Total cost of ownership for blockchain solutions

Amendment of *Fundamental cost of ownership for private blockchain solutions*, with updated information on public blockchain deployment options and updated conclusions

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Building a better working world

Table of contents

I. Executive summary

Blockchain technology is touted by many as the be-all-end-all solution for the digital transfer of value. Volatility in the price of major cryptocurrencies, such as bitcoin and ether, accompanied by a wave of institutional investments primarily from the banking industry, has continued to fuel widespread participation in a market once dominated and controlled by cryptographers and engineers. Today, solutions are being built to experiment with payments, supply chain management and provenance, identity management, property rights and post-trade settlement.

Public blockchains, such as Ethereum and Bitcoin, enable collaboration and permission-less access to an assortment of products and services. Contrarily, private blockchains are developed and operated within controlled environments and with permissioned access, sacrificing valuable network effects but allowing for more privacy.

Despite the technology's popularity, particularly as it relates to corporate adoption, several basic questions remain unanswered at the institutional level, driving skepticism and resistance from business managers. While research and development teams at large organizations have ideated blockchain use cases, few working scalable solutions have materialized.

This paper lays the groundwork for answering one of the most important questions asked by business leaders today: **what would a production-scale blockchain solution cost for my organization?**

With new projects and upgrade proposals released regularly and a limited history of implementations to leverage, forecasting a reliable one-size-fits-all cost framework for a production-scale implementation is currently difficult. So, to begin answering this question, the EY Blockchain Team used data from global client proof-of-concept, pilot and production engagements, as well as internal platform builds, to develop a framework for understanding and forecasting the costs of a production-scale, commercial blockchain solution.

II. Key inputs

Four inputs predominantly impact the costs of both public and private blockchain solutions and depend entirely on the use case and objectives an organization aims to accomplish. There are additional inputs to consider, but for the purpose of simplicity and standardization, only the most influential are highlighted here:

- Transaction volume
- Transaction size
- Node hosting method
- Consensus protocol

Transaction volume relates to the amount of activity performed on a blockchain. Transaction volume requirements determine the scalability characteristics a blockchain solution should possess for particular use cases.

The speed of a database system is measured by its transaction "throughput," referring to its transaction volume per second. For reference, a select sample of our most visible engagements yields an average annual transaction count of anywhere between 5,000 and 109.5m transactions per year, with a large majority falling under the 365,000 annual transactions mark (1,000 transactions per day).

Transaction size refers to the storage requirements for one unit of value transacted on the network. Transaction size primarily impacts, among others, transaction review and audit costs. Transaction size inputs were leveraged from the fundamental cost of ownership for private blockchains, in which data from blockchains, such as Bitcoin, Ethereum and Monero, were used to determine the transaction-size input options. These blockchains have varying transaction sizes because of the difference in their use cases (e.g., Monero's added privacy features lead to a significantly larger transaction size). Specifically, the input depends on the amount and complexity of data required for each transaction, as well as on-chain and off-chain data storage practices. As an example, applications that require the use of smart contracts to execute agreements based on programmable conditions result in a larger transaction size than applications that facilitate the transfer of value, such as payments or securities.

The **node hosting method** refers to the chosen method for storing a blockchain platform and all of its ancillary technological requirements. The three most common stand-alone methods are on-premises (new systems), on-premises (existing technology) and cloud-based. This input is less material for public blockchain software but is critical in costing private blockchains.

Consensus protocol refers to the method of verifying the legitimacy of blocks of transactions. The following consensus protocols are utilized by both public and private blockchains:

- Proof of work uses a large amount of computing power to mine blocks of transactions.
- Proof of stake uses financial assets as an incentive to mine blocks with integrity.
- Proof of authority allocates the responsibility of verifying blocks to specified participants.
- Byzantine fault tolerance employs a voting system, usually within private blockchains, through which consensus is met once identical responses are received from trusted nodes.

