Frontiers of Blockchain for Railways

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Abstract The objective of this chapter is to provide the reader with the application of blockchain technology in railway system. As the focus of this book is Big Data and Service Operations Management, it is pertinent to understand Big data-blockchain relationship first before we can delve into Railway service operations and application. We begin by linking Big Data and Blockchain, followed by studying blockchain applications in various sectors, in order to provide a solid foundational understanding of the same. Thereafter, we set the context of Indian Railways, moving on to a structured understanding of the railway service and blockchain applications. followed by creating a specific provenance framework followed by conclusion, limitation. Big data signifies a novel technology paradigm for data that are generated at high velocity and high volume, and with high variety. The significance of Blockchain technology has drastically enhanced with the advent of Big Data because blockchain technology can help in recording and storing data for long duration. These technologies are envisioned as a game changer capable of revolutionizing the business drastically. Blockchain which is essentially a 'distributed ledger' has found applications in the financial and supply chain space. The value derived through this technology is in terms of transparency, veracity, track ability, traceability and auditing. The possibility of transparent information that can be traced to the origin of materials and processes and operations which are shared on blockchain ledger can provide product provenance, chain of custody and authenticity. Transport is an important service and represents the essence of service operations management. Railways is an eco-system. It provides a service that is asset intensive which has its own challenges in terms of maintenance and infrastructure. At the same time there are service concerns in terms of human safety and comfort. This provides a complex eco-system to work with. Blockchain as a digital tool intervention providing transparency, provenance and auditability can enhance the performance of the system This study attempts to create a model to understand the contribution of blockchain in the Indian Railway system.

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1 Introduction

The Blockchain characteristics which make it a disruptive technology lies in its following characteristics. The data on Blockchain is always complete, accurate, reliable and authentic thereby providing Integrity. It is believed that the overall cost of the chain shall also decrease as many intermediaries which are into auditing, assurance and quality and thus might get supernumerary. It is Cryptographically secure which is due to the consensus mechanism. Further, Transparency can be attributed to the non- alteration feature along with the time-stamped version.

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The chapter is organised as follows. First chapter explains the relationship between big data and blockchain. The next section looks at comprehending blockchain as a technology and its various applications in business. This is followed by the relevant background studies of blockchain to understand the spread of applications. This is followed by creating the background with the details of the context of Indian Railways. Further, mapping the provenance framework to blockchain application is accomplished followed by conclusion [15], future research and limitations.

2 Big Data and Blockchain

The era of 'Big data' has arrived. It is not limited to a mere concept, fad but has started impacting the lives and businesses significantly [15]. Big data is the compilation of huge data sets that can be analysed computationally to provide insights and patterns, trends and associations relating to behaviour and interactions [1, 2, 9, 10]. It has applications in almost all industries: retail, healthcare, financial services, government, agriculture, customer service among others.

In the initial study four specific features characterized big data [24]. These include:

- Volume which represents the large scale of big data, which requires innovative tools for their collection, storage, and analysis.
- Velocity refers to the rate at which the data are generated or updated, pointing to the real-time nature of big data.

- Variety refers to the variation in types of data. Big data can come in diverse and dissimilar forms from multiple sources, such as texts, spreadsheets, audios, videos, and sensors.
- Veracity refers to the complex structures of big data assets that make them ambiguous, imprecise and inconsistent.

The process of Big data analytics includes the process of examining large data sets to find and visualise business insights viz. hidden patterns and correlations, environmental impacts, business trends, customer choices. These insights and analytical results can help targeted approach towards marketing, better operational control and efficacy new revenue opportunities, and better customer service. The successful application of big data requires a well-researched and realistic deployment of big data analytical tools. The steps include data generation, data acquisition, data storage, advanced data analytics, and decision making for value creation. One of the ways of recording and storing data is to use cloud-based storage, but it is an expensive solution. Further, Blockchain provides a cheaper, efficient solution for storing data through its traceability and distributed ledger solution. Its ability to guarantee the accuracy and transparency of data has shifted the focus onto blockchain.

