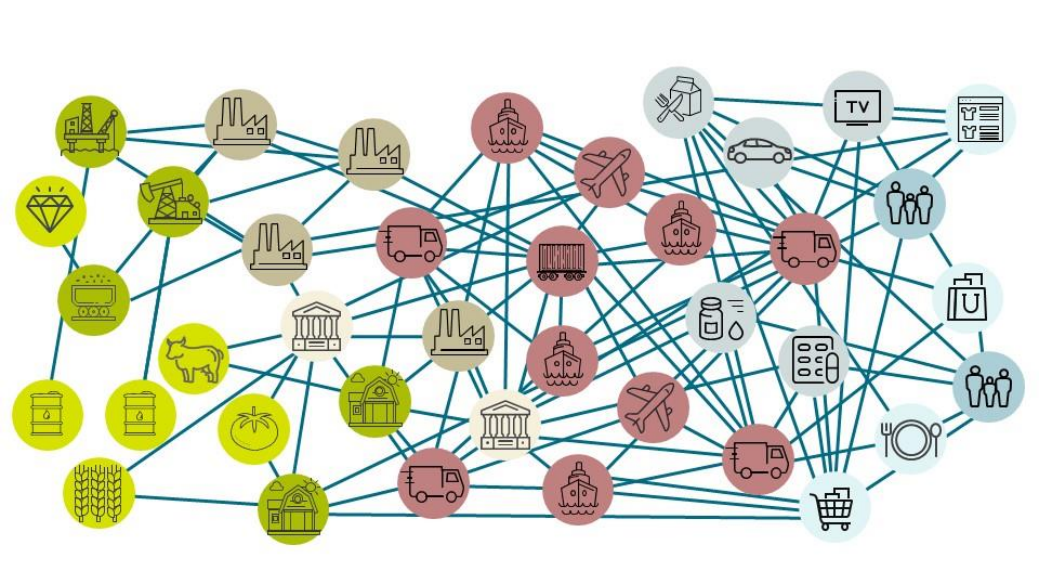


Source: MWD Advisors

However the modern phenomenon of global mass interconnectivity has brought in more and more flexibility, and greater scales of operations – giving rise to increasingly diverse and complex ecosystems (as shown in Figure 2, below).

This still shows raw materials or ingredients (on the left-hand side), being supplied to farms and factories where they're made into goods or food, which are then shipped out to a variety of retail points, and ultimately sold to consumers (on the right-hand side) – but with the inclusion of some regulators and other interested parties thrown into the mix to illustrate the complexities that quickly invade the system as soon as the number of partners involved scales significantly. Nowadays supply chain transactions may be co-ordinated across multiple parties, and spread across multiple geographies and legal jurisdictions. Some of these 'parties' will be organisations; some will be individuals; and some may be automated, network-connected devices and business infrastructure components. Collectively they all represent customers, suppliers, partners, regulators, and so on – each with a stake in the market they're operating in.

Figure 2 Supply chain networks



Source: MWD Advisors

Current business networks are therefore evolving into digital *ecosystems* where there's a much stronger emphasis on co-creation and collaboration amongst the myriad parties involved, and where the relationships and transactions between the people, systems, things, etc., across multiple boundaries (and in different 'zones of trust') all have to be managed effectively and efficiently… which can prove challenging and costly to orchestrate, if we only have the 'traditional' means at our disposal.

We need a way of re-imagining supply chains or supply networks more as collaborative ecosystems, and for that we need to introduce new technologies and practices into the mix – ones that facilitate this modern way of working, at scale, at speed, and with greater efficiency; not only improving and enhancing today's processes, but also innovating new services which weren't even possible (or, at least, affordably practical!) before.

Introducing the 'autonomous supply chain'

Laying the digital foundation

However, before we get into any of the new technologies in detail, it's worth stressing that modern supply ecosystems first need to be running on a 'digital backbone' to enable any of these other technological advances to bear fruit. If companies don't have a fully-connected digital supply chain (i.e. exchanging business transactions electronically), as the foundation of their network, then they won't be able to exploit IoT, AI, and blockchain to realise any of the benefits discussed in this paper. It's imperative that supply chain ecosystem processes are digitised across the board, with the data made available across an interoperable platform, so that key transaction data (as well as IoT sensor data) is available in machine-readable form all parties in the network.

Basically, if (say) half your supply chain is still exchanging paper-based orders and invoices, etc. then any gains you might hope to see from deploying this new tech will be outweighed by the inefficiencies remaining in your manual, paper-based processes. It'd be like trying to fill the bath without putting the plug in!

