Improving Vendor-managed Inventory Strategy Based on Internet of Things (IoT) Applications and Blockchain Technology

Tom Dasaklis* and Fran Casino *Member, IEEE,*
Department of Informatics. University of Piraeus. Piraeus, Greece
Corresponding author e-mail: dasaklis@unipi.gr

Abstract—Vendor-managed inventory (VMI) is a widely used collaborative inventory management policy in which manufacturers/vendors manage the inventory of retailers and take responsibility for making decisions related to the timing and extent of inventory replenishment. There exist several prerequisites for a successful VMI strategy implementation like information sharing, trust, systems integration and long-term collaboration. However, in nowadays logistics flows, complex processes, high number of participants and complex distribution channels impede the successful adoption of VMI strategies. In this paper, we propose a new interaction framework based on smart contracts and blockchain for governing the relationship between the vendor and the buyer. A use-case VMI scenario is presented along with a functional smart contract. Tests performed using a local private blockchain illustrate the applicability of the proposed architecture along with the significant benefits for each participant.

Keywords—Vendor Management Inventory, Supply Chain management, Blockchain, Smart Contracts

I. INTRODUCTION

The Fourth Industrial Revolution is characterized by the convergence of various disruptive technologies such as the Internet of Things (IoT), artificial intelligence and blockchain. Similar to many other industry sectors, logistics is in the midst of a major technological shift. Global SC networks are being re-shaped to an unprecedented degree and at an unprecedented pace, and they are being transformed into almost complete digitized ecosystems [1], [2]. SC digitization offers unprecedented business velocity and agility as well as the creation of SC networks that are interconnected, inclusive, trustworthy and secure.

Vendor-managed inventory (VMI) is a supply chain (SC) management approach for improving multi-firm SC performance while establishing a mutually beneficial relationship between a vendor and a retailer. The key concept of VMI is that the vendor is authorized to oversee product inventory for the retailer. The adoption of VMI approaches may have significant benefits for retailers, vendors and the supply chain as a whole [3]. For retailers, VMI provides a more efficient framework for order processing while reducing operating and administrative costs. For vendors, VMI offers the necessary visibility for better demand forecasting and, therefore, more accurate inventory management. Although VMI has become a widely used tool for SC performance improvement, not all VMI implementations are successful. In fact, there exist several barriers for successfully implementing a VMI model such as SC complexity and the difficulty in information sharing and opportunistic behavior among key SC participants (which participant will reap the most benefits from VMI implementation). Other important barriers for VMI implementation may relate to security issues attributed to systems integration and inherent cost involved in managing SC intermediaries and relevant VMI processes. The paper addresses this gap in the literature by providing a distributed trustless and secure architecture for VMI implementation based on blockchain technology. In particular, an autonomous and effective back-end data sharing architecture based on smart contracts and blockchain technology for governing the relationship between a vendor and a buyer is used. A use-case VMI scenario is presented illustrating the applicability of the proposed architecture along with the significant benefits for each participant. Finally, some limitations of the developed architecture are discussed, and several fruitful areas for future research are proposed.

II. LITERATURE REVIEW

VMI has been extensively studied within the SC literature [4]–[9]. Several authors have also tried to determine the importance of critical success factors for actually implementing VMI strategies [10]–[13] along with the value of information [14] and information exchange [15] in VMI implementation. In particular, VMI has been used for optimizing market strategies within SC networks [16], reducing the bullwhip effect [17], measuring performance [18], establishing better pricing strategies [19], [20], managing backorders [21], better retailer service [22] and, finally, for improving environmental performance [23]. Some authors have also used VMI as a driver for suppliers' selection [24] and better SC coordination [25]. An important aspect of VMI strategy relates to determining the significant benefits the various SC members enjoy for actually implementing VMI strategies [26], particularly in terms of cost [27], [28] and inventory reduction [29]. Various decision support systems have also been developed related to VMI implementation [30], [31]. VMI-related frameworks have been developed across a wide variety of sectors, like the automotive industry [32], groceries industry [33], healthcare [34] and e-commerce [35]. Regarding the methodologies applied, several authors use optimization techniques [36]–[39], simulation [40], [41] and fuzzy systems approaches [42], [43]. In addition, several frameworks include disruptive technologies like IoT applications in VMI application [44], [45].