Blockchain can be an efficient mode for online data storage [11]. In addition to this, the decentralized network can grant access to many users. Various parties in a transaction store the transactional information in different ledgers. All of these parties can be granted access to one single network with the help of Blockchain. Transactions can be recorded in the network which can be further validated by all the concerned parties. Since all the information will be stored in the Blockchain it will be convenient to access these details. Because of the design of the Blockchain technology, users can view historical transactions effortlessly. Tracking the origins of a transaction becomes effortless.

3 Comprehending Blockchain Technology

Blockchain technology can be perceived as a kind of open distributed digital ledger that can record transactions between two parties efficiently and in an authentic way. Rather than relying on a third trusted party such as a bank, it uses a peer to peer approach where verification and validation are done by the nodes of the distributed network. Not only this technology eliminates the involvement of a Third Party for the purpose of authentication (because very often these third parties become the source of security breach). Using this approach, the possibility of fraudulent transaction is minimized to zero because the group of transactions called blocks is not only protected by digital signature that subsequently goes through a mathematical puzzle for time alignment, but also needs to be the longest and fastest one in the network amongst the existing good nodes to succeed. This means that all transactions are fully secured and fraudulent transactions, if any shall form a long chain of such blocks which will be transparently visible to all parties clearly identifying the perpetrators for

disciplinary action and also such fraudulent transactions will be next to impossible to get overlooked. Thus this mechanism is completely secured from hacking by outsiders through spoofing, phishing, etc.

4 Recent Background Studies

Researchers have combined supply chain and block chain and analysed the potential for value creation for various stakeholders both in the upstream and downstream business ecosystems. The model builds a common IT based platform centred on distributed data storage using the node consensus algorithm to generate and update the same. The fact that the data is encrypted ensures security of transmission and restricted access. This helps in speeding up the cash flow in an enterprise and thereby improving asset creation and utilization [19]. Studies cite that Blockchain is a digitally signed account transaction with a highly trusted record [3, 4]. in some policy studies it has been shown that Transparency, traceability and auditability provided by blockchain help minimize system corruption and fraud while keeping the system under control [3, 14]. Integration of blockchain with supply chain would ensure product tracking which is a big challenge; [5, 6]. The intermediary can be eliminated and information exchange between parties is structured and controlled. It has been propounded that overall efficiency of the system is increased because of transparency provided by physical traceability in supply chains, information and financial security in management systems, leading to an increase in overall efficiency [6, 8]. Blockchain technology has the ability to address all three dimensions to address collaboration, cost optimization, and risk management. This technology allows companies to gain total access of the end-to-end supply chain data while ensuring that it can be securely stored and privately shared with authorized stakeholders [23]. There are many industry specific studies for application and challenges of block chain application like the construction industry [22]. Researchers have looked at the possibility of Distributed Ledger Technologies (DLTs) to overcome such events [16]. As has been illustrated by Muniandi blockchain can help achieving the goals of providing a platform with more transparency, fit for use by all passengers without any exclusions, prevents siloation and prevents frauds.

Researchers have looked at the potential application of block chain for digital ticketing and enhancing customer experience [20, 21]. This can be done by a mix node which may be active or passive. The passive nodes only maintain the latest data and do not perform any mining operation [18]. Since, the data is verified by simultaneously cross checking with adjoining nodes, it is fail safe, collusion resistant and resilient to external attacks. Thus this technology is useful in various facets of train operation and maintenance [20, 21]. Researchers have also found utility for block chain in ensuring safety in heavy haul operations by reducing manual decision making [12, 13].

