InoculLedger: A Secure and Scalable Distributed Ledger for Efficient Vaccine Supply Chain Management

Presenter: Vishnu Bathalapalli

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Faisal Alamri [1], Anand K. Bapatla [2], V. K. Vishnu. V. Bathalapalli[3], S. Mohanty[3], E. Kougianos[4]

University of North Texas, Denton, TX, USA.[1,3,4,5] and

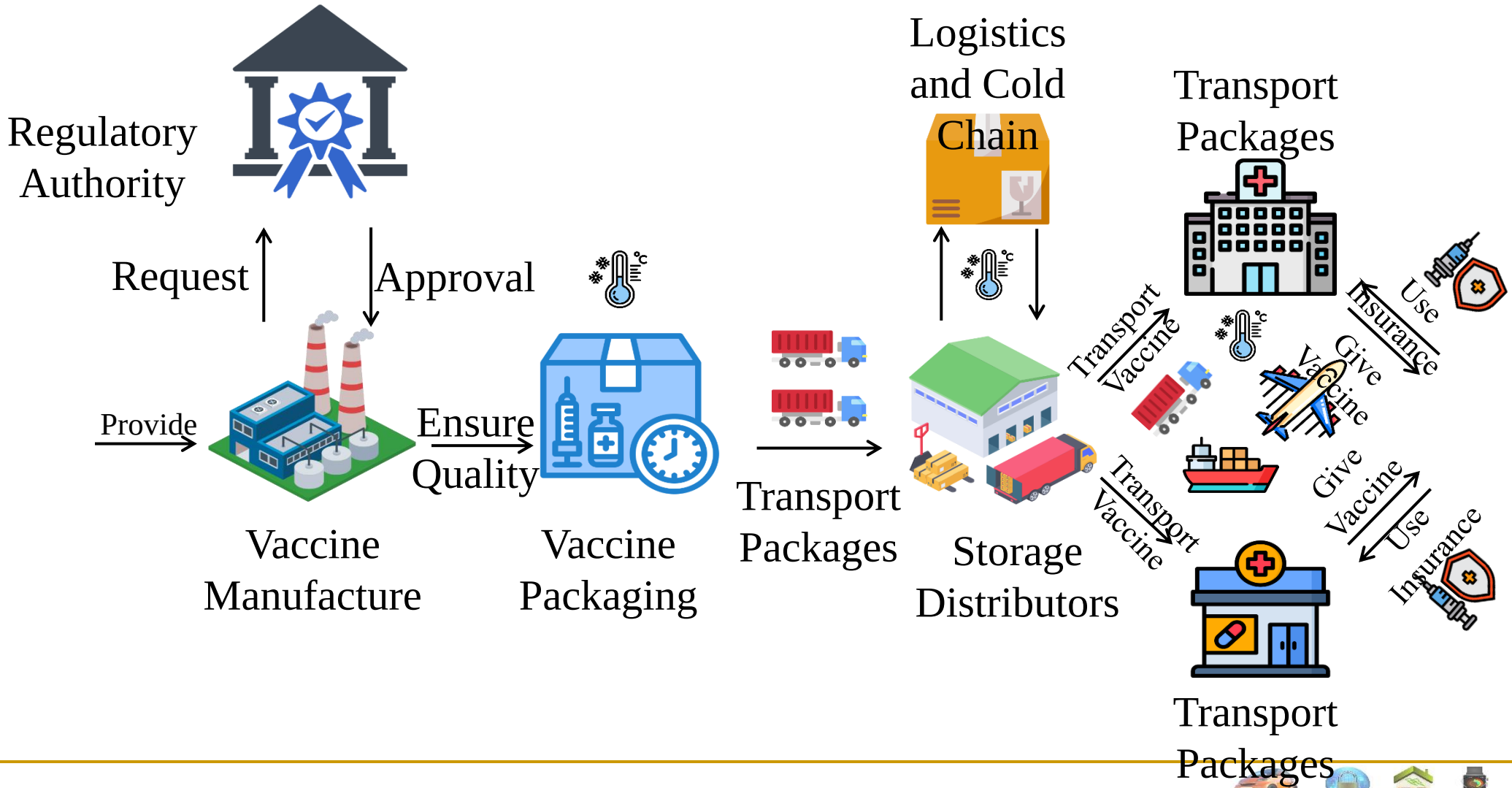
University of Central Missouri[2].