Figure 1: Blockchain-based VMI overview.
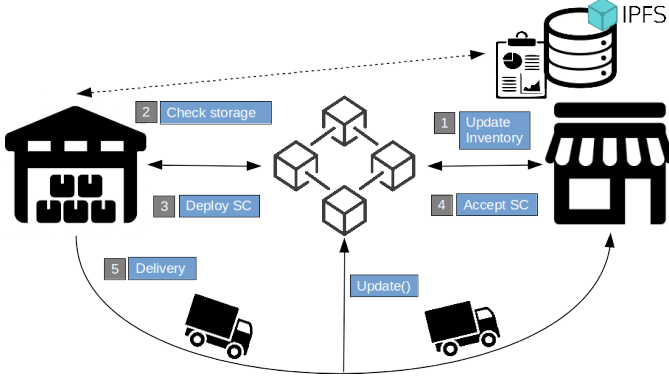
III. Information system architecture for VMI based on IoT and blockchain

Figure 1 shows the overview of the VMI-based blockchain architecture. The main actors of the system are the following:

Vendor: Manages inventory by proposing replacement orders or deploying smart contracts in the blockchain.
Retailer: Interacts with the vendor via blockchain and smart contracts, places orders or lets the vendor manage his resources.
Delivery companies: Their main role is to provide quality delivery according to some parameters (established in the smart contract or defined by quality policies). In addition, they can interact with blockchain to update information about products.

Therefore, a standard procedure in the case of direct vendor-retailer connection is described as follows:

1) The retailer keeps an updated track of its inventory in two ways: (i) it sends its inventory status to the blockchain periodically (e.g. daily) using well-known off-chain storage such as the InterPlanetary File System (IPFS) [46] to enable scalability, or (ii) it stores the inventory in a local database.
2) The vendor checks the inventory of the retailer via blockchain or directly accessing the local retailer DB (if they have the permission to do so, depending on the VMI model). These options are compatible with the retailer requesting an order to the vendor, like in traditional VMI.
3) The vendor detects a series of needs and deploys a smart contract with a new order to refill the retailer, according to specific conditions, periods and other information. Other participants (declared in the smart contract) such as delivery companies may update and change the status of products.
4) The retailer checks the smart contract's contents and accepts it, confirming the transaction.
5) The vendor delivers the products to the retailer. The status of the products (e.g. location, transportation conditions, delivery times, temperatures) will be updated throughout all the SC to keep track of events.

When the products reach their final destination and are verified by the retailer, the transaction is completed. The structures, descriptions and available information can be adapted to be compliant with some directives, and thus, efficient auditability

may be provided. For example, in the case of food supply, risk management systems that identify, evaluate, and control hazards related to food safety could be easily embedded within the smart contract as described above.

We provide experiments using a local private blockchain to show the feasibility of the proposed architecture. More concretely, we created an ethereum-based blockchain using `node` [47] and `ganache-cli` [48], and we used `truffle` [49] to deploy a functional smart contract. In this regard, contents can be retrieved and/or modified only by participants with specific roles (each function is implemented with concrete permissions, e.g. using the *require* clause of solidity and variables such as *msg:sender* to check account authenticity). The code implementation is available on GitHub [50].