5 Application Context of Indian Railways

Railways are the preferred choice of transportation mode in the world population due to their environment-friendly, safer, long-distance interstate, and intercity mobility options. Indian Railways (IR) is the fourth largest Railway network in the World and considered the lifeline of the country. About 22,000 trains run on the network in a day. It therefore has a large fleet of about 11,000 locomotives, 70,000 coaches and about 2.94 lakh wagons. During 2018–19, it carried 8,439 million passengers and 1221.48 million tonnes of freight traffic. The present rail share of freight is 27% and is mainly attributable to traditional bulk commodities like fertilizers, coal, iron ore and food grains. These constitute approximately ~60 % of IR's freight business. IR needs to cater to freight increase for commodities which are dominated by road movement through appropriate strategies/product offerings. Such a modal shift is possible by improving the transit through speed and predictability and by improving the capacity through better terminal and network access and improved availability of rolling stock. The service in terms of product offering and costing also has to improve to meet the customer needs in real time. Thus the objective of railway to provide a safe, secure, dependable, economical and reliable service. It represents a service which is both technology and human intensive and applies all the essential elements of service operations. This is the basis of including the chapter in this book.

The application of Blockchain in Railways can be classified into three broad categories (Fig. 1).

1. Infrastructure and Real Time Operations.
2. Equipment Maintenance Management.
3. Customer oriented Service Operations.

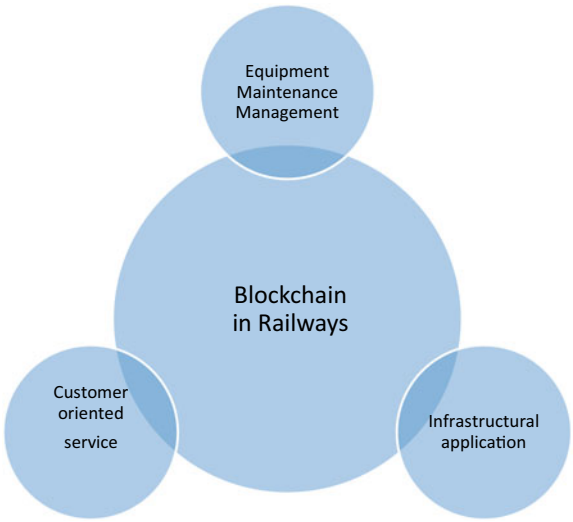

Fig. 1 Application of blockchain in railways

Given the objective of Indian railways to provide safe, reliable, dependable and comfortable service, the blockchain intervention shall secure both financial transactions but also train running (Fig. 2).

Railway systems are infrastructure intensive and these have to be maintained in proper fettle so that trains can ply smoothly. The fixed infrastructure consists of tracks, overhead wires for electric traction and the signaling system. The moving assets are the rolling stock consisting of the coaches, wagons and locomotives. The Fig. 3 gives a succinct details of the application which has been elaborated further.