The type of consensus protocol used depends on an organization's current situation and objectives. Each option offers different levels of decentralization, security, power consumption and hardware requirements. Participants in a public blockchain may use proof of work to ensure that blocks (and, therefore, transactions) are verified with computational integrity rather than based simply on authorized permission. However, a computationally intensive consensus protocol, such as proof of work, results in higher electricity costs, higher hardware costs and greater processing times for transactions executed on the system.

III. Assumptions

There is little historical data available on the costs of private blockchain solutions, and the cost structure for public blockchain solutions is significantly different than private blockchain solutions. Our process to develop a cost framework included:

- Benchmarking costs against existing technologies, such as electronic data interchange and cloud IT
- Benchmarking costs against data available for public blockchains, such as Bitcoin, Ethereum and Monero
- Seeking feedback from developers, R&D specialists and blockchain business development professionals

While we used this process to determine the initial build costs, hardware costs, computing costs and cloud costs associated closely with blockchain implementations, an often-overlooked category critical for a cost model is governance-related costs. Given the lack of large-scale production solutions with well-documented governance costs to draw from, governance-related assumptions embedded in the model were formulated by examining comparable IT implementations and adjusting the data for the unique characteristics of blockchain technology and its market. Wherever applicable, our experience with previous and current blockchain projects was also leveraged to determine cost assumptions.

As an example, the documentation and record-keeping costs associated with each user of the system were estimated by averaging the market data from well-established IT implementation projects. Those averages were then adjusted for the incremental differences in requirements due to the fact that blockchain technology is in its early stages. Under the assumption that documentation should be optimized rapidly over time given the technology's inherent record-keeping functionality, a decreasing step function was incorporated. Similar assumptions were made for items such as hourly instructor costs, annual user turnover and training hours per end user.

The following key assumptions were formulated and incorporated into the model to enable standardization of the forecasting of costs across a variety of solutions.

Initial build or software implementation costs are partially benchmarked as a percentage of initial build for private blockchains and partially benchmarked against historical EY client engagements.

Onboarding cost forecasts assume 10 full nodes and 250 end users. These are key assumptions that also underlie several calculations throughout the model, including cloud costs and user education costs. Public blockchain networks require a large number of dispersed full nodes verifying transactions to prevent certain malicious activity, such as a 51% attack. On the contrary, private blockchain solutions assign the responsibility of verifying transactions to a select group of individuals. Therefore, the number of full nodes is not linked directly to the number of users or transaction volume of the platform, but is instead linked primarily to a) the number of members in a consortium and/or b) the minimum number of nodes necessary to mitigate the risk of collusion from a first-line-of-defense perspective. While each organization's full node and user breakdown will deviate, based on existing private blockchain implementations, the assumption of 10 full nodes and 250 end users represents a reasonable average and portrays realistic costs for the majority of implementations.

The on-premises (new systems) node hosting method also requires an assumption pertaining to hardware costs. These hardware costs assume that enterprise-grade servers will be acquired to facilitate the storage of transaction data for an extended period of time, with the capacity to manage increases in transaction size or volume.

Cloud cost forecasts, per data collected from a major cloud provider, assume one virtual machine (VM) per full node at an average cost of $2,000 per VM. Unlike the onboarding costs detailed previously, remaining cloud costs, such as those for storage capacity and transaction storage, directly depend on transaction volume and transaction size.

Ongoing maintenance cost forecasts assume that, on average, an organization requires a full-time employee dedicated to blockchain technical support. This assumption, as well as the ongoing education costs per user, annual user turnover and hardware administration costs, which are all also included in ongoing maintenance, is based on existing data from comparable technology implementations.

Monitoring cost forecasts are based on two basic, but important, assumptions: $15 in quality review costs per 100,000 transactions and $1,495 in annual network assessment costs. Both figures were reviewed with multiple internal teams and assessed based on the quality assurance and audit costs of existing engagements.

Because of the early stages of enterprise blockchain solutions, governance costs could initially be unnecessarily high. Basic system-inherent controls, such as the distributed nature of blockchain, reduce the need for audit reviews, redundant backup processes and disaster recovery programs compared with a normal IT upgrade. However, departmental managers might still be skeptical and tolerate additional costs as a result.

