**Appendices**

**Appendix A**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Paper** | **Sector** | | | **Type of study** | | **Limitations** |
| **Healthcare** | | **Other** | **Review** | **Empirical** |
| **Pharmaceutical** | **General** |  |
| Schmidt et al. (2024) |  |  | Circular economy | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2024) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hawashin et al. (2024) |  |  | Robotics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Farah et al. (2024) |  |  | Maritime | X |  | - Not specific on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hoque et al. (2024) |  |  | Financial service | X | X | - Not specific on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Surucu-Balci et al. (2024) |  |  | Maritime | X |  | - Not specific on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kannan et al. (2024) |  |  | Circular economy | X | X | - Not specific on pharmaceutical/medical sector  - No countermeasures proposed |
| Gupta et al. (2024) |  |  | Logistics | X | X | - Not specific on pharmaceutical/medical sector  - No countermeasures proposed |
| Akram et al. (2024) |  |  | Food | X | X | - Not specific on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Yousefi and Tosarkani (2024) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kassen (2024) |  |  | General |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Quayson et al. (2024) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Terrizzi et al. (2024) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| BelMannoubi et al. (2023) |  |  | Intelligent transport systems | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2023b) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No challenge prioritization |
| Jiang et al. (2023) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Singh et al. (2023a) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Ullah et al. (2023) |  |  | Smart cities | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Chen et al. (2023) |  | X |  |  | X | - Not specific on pharmaceutical sector  - No challenge prioritization  - No countermeasures proposed |
| Vafadarnikjoo et al. (2023) |  |  | Manufacturing | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Das et al. (2023) |  |  | Intelligent transport systems | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Su et al. (2023) |  |  | Manufacturing | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kumar Singh et al. (2023) |  |  | Construction | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| J et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Komulainen and Nätti (2023) |  |  | Financial service |  | X | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Bak et al. (2023) |  | X |  |  | X | - Not specific on pharmaceutical sector  - No challenge prioritization  - No countermeasures proposed |
| Liu et al. (2023) |  |  | Maritime | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Li et al. (2023) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Qahtan et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yadav et al. (2023) |  | X |  | X | X | - Focus only on vaccine supply chain  - No countermeasures proposed |
| Arbabi et al. (2023) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Ghadge et al. (2023) | X |  |  | X |  | - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Govindan et al. (2023) |  | X |  | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Vern et al. (2023) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Mohammed et al. (2023a) |  |  | Food |  | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Mohammed et al. (2023a) |  |  | Food | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yadlapalli et al. (2022) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Govindan (2022) |  |  | Circular economy | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Erol et al. (2022) |  |  | Tourism | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Bamakan et al. (2022) |  |  | Waste management | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Yu et al. (2022) |  |  | Electronics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Wang et al. (2022) |  |  | Energy | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Okorie et al. (2022) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Srivastava and Dashora (2022) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Balci and Surucu-Balci (2021) |  |  | Maritime | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Srinivas Aditya et al. (2021) |  |  | Robotics | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Toufaily et al. (2021) |  |  | General |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Hosseini Bamakan et al. (2021) | X |  |  | X |  | - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Mathivathanan et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Ghode et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Kouhizadeh et al. (2021) |  |  | Supply chain | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Namasudra et al. (2021) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Thakker et al. (2021) |  |  | Diamond | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Nurgazina et al. (2021) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Dutta et al. (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Ali et al. (2020) |  |  | Financial service | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Upadhyay (2020) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Durneva et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Feng et al. (2020) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Wamba and Queiroz (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Y. Chang et al. (2020) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Lohmer and Lasch (2020) |  |  | Manufacturing | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| V. Chang et al. (2020) |  |  | Financial service |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Yadav et al. (2020) |  |  | Food | X | X | - Not specific on pharmaceutical sector  - No countermeasures proposed |
| Farooque et al. (2020) |  |  | Lifecycle assessment |  | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Rejeb et al. (2020) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hughes et al. (2019) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kumar et al. (2020) |  |  | Supply Chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Biswas and Gupta (2019) |  |  | General | X | X | - Not on pharmaceutical/medical sector  - No countermeasures proposed |
| Zhao et al. (2019) |  |  | Food | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Namasudra et al. (2021) |  |  | General | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Saberi et al. (2019) |  |  | Supply chain | X |  | - Not on pharmaceutical/medical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Queiroz and Fosso Wamba (2019) |  |  | Supply chain |  | X | - Not on pharmaceutical/medical sector  - No challenge prioritization  - No countermeasures proposed |
| Bathula et al. (2024) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Mackey et al. (2019) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Kamel Boulos et al. (2018) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| McGhin et al. (2019) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Saeed et al. (2022) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hasselgren et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Tandon et al. (2020) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Pesqueira et al. (2024) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Hock et al. (2020) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Uddin et al. (2021) | X |  |  | X |  | - On a specific pharmaceutical application  - No empirical data  - No challenge prioritization  - No countermeasures proposed |
| Dash et al. (2021) |  | X |  | X |  | - Not specific on pharmaceutical sector  - No empirical data  - No challenge prioritization  - No countermeasures proposed |

**References**

Akram, M.W., Akram, N., Shahzad, F., Rehman, K.U., Andleeb, S., 2024. Blockchain technology in a crisis: Advantages, challenges, and lessons learned for enhancing food supply chains during the COVID-19 pandemic. J Clean Prod 434.

Ali, O., Ally, M., Clutterbuck, Dwivedi, Y., 2020. The state of play of blockchain technology in the financial services sector: A systematic literature review. Int J Inf Manage 54.

Arbabi, M.S., Lal, C., Veeraragavan, N.R., Marijan, D., Nygard, J.F., Vitenberg, R., 2023. A Survey on Blockchain for Healthcare: Challenges, Benefits, and Future Directions. IEEE Communications Surveys and Tutorials 25, 386–424.

Bak, O., Braganza, A., Chen, W., 2023. Exploring blockchain implementation challenges in the context of healthcare supply chain (HCSC). Int J Prod Res.

Balci, G., Surucu-Balci, E., 2021. Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade. Transp Res E Logist Transp Rev 156.