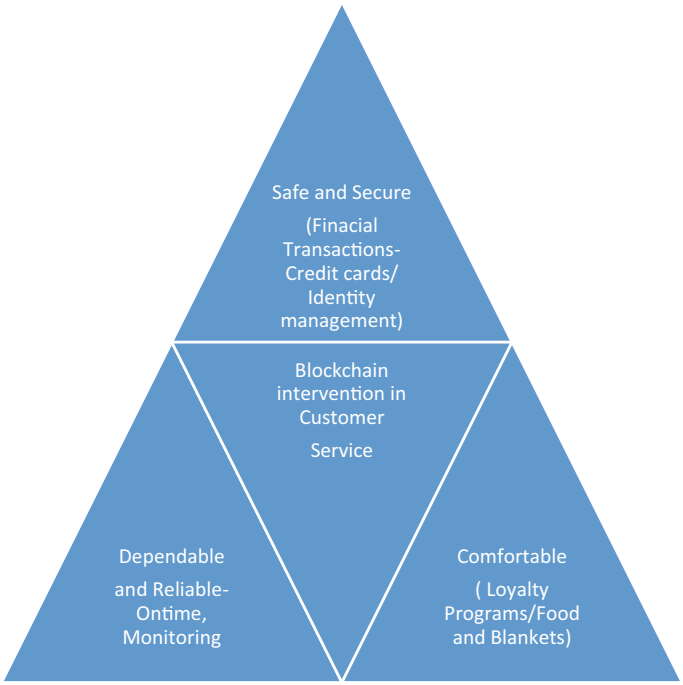

Fig. 2 Broad objectives of blockchain application

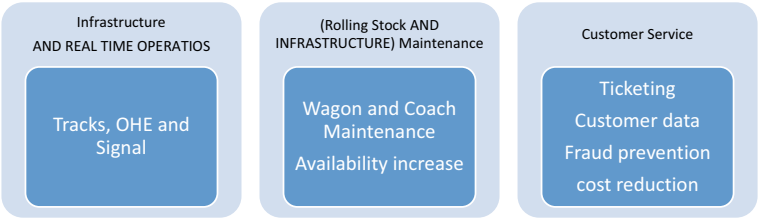

Fig. 3 Detailed blockchain application

5.1 Infrastructure

With the primary focus on safety and given the enormity, complexity, heterogeneity an interoperability issues of the present system, blockchain can be a solution for the same. The existing system in Indian Railways has decentralized train operations. There are huge challenges which include system dissonance at the interface, communication failure, SPAD due to wrong signal. The fixed infrastructure is monitored through IT systems like the track management system for track, the Supervisory control and data acquisition (SCADA) system for the overhead wires and the electronic interlocking systems for the signaling system. These systems presently work in isolation, however the benefits can be enormous if these communicate with each other and share relevant data authentically and proper coordination is there. Through the application of blockchain, the actors in the system can access data real time and transparently.

The condition of the infrastructure elements can also be captured in tamper-proof records. This data can further be utilized to ensure that the work of maintenance is carried out in an optimized manner thereby reducing the down time and improving the availability for train operations. Communicating through smart contracts with the track elements which include level crossings, signals, interlocking track circuits, releasing them and setting diversion points will provide efficiency in the system. No manual intervention will be required and would be done by the automated central system based on rules and without conflict. This can enhance the total track availability of the track thereby impacting the throughput of the track.

Presently train operations are controlled centrally, however these can be made more dynamic by decentralising the decision making of routing in a manner which is safe, reliable, efficient and auditable. The European train control system which Indian Railways plans to adopt is a step in this direction as it maintains "safe blocks" in which trains operate and takes corrective action in case the operator does not react timely. Most of the operations change every minute based on failure of equipment or other unforeseen circumstances. This decentralized system shall make it possible for the trains and track elements to work as first-level active participants and carry out several actions such as route locking, setting a changing point position, communicating with other trains, automatic speed control and braking, GPS drove Train localization. All these actions shall be network-driven and ensure compliance with the standard working rules. The reliability of which shall be derived from the matching of physical reality (trackside equipment) and the IT counterpart (Digital twin). This would enable the detection of trackside malfunctions and the prevention of accidents. Going by the cardinal principles of Railway Signaling which give utmost priority to the safety of human life, the validation of every decision on the go shall be done by strong authorities as multiple parties such as station masters. Or even a better alternative will be to involve the signaling rules and control procedures in the smart contract, a copy of which shall be carried by each train to be followed while making their own route-based decisions. In this case, a Blockchain API shall be superimposed over such Rail network enabling all the trains with conflicting movements for a particular

route to act as the 'active nodes' dynamically and make a 'consensus-based-decision' as elaborated in the schematic.

Further, combination of these emerging technologies like blockchain, VC, RBC, the heartbeat signal from trains, ATO control algorithms, 5G using train-to-track/track-to-track communication links, can solve the problem of railway traffic conflict control along with the objective to minimize or nullify the overall individual train delay progressively. Blockchain can be used for all other transactions for example, for checking the driver's license and driver authorization, checking the compatibility of sub-systems and billing the infrastructure. As of now, the technology is in an experimental state where potential use cases are being developed and tested to affect the following areas.