IV. Private blockchain cost model and scenario

A general cost model can be reasonably constructed using the assumptions and inputs previously discussed. To demonstrate the costing methodology, see the example scenarios below, which are based on inputs, assumptions and outputs incorporated in the model framework. Costs are separated into four major categories, with many declining over time in accordance with the experience curve.

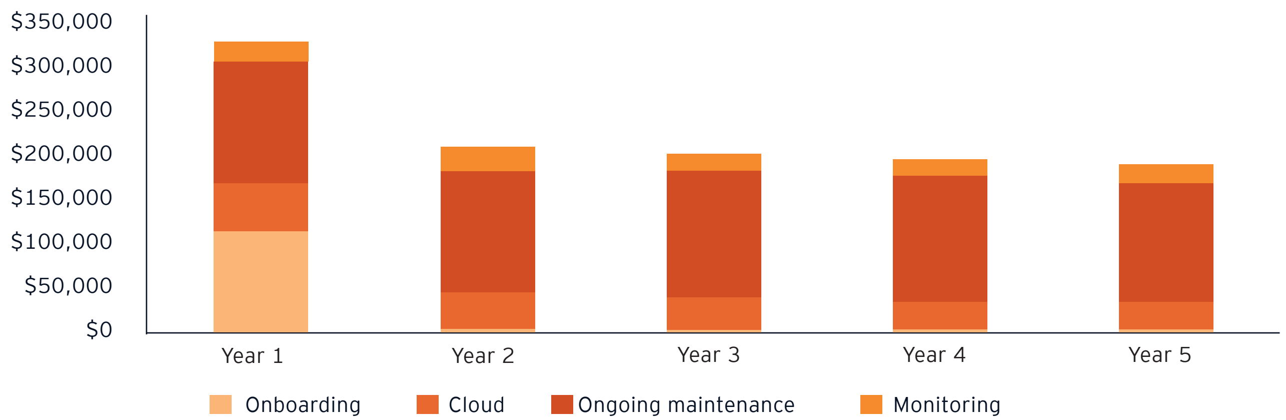
Inputs	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Daily transaction volume	250,000	50,000	500,000	500,000
Transaction size	Large – 500 bytes	Medium – 250 bytes	Small – 150 bytes	Medium – 250 bytes
Node hosting	Cloud-based	On-premises (existing technology)*	On-premises (new systems)*	Cloud-based
Consensus protocol	Proof of work	Proof of authority	Byzantine fault tolerance	Proof of stake

*Fully on-premises solutions assume $0 in cloud costs.

Scenario 1

	Year 1	Year 2	Year 3	Year 4	Year 5
Onboarding costs	$115,146	$3,880	$3,688	$3,506	$3,335
Cloud costs	$50,006	$42,756	$36,557	$31,257	$26,725
Ongoing maintenance costs	$142,280	$142,014	$141,755	$141,505	$141,263
Monitoring costs	$19,663	$18,773	$17,928	$17,125	$16,362
Total costs	**$327,095**	**$207,423**	**$199,928**	**$193,393**	**$187,685**

Five-year costs



Scenario 2	Year 1	Year 2	Year 3	Year 4	Year 5
Onboarding costs	$97,720	$3,868	$3,676	$3,495	$3,323
Cloud costs	$0	$0	$0	$0	$0
Ongoing maintenance costs	$140,640	$140,456	$140,275	$140,099	$139,927
Monitoring costs	$4,233	$4,096	$3,966	$3,842	$3,725
Total costs	**$242,593**	**$148,420**	**$147,917**	**$147,436**	**$146,975**

Scenario 3	Year 1	Year 2	Year 3	Year 4	Year 5
Onboarding costs	$105,564	$15,338	$14,535	$13,810	$13,155
Cloud costs	$0	$0	$0	$0	$0
Ongoing maintenance costs	$142,340	$136,467	$130,952	$125,762	$120,864
Monitoring costs	$26,058	$23,594	$21,377	$19,381	$17,585
Total costs	**$273,962**	**$175,399**	**$166,864**	**$158,953**	**$151,604**