Also, whilst you're laying this 'digital foundation', it's worth bearing in mind the advantages that come with moving operations to the cloud – especially when you need to scale as your supply chain operations change in order to meet new market conditions, or expand into new sectors. These are precisely the scenarios when you need the flexibility, elasticity, and accelerated time-to value that comes with cloud deployments; and when you need a platform accessible by multiple parties both inside and outside your organisation.

The road to supply chain autonomy

Any one out of IoT, AI or blockchain technologies in isolation can enrich the processes of supply chain management; but in combination their infusion with traditional business systems and business networks extends the reach, and increases the granularity, of the data companies are able to collect. It can then be used to model ecosystem behaviour and provision smart assistance to supply chain processes (and even automate some aspects of business, such as negotiating with logistics partners based on market conditions and predictions about service quality).

Companies can be assured of the veracity of the data because it's indelibly recorded on an immutable ledger; plus they can use other blockchain capabilities to extend business processes beyond organisational boundaries – using decentralised applications encoded in so-called 'smart contracts' that operate autonomously (triggered by events and fed by both on-chain and off-chain data sources). Examples include automatically initiating insurance cover when shipments cross into particular jurisdictions; or automating pay-outs based on known world events, etc.

In short, together these technologies have the potential to make supply chain operations better connected, smarter, and give substance to the concept of 'autonomous freight'… or the smarter, autonomous supply chain. Their contributions are outlined below.

IoT

IoT and big data analytics have already brought predictive maintenance, re-order, and supply practices to modern businesses. Embedded sensors on cars, ships, planes, trains, plant machinery, or buildings are already able to provide data that's either analysed *in situ* at the edge, or sent up to be crunched in the cloud in order to derive insight into that device's behaviour and the wearing and tearing effects on its components – whereupon decisions can be made to advance a scheduled maintenance stop, perhaps swapping out a failing part before it actually fails and causes an accident (or at least leads to costly unplanned downtime).

Integration between these IoT platforms, their analytics layer, and supply chain management systems enables

parts to be sourced, proactively replenished, and delivered to the most convenient location – providing a more seamless experience for the end customer.

AI

Add a modicum of AI or machine learning into the mix, and you have the potential to operate a 'learning system', where the behaviour of assets under management (and the ecosystem they exist within) are modelled to establish feedback loops, that help refine those recommendations – say, looking at component behaviour over time right across the ecosystem it's in use, correlating with other datapoints, like weather or market data, to get a more highly granular, and more reliable, 360-degree view of the environment; and become 'prescriptive' – automating (within reason) the actions taken on the back of predictions so they have aspects that appear autonomous, to an extent – making the whole system 'smarter' as a result.

(There's also, of course, a whole world of customer-facing AI opportunities to make the interface between the supply chain system and the people who operate and benefit from it more intuitive, and tuned to particular scenarios (like diagnostics), which also benefit from the wealth of data that's gone into refining the model… but in this paper we concentrate on the application of AI or machine learning 'below the surface'.)

Blockchain

There are two main ways that blockchain adds value in the mix. They can provide:

- the ability to execute code autonomously, across a distributed application that resides on a blockchain smart contract platform and under no single entity's control. This is ideal in ecosystem environments where multiple parties have a desire to interoperate without recourse to a potentially expensive intermediary and provides ability to take action autonomously *en route* using trusted data; and
- the irrefutable provenance that comes with an immutable ledger. This means that the data that's used to establish an audit trail of shipment conditions – or which is fed into the analytics and AI services that seek to learn from behavioural snapshots taken at various points across an end-to-end journey – can be trusted (so you can make decisions with confidence).

Both of these characteristics augment the 'smartening' supply chain, and bring us closer to a system that can start to operate in a self-governing, self-sufficient way – but with transparency that should satisfy governance requirements and help strengthen direct relationships between members of the network conducting business through these platforms.