Bamakan, S.M.H., Malekinejad, P., Ziaeian, M., 2022. Towards blockchain-based hospital waste management systems; applications and future trends. J Clean Prod 349.

Bathula, A., Gupta, S.K., Merugu, S., Saba, L., Khanna, N.N., Laird, J.R., Sanagala, S.S., Singh, R., Garg, D., Fouda, M.M., Fouda, M.M., Suri, J.S., 2024. Blockchain, artificial intelligence, and healthcare: the tripod of future—a narrative review. Artif Intell Rev 57.

BelMannoubi, S., Touati, H., Hadded, M., Toumi, K., Shagdar, O., Kamoun, F., 2023. A comprehensive survey on blockchain-based C-ITS applications: Classification, challenges, and open issues. Vehicular Communications 43.

Biswas, B., Gupta, R., 2019. Analysis of barriers to implement blockchain in industry and service sectors. Comput Ind Eng 136, 225–241.

Chang, V., Baudier, P., Zhang, H., Xu, Q., Zhang, J., Arami, M., 2020. How Blockchain can impact financial services – The overview, challenges and recommendations from expert interviewees. Technol Forecast Soc Change 158.

Chang, Y., Iakovou, E., Shi, W., 2020. Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities. Int J Prod Res 58, 2082–2099.

Chen, Z.-S., Zhu, Z., Wang, Z.-J., Tsang, Y., 2023. Fairness-aware large-scale collective opinion generation paradigm: A case study of evaluating blockchain adoption barriers in medical supply chain. Inf Sci (N Y) 635, 257–278.

Das, D., Banerjee, S., Chatterjee, P., Ghosh, U., Biswas, U., 2023. Blockchain for Intelligent Transportation Systems: Applications, Challenges, and Opportunities. IEEE Internet Things J 10, 18961–18970.

Dash, S., Gantayat, P.K., Das, R.K., 2021. Blockchain technology in healthcare: Opportunities and challenges, Intelligent Systems Reference Library.

Durneva, P., Cousins, K., Chen, M., 2020. The current state of research, challenges, and future research directions of blockchain technology in patient care: Systematic review. J Med Internet Res 22.

Dutta, P., Choi, T.-M., Somani, S., Butala, R., 2020. Blockchain technology in supply chain operations: Applications, challenges and research opportunities. Transp Res E Logist Transp Rev 142.

Erol, I., Neuhofer, I.O., Dogru (Dr. True), T., Oztel, A., Searcy, C., Yorulmaz, A.C., 2022. Improving sustainability in the tourism industry through blockchain technology: Challenges and opportunities. Tour Manag 93.

Farah, M.B., Ahmed, Y., Mahmoud, H., Shah, S.A., Al-kadri, M.O., Taramonli, S., Bellekens, X., Abozariba, R., Idrissi, M., Aneiba, A., 2024. A survey on blockchain technology in the maritime industry: Challenges and future perspectives. Future Generation Computer Systems 157, 618–637.

Farooque, M., Jain, V., Zhang, A., Li, Z., 2020. Fuzzy DEMATEL analysis of barriers to Blockchain-based life cycle assessment in China.

Feng, H., Wang, X., Duan, Y., Zhang, J., Zhang, X., 2020. Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. J Clean Prod 260.

Ghadge, A., Bourlakis, M., Kamble, S., Seuring, S., 2023. Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework. Int J Prod Res 61, 6633–6651.

Ghode, D.J., Yadav, V., Jain, R., Soni, G., 2021. Blockchain adoption in the supply chain: an appraisal on challenges. Journal of Manufacturing Technology Management 32, 42–62.

Govindan, K., 2022. Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: A circular manufacturing perspective. Bus Strategy Environ 31, 3769–3785.

Govindan, K., Nasr, A.K., Saeed Heidary, M., Nosrati-Abarghooee, S., Mina, H., 2023. Prioritizing adoption barriers of platforms based on blockchain technology from balanced scorecard perspectives in healthcare industry: a structural approach. Int J Prod Res 61, 3512–3526.

Gupta, A., Singh, R.K., Kamal, M.M., 2024. Blockchain technology adoption for secured and carbon neutral logistics operations: barrier intensity index framework. Ann Oper Res.

Hasselgren, A., Kralevska, K., Gligoroski, D., Pedersen, S.A., Faxvaag, A., 2020. Blockchain in healthcare and health sciences—A scoping review. Int J Med Inform 134.

Hawashin, D., Nemer, M., Gebreab, S.A., Salah, K., Jayaraman, R., Khan, M.K., Damiani, E., 2024. Blockchain applications in UAV industry: Review, opportunities, and challenges. Journal of Network and Computer Applications 230.

Hock, S.C., Tay, V., Sachdeva, V., Wah, C.L., 2020. Pharmaceutical Data Integrity: issues, challenges and proposed solutions for manufacturers and inspectors. GaBI J 9, 171–182.

Hoque, M.M., Kummer, T.-F., Yigitbasioglu, O., 2024. How can blockchain-based lending platforms support microcredit activities in developing countries? An empirical validation of its opportunities and challenges. Technol Forecast Soc Change 203.

Hosseini Bamakan, S.M., Ghasemzadeh Moghaddam, S., Dehghan Manshadi, S., 2021. Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends. J Clean Prod 302.

Hughes, L., Dwivedi, Y.K., Misra, S.K., Rana, N.P., Raghavan, V., Akella, V., 2019. Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda. Int J Inf Manage 49, 114–129.

J, A., Isravel, D.P., Sagayam, K.M., Bhushan, B., Sei, Y., Eunice, J., 2023. Blockchain for healthcare systems: Architecture, security challenges, trends and future directions. Journal of Network and Computer Applications 215.

Jiang, P., Zhang, L., You, S., Fan, Y.V., Tan, R.R., Klemeš, J.J., You, F., 2023. Blockchain technology applications in waste management: Overview, challenges and opportunities. J Clean Prod 421.

Kamel Boulos, M.N., Wilson, J.T., Clauson, K.A., 2018. Geospatial blockchain: Promises, challenges, and scenarios in health and healthcare. Int J Health Geogr 17.