Email: **faisalalimalamri@my.unt.edu[1], bapatla@ucmo.edu[2],vb0194@unt.edu[3], saraju.mohanty@unt.edu[3], elias.kougianos@unt.edu[4]**

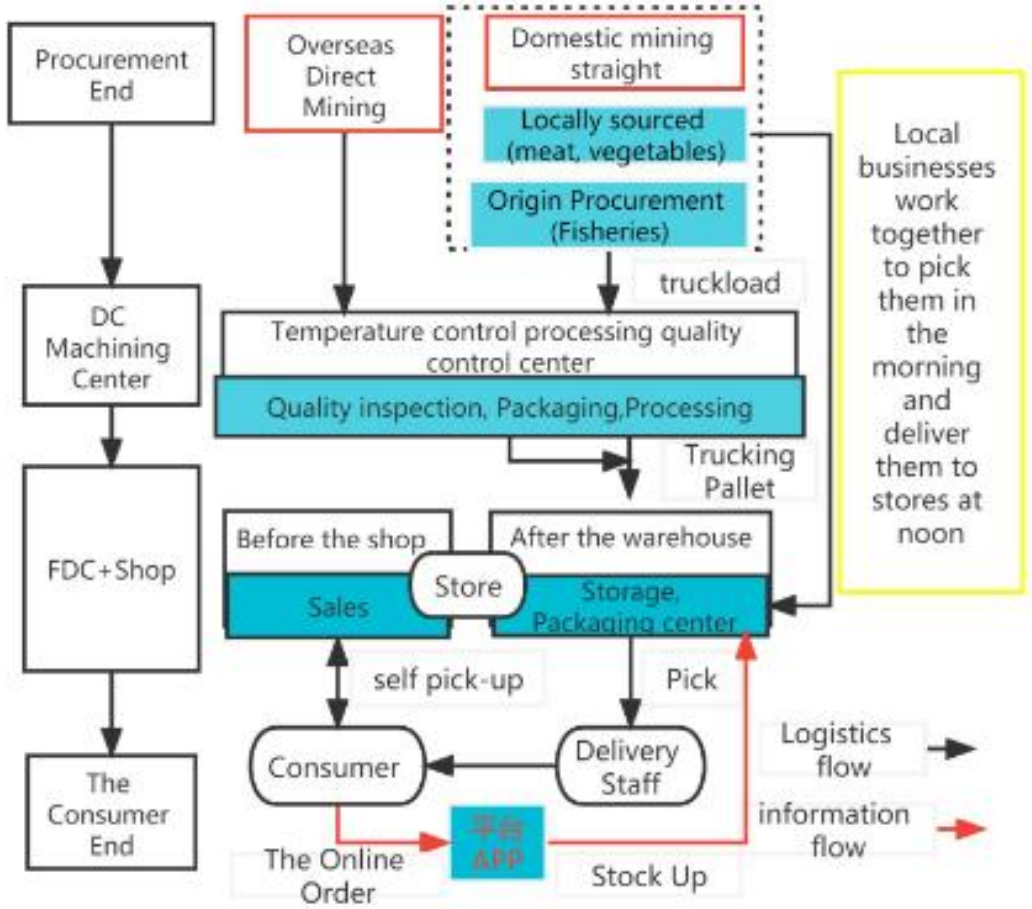
Outline

- Vaccine Supply Chain
- Introduction to Cold Chain
- Blockchain Application Issues
- Tangle Vs Blockchain
- Proposed InnocuLedger
- Experimental Evaluation

Typical Vaccine Supply Chain



Cold Chain Entities



J. Zhao, F. Ye and S. Li, "Research on Cold Chain Logistics Risk Control of Fresh E-commerce under New Retail," *2023 7th International Conference on Management Engineering, Software Engineering and Service Sciences (ICMSS)*, Wuhan, China, 2023, pp. 121-126, doi: 10.1109/ICMSS56787.2023.10118218.

Related Research

Aspect	Traditional Blockchain Applications	Ethereum Blockchain & IoT Applications	InoculLdeger (IOTA Tangle-based)
Platform	[✓]	[✓]	[✓]
Business Functions	[✓]	[✓]	[✓]
Mechanism	[✓]	[✓]	[✓]
Scalability	[✗]	[✗]	[✓]
Cost	[✗]	[✗]	[✓]
Security	[✓]	[✓]	[✓]
Access Control	[✓]	[✓]	[✓]
Real-time Decision	[✓]	[✗]	[✓]
Throughput	[✗]	[✗]	[✓]