Scenario 4	Year 1	Year 2	Year 3	Year 4	Year 5
Onboarding costs	$101,282	$3,874	$3,682	$3,501	$3,329
Cloud costs	$26,409	$22,581	$19,308	$16,509	$14,116
Ongoing maintenance costs	$140,968	$140,767	$140,571	$140,381	$140,194
Monitoring costs	$30,314	$28,876	$27,511	$26,214	$24,982
Total costs	**$298,973**	**$196,098**	**$191,072**	**$186,605**	**$182,621**

The original model has been posted to the EY GitHub repository, and all parties are encouraged to fork, edit and improve it based on their unique experiences: https://github.com/EYBlockchain/total-cost-of-ownership.

V. Public blockchain (zero-knowledge proof) transaction costs

Similarly, see below for a scenario that compares public and private blockchain transactions costs. Public blockchain solutions are represented by zero-knowledge proof (ZKP) transaction software that enables users to transact on public blockchains, without exposing any revealing data about those transactions. However, given the enormous time and power required to compute proofs, ZKP transactions are currently approximately 143 times more expensive than non-ZKP transfers of ether.

Currently in its second generation phase, our upcoming third generation of ZKP technology is expected to reduce transaction costs by 90% percent or more. Therefore, the model below addresses costs from an entirely new perspective: **public blockchain transaction costs versus private blockchain transactions costs.**

Inputs	Private blockchain	Zero-knowledge proofs
Daily transaction volume	1,000	1,000
Annual transaction volume*	**365,000**	**365,000**
Transaction size	Large – 500 bytes	Large – 500 bytes
Node hosting	Cloud-based	Ethereum-based
Consensus protocol	Proof of authority	Proof of work

* As it relates to public blockchain solutions, transaction volume-related inputs are the most material to the outcome.

Private blockchain transaction costs

Private blockchain		Year 1	Year 2	Year 3	Year 4	Year 5
	Initial platform build	$660,000	n/a	n/a	n/a	n/a
	Onboarding/deployment costs	$98,376	$3,868	$3,676	$3,495	$3,323
	Cloud costs	$22,000	$18,810	$16,083	$13,751	$11,757
	Ongoing maintenance costs	$140,640	$140,456	$140,275	$140,099	$139,927
	Monitoring costs	$1,710	$1,707	$1,704	$1,701	$1,698
	Total fixed costs	**$922,726**	**$164,841**	**$161,738**	**$159,046**	**$156,705**

$1,565,055 fixed costs over five years	**$313,011** average annual cost	**365,000** annual transactions	**~$0*** variable cost per transaction	**$0.858** average transaction cost

* The private blockchain cost model assumes only partial variable costs (e.g., audit costs per 100,000 transactions, cloud storage costs per GB of data), and several costs are tied directly to transaction size.

ZKP transaction costs – current state

ZKP transaction costs	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Initial platform build	$50,000	n/a	n/a	n/a	n/a	-92.4%
Onboarding/deployment costs	$3,390	$155	$148	$140	$133	-96.5%
Cloud costs	$8,799	$8,359	$7,941	$7,544	$7,167	-51.7%
Ongoing maintenance costs	$1,640	$1,636	$1,632	$1,628	$1,624	-98.8%
Monitoring costs	$1,940	$1,936	$1,869	$1,869	$1,869	11.3%
Total fixed costs	**$65,769**	**$12,086**	**$11,590**	**$11,181**	**$10,793**	**-92.5%**

$110,276 fixed costs over five years	**$22,284** average annual cost	**365,000** annual transactions	**~$5*** variable cost per transaction	**$5.061** average transaction cost

* Assumptions are detailed in the table below.