Kannan, D., Amiri, A.S., Shaayesteh, M.T., Nasr, A.K., Mina, H., 2024. Unveiling barriers to the integration of blockchain-based circular economy and Industry 5.0 in manufacturing industries: A strategic prioritization approach. Bus Strategy Environ.

Kassen, M., 2024. Prospects of blockchain governance: Understanding key public values, principles, challenges, and opportunities. Policy Internet 16, 33–64.

Komulainen, R., Nätti, S., 2023. Barriers to blockchain adoption: Empirical observations from securities services value network. J Bus Res 159.

Kouhizadeh, M., Saberi, S., Sarkis, J., 2021. Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. Int J Prod Econ 231.

Kumar, A., Liu, R., Shan, Z., 2020. Is Blockchain a Silver Bullet for Supply Chain Management? Technical Challenges and Research Opportunities. Decision Sciences 51, 8–37.

Kumar Singh, A., Kumar, V.R.P., Dehdasht, G., Mohandes, S.R., Manu, P., Pour Rahimian, F., 2023. Investigating the barriers to the adoption of blockchain technology in sustainable construction projects. J Clean Prod 403.

Li, K., Lee, J.-Y., Gharehgozli, A., 2023. Blockchain in food supply chains: a literature review and synthesis analysis of platforms, benefits and challenges. Int J Prod Res 61, 3527–3546.

Liu, J., Zhang, H., Zhen, L., 2023. Blockchain technology in maritime supply chains: applications, architecture and challenges. Int J Prod Res 61, 3547–3563.

Lohmer, J., Lasch, R., 2020. Blockchain in operations management and manufacturing: Potential and barriers. Comput Ind Eng 149.

Mackey, T.K., Kuo, T.-T., Gummadi, B., Clauson, K.A., Church, G., Grishin, D., Obbad, K., Barkovich, R., Palombini, M., 2019. “Fit-for-purpose?” - Challenges and opportunities for applications of blockchain technology in the future of healthcare. BMC Med 17.

Mathivathanan, D., Mathiyazhagan, K., Rana, N.P., Khorana, S., Dwivedi, Y.K., 2021. Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modelling (TISM) approach. Int J Prod Res 59, 3338–3359.

McGhin, T., Choo, K.-K.R., Liu, C.Z., He, D., 2019. Blockchain in healthcare applications: Research challenges and opportunities. Journal of Network and Computer Applications 135, 62–75.

Mohammed, A., Potdar, V., & Quaddus, M., 2023a. Exploring Factors and Impact of Blockchain Technology in the Food Supply Chains: An Exploratory Study. Foods 12(10), 2052

Mohammed, A., Potdar, V., & Quaddus, M., Hui, W., 2023b. Blockchain Adoption in Food Supply Chains: A Systematic Literature Review on Enablers, Benefits, and Barriers. IEEE Access 11, 14236-14255

Namasudra, S., Deka, G.C., Johri, P., Hosseinpour, M., Gandomi, A.H., 2021. The Revolution of Blockchain: State-of-the-Art and Research Challenges. Archives of Computational Methods in Engineering 28, 1497–1515.

Nurgazina, J., Pakdeetrakulwong, U., Moser, T., Reiner, G., 2021. Distributed Ledger Technology Applications in Food Supply Chains: A Review of Challenges and Future Research Directions. Sustainability 13(8), 4206.

Okorie, O., Russell, J., Jin, Y., Turner, C., Wang, Y., Charnley, F., 2022. Removing barriers to Blockchain use in circular food supply chains: Practitioner views on achieving operational effectiveness. Clean. Logist. Supply Chain. 5, 100087.

Pesqueira, A., Sousa, M.J., de Bem Machado, A., 2024. Addressing Counterfeiting and Fraud Concerns in Healthcare Packaging and Labeling with Blockchain: Opportunities and Challenges. WSEAS Transactions on Information Science and Applications 21, 246–263.

Qahtan, S., Yatim, K., Zulzalil, H., Osman, M.H., Zaidan, A.A., Alsattar, H.A., 2023. Review of healthcare industry 4.0 application-based blockchain in terms of security and privacy development attributes: Comprehensive taxonomy, open issues and challenges and recommended solution. Journal of Network and Computer Applications 209.

Quayson, M., Bai, C., Sarkis, J., Hossin, M. A., 2024. Evaluating barriers to blockchain technology for sustainable agricultural supply chain: A fuzzy hierarchical group DEMATEL approach. Oper Manag Res 17, 728–753.

Queiroz, M.M., Fosso Wamba, S., 2019. Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. Int J Inf Manage 46, 70–82.

Rejeb, A., Keogh, J. G., Zailani, S., Treiblmaier, H., Rejeb, K., 2020. Blockchain Technology in the Food Industry: A Review of Potentials, Challenges and Future Research Directions. Logistics 4(4), 27.

Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L., 2019. Blockchain technology and its relationships to sustainable supply chain management. Int J Prod Res 57, 2117–2135.

Saeed, H., Malik, H., Bashir, U., Ahmad, A., Riaz, S., Ilyas, M., Bukhari, W.A., Khan, M.I.A., 2022. Blockchain technology in healthcare: A systematic review. PLoS One 17.

Schmidt, J.L., Sehnem, S., Spuldaro, J.D., 2024. Blockchain and the transition to the circular economy: A literature review. Corp Soc Responsib Environ Manag 31, 2010–2032.

Singh, A.K., Kumar, V.R.P., Dehdasht, G., Mohandes, S.R., Manu, P., Pour Rahimian, F., 2023a. Investigating barriers to blockchain adoption in construction supply chain management: A fuzzy-based MCDM approach. Technol Forecast Soc Change 196.

Singh, A.K., Kumar, V.R.P., Shoaib, M., Adebayo, T.S., Irfan, M., 2023b. A strategic roadmap to overcome blockchain technology barriers for sustainable construction: A deep learning-based dual-stage SEM-ANN approach. Technol Forecast Soc Change 194.