5.2 Maintenance (Rolling Stock and Infrastructure)

Trains are complex equipment and have large number of subparts and assemblies. Maintenance is an important function to meet the objective of reliability, safety and dependability of the train. Maintenance are broadly of two types: Preventive-Scheduled and Reactive-Unscheduled Maintenance. It is seen that with higher preventive maintenance, need and cost for reactive maintenance gets reduced. Further, reactive maintenance has more negative impact because of unscheduled breakdowns and higher downtime cost. Scheduled maintenance are triggered by time period, usage or monitoring the condition of parts. Currently the rolling stock is maintained based on preventive maintenance and follow scheduled repairs based on time or usage. Another possibility is to have condition based monitoring wherein it is essential to monitor the performance of the parts in real time based on the condition of the equipment. This implies that we can predict when things will go wrong and pull back the train for repairs at the right time. Also these individual components or sub-assemblies are connected together and their performance can be observed in tandem. Remote monitoring of diesel locomotives by providing sensors in critical subassemblies has been in practice. The alerts are sent to a central control centre and corrective or preventive action initiated to prevent failure. These alerts can also be shared in real time with the manufactures and designers and this will help to close the loop and ensure better quality of the products as all defects and failures get logged and can be investigated using the data prior to the failure. It will be easier for the suppliers to link these to individual batches in their production and they would be able to zero in on the operators and the machines. The transaction costs of this traceability which is presently done manually will also be nominal.

This would also help in reduction in the warranty claims and effective spare parts management. The spares mostly rotables can be tracked and performance logged, thereby providing better control at a reduced cost. The onetime cost of the technology has to be traded off against the long-term benefit.

Since the components from many Original equipment manufacturers (OEMs) have to talk to each other, blockchain technology can be the solution for securing the

network and linkages with complete traceability. Similar usage can be there in the smart coaches being developed by Indian Railways wherein different components for passenger interface, electrical and braking systems, water and infotainment etc. are monitored through sensors. Once this is done then all the data from all the coaches and locomotives can be shared and used for improving the maintenance thereby reducing the downtime and enhancing the utilisation of the asset. Further, there are track side equipment like hot box detectors, wheel impact load detectors etc. which externally monitor the condition of rolling stock. The data from these can also be integrated to enhance the overall output and understanding of the rolling stock. The movement of these stock is being planned based on the operational software which can share inputs with this system and this will ensure that the maintenance can be planned with least disturbance to the movement of trains. All these are important in the context multi operator regime when clear responsibility and traceability has to be ensured from a legal and contractual perspective. Smart contracts can be implemented to make rule based contracting. Further block chain supported by IOT and sensor technology shall provide the fundamentals for modern maintenance. IOT based condition monitoring and sensors which shall form dense, connected networks will transmit data to central data centres but alongside the strengths the threats to the system is equally precarious. Blockchain through its encrypted tamperproof system can provide a trustworthy system which is verifiable and the data trail is auditable.

5.3 Customer Service

The next set of service operations application for Blockchain is focussed around the customer experience and journey seamless and hassle free. Presently the customer buys tickets and orders for services like E-catering and blankets for which payments are made through different gateways and there is also the need to authenticate the identity of the traveller to ensure that only authorised passengers are travelling. This is even more important from the security perspective, Blockchain ledger can be useful in ensuring the above and facilitating instant payments with no need to authenticate further and also guaranteeing the identity. This can further be extended to intermodal transfers and movements which will further enhance the customer experience and provide seamless transport solutions. These would help journey planners to provide end-to end solutions across sea, road, air and rail. The same is the case for freight customers or in the parcel business where the need to carry the railway receipts as proof will be eliminated with use of blockchain technology. This will also be useful in delivering consignments to third parties and avoid documentations like Goods Receipt Note. Challenges of Short delivery, Incorrect deliveries can be addressed like many times the consignment would not get loaded in the train or would get over carried. Block chain will be a reliable and accurate medium to confirm the transaction. This shall help in building the brand image of the Railways as a safe and secure service provider and earn the loyalty of the customers.

There has been a focus on customer retention by rewarding travellers for their loyalty. It is being done both by the credit card companies and railways. For this, loyalty programs need to be accurate and user-friendly to ease the complexity involved in keeping an account of passenger's loyalty points and redemption as per the defined policies. In accuracy is a deterrent to future loyalty. Blockchain can be used to develop a platform to improve the interoperability between multiple schemes but also allows invoicing and payment transfer between partners using smart contracts. Redemption of reward points from one service to another such as automatic credit of points after a train journey, which can further be used to pay an online cab service shall add to a better travel experience.