ZKP transaction costs – future state

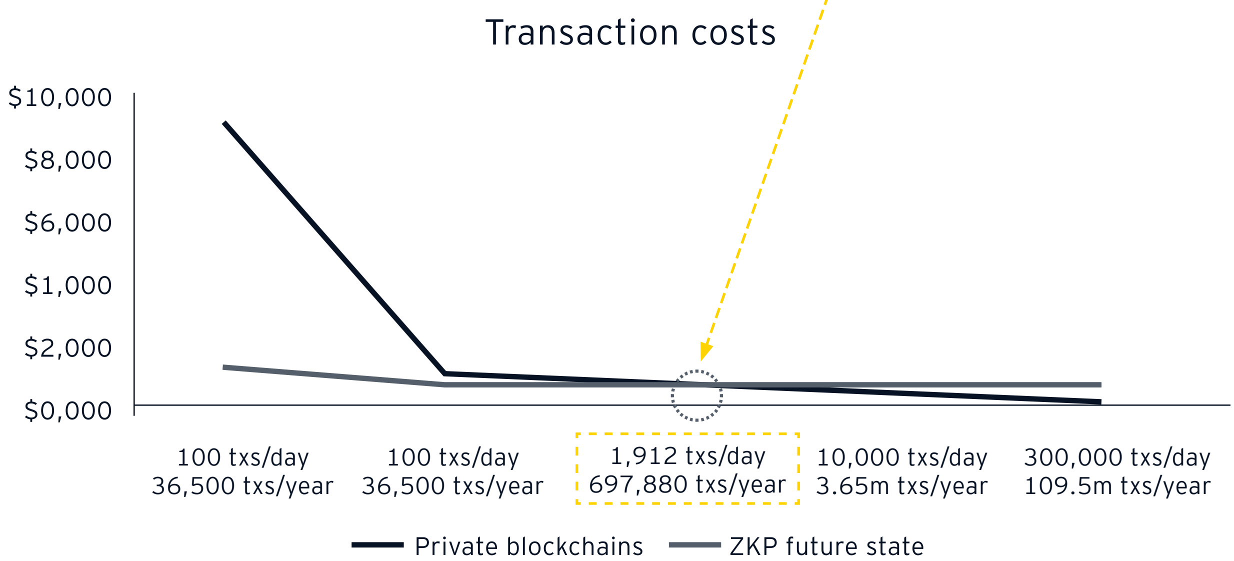
	Current state – second generation ZKPs	Future state – third generation ZKPs
Variable	Initial assumptions: ‣ Average ZKP transaction gas limit – 2.5m ‣ Long-run price of ether – $100 Variable transaction cost: $5.000	Initial assumptions: ‣ Improvements to software, allowing users to compute proofs at a significantly higher rate ‣ Average ZKP transaction gas limit – 208k Variable transaction cost: $0.417
Fixed	Fixed transaction cost: $0.061	Fixed transaction cost: $0.061
Total	**Total transaction cost: $5.061**	**Total transaction cost: $0.478**

The transaction volume associated with a particular use case is significantly more important for public blockchains compared to private blockchains, mostly due to lower fixed governance costs and more variable compute power necessary to execute individual transactions on Ethereum. In comparing transaction costs, use cases with very high transaction volumes are often well-suited for private blockchains, as high fixed costs are averaged out across a larger number of transactions. Use cases with more complex assets and transactions, as well as low-to-moderate volume, are well-suited for ZKP software.

V. Public blockchain (zero-knowledge proof) transaction costs

Given the inputs on page 10 and software improvement deals on page 11, below is a sensitivity table to determine, at exactly what transaction volume, public blockchains become more expensive than private ones.

Transactions per day	25	160	1,000	**1,912**	10,000	300,000
Transactions per year	9,125	58,400	365,000	**697,880**	3,650,000	109,500,000
Private blockchains	$34.296	$5.359	$0.858	**$0.449**	$0.086	$0.003
ZKP – future state	$2.856	$0.798	$0.478	**$0.449**	$0.423	$0.417



Per the initial model, with huge third generation changes to the EY ZKP protocol, transaction costs for use cases with a daily transaction volume below approximately 1,912 and annual transaction volume below approximately 697,880 will be lower using ZKP on public blockchains than using private blockchains.