Singh, S., Chhabra, R., Arora, J., 2024. A Systematic Review of Waste Management Solutions Using Machine Learning, Internet of Things and Blockchain Technologies: State-of-Art, Methodologies, and Challenges. Archives of Computational Methods in Engineering 31, 1255–1276.

Srinivas Aditya, U.S.P., Singh, R., Singh, P.K., Kalla, A., 2021. A Survey on Blockchain in Robotics: Issues, Opportunities, Challenges and Future Directions. Journal of Network and Computer Applications 196.

Srivastava, A. Dashora, K., 2022. Application of blockchain technology for agrifood supply chain management: a systematic literature review on benefits and challenges. Benchmarking: An International Journal 29(10), 3426-344

Su, D., Zhang, L., Peng, H., Saeidi, P., Tirkolaee, E.B., 2023. Technical challenges of blockchain technology for sustainable manufacturing paradigm in Industry 4.0 era using a fuzzy decision support system. Technol Forecast Soc Change 188.

Surucu-Balci, E., Iris, Ç., Balci, G., 2024. Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities. Technol Forecast Soc Change 198.

Tandon, A., Dhir, A., Islam, N., Mäntymäki, M., 2020. Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda. Comput Ind 122.

Terrizzi, G., Marino, A., Cinici, M.C., Baglieri, D., 2024. Blockchain applications in the agri-food sector: current insights, challenges and research avenues, British Food Journal 126(13), 504-520.

Thakker, U., Patel, R., Tanwar, S., Kumar, N., Song, H., 2021. Blockchain for Diamond Industry: Opportunities and Challenges. IEEE Internet Things J 8, 8747–8773.

Toufaily, E., Zalan, T., Dhaou, S.B., 2021. A framework of blockchain technology adoption: An investigation of challenges and expected value. Information and Management 58.

Uddin, M., Salah, K., Jayaraman, R., Pesic, S., Ellahham, S., 2021. Blockchain for drug traceability: Architectures and open challenges. Health Informatics J 27.

Ullah, Z., Naeem, M., Coronato, A., Ribino, P., De Pietro, G., 2023. Blockchain Applications in Sustainable Smart Cities. Sustain Cities Soc 97.

Upadhyay, N., 2020. Demystifying blockchain: A critical analysis of challenges, applications and opportunities. Int J Inf Manage 54.

Vafadarnikjoo, A., Badri Ahmadi, H., Liou, J.J.H., Botelho, T., Chalvatzis, K., 2023. Analyzing blockchain adoption barriers in manufacturing supply chains by the neutrosophic analytic hierarchy process. Ann Oper Res 327, 129–156.

Vern, P., Panghal, A., Mor, R.S., Kamble, S. S., Shamimul Islam, M., Rehman Khan, S. A., 2023. Influential barriers to blockchain technology implementation in agri-food supply chain. Oper Manag Res 16, 1206–1219.

Wamba, S.F., Queiroz, M.M., 2020. Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities. Int J Inf Manage 52.

Wang, T., Hua, H., Wei, Z., Cao, J., 2022. Challenges of blockchain in new generation energy systems and future outlooks. International Journal of Electrical Power and Energy Systems 135.

Yadav, V. S., Singh, A. R., Raut, R. D., Govindarajan, U. H., 2020. Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach. Resour. Conserv. Recycl. 161, 104877.

Yadav, A.K., Shweta, Kumar, D., 2023. Blockchain technology and vaccine supply chain: Exploration and analysis of the adoption barriers in the Indian context. Int J Prod Econ 255.

Yadlapalli, A., Rahman, S., Gopal, P., 2022. Blockchain technology implementation challenges in supply chains – evidence from the case studies of multi-stakeholders. International Journal of Logistics Management 33, 278–305.

Yousefi, S., Tosarkani, B.M., 2024. Enhancing sustainable supply chain readiness to adopt blockchain: A decision support approach for barriers analysis. Eng Appl Artif Intell 133.

Yu, X., Tang, C., Palensky, P., Colombo, A.W., 2022. Blockchain: What Does It Mean to Industrial Electronics?: Technologies, Challenges, and Opportunities. IEEE Industrial Electronics Magazine 16, 4–14.

Zhao, G., Liu, S., Lopez, C., Lu, H., Elgueta, S., Chen, H., Boshkoska, B.M., 2019. Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions. Comput Ind 109, 83–99.

**Appendix B**

***Data immutability***

Data immutability, meaning that data *“cannot be changed or modified”*, is one of the main characteristics of blockchain technology (Mahjoub et al., 2022). This characteristic represents one of the most attracting characteristics of blockchain as it *“ensures reliability and authenticity of information”* (Kouhizadeh et al., 2021). However, despite its attracting feature, data immutability is accompanied also by an issue. Indeed, as reported by Kouhizadeh et al. (2021), *“an issue that arises with immutability is that previous data and errors within the records are permanent, as they will continue to live with the blockchain”*.

In conclusion, we can derive the following proposition:

***Proposition P1:*** Once data are recorded in a blockchain, they cannot be easily altered or deleted: while this is a key feature of blockchain, it can pose some challenges if errors are made or if there is a need to update information

***High investment costs***

As in any other sector (Abadi and Brunnermeier, 2018; Ruoti et al., 2020), also in the pharmaceutical sector the cost of implementing blockchain is high and it is considered a barrier (Radanović and Likić, 2018; Toufaily et al., 2021). As an example, Dhingra et al. (2024)stated that *“Another noteworthy observation is that a high cost is associated with establishing and managing the blockchain network”*. Saberi et al. (2019) justifies such high costs with the required investments in terms of software and hardware. Indeed, they stated that *“blockchain technology requires investing in new hardware and software for information collection, which is costly for organisations and network partners”*.