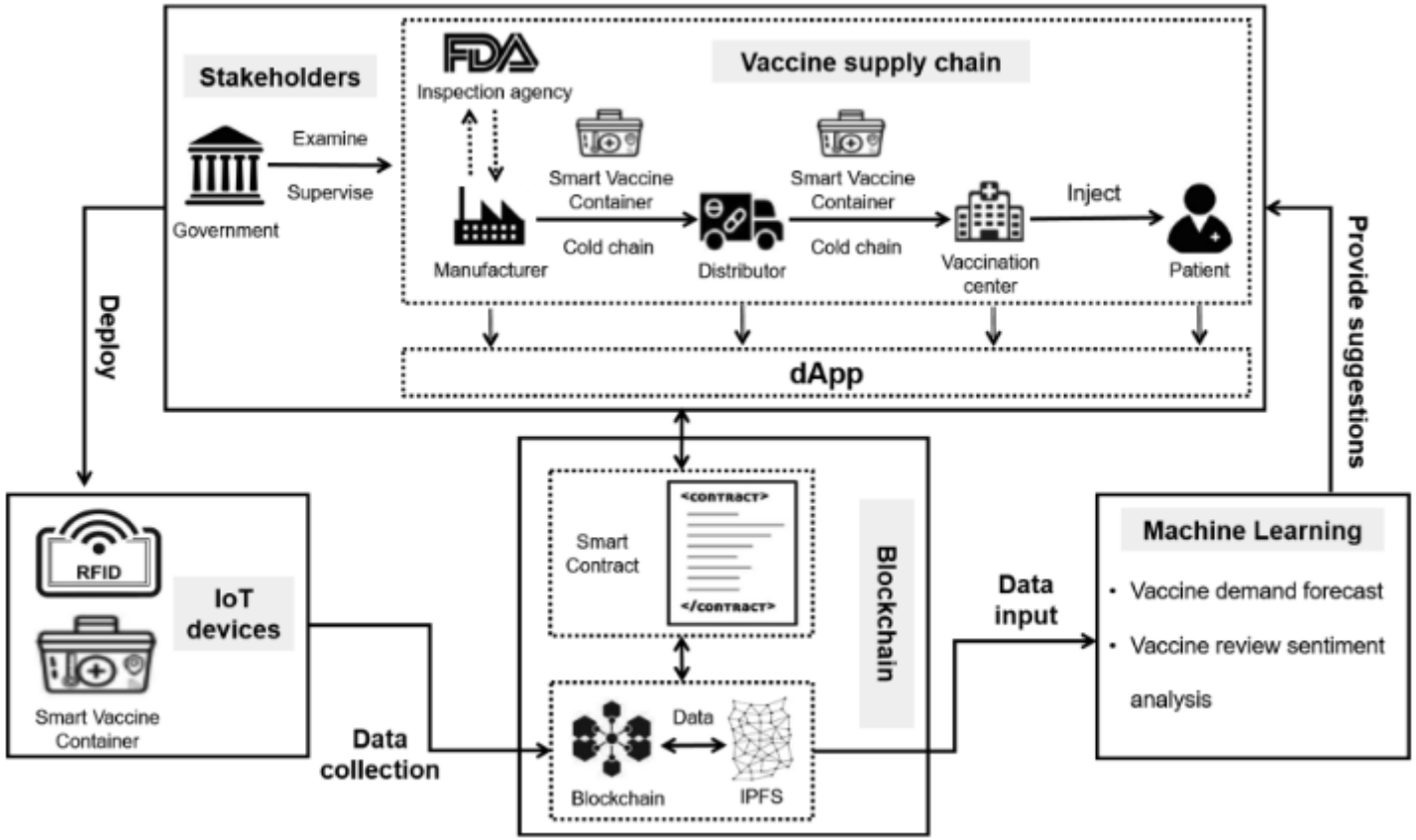
Problems Addressed

- Centralized authorities in the current VSC lead to several security threats and are prone to Single Point of Failure (SPOF).
- Detection delay of vaccine conditions can risk the efficiency of vaccines.
- Ensuring proper storage and transportation for vaccines is critical, yet it is challenging with traditional systems.
- Ethereum and other blockchain solutions are expensive and might not scale sufficiently for a higher VSC with billions of transactions. Vaccine authenticity is highly concerning to consumers due to counterfeit vaccines and mishandled doses.