Looking one step further, material to a comparison of costs between public blockchain solutions and private blockchain solutions is the costly process of having to integrate multiple private blockchains someday or, even worse, having to write off the investment entirely to start building on public blockchains. The probabilities and impacts of these events are quantified on the following page.

Note: As this is a generalized model, it is assumed that the client is considering building on either Quorum or Hyperledger and may end up either integrating with other private networks or converting to a public network.

Scenario	Result	Financial impact[1]	Probability of situation	Private blockchain transaction costs[2]	Threshold — ZKP more cost effective until:
Current calculation (previous page)	*N/A*	*N/A*	*N/A*	*$0.858*	*1,912 txs/day 697,880 txs/year*
Integration with multiple private blockchains	Assuming different protocols, integration involves continuously altering the entire stack, amounting to about 25% of initial build costs	$165k cost at end of five years	25.0%	$0.948	2,129 txs/day 777,085 txs/year
Integration into public blockchain (assumes Hyperledger)	Given fully developed ZKP transaction OSS, 100% write-off of initial build costs	$660k write-off at end of five years	37.5%	$1.219	2,780 txs/day 1,014,700 txs/year
Integration into public blockchain (assumes Quorum)	Given fully developed ZKP transaction OSS but compatability with Ethereum, 5% of initial build costs	$33k cost at end of five years	37.5%	$0.876	1,956 txs/day 713,940 txs/year
Generalized, probability-weighted client situation to represent broad applicability		**$301,125 at end of five years**	**N/A**	**$1.023**	**2,308 txs/day 842,511 txs/year**

[1] While only costs are called out in this table, private blockchains still result in a net positive ROI through efficiencies, cultural and organizational changes, provenance.

[2] Assumes 1,000 transactions per day (365,000 per year).

As displayed above, until transaction volume hits approximately 2,308 per day, or approximately 842,511 per year, high fixed costs associated with private blockchains are not spread across enough transactions to result in a lower transaction cost.

VI. Considerations

As blockchain technology is, and will be for some time, quickly maturing, any cost forecasting model will depend on assumptions and benchmarking data until enterprise blockchain data becomes more readily available, applications become more standardized and pricing becomes more consistent.

There is a wide range of possible use cases for blockchain technology. Different applications will have specialized technological, governance and regulatory requirements. As an example, an application to track derivatives trades is expected to have higher quality assurance costs than a platform to send micro-payments directly to developers.

VII. Conclusion

Discussed in this paper are the key drivers and assumptions taken into consideration to calculate transaction costs for both private blockchain and public blockchain solutions. Leveraging this guidance, IT managers can quantify the financial impact of specific input decisions.

Ultimately, the substantial costs of training, audit and technical support highlight the importance of appropriate governance processes and practices, particularly as it relates to private blockchains.

The ultimate story for public blockchains is that for most enterprise blockchain projects, ZKP transaction costs will be lower than private blockchain transaction costs by Q3 2019 (or when the third generation is released):

- An estimated reduction in ZKP variable transaction costs of 90.6% means that most production and all pilot and proof-of-concept volume blockchains will cost less to operate using public, rather than private, networks.
- Until transaction volume hits approximately 2,308 per day, or approximately 842,511 per year, high fixed costs associated with private blockchains are not spread across enough transactions to result in a lower transaction cost.
- ZKP software continues to lend itself to moderate volume, high-value and potentially complex transactions.

Looking forward, further improvements could again increase scalability and reduce costs by a comparable amount (90%+), and improvements to the Ethereum protocol could significantly reduce compute power necessary to transact on the network. In summary, costs for zero-knowledge proof transactions are likely to decelerate at a far faster rate than costs for private blockchain transactions.