In conclusion, we can derive the following proposition:

***Proposition P2:*** Implementing blockchain requires significant investment costs, with companies needing to develop software and invest in expensive hardware

***High need of resources***

When adopting a new technology, one should not consider only the costs for purchasing software and hardware, i.e. the mere installation costs, but it should also consider the time and resources required to learn how to use such new technology. This is the case for all the new technologies (Hung and Chu, 2006; Khan and Turowski, 2016; Salomon and Martin, 2008), and blockchain is not exempt from it. Indeed, as stated by Balci and Surucu-Balci (2021), *“organisations need to train and upskill employees and invest some time and resources”*. Similarly, Dhingra et al. (2024) reported that training-associated costs concur to *“increase the associated cost”* and hence pose a risk to the blockchain adoption

In conclusion, we can derive the following proposition:

***Proposition P3:*** A correct implementation and adoption of blockchain requires significant requirements in terms of time and resources

***IT security***

Many papers mention that the implementation and use of blockchain is subject to IT security issues, not only in the pharmaceutical sector but also in other sectors (as an example the Bitcoin network is characterized by an increasing number of hacking attacks (Chen et al., 2023)) (Saberi et al., 2019) As an example, Saberi et al. (2019) stated that *“data security and privacy concerns are also challenges of using blockchain technology”* and Hosseini Bamakan et al. (2021) that *“the data faces potential privacy and security risks”*. More exhaustive in this perspective is the statement of Toufaily et al. (2021): *“Security, as a possibility of 51% attack, hard forks and system bugs for permissionless blockchains, and a risk of fraud, centralized control, risk of data tampering and lack of consensus mechanisms for permissioned blockchains is a challenge to the adoption of the technology”*.

Hence, we can derive the following proposition:

***Proposition P4:*** The implementation and use of blockchain is subject to IT security issues, such as data vulnerabilities, hacking risks, etc.

***Lack of customers’ acceptance***

As stated by Chen et al. (2021), “customers’ and users’ acceptance also needs to be considered during blockchain implementation”. However, according to Kouhizadeh et al. (2021), *“the adoption of blockchain technology, although hyped for years, has not seen rapid acceptance”*. Similarly, Sander et al. (2018) stated that *“BCT is still in its early stages and needs more time to achieve full acceptance, application and potential”*. Such low customers’ acceptance, in turn, acts as a deterrent for blockchain adoption: as stated by Kouhizadeh et al. (2021) *“it is evident that risk and (low) customers’ acceptance are critical initial concerns for this emergent technology and its application to practice”* and according to Sander et al. (2018) there is “the need for a change in mentality” to ensure blockchain’s diffusion.

In conclusion, we can derive the following proposition:

***Proposition P5:*** Customers’ acceptance is crucial for convincing managers to adopt blockchain. If this is missing, this acts as a deterrent for blockchain adoption

***Lack of governmental support***

According to Hussien et al. (2019), the lack of governmental initiatives was among the most crucial challenges to hinder blockchain adoption. A similar result was reported in Kassab et al. (2021). Notably, among the governmental initiatives, they did not only consider economic initiatives such as incentives or other similar economic benefits to support the blockchain adoption, but also the introduction of regulations. Indeed, as stated by Upadhyay et al. (2021), *“government regulations are not yet completely supportive of blockchain technology”*. Similarly, Saberi et al. (2019) reported that the *“lack of appropriate governmental policy (…) is a hurdle for achieving advanced technological (i.e. blockchain) supporting mechanisms”*. In conclusion, as stated by Orji et al. (2020), *“government policy and support is an influential environmental factor of blockchain adoption”*.

Hence, we can derive the following proposition:

***Proposition P6:*** Governmental support in terms of economic incentives and regulations is needed; this is however currently lacking, hence hindering blockchain adoption

***Lack of interoperability***

As reported by Toufaily et al. (2021), *“a lack of interoperability between different blockchain frameworks, networks and platforms, as well as between blockchain networks and legacy systems, is a significant concern acknowledged in the literature”*. Indeed, *“each blockchain has its own distinctive characteristics, e.g., consensus mechanism, governance mechanism, different protocols, and coding languages, which restricts these blockchain from interacting with each other”* (Mahjoub et al., 2022). Therefore, to maximize the power of blockchain, *“agreements will need to be reached about data interoperability”* (Hileman and Rauchs, 2017). This is however currently missing, and *“interoperability is anticipated to be a challenge that will take time, skills and facilities to be resolved”* (Toufaily et al., 2021).

In conclusion, we can derive the following proposition:

***Proposition P7:*** Interoperability is the capability of different blockchain networks or systems to communicate and share data seamlessly. If this is missing, efficient data exchange is hence hindered.

***Lack of managerial support***

As stated by Toufaily et al. (2021), top management support *“is crucial for (any) technology adoption”*, and this is the case also for blockchain. Indeed, Dhingra et al. (2024) stated that *“top management support are the top-ranked or high-intensity challenges”* hindering blockchain adoption. Similar findings were reported by many other authors, such as Hussien et al. (2019), Kassab et al. (2021) and Shukla et al. (2021).

In conclusion, we can derive the following proposition:

***Proposition P8:*** Support from senior management is crucial for the successful implementation and adoption of blockchain

***Lack of regulations***

As stated by Toufaily et al. (2021), *“even though blockchain has the potential to positively impact many industries, some applications have called into question the legitimacy of the technology, given security and privacy concerns”*. However, currently no regulations exist to control such issues. Indeed, Toufaily et al. (2021) stated that *“regulatory uncertainty is a key challenge hindering blockchain applications and a wider adoption”* and that the *“absence of legal frameworks is stifling innovation”*. Similarly, Bai et al. (2022) reported that the *“immature regulation of this technology might raise concerns among stakeholders and become a barrier to the adoption of blockchain”*. Indeed, according to Janssen et al. (2020), laws and regulations can influence how fast the technology could develop.

In conclusion, we can derive the following proposition:

***Proposition P9:*** Regulations about data security and privacy laws need to be put in place by governmental bodies to support the widespread adoption of blockchain. These are however currently missing

***Lack of scalability***

*“Scalability refers to the ability of the system to sustain performance while growing and expanding, such as increasing the number of nodes, storage requirements and the response time per transaction as the network grows”* and it is *“a key technical challenge in blockchain adoption”* (Toufaily et al., 2021). More in details, Rana et al. (2022) stated that *“the blocks in the blockchain continue to grow with use and each transaction needs more time to be processed. The blockchain scalability problem relates to the fact that records (or blocks) in the blockchain are limited in size and frequency”*. Similarly, Hosseini Bamakan et al. (2021) stated that *“usages of blockchain are transaction-based, and therefore the databases used for this technology tend to rise at a rapid rate. The increasing size of databases causes the speed of record-searching and -accessing becomes decrease, which is highly inappropriate for the kinds of transactions where speed is crucial”*.