Novel Contributions

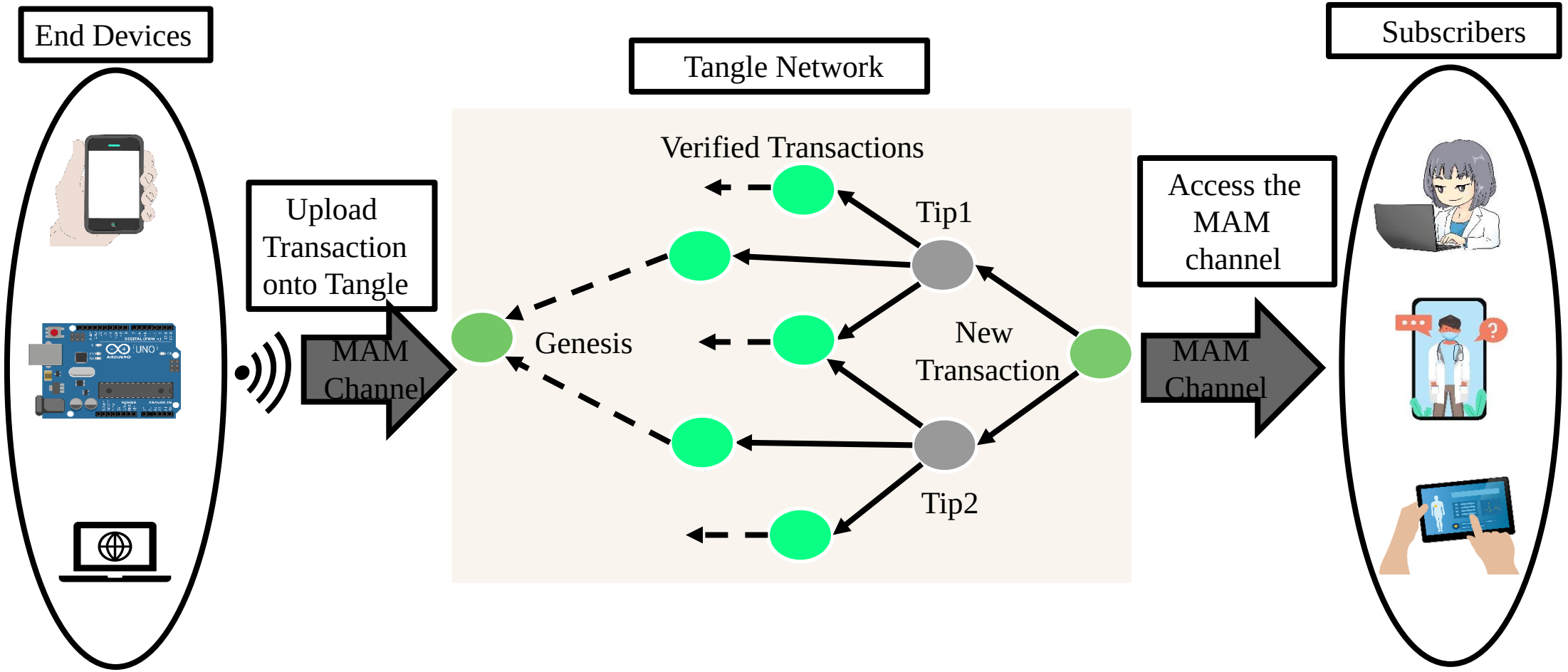
- Enabling a P2P network among trusted nodes significantly addressed the security threats.
- The immutable nature of IOTA Tangle guarantees vaccine data security.
- Implemented InoculLedger leveraging the IOTA platform which is cost-effective compared to other blockchain platforms.
- Designed Smart Container can provide continuous monitoring and alerting mechanisms to effectively manage the vaccine environment during transport and storage.
- Th developed InoculLedger's immutable record of all transactions provides fool foolproof way of authenticating vaccinations before administering.

Blockchain-based Smart Cold Chain Management



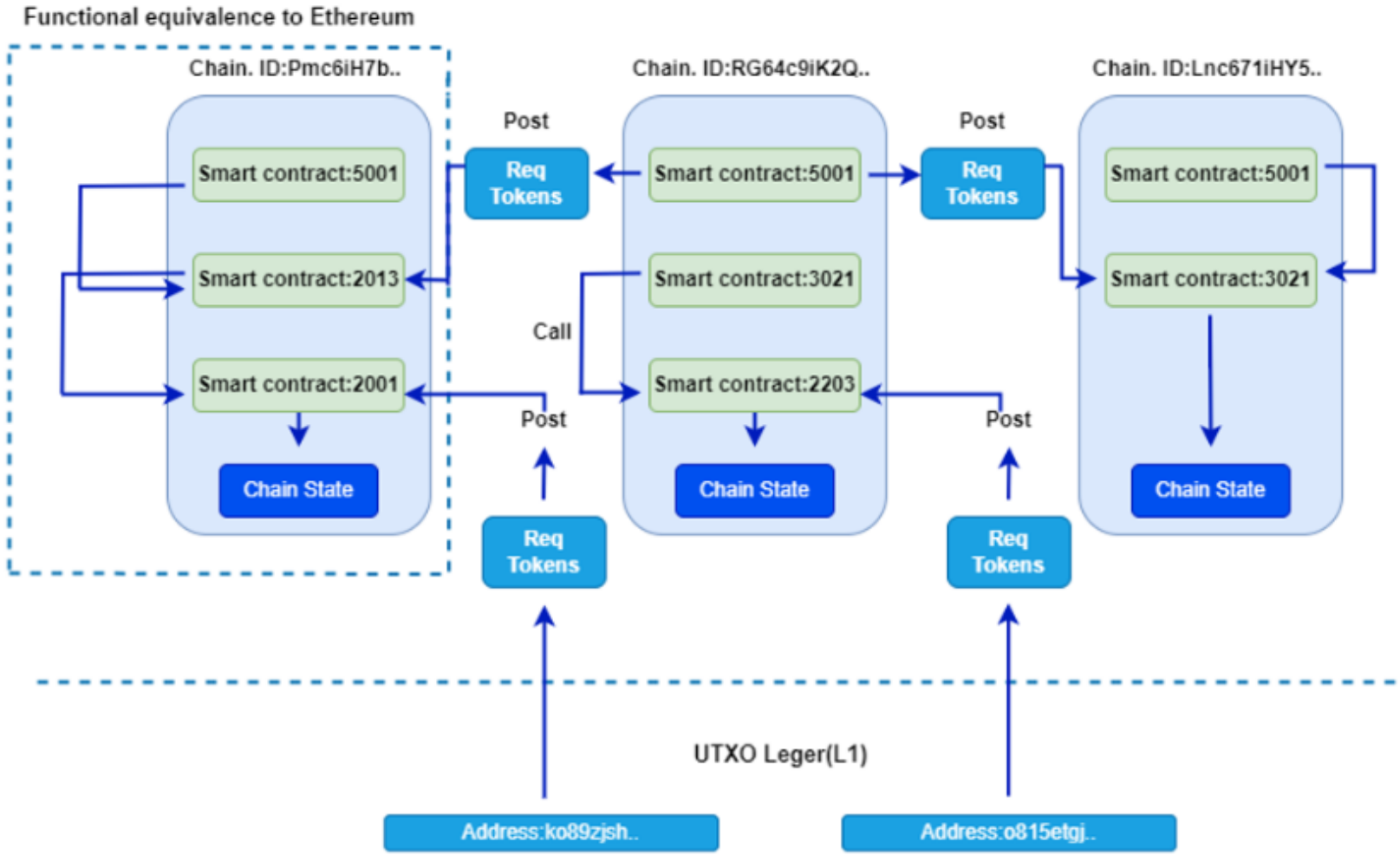
Source: Hu, H., Xu, J., Liu, M., & Lim, M. K. (2023). Vaccine supply chain management: An intelligent system utilizing blockchain, IoT, and machine learning. *Journal of business research*, *156*, 113480.