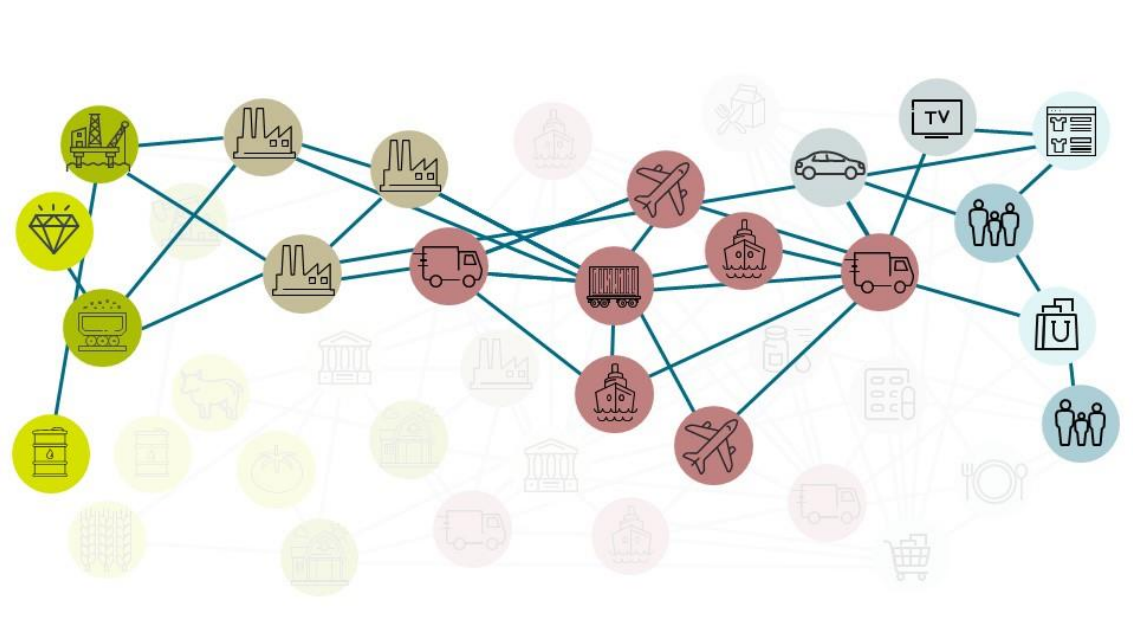
The autonomous supply chain in action

Figure 3 (overleaf) depicts a supply chain similar to the example illustrated earlier in Figure 2, with raw materials being extracted, processed, and going to factory in order to be turned into goods (in this case cars and TVs) which are then shipped around the world via a number of transport routes before being sold on through online or traditional shops / dealers to end customers. However this time the diagram includes a few more parties to illustrate a greater degree of complexity (though of course, in real world situations, you'd typically be looking at many *thousands* of suppliers ultimately involved in the manufacture and shipping of such products to consumers).

Imagine how you'd co-ordinate across the full supply chain network, especially if there were thousands of parties in play, if there were some compliance requirement to report against. For example, a high tech manufacturing company needing to audit its component sourcing to confirm the elimination of conflict minerals from its supply chain; or supermarkets and restaurants needing to quickly track and trace (and irrefutably prove) the source of contamination or spoiling in a food supply chain after their customers fall ill

(without causing the entire market to collapse for that type of food because consumers are no longer able trust that they're buying from a safe, reputable supplier).

Figure 3 An example supply chain network



Source: MWD Advisors

IoT platform

All the machinery that drives the supply chain journey (plus the goods and their packaging themselves) can be instrumented with sensors, integrated with your supply chain network as IoT connections, bringing vast quantities of rich monitoring data – enabling process decisions to be made 'in the moment'.

They also provide fuel for a wide spectrum of data-driven decision-making by myriad business systems, which can now benefit from insight about the behaviour of artefacts in use (rather than simply relying on how people say they're being used) – such as enriching the understanding of supply chain processes and transit monitoring, or providing ongoing connections for aftersales care, updates, and maintenance – say, in the case of connected cars or household electronics equipment, as per the example shown in Figure 3.

Of course, as we describe the scenario here it's still a single entity which is seeking to control the access to this data (and hence be the primary beneficiary of insight), and that might prove incompatible with a more collaborative ecosystem without further technical assistance – not necessarily to "bring trust to the community", but at least to "bring a trustable capability" which can be exploited by multiple members of the community.

Blockchain platform

Each of those entities on the network which can take IoT sensors, plus the retail applications which communicate (by way of traditional transactions) with the supply chain management business applications, can act as nodes on a peer-to-peer blockchain network – enabling data to be committed to the chain as an indelible ledger from which a consensus-based source of truth can be extracted and used in audit; or to feed

analytics and AI layers with verifiable data sources; and also extend the 'process zone' outwards amongst ecosystem partners as smart contract supply chain applications are executed on-chain.

NB 'Traditional supply chain management' connections are still vital to the running of a supply chain business network – companies aren't going to be able to replace all that B2B transaction monitoring with a series of decentralised applications running on blockchain smart contracts overnight.