Hence, we can derive the following proposition:

***Proposition P10:*** Blockchains are characterized by restricted block size, which cannot be increased. This reduces transactions speed, which limits blockchain adoption by affecting the ability to handle growing transactions.

***Lack of standardization***

Due to the *“newness of blockchain”* (Govindan et al., 2023), many different ways of handling data collection and exchanges, transactions, validation, and security exist (Govindan et al., 2023; Kaur et al., 2024; Moretto and Macchion, 2022). However, *“process standardization can further advance the development of blockchain by providing internationally agreed ways of working”* (Kaur et al., 2024). Indeed, Hosseini Bamakan et al. (2021) stated that “to implement blockchain in this system (i.e. pharmaceutical sector) successfully there should be a suitable way of data storage of patients’ health record and information exchange between different systems takes part in blockchain application. In the light of this, Toufaily et al. (2021) stated that *“companies, start-ups, public actors and industries need to work together to define standards (…) for advancing the blockchain and stay ahead of the technology curve to accelerate adoption”*. Indeed, *“although many pressures exist”* (Kouhizadeh et al., 2021), *“blockchain systems are not standardised”* (Upadhyay et al., 2021) and *“a lack of standard (…) is preventing”* the blockchain diffusion.

In conclusion, we can derive the following proposition:

***Proposition P11:*** Various blockchain applications are following different blockchain standards. The lack of standardization about transaction structures, validation, and security complicates the adoption of blockchain since companies lack clear rules and standards to follow

***Need for maintenance***

As stated by Rana et al. (2022), in addition to cost to install, also *“cost to maintain blockchain has a negative impact on the implementation and use of this technology (i.e. blockchain)”*. Similar finding are reported also by other researches, who reported that the lack of maintenance could results in lower performances in terms of, e.g. transaction speeds, efficiency, and data security (Dhingra et al., 2024; Kouhizadeh et al., 2021; Rana et al., 2022).

Hence, we can derive the following proposition:

***Proposition P12:*** Blockchain requires regular maintenance, otherwise it experiences slower transaction speeds, reduced efficiency, and higher data security issues.

***Lack of collaboration***

As stated by Bai et al. (2022), *“engagement and collaboration from all the (network) participants are vital”* for a successful blockchain implementation. Indeed, the lack of collaboration is reported by Saberi et al. (2019) to *“disturb the implementation of blockchain to create value”*. However, currently, “*collaboration (…) is seen as a considerable challenge”* (Toufaily et al., 2021). Specifically, they (Toufaily et al., 2021) better elaborated on this specifying that this is due to the low trust in the technology due to its newness and to the “lack of solid rules”.

In the light of this, we can derive the following proposition:

***Proposition P13:*** A successful blockchain network requires the participation and commitment of all involved parties. It is however hard to convince all the involved parties and to ensure their cooperation, communication, and coordination

***Lack of knowledge on benefits***

As already mentioned in other challenges, the “*newness of blockchain”*, as defined it by Saberi et al. (2019), creates many setbacks for the technology. According to Asad and Popesko (2023), another challenge deriving from it is the lack of knowledge on blockchain benefits. This, in turn, according to Toufaily et al. (2021) limits blockchain adoption: *“a lack of top management knowledge of blockchain is hindering its adoption”*. Similar findings were found by, e.g., Kouhizadeh et al. (2021) and Govindan et al. (2023).

In the light of this, we can derive the following proposition:

***Proposition P14:*** Blockchain is new and in a developmental phase. Therefore, managers do not know what would be the benefit achievable and hence doubt about its adoption

***Lack of skilled personnel***

As stated by Mahjoub et al. (2022), there is *“an acute shortage of skilled developers and a lack of expertise”*, which *“represents an important obstacle in wider deployment of this technology (i.e. blockchain)”*. Similarly, Toufaily et al. (2021) defined *“the skills, competencies and talents in the organization as a crucial challenge for adoption”*. Indeed, *“without a solid grasp of the intricacies of blockchain technology, there is a higher likelihood of poorly designed or executed blockchain projects”*.

In the light of this, we can derive the following proposition:

***Proposition P15:*** There is limited amount of personnel skilled in blockchain, which is instead needed to fully exploit the benefits of blockchain.

***Privacy concern***

As reported by Pattanayak et al. (2024), blockchain, as a distributed ledger, is designed to disclose more data to other participants than traditional centralized databases. In the light of this, Toufaily et al. (2021) reported that *“overcoming privacy and confidentiality issues constitutes one of the key challenges to widespread blockchain adoption”* as they report the openness of public blockchain as a major disadvantage.

In the light of this, we can derive the following proposition:

***Proposition P16:*** Blockchain transactions are recorded on a public database accessible to anyone. This gives rise to privacy concerns.

***Workforce resistance***

As stated by Queiroz and Fosso Wamba (2019), the *“individual (employee’s) motivation to accept and use a new technology is related to his/her perception of some advantages (including the useful level) of the technology in his or her job routine”*. Since, as discussed above, there is a limited knowledge on the benefits of blockchain, Lohmer and Lasch (2020)reported *“staff difficulties”* to be one of the major barriers to blockchain adoption. Similarly, Hosseini Bamakan et al. (2021) stated that “accepting this technology (i.e. blockchain) that is so different from the traditional work methods never comes easy. Although the pharmaceutical industry is slowly moving towards blockchain, it takes a long time to use this technology completely.” In the light of this, Kouhizadeh et al. (2021) suggested to *“prepare employees for blockchain implementation”*.

***Proposition P17:*** Employees are reluctant to adopt blockchain and to change their processes to accommodate its implementation

**References**

Abadi, J., Brunnermeier, M.K., 2018. Blockchain Economics, in: NBER Working Paper No. W25407.