IV. Discussion and conclusions

Blockchain enables a set of SC stakeholders to maintain a safe, permanent, and tamper-proof digital record of transactions, without the interference of a central trusted authority. This makes blockchain a candidate building block for a distributed SC management system, which will ensure the integrity of the SC itself. Due to its distributed nature, blockchain may simultaneously assure the availability and resilience of the SC management system efficiently. In this paper, we propose a novel VMI architecture based on blockchain and smart contracts for improving inventory policies between a vendor and a retailer. The purpose of using blockchain is to overcome certain impediments traditional VMI approaches present like lack of security, integration difficulties and opportunistic behavior. Moreover, we use a local private blockchain and a smart contract, which implements a set of functions that enable different characteristics/benefits of VMI. The proposed blockchain-enabled architecture presents other benefits, such as efficient storage management, verifiability and reduced interaction and communication between vendor and retailer, features that are translated into a notable cost reduction. Despite the aforementioned benefits, some limitations should be kept in mind. For example, our approach addresses a relatively simple SC relationship (one buyer and one retailer). Therefore, it would be very interesting to create some use case VMI scenarios in which multiple vendors interact at the same time with multiple retailers. In this case, it is expected that features of trust and visibility would be further exemplified by the use of smart contracts. In addition, despite the improvements of the blockchain and its heterogeneous applications [51], it is still not currently suitable (albeit appropriate) for storage of vast amounts of data, and many recognize that scalability is one of the main challenges to solve. In this regard, the implementation of a multiple-participants VMI approach would necessitate the processing of a large number of transactions in a relatively short period, therefore, scalability issues may arise. We expect this study to be of significant value for practitioners and researchers interested in the field of blockchain and SC applications.

REFERENCES

[1] F. Vendrell-Herrero, O. Bustinza, G. Parry, and N. Georgantzis, "Servitization, digitization and supply chain interdependency," *Industrial Marketing Management*, vol. 60, pp. 69–81, 2017.

[2] F. Bienhaus and A. Haddud, "Procurement 4.0: factors influencing the digitisation of procurement and supply chains," *Business Process Management Journal*, vol. 24, no. 4, pp. 965–984, 2018.

[3] K. Sari, "Exploring the benefits of vendor managed inventory," *International Journal of Physical Distribution and Logistics Management*, vol. 37, no. 7, pp. 529–545, 2007.

[4] G. Marques, C. Thierry, J. Lamothe, and D. Gourc, "A review of vendor managed inventory (VMI): From concept to processes," *Production Planning and Control*, vol. 21, no. 6, pp. 547–561, 2010.

[5] J. Y. Lee, S. K. Paik, and R. K. Cho, "Vendor-managed inventory: A literature review on theoretical and empirical studies and future research directions," *International Journal of Advanced Operations Management*, vol. 7, no. 3, pp. 199–228, 2015.

[6] R. W. Salem and A. Elomri, "Vendor managed inventory (VMI): From theory to practical implementation a literature review," *International Journal of Supply Chain Management*, vol. 6, no. 1, pp. 68–93, 2017.

[7] K. Govindan, "Vendor-managed inventory: A review based on dimensions," *International Journal of Production Research*, vol. 51, no. 13, pp. 3808–3835, 2013.

[8] C. S. Ryu, "Review of vendor managed inventory: Investigation on how it improves supply chain performance," *Journal of Distribution Science*, vol. 14, no. 9, pp. 47–64, 2016.

[9] S. Nachiappan and N. Jawahar, "Information technology enabled vendor managed inventory in modelling supply chain issues: A review," in *Enterprise Information Systems and Implementing IT Infrastructures: Challenges and Issues*, 2010, pp. 226–252.

[10] R. K. Singh, "Analyzing the Factors for VMI Implementation: A Framework," *Global Business Review*, vol. 14, no. 1, pp. 169–186, 2013.

[11] T. T. Niranjan, S. M. Wagner, and S. M. Nguyen, "Prerequisites to vendor-managed inventory," *International Journal of Production Research*, vol. 50, no. 4, pp. 939–951, 2012.

[12] C. S. Huoy, S. A. Rahim, N. A. A. Rahman, M. N. M. Nawi, and A. Ahmi, "Determination the key success factor for the success implementation and long-term sustainability of vendor managed inventory (VMI)," *International Journal of Supply Chain Management*, vol. 7, no. 2, pp. 62–67, 2018.

[13] M. J. T. Claassen, A. J. Van Weele, and E. M. Van Raaij, "Performance outcomes and success factors of vendor managed inventory (VMI)," *Supply Chain Management*, vol. 13, no. 6, pp. 406–414, 2008.

[14] Y. Yao and M. Dresner, "The inventory value of information sharing, continuous replenishment, and vendor-managed inventory," *Transportation Research Part E: Logistics and Transportation Review*, vol. 44, no. 3, pp. 361–378, 2008.