For the time being, the key thing is going to be how blockchain (and AI, and IoT) works *with* existing, traditional supply chain management systems. We can expect to see bounded examples of 'adjunct services' taken to the blockchain over time, as proof of concept projects start to bear fruit (and enterprise-grade blockchain services ease the path to production scale deployments), but they'll be on an 'assist' and 'targeted replace' adoption path for a while. That's not to say that there isn't the potential there for more wholesale disruption in the supply chain space – but we're a way off blockchain product maturity bringing that to the mainstream just yet. However, do look out (in the near term) for a 'post-blockchain' movement of applications built on blockchain (in combination with IoT and AI technologies) coalescing into more well definable areas like asset provenance (also, coincidently, where the value can start to be better articulated too).

These may well be blockchain powered, but they may start to shed their blockchain label as that becomes an increasingly meaningless shorthand for such a wide range of technological capabilities – from payments platforms, through proofs of existence and immutable systems of record, to decentralised application platforms. In a sense, as blockchain interest 'moves up the stack'.

AI / machine learning services

From an AI or machine learning point of view, there will need to be tight integration across the platforms to enable data (ingested through the IoT platform, and assured by blockchain records) to be fed to the AI services that power smart, 'intelligent' supply chain applications at the user end (and contribute to autonomous running of the supply chain business 'under the hood').

Again, data is at the core of effective AI deployment – in terms of training a model which can then supply 'intelligent' input to the running of the system; and the ongoing of provision of data from disparate sources to refine that model and also fuel the analytics.

Illustrative use case examples

This section looks at how these technologies (and the new practices, and ways of working they bring with them) can be used in some specific areas – starting with asset traceability and provenance (which has applicability in a number of scenarios – from food safety and product recalls, through counterfeit drugs identification, and the elimination of inappropriately sourced raw materials, to full-inventory component tracking that builds up a product's 'digital passport' or 'digital log book' to facilitate highly granular – and trusted evidence-based – predictive maintenance programmes).

Tracking, traceability, and provenance

Consider the journey that physical assets take across an end-to-end supply chain network – and what the data from a blockchain can tell you about where they came from, where they've been, who's handled them, and how they've been treated, etc. when it's fed with data from an IoT platform.

A blockchain's immutable asset register can provide provenance information about every component part in a product, and the specific nature of the information held there (identifying features, origin information – even highly granular records of treatment in transit, if the data is available from IoT sensors, etc.) can greatly enhance the quality of decisions made about product or food safety issues because of the timely availability of richer data.

Not only can faulty components or spoiled ingredients be pinpointed quickly and with a greater degree of accuracy; but also it becomes much easier to audit the process and determine which party was responsible for a breach in handling protocol, or the supply of unfit goods, etc.

That same traceability characteristic also allows for the tracking of high-value goods across the supply chain; the rooting out of counterfeit items; and elimination of inappropriately-sourced raw materials (such as conflict minerals destined for high-tech manufacturing).

It's not just origin information which could be assured by a blockchain record (especially if backed up by multiple IoT sensor datapoints corroborated against other real world data – such as GPS and barometric cross-checked with weather data); or pertinent after-care instructions, etc. A ledger entry could equally well incorporate other credentials relevant downstream in subsequent buying decisions – such as whether food is from certified Fair Trade or organic growers, or whether clothing comes from factories free from child labour, or the environmental impact of manufacture, etc. In combination with digital signature technologies, if committed to a supply chain blockchain, this information could be verifiable and comprise a type of 'digital corporate social environmental impact passport' to reinforce brand ethics (and empower customers to make informed purchasing choices). Blockchain's inherent transparency means that this information can be made available to all relevant parties, and the record is irrefutable. Plus, an indelible blockchain record also provides for easier sharing of tracking history, etc. with third parties like insurers or regulators.

NB This is IoT 'edge computing' at its extreme. If you're expecting these devices – smart crates, smart pallets, if you like – to operate out in the field, in someone else's environment, then you may need power, internet connectivity, etc. Handily blockchain technology also has the capability to record micropayment transactions which could pay for access to power and so-on along the way.

NB Remote sensors connected to an IoT platform on its own could still provide insight into the condition of goods *en route* across the supply chain, but it'd be under the control of a central authority. What the integration of IoT with blockchain brings is the capability to log that sensor data onto a distributed ledger that all parties to the supply chain have independent access to; and provide an irrefutable record of the event, in case of dispute between partners.