Asad, A.I., Popesko, B. 2023. Contemporary challenges in the European pharmaceutical industry: a systematic literature review. Measuring Business Excellence, 27(2), pp. 277-290.

Bai, Y., Liu, Y., Yeo, W.M., 2022. Supply chain finance: What are the challenges in the adoption of blockchain technology? Journal of Digital Economy 1, 153–165.

Chen, S., Liu, X., Yan, J., Hu, G., Shi, Y., 2021. Processes, benefits, and challenges for adoption of blockchain technologies in food supply chains: a thematic analysis. Information Systems and e-Business Management 19, 909–935.

Chen, Y.-L., Chang, Y.T., Yang, J.J., 2023. Cryptocurrency hacking incidents and the price dynamics of Bitcoin spot and futures. Financ Res Lett 55.

Dhingra, S., Raut, R., Gunasekaran, A., Rao Naik, B.K., Masuna, V., 2024. Analysis of the challenges for blockchain technology adoption in the Indian health-care sector. Journal of Modelling in Management 19, 375–406.

Hileman, G., Rauchs, M., 2017. 2017 Global Blockchain Benchmarking Study. SSRN Electronic Journal.

Hosseini Bamakan, S.M., Ghasemzadeh Moghaddam, S., Dehghan Manshadi, S., 2021. Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends. J Clean Prod 302.

Hung, S.-C., Chu, Y.-Y., 2006. Stimulating new industries from emerging technologies: Challenges for the public sector. Technovation 26, 104–110.

Hussien, H.M., Yasin, S.M., Udzir, S.N.I., Zaidan, A.A., Zaidan, B.B., 2019. A Systematic Review for Enabling of Develop a Blockchain Technology in Healthcare Application: Taxonomy, Substantially Analysis, Motivations, Challenges, Recommendations and Future Direction. J Med Syst 43.

Janssen, M., Weerakkody, V., Ismagilova, E., Sivarajah, U., Irani, Z., 2020. A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. Int J Inf Manage 50, 302–309.

Kassab, M., Defranco, J., Malas, T., Laplante, P., Destefanis, G., Neto, V.V.G., 2021. Exploring Research in Blockchain for Healthcare and a Roadmap for the Future. IEEE Trans Emerg Top Comput 9, 1835–1852.

Kaur, J., Kumar, S., Narkhede, B.E., Dabić, M., Rathore, A.P.S., Joshi, R., 2024. Barriers to blockchain adoption for supply chain finance: the case of Indian SMEs. Electronic Commerce Research 24, 303–340.

Khan, A., Turowski, K., 2016. A survey of current challenges in manufacturing industry and preparation for industry 4.0, Advances in Intelligent Systems and Computing.

Kouhizadeh, M., Saberi, S., Sarkis, J., 2021. Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. Int J Prod Econ 231.

Lohmer, J., Lasch, R., 2020. Blockchain in operations management and manufacturing: Potential and barriers. Comput Ind Eng 149.

Mahjoub, Y.I., Hassoun, M., Trentesaux, D., 2022. Blockchain adoption for SMEs: opportunities and challenges, in: IFAC-PapersOnLine. pp. 1834–1839.

Moretto, A., Macchion, L., 2022. Drivers, barriers and supply chain variables influencing the adoption of the blockchain to support traceability along fashion supply chains. Operations Management Research 15, 1470–1489.

Orji, I.J., Kusi-Sarpong, S., Huang, S., Vazquez-Brust, D., 2020. Evaluating the factors that influence blockchain adoption in the freight logistics industry. Transp Res E Logist Transp Rev 141.

Queiroz, M.M., Fosso Wamba, S., 2019. Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. Int J Inf Manage 46, 70–82.

Radanović, I., Likić, R., 2018. Opportunities for Use of Blockchain Technology in Medicine. Appl Health Econ Health Policy 16, 583–590.

Rana, N.P., Dwivedi, Y.K., Hughes, D.L., 2022. Analysis of challenges for blockchain adoption within the Indian public sector: an interpretive structural modelling approach. Information Technology and People 35, 548–576.

Ruoti, S., Kaiser, B., Yerukhimovich, A., Clark, J., Cunningham, R., 2020. Blockchain technology: What is it good for? Commun ACM 63, 46–53.

Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L., 2019. Blockchain technology and its relationships to sustainable supply chain management. Int J Prod Res 57, 2117–2135.

Salomon, R., Martin, X., 2008. Learning, knowledge transfer, and technology implementation performance: A study of time-to-build in the global semiconductor industry. Manage Sci 54, 1266–1280.

Sander, F., Semeijn, J., Mahr, D., 2018. The acceptance of blockchain technology in meat traceability and transparency. British Food Journal 120, 2066–2079.

Shukla, R.G., Agarwal, A., Shekhar, V., 2021. Leveraging Blockchain Technology for Indian Healthcare system: An assessment using value-focused thinking approach. Journal of High Technology Management Research 32.

Toufaily, E., Zalan, T., Dhaou, S.B., 2021. A framework of blockchain technology adoption: An investigation of challenges and expected value. Information and Management 58.

Upadhyay, A., Ayodele, J.O., Kumar, A., Garza-Reyes, J.A., 2021. A review of challenges and opportunities of blockchain adoption for operational excellence in the UK automotive industry. Journal of Global Operations and Strategic Sourcing 14, 7–60.

**Appendix C**

Questionnaire Delphi Study

**Delphi Study - BlockChain in Pharma Sector: Round 1**

Round 1:

This round requires an assessment of the relevance of the challenges identified by the panel of Experts in Round 0, understood as a summary of the likelihood and limiting effect of the challenge itself on BlockChain adoption. In addition, you will be asked to provide an assessment of the relevance of the countermeasures indicated to overcome the challenges.

\* Mandatory

Research and Round Description

This study will map the current **challenges** and possible **countermeasures** of adopting a BlockChain in the pharmaceutical industry.

These will be provided to all participants in the Delphi study and will be used to define future research directions for academics.

This round requires you to rate the relevance of the proposed **challenges** to the use of Blockchain in the pharmaceutical sec- tor on a scale of 1 - not relevant to 5 - extremely relevant. Challenges are proposed as affirmative sentences on which the participant must give his or her opinion. Moreover, in this round experts are required to suggest possible **countermeasures** to the proposed challenges. Individual participant ratings will not be shared with others to ensure anonymity.