IOTA Tangle



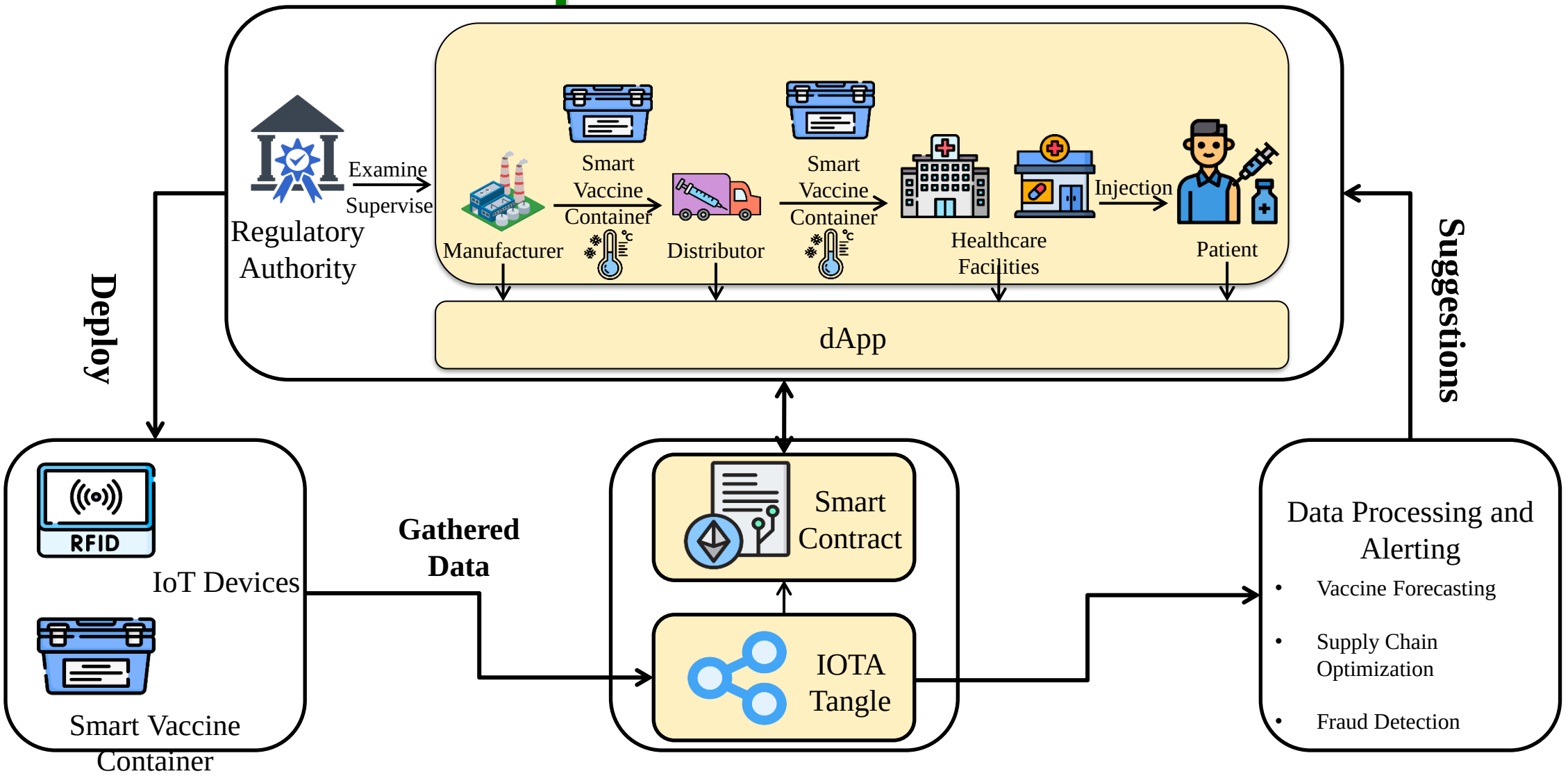
V. K. V. V. Bathalapalli, **S. P. Mohanty**, E. Kougianos, B. K. Baniya, and B. Rout, "PUFchain 3.0: Hardware-Assisted Distributed Ledger for Robust Authentication in the Internet of Medical Things", in *Proceedings of the IFIP International Internet of Things Conference (IFIP-IoT)*, 2022, pp. 23--40, DOI: https://doi.org/10.1007/978-3-031-18872-5_2.