For undertaking the journey in any reserved class on Indian railway, a prescribed proof of identity shall be available online. On the blockchain, identification of the passenger, change of booking or enquiry can be done using traveller IDs which eliminates the need to carry any hard copy of id proof during travel. This will enhance the travel experience of the passenger and the same can also be used for seamless inter-modal connectivity as most passengers use road or metro etc. for the first mile and last mile connectivity to the rail system.

Automatic billing can be done on Rail networks which provide access to other passenger and freight railways at regulated infrastructure charges. The passengers buy tickets manually and the payments to subcontractors and vendors are made through traditional methods. Blockchain technology enable all these payments to happen instantly on a secure network using Blockchain ledger. The apportionment of earnings between various players and also between various railway systems can be done easily without having system of manual checks which add to the inefficiency and delays. This will simplify the accounting as well as the statistical formulations. The traceability will also help in case of accidents where compensation is tenable as this can be handled easily and securely using the block chain technology.

On the freight side too blockchain can help connect the customer and the logistics provider in a better way. The access to real time loading information, train and truck movement during transfer and availability of crew can help reduce the cycle time and thereby bring down the logistics cost. The smoother flow of authenticated information across the various players can be a game changer and this can reduce the needs for the manual interfaces used presently to collect the information which is subject to noise and leads to sub-optimal decision making and planning.

6 Mapping the Railway Application to the Provenance Framework

From the literature, a Standard Provenance knowledge framework has been developed by [17] that has its application in showing how provenance knowledge can enhance assurances and reduce perceived risks via the application of blockchain (Fig. 4).

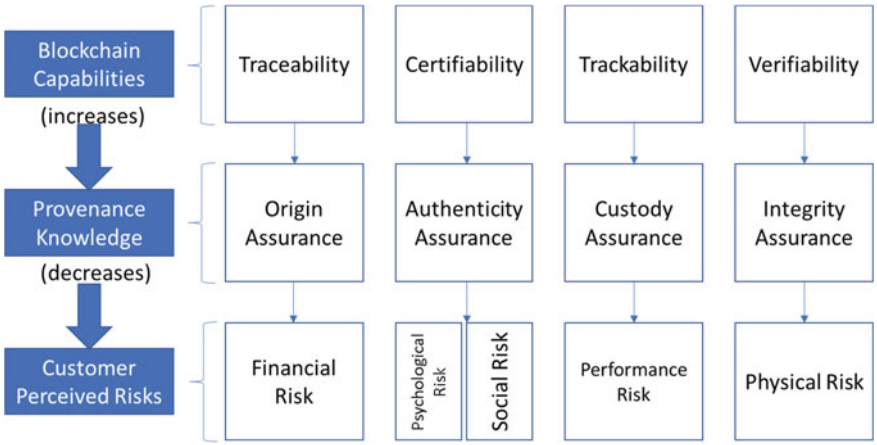

Fig. 4 Standard provenance knowledge framework

This model is very comprehensive and captures the contribution of Blockchain very succinctly. The risks perceived by the customer can broadly be classified into physical risk, financial risk, psychological risk, social risk and physical risk. These risks help in providing origin, authenticity, trust of custody and integrity to the supply chain. This eventually links to the blockchain capability of traceability, Certifiability, trackability and verifiability.

This standard model was explained by the authors to the focus group members. The focus group of seven Railway Experts through a brainstorming exercise have mapped it to the Railway Application Provenance Model. One of the author is a railway expert with 30 years of experience in Indian Railways. The total experience of the focus group is 140 years. This provides an understanding of the intrinsic reason of blockchain application.

It was observed that the blockchain capabilities that provide value to the chain are different. Whereas in the infrastructure and rolling stock vertical, the value is derived through trackability but in the case of Customer service it is authenticity of transactions and assurance that is required (Fig. 5).