Digital twins, and end-to-end lifecycle management

The technologies of an 'autonomous supply chain' can also support digital twinning of physical artefacts (supporting predictive maintenance protocols, and end-to-end lifecycle management). It's another example of pairing IoT with blockchain, as instrumented devices in the 'real world' can sense and relay pertinent information via smart contract applications that commit the data to the chain for subsequent analysis and review. Full lifecycle digital twins can be created for products that enable a blockchain to maintain a digital maintenance book that tracks the provenance of component parts and fine-tunes predictive maintenance schedules – particularly useful if they have special aftercare requirements, or are subsequently found to have a disproportionately high failure rate, etc.

Blockchain's asset provenance and traceability capabilities can help companies clarify what components were used in the manufacture of a particular batch of a product. It can also help manage the product as ownership passes through multiple parties (e.g. car dealership, leasing agent, owner, etc.), right through to disposal.

Add AI into the mix and you're scaling your understanding of how products are used; learning from and modelling wear and tear behaviour – to spot patterns and act on intelligence to provide recommendations to customers that enhance their experience and increase the useful life of the item.

Insurance, payments, and administrative overheads

An 'autonomous supply chain' can bring efficiencies and cost savings to a more dynamic insurance market, faster reconciliation of payments amongst trading partners, and reduce the admin costs of shipping across

multi-partner and multi-jurisdiction supply routes, as detailed below:

- **Insurance.** By enshrining insurance conditions into smart contracts, blockchains provide opportunities for processes to become automated by dealing directly with customers without intermediaries, accessing public data from the Internet or IoT sensors attached to the assets being insured, etc. and in some cases executing end-to-end without human intervention.

  Whilst there are numerous explorations of blockchain automation in travel, vehicle, health, life, and property insurance, the same benefits can also be applied to insurance of goods as they traverse global supply chains by sea, air, and land. For example, a seamless flow of relevant information on a blockchain amongst manufacturers and logistics partners, etc. has the potential to enable more tailored premium calculation; insurance provision could be activated and deactivated by an event trigger (such as goods arriving into a particular jurisdiction, or transferring to a particular partner); blockchains could also help disintermediate the processes connecting insurers with beneficiaries and other interested parties in the event of a claim to speed up its settlement.

- **Payments.** Blockchain can help a supply chain ecosystem establish an agile, fluid pricing environment – with smart contracts automatically negotiating and completing transactions by monitoring the status of key variables (like prices and delivery times) – which can feed into an AI layer which has learnt how to model the system and make best recommendations for on-demand partnerships (say, in logistics).

  They remove the need for a trusted counterparty as intermediary, eliminating the risk of a single point of failure, and providing transparency – so they're well-suited to the simplification of cross-border payments, (say, across a trading group) providing automated reconciliation of accounts and shortening of settlement periods to free up capital in the supply chain.

  They can support micropayments amongst highly distributed parties in transactions for microservices. This can be of particular interest when IoT devices operating at, or beyond, 'the edge' of an enterprise's reach are integrated into blockchain applications which consume data from their sensors. For instance, micropayments could be made via the blockchain in return for devices' consumption of energy at different points in their journey.

- **Administrative overheads.** Lastly, consider the administrative paperwork for transporting a shipment of goods (because of the number of transactions involved, through a vast network of intermediaries in different countries, etc.). The Maersk shipping line have gone on record recently saying that this could represent as much as 15% of the total shipping cost itself. Desk research from UN figures puts a figure of over $1.6B on these overheads last year – costs which could be cut dramatically if the trade instead relied on autonomous smart contracts running on a blockchain platform so the administrative friction were reduced and intermediaries no longer required.

  Records of ownership or leasing agreements for manufactured products could be made available on a blockchain – enabling the process of transferring and tracking ownership more transparent and connecting buyers and sellers, lessees and lessors, etc. directly (with potentially more scope for on-demand short-term leasing).

Benefits and risks

Business benefits

There's massive potential to use IoT, AI / machine learning, and blockchain technologies in combination to provide services to supply chain partners – like irrefutable asset provenance – much faster than was possible before all the relevant data was logged to a shared ledger. This immediately improves transparency in the market and makes it much easier for suppliers to issue targeted product recalls and safety advice – thereby

minimising brand damage (or indeed, whole market damage – as has been the case with the public's response to food 'scares' when detailed information, needed to narrow down sources of contamination, is not available quickly enough).