Anagraphical Informations

1. Name: \*
2. Surname: \*
3. Email: \*

Evaluation of Challenges

Challenge 1

4. Evaluate the relevance of the challenge **“High investment costs”** as described below:

"Implementing blockchain requires significant investment costs, with companies needing to develop software and invest in expensive hardware"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

5. With reference to the previous challenge (**“High investment costs”**), please indicate eventual countermeasure(s) \*

Challenge 2

6. Evaluate the relevance of the challenge **“Lack of regulations”** as described below:

"Regulations about data security and privacy laws need to be put in place by governmental bodies to support the widespread adoption of blockchain. These are however currently missing"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

7. With reference to the previous challenge (**“Lack of regulations”**), please indicate eventual countermeasure(s) \*

Challenge 3

8. Evaluate the relevance of the challenge **“Lack of managerial support”** as described below:

"Support from senior management is crucial for the successful implementation and adoption of blockchain"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

9. With reference to the previous challenge (**“Lack of managerial support”**), please indicate eventual countermeasure(s) \*

Challenge 4

10. Evaluate the relevance of the challenge **“IT security”** as described below:

"The implementation and use of blockchain is subject to IT security issues, such as data vulnerabilities, hacking risks, etc."

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

11. With reference to the previous challenge (**“IT security”**), please indicate eventual countermeasure(s) \*

Challenge 5

12. Evaluate the relevance of the challenge **“Data immutability”** as described below:

"Once data are recorded in a blockchain, they cannot be easily altered or deleted: while this is a key feature of blockchain, it can pose some challenges if errors are made or if there is a need to update information"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

13. With reference to the previous challenge (**“Data immutability”**), please indicate eventual countermeasure(s) \*

Challenge 6

14. Evaluate the relevance of the challenge **“Lack of interoperability”** as described below:

"Interoperability is the capability of different blockchain networks or systems to communicate and share data seamlessly. If this is missing, efficient data exchange is hence hindered"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

15. With reference to the previous challenge (**“Lack of interoperability”**), please indicate eventual countermeasure(s) \*

Challenge 7

16. Evaluate the relevance of the challenge **“Lack of standardization”** as described below:

"Various blockchain applications are following different blockchain standards. The lack of standardization about transaction structures, validation, and security complicates the adoption of blockchain since companies lack clear rules and standards to follow"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

17. With reference to the previous challenge (**“Lack of standardization”**), please indicate eventual countermeasure(s) \*

Challenge 8

18. Evaluate the relevance of the challenge **“High need of resources”** as described below:

"A correct implementation and adoption of blockchain requires significant requirements in terms of time and resources"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

19. With reference to the previous challenge (**“High need of resources”**), please indicate eventual countermeasure(s) \*

Challenge 9

20. Evaluate the relevance of the challenge **“Lack of governmental support”** as described below:

"Governmental support in terms of economic incentives and regulations is needed; this is however currently lacking, hence hindering blockchain adoption"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

21. With reference to the previous challenge (**“Lack of governmental support”**), please indicate eventual countermeasure(s) \*

Challenge 10

22. Evaluate the relevance of the challenge **“Lack of customers’ acceptance”** as described below:

"Customers’ acceptance is crucial for convincing managers to adopt blockchain. If this is missing, this acts as a deterrent for blockchain adoption"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

23. With reference to the previous challenge (**“Lack of customers’ acceptance”**), please indicate eventual countermeasure(s) \*

Challenge 11

24. Evaluate the relevance of the challenge **“Lack of scalability”** as described below:

"Blockchains are characterized by restricted block size, which cannot be increased. This reduces transactions speed, which limits blockchain adoption by affecting the ability to handle growing transactions"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

25. With reference to the previous challenge (**“Lack of scalability”**), please indicate eventual countermeasure(s) \*

Challenge 12

26. Evaluate the relevance of the challenge **“Need for maintenance”** as described below:

"Blockchain requires regular maintenance, otherwise it experiences slower transaction speeds, reduced efficiency, and higher data security issues"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

27. With reference to the previous challenge (**“Need for maintenance”**), please indicate eventual countermeasure(s) \*

Challenge 13

28. Evaluate the relevance of the challenge **“Lack of skilled personnel”** as described below:

"There is limited amount of personnel skilled in blockchain, which is instead needed to fully exploit the benefits of blockchain"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

29. With reference to the previous challenge (**“Lack of skilled personnel”**), please indicate eventual countermeasure(s) \*

Challenge 14

30. Evaluate the relevance of the challenge **“Privacy concern”** as described below:

"Blockchain transactions are recorded on a public database accessible to anyone. This gives rise to privacy concerns"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

31. With reference to the previous challenge (**“Privacy concern”**), please indicate eventual countermeasure(s) \*

Challenge 15

32. Evaluate the relevance of the challenge **“Lack of collaboration”** as described below:

"A successful blockchain network requires the participation and commitment of all involved parties. It is however hard to convince all the involved parties and to ensure their cooperation, communication, and coordination"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

33. With reference to the previous challenge (**“Lack of collaboration”**), please indicate eventual countermeasure(s) \*

Challenge 16

34. Evaluate the relevance of the challenge **“Lack of knowledge on benefits”** as described below:

"Blockchain is new and in a developmental phase. Therefore, managers do not know what would be the benefit achievable and hence doubt about its adoption"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

35. With reference to the previous challenge (**“Lack of knowledge on benefits”**), please indicate eventual countermeasure(s) \*

Challenge 17

36. Evaluate the relevance of the challenge **“Workforce resistance”** as described below:

"Employees are reluctant to adopt blockchain and to change their processes to accommodate its implementation"

*(1 – not relevant; 2 – slightly relevant; 3 – moderately relevant; 4 – relevant; 5 – very relevant)*

\*

1

2

3

4

5

Not relevant Very relevant

37. With reference to the previous challenge (**“Workforce resistance”**), please indicate eventual countermeasure(s) \*