IOTA Smart Contracts

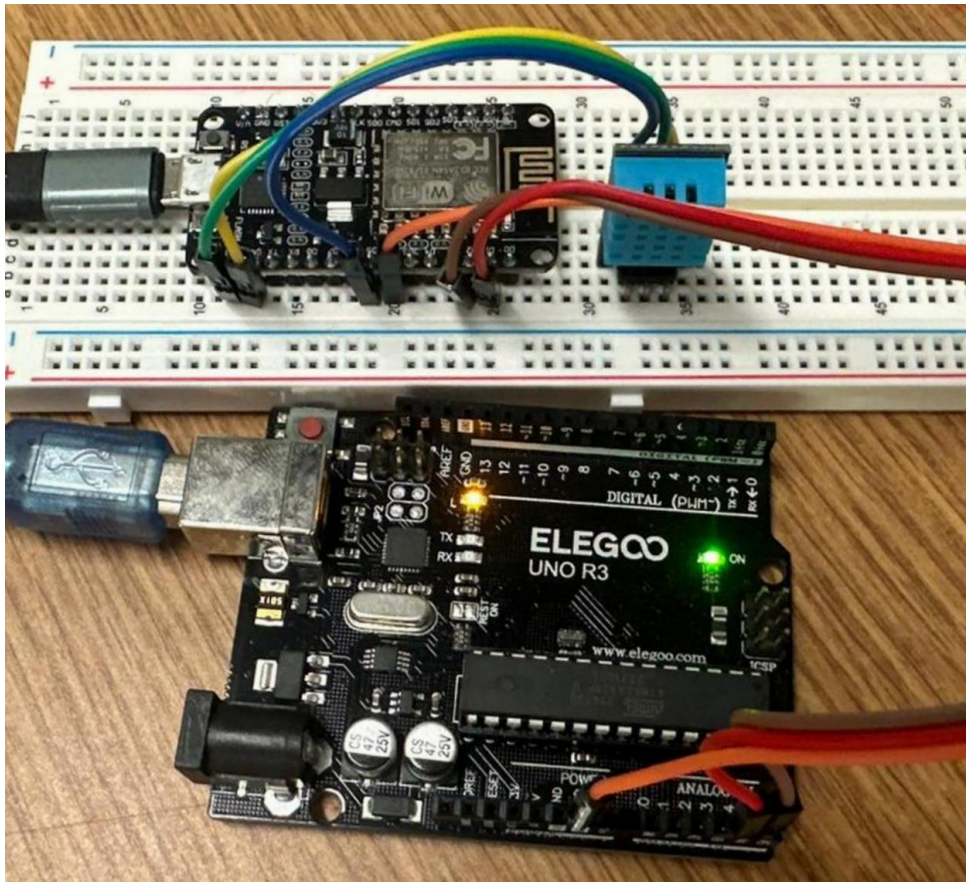


Fartitchou, M., Lamaakal, I., Maleh, Y., El Makkaoui, K., El Allali, Z., Pławiak, P., Alblehai, F., & A. Abd El-Latif, A. (2024). IOTASDN: IOTA 2.0 Smart Contracts for Securing Software-Defined Networking Ecosystem. *Sensors*, *24*(17), 5716. https://doi.org/10.3390/s24175716