[15] A. Vigtil, "Information exchange in vendor managed inventory," *International Journal of Physical Distribution and Logistics Management*, vol. 37, no. 2, pp. 131–147, 2007.

[16] Y. Yu and G. Q. Huang, "Nash game model for optimizing market strategies, configuration of platform products in a Vendor Managed Inventory (VMI) supply chain for a product family," *European Journal of Operational Research*, vol. 206, no. 2, pp. 361–373, 2010.

[17] S. M. Disney and D. R. Towill, "Vendor-managed inventory and bullwhip reduction in a two-level supply chain," *International Journal of Operations and Production Management*, vol. 23, no. 5-6, pp. 625–651, 2003.

[18] K. S. Choi, J. G. Dai, and J. S. Song, "On measuring supplier performance under vendor-managed-inventory programs in capacitated supply chains," *Manufacturing and Service Operations Management*, vol. 6, no. 1, pp. 53–72, 2004.

[19] F. Bernstein, F. Chen, and A. Federgruen, "Coordinating supply chains with simple pricing schemes: The role of vendor-managed inventories," *Management Science*, vol. 52, no. 10, pp. 1483–1492, 2006.

[20] A. Haji, M. Afzalabadi, and R. Haji, "Pricing and inventory decisions in a vendor managed inventory system with revenue sharing contract," *Uncertain Supply Chain Management*, vol. 6, no. 3, pp. 299–320, 2018.

[21] Y. Yao, Y. Dong, and M. Dresner, "Managing supply chain backorders under vendor managed inventory: An incentive approach and empirical analysis," *European Journal of Operational Research*, vol. 203, no. 2, pp. 350–359, 2010.

[22] J. Shi and T. Xiao, "Service investment and consumer returns policy in a vendor-managed inventory supply chain," *Journal of Industrial and Management Optimization*, vol. 11, no. 2, pp. 439–459, 2015.

[23] M. Karimi and A. H. Niknamfar, "A vendor-managed inventory system considering the redundancy allocation problem and carbon emissions," *International Journal of Management Science and Engineering Management*, vol. 12, no. 4, pp. 269–279, 2017.

[24] Y. Yu, Z. Hong, L. L. Zhang, L. Liang, and C. Chu, "Optimal selection of retailers for a manufacturing vendor in a vendor managed inventory system," *European Journal of Operational Research*, vol. 225, no. 2, pp. 273–284, 2013.

[25] J. Y. Lee, R. K. Cho, and S. K. Paik, "Supply chain coordination in vendor-managed inventory systems with stockout-cost sharing under limited storage capacity," *European Journal of Operational Research*, vol. 248, no. 1, pp. 95–106, 2016.

[26] Y. Dong, M. Dresner, and Y. Yao, "Beyond information sharing: An empirical analysis of vendor-managed inventory," *Production and Operations Management*, vol. 23, no. 5, pp. 817–828, 2014.

[27] M. Braglia, D. Castellano, and M. Frosolini, "A note concerning physical space occupation costs in vendor managed inventory with consignment agreement models," *International Journal of Logistics Systems and Management*, vol. 19, no. 2, pp. 151–162, 2014.

[28] T. Zhang, L. Liang, Y. Yu, and Y. Yu, "An integrated vendor-managed inventory model for a two-echelon system with order cost reduction," *International Journal of Production Economics*, vol. 109, no. 1-2, pp. 241–253, 2007.

[29] J. Ru, R. Shi, and J. Zhang, "When Does A Supply Chain Member Benefit from Vendor-Managed Inventory?" *Production and Operations Management*, vol. 27, no. 5, pp. 807–821, 2018.

[30] A. B. Borade and E. Sweeney, "Decision support system for vendor managed inventory supply chain: A case study," *International Journal of Production Research*, vol. 53, no. 16, pp. 4789–4818, 2015.

[31] D. D. Achabal, S. H. McIntyre, S. A. Smith, and K. Kalyanam, "A decision support system for vendor managed inventory," *Journal of Retailing*, vol. 76, no. 4, pp. 430–454, 2000.