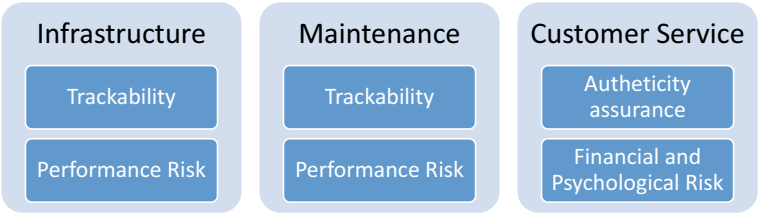

Fig. 5 Railway application provenance model

Implementation of Blockchain are filled with challenges. Rail system being a complex ecosystem having convergence of many supply chains – interoperability amongst different chains require huge scale. Indian Railway system is going through a major transition along technology, regulation, energy source and all of them create their own set of uncertainties. Cybersecurity and unrestricted access available to the auditors may itself be misused, either intentionally or inadvertently. This needs to be considered and where possible, mitigations should be applied. The geographical span of Indian railways network is huge and Blockchain network alongside through the nook and corner of the country faces huge scalability constraints such as network bandwidth and data storage. Other factors such as size of block and time gap between two consecutive blocks also effect the scalability. There is an inverse relationship between the size of the block and the no. concurrent of transactions taking place. India as a country is developing and the geographical spread of the country and railway network is huge. The availability of 24×7 network at remote locations from where the data is generated can also be a constraint in the implementation, however, this is a steady slow process of technology acceptability and eventually the infrastructure constraints are overcome.

7 Conclusion

Transport is an important service and represents the essence of service operations management. Amongst the different modes of transportation railway system remains one of the most complex systems. In this book on 'Big data and service operations management' in this chapter, we have explored Blockchain-based application in the railway ecosystem from service operations perspective.

This is an era of Big data. The volume and variety of data generated is enormous and it is generated by human-users and machines. Any business or organization that can assimilate data to address the difficult questions about their operations can benefit from big data. the demand for big data transcend across all sectors and business. Those who work to understand their customers' business and their problems will be able to proactively identify big data solutions appropriate to their needs, and thus gain competitive advantage over their competitors. Blockchain which is radically changing the future of transactions in industries can help in smart contracts and as a digital currency. It can help in digital record keeping in operations and maintenance as well as for IPRs and Research. It can help in descriptive analytics, diagnostic, prescriptive, predictive and cognitive analytics.

Although the technology of Blockchain has been there for quite some time, but the advent of big data has made the application of Blockchain more significant. Blockchain can effectively store online data and perform monitoring and controlling accessibility of data across in an efficient manner. Various parties in a transaction store the transactional information in different ledgers. All of these parties can be granted access to one single network with the help of Blockchain.

Broadly considering three verticals along which the application can be categorized. These include infrastructure, rolling stock and customer service. All three orchestrate synchronously to provide the safe and reliable service. Thus we can understand what happened, why it happened and what will happen. Organizationally, this digital transformation which will have a cross functional impact will need multi-disciplinary teams for innovating, operationalizing and transforming. Each department like accounts, HR, operations, infrastructure, business development and procurement will be impacted and will need to modify their systems and processes to cope with the change. Thus IR will need to change how it educates its managers to understand, assimilate and champion the transformation. This would be a cultural transformation and would also need chief technology officers at all levels so as to help leaders think, act and react differently. Since new possibilities will arise they need to comprehend the same and think divergently. Teams will become collaborative and mobile and it will be easier to connect virtually across the geographical boundaries.

We can use simulation based decision making and the system can self-learn thereby reducing the human intervention and improving the quality of decision making. Each of these vertical application is a study in itself, infest with its own specific challenges. These can be specific directions for the study.

This is a conceptual paper of application of blockchain for Indian railways. The contribution of this paper is to provide a structure to understand blockchain application in Indian railways and provide a framework for blockchain applications in railway specific operations management. Future research can look at technology adoption models and being a complex ecosystem, the technology adoption and diffusion also will be fest with complications and difficulty. Models can be devised to address these issues.

The technology adoption will also include change management and human resource challenges which can be researched. This shall have socio-technical ramifications. This can also be a potential area of research. The interface and interaction of blockchain and supply chain is significant and has to prudently understood and analyzed before and during implementation. The supply chains of electronics, mechanical, electrical spare parts have to be properly aligned.