Proposed Framework

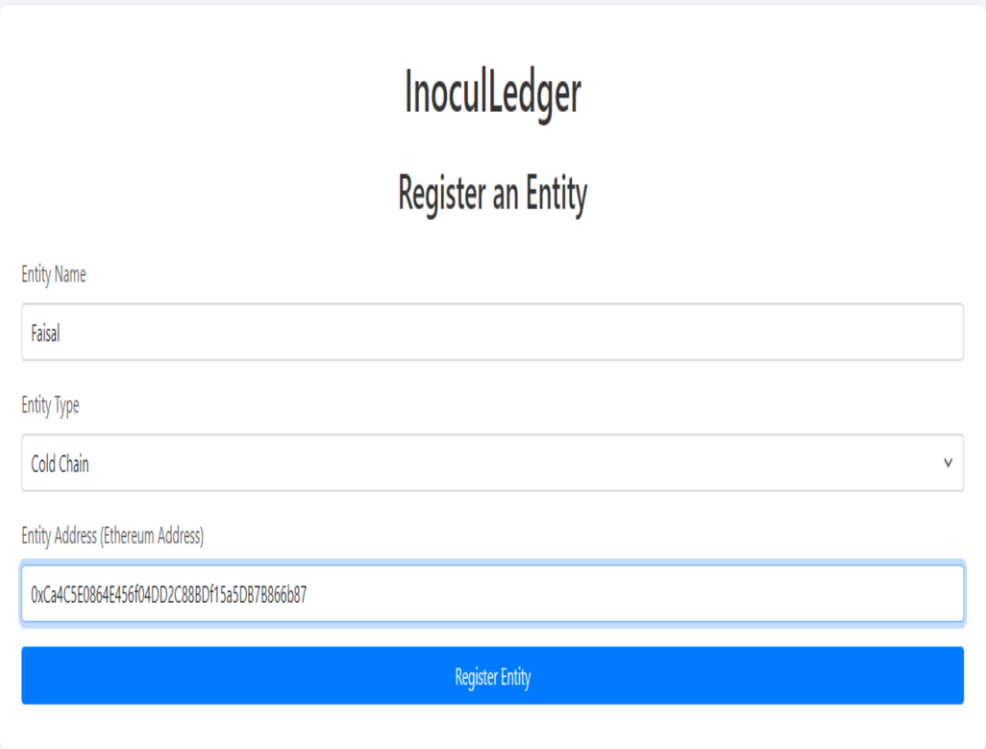


Prototype of Smart Vaccine Container



Cost and scalability analysis of the implemented InoculLedger are done to analyze the adaptability in real-world scenarios.
As the implemented application leverages the IOTA blockchain, it supports many micro-transactions at a minimal fee. With the shimmer token at 0.0025$ as of 11th December 2024, the cost of transactions on implemented InoculLedger is much lower, making it a scalable solution to VSC.