The lack of transparency in the blockchain space continues to give managers pause when they consider the technology. A comprehensive fundamental cost-of-ownership model shines a light on the rarely discussed cost drivers associated with a blockchain implementation and provides a clearer picture of what to expect. With further input from the blockchain community, EY will incorporate feedback from various organizations to help mature the framework.

Blockchain is a transformative technology with the potential to impact businesses across all verticals. Informed cost estimates for public blockchain solutions naturally bring the technology one step closer to widespread commercial adoption.

VIII. Contacts

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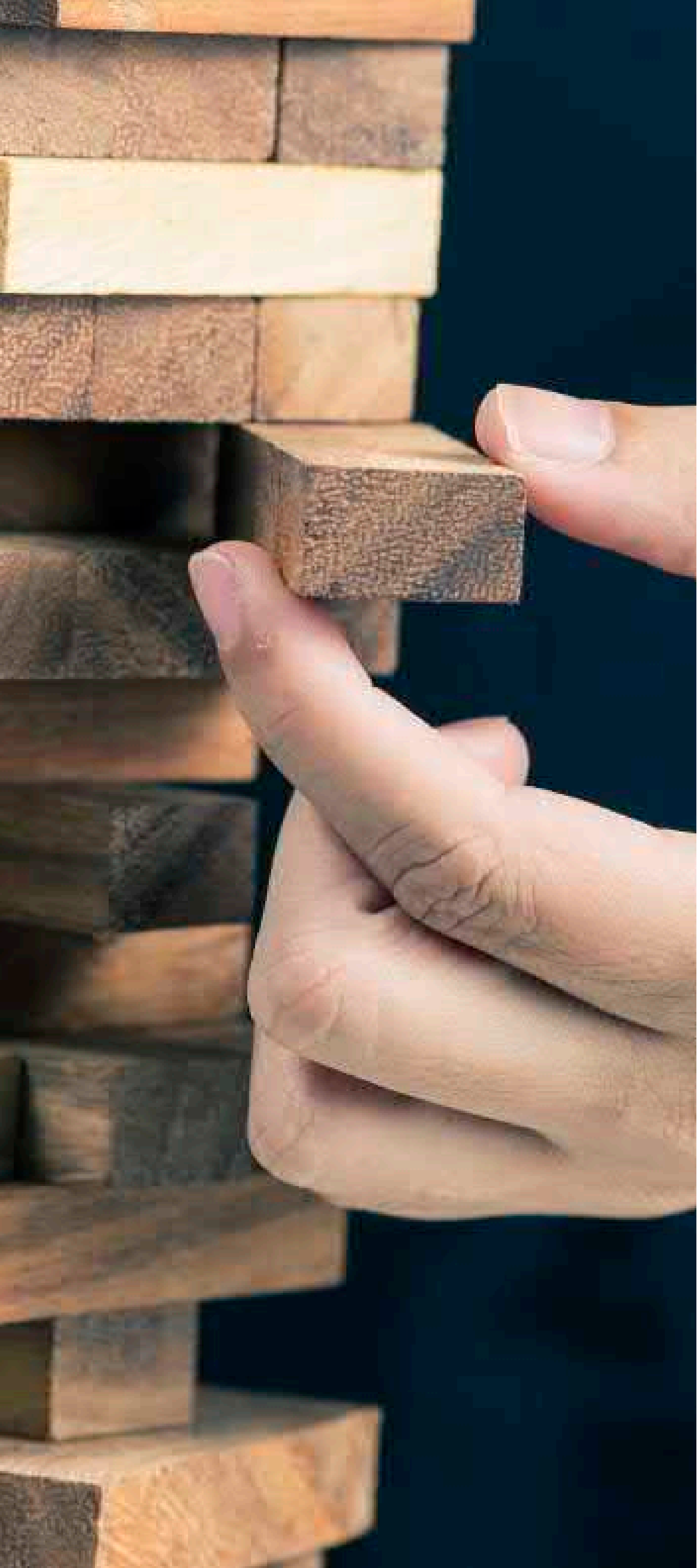

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