[32] S. Nagarajan, K. Ganesh, M. K. Barua, A. T. Resmi, and S. P. Anbuudayasankar, "Design of vendor managed inventory system for automotive company - A case study," *International Journal of Management and Enterprise Development*, vol. 12, no. 2, pp. 106–131, 2012.

[33] J. Tyan and H. M. Wee, "Vendor managed inventory: A survey of the Taiwanese grocery industry," *Journal of Purchasing and Supply Management*, vol. 9, no. 1, pp. 11–18, 2003.

[34] S. H. W. Stanger, "Vendor managed inventory in the blood supply chain in Germany:Evidence from multiple case studies," *Strategic Outsourcing: An International Journal*, vol. 6, no. 1, pp. 25–47, 2013.

[35] A. P. Katariya, S. Çetinkaya, and E. Tekin, "Cyclic consumption and replenishment decisions for vendor-managed inventory of multisourced parts in dell's supply chain," *Interfaces*, vol. 44, no. 3, pp. 300–316, 2014.

[36] A. Roozbeh Nia, M. Hemmati Far, and S. T. Akhavan Niaki, "A fuzzy vendor managed inventory of multi-item economic order quantity model under shortage: An ant colony optimization algorithm," *International Journal of Production Economics*, vol. 155, pp. 259–271, 2014.

[37] M. Rabbani, H. Rezaei, M. Lashgari, and H. Farrokhi-Asl, "Vendor managed inventory control system for deteriorating items using meta-heuristic algorithms," *Decision Science Letters*, vol. 7, no. 1, pp. 25–38, 2018.

[38] A. A. Taleizadeh, M. Noori-Daryan, and L. E. Cárdenas-Barrón, "Joint optimization of price, replenishment frequency, replenishment cycle and production rate in vendor managed inventory system with deteriorating items," *International Journal of Production Economics*, vol. 159, pp. 285–295, 2015.

[39] R. H. Rad, J. Razmi, M. S. Sangari, and Z. F. Ebrahimi, "Optimizing an integrated vendor-managed inventory system for a single-vendor two-buyer supply chain with determining weighting factor for vendors ordering cost," *International Journal of Production Economics*, vol. 153, pp. 295–308, 2014.

[40] C. Larsen and M. Turkensteen, "A vendor managed inventory model using continuous approximations for route length estimates and Markov chain modeling for cost estimates," *International Journal of Production Economics*, vol. 157, no. 1, pp. 120–132, 2014.

[41] S. Vonolfen, M. Affenzeller, A. Beham, E. Lengauer, and S. Wagner, "Simulation-based evolution of resupply and routing policies in rich vendor-managed inventory scenarios," *Central European Journal of Operations Research*, vol. 21, no. 2, pp. 379–400, 2013.

[42] M. Mohammadzadeh and A. Mirzazadeh, "A production-inventory model in vendor managed inventory system with deteriorating items and pricing in fuzzy environment," *International Journal of Logistics Systems and Management*, vol. 29, no. 3, pp. 296–326, 2018.

[43] Y. Kristianto, P. Helo, J. Jiao, and M. Sandhu, "Adaptive fuzzy vendor managed inventory control for mitigating the Bullwhip effect in supply chains," *European Journal of Operational Research*, vol. 216, no. 2, pp. 346–355, 2012.

[44] X. Liu and Y. Sun, "Information flow control of vendor-managed inventory based on internet of things," pp. 448–454, 2011.

[45] S. Yerpude and T. K. Singhal, "Augmentation of effectiveness of vendor managed inventory (VMI) operations with IoT Data - A research perspective," *International Journal of Applied Business and Economic Research*, vol. 15, no. 16, pp. 469–482, 2017.

[46] J. Benet, "Ipfs-content addressed, versioned, p2p file system," *arXiv preprint arXiv:1407.3561*, 2014.

[47] "Node.js." [Online]. Available: https://nodejs.org/

[48] "Ganache-cli." [Online]. Available: https://github.com/trufflesuite/ganache-cli

[49] "Truffle." [Online]. Available: http://truffleframework.com

[50] F. Casino, "A practical smart contract to enable blockchain-based vmi," 2019. [Online]. Available: https://github.com/francasino/VMISC

[51] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: current status, classification and open issues," *Telematics and Informatics*, 2018.