Registering and Certification




```
    status:     ,
    effectiveGasPrice:          ,
    type: '0x2',
    rawLogs: [ [Object] ]
  },
  logs: [
    {
      address: '0x681CB0237a6FE6f9DE109AFddA46B0341a6AeCC0',
      blockHash: '0xde86907a3b8c7a2b270acc526bc2a6ac99f33b4921db66340f149162a1ef00ea',
      blockNumber:   ,
      logIndex:  ,
      removed:      ,
      transactionHash: '0xaa64747be922865a4103c23237b4c4c2db37a609d0e90b2495d09e8f42bae128',
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      id: 'log_981b9a5a',
      event: 'VaccineCertified',
      args: [Result]
    }
  ]
}
```
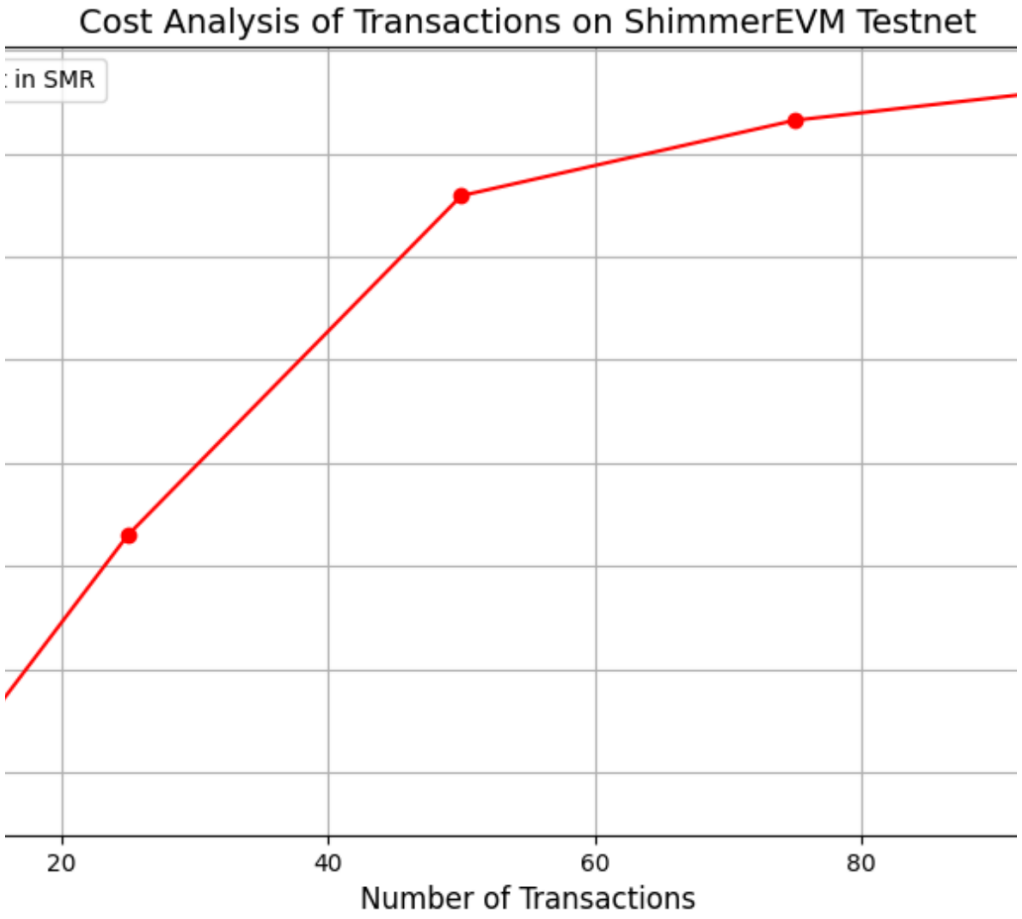
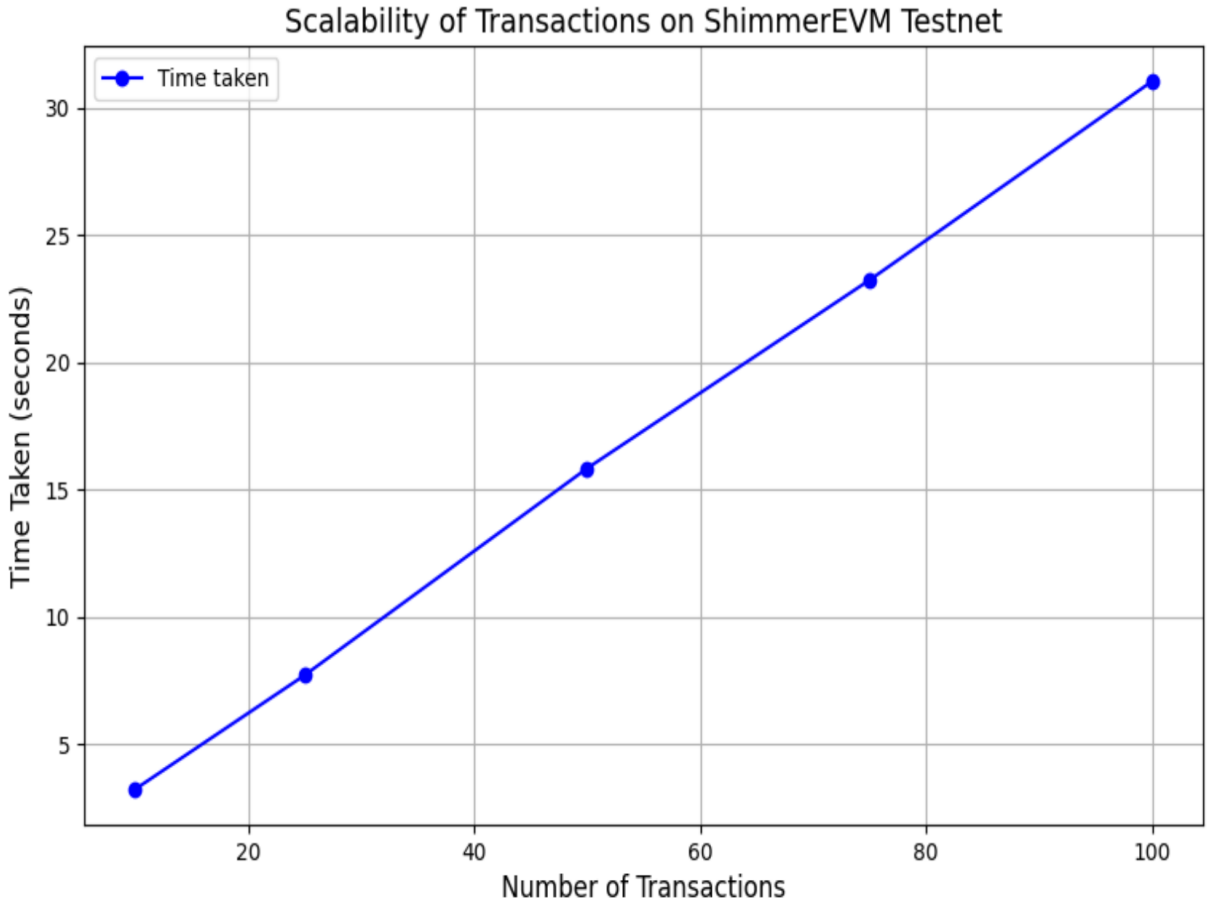

Experimental Evaluation





Conclusion

- InoculLedger utilizes IOTA Tangle-based architecture to enhance vaccine tracking and management throughout the supply chain.
- It ensures real-time temperature monitoring and the integrity of vaccines from manufacturing to administration, while significantly reducing transaction costs in favor of scalability and affordability.

Future Research

- In future research, we will include more complex interactions in the supply chain to provide a more complete solution. Also, machine learning models will be introduced to analyze the ledger data to automate processes.
- An intuitive interface eases the activities around shipment tracking and environmental monitoring, which allows stakeholders to have real-time oversight.