This same information can also be used in a positive way (i.e. even if there isn't found to be any 'problem' with the product) as a way of certifying adherence to production standards that a brand may associate itself with (such as ecological credentials, fair trade, labour rights, etc.), and giving it the opportunity to trade on that assurance as a transparency premium.

Blockchain's ability to disintermediate systems and for its decentralised smart contract applications to act autonomously, has been proven across numerous proofs of concept projects to reduce the overhead costs of doing business and remove single points of failure in the system. And also its peer-to-peer nature has the potential to re-balance the asymmetric relationships inherent in some of today's supply chain networks, improving direct relationships amongst partners in a way that couldn't have been effectively supported at scale before.

IoT in the supply chain, leveraging AI and analytics capabilities, greatly enhances the 360-degree view you can maintain of the components and products in your supply chain. And, by referencing verifiable digital passport and log book records on a blockchain, the end-to-end lifecycle can be more effectively managed from sourcing to scrappage (with highly granular predictive maintenance and aftercare arrangements enacted while products are 'live').

Challenges and risks

Firstly, for effective asset tracking and provenance information (one of the main use cases for the autonomous supply chain) you need to be assured of the veracity of any data you're committing to a blockchain that supposedly states where something was, or what condition it was in at the time. Blockchain technology will only guarantee that the data is verifiably untampered with. It can't vouch for the correctness of the data in the first place. Therefore you need to design your IoT sensor net accordingly, corroborate the data you're getting from it, and manage the integrity of your devices at all times. Security at the edge (as well as at the core, and all points in between) is therefore of paramount importance – and you'll need to take steps (and potentially integrate with other services) to cover this off.

Disparate blockchain networks and IoT grids present performance and scalability concerns. Do you have the bandwidth to consume the data you're expecting your AI and other systems to need? Consider how your sensors will operate at the 'edge', and how your systems will consume their data.

Infusing your existing supply chain operations with IoT, AI, and blockchain services will present integration challenges amongst your existing systems. In that regard, development and deployment concerns are similar to any other enterprise IT project. Whilst new technologies (like blockchain) do bring their own particular challenges, don't underestimate the more 'expected' aspects (onboarding, resilience, security, performance, application development, etc.) that come with *any* project.

Focusing on blockchain in particular for a moment, the technology is immature – as is the market. Industry standards for integration are only just emerging, and the vendor ecosystem is still forming. However, many partnerships are already coalescing around open source projects such as Ethereum and Hyperledger (and some of these partnerships are actively looking to make their blockchain products more robust, scalable, secure. performant, and generally 'enterprise-friendly' – so that suitable, production-ready commercial services can bring these capabilities to the masses).

When using a public blockchain, be aware that its immutability means that the (encrypted) data will be around for the life of the ledger; however, the chosen encryption algorithms may not remain as secure 5 or 10 years or so into the future, especially if quantum computers deliver on their code-cracking promises.

There's also currently a lack of regulatory clarity on blockchain implementations – relating to questions around exactly what's allowed to be stored on a distributed blockchain, and where; and who should have access to it, and so on. The law is playing catch-up, and it's doing it across all the legal jurisdictions the members of a network may inhabit (so any legal position is going to be inconsistent). Inevitably there will be risks; so make sure you and your stakeholders on the network are aware of them, and have the appetite for it.

Finally, consider the shared governance of autonomous, decentralised smart contract applications. What mechanisms are there to effect changes to the contracts should that become necessary (for example, because of subsequent legislation after the code has been implemented; or if the contracts are found to contain an error or vulnerability). Essentially, how can they be 'patched', and what happens if something unexpected happens – are your organisation's legal policies able to accommodate the operation of autonomous applications operating on its behalf?

Conclusions

Once a supply chain is able to run on a 'digital backbone' (i.e. with business transactions exchanged electronically), then there are considerable benefits to be realised by integrating disruptive technologies (such as IoT, AI and blockchain) with traditional supply chain management systems. Each has a part to play as an enabler of digital supply networks – ecosystems that are connected, intelligent, collaborative, and trusted; but it's in combination that they add the most value. Integration between IoT platforms and supply chain management systems brings richer, more highly granular datasets into the mix; AI and machine learning enhanced system understanding; anchor to a blockchain network, or devolve some cross-boundary processes to blockchain-based smart contracts and you have autonomous, decentralised applications that can facilitate the widening of a 'process zone' to include multiple third parties who may need to exercise control over data or act upon it… only this time the radius isn't drawn from a single network member outwards; instead, all parties to the ecosystem can behave as peers (where appropriate) and the blockchain enables them to trust in the data that's shared with them.

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