The limitation of this study is that it has limited number of members in the focus group and biases might arise. Further, the focus has been on one technology but AI, IOT along with Blockchain will provide a more comprehensive understanding and trajectory of technology change. Future studies can include the total impact of all these technologies jointly.

To Conclude, understanding the tradeoffs of security, privacy, transparency, functionality, auditability, risk, and scalability are delicate balances which have to be analyzed while consideration of the blockchain implementation in Indian railways.

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References

1. Charles, V. & Emrouznejad, A. (2019). Big Data for the greater good. In: *An introduction: Big data for the greater good.* Studies in Big Data. s.l.:Springer.
2. Charles, V., & Gherman, T. (2019). Big data analytics and ethnography: together for the greater good. In: *Studies in big data.* s.l.:Springer.
3. Choi, T. (2020). Creating all-win by blockchain technology in supply chains: Impacts of agents' risk attitudes towards cryptocurrency. *Journal of Operational Research Society.*
4. Choi, T., Feng, L. & Li, R. (2020a). Information disclosure structure in supply chains with rental service platforms in the blockchain technology era. *International Journal of Production Economics, 221*, 1–14.
5. Choi, T., Guo, S. & Luo, S (2020b). When blockchain meets social-media: Will the result benefit social media analytics for supply chain operations management? *Transportation Research Part E, 135*(101860), 1–21.
6. Choi, T., & Luo, S. (2019a). Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes. *Transportation Research Part E: Logistics and Transportation Review*, *131*, 139-152.
7. Choi, T., Wen, X., Sun, X. & Chung, S. (2019b). The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. *Transportation Research Part E: Logistics and Transportation Review, 127*, 178–191.
8. Dutta, P., Choi, T. M., Somani, S., & Richa, B. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transportation Research Part E: Logistics and Transportation Review*, *142*(102067), 1–33.
9. Emrouznejad, A. (2016). Big data optimization: Recent developments and challenges. In: the series of *Studies in big data.* Verlag: Springer.
10. Emrouznejad, A. & Marra, M. (2017). Big data: Who, what and where? Social cognitive and journals map of big data publication. In: *Big data optimization: Recent developments and challenges, studies in big data.* s.l.:Springer.
11. Es-Samaali, H., Outchakoucht, A., & Leroy, J. P. (2017). A blockchain-based access control for big data. *International Journal of Computer Networks and Communications Security, 5*(7), 137–147.
12. Gaofeng, H., et al. (2020a). Blockchain based federated learning for intelligent control in Heavy haul railway digital object identifier. *IEEE Access, 8*, 176830–176839.
13. Gaofeng, H., et al. (2020b). Blockchain-based federated learning for intelligent control in heavy haul railway. *IEEE Access, 8*, 176830–176839.
14. Hastig, G., & Sodhi, M. (2019). Blockchain for supply chain traceability: Business requirements and critical success factors. *Production Operations Management, 29*(4), 935–954.
15. Lee , I. (2017). Big data: Dimensions, evolution, impacts and challenges. *Business Horizons, 60*(3), 293–303.
16. Kuperberg, M., Kindler, D. & Jeschke, S. (2020). Are smart contracts and blockchains suitable for decentralized railway control? *Ledger 5*.
17. Montecchi, M., Plangger, K. & Etter, M. (2019). It's real, trust me! Establishing supply chain provenance using blockchain. *ScienceDirect,* 283–293.
18. Muniadi, G. (2020). Blockchain-enabled virtual coupling of automatic train operation fitted main line trains for railway traffic conflict control. *IET Intelligent Transport Systems, 14*(6), 611–619.
19. Peng, X., et al. (2020). Research on financial platform of railway freight supply chain based on blockchain. *Smart and Resilient Transport, 2*(2), 69–84.
20. Preece, J. D. & Easton, J. M. (2019a). A review of prospective applications of blockchain technology in the railway industry. *The International Journal of Railway Technology,* 1–21.
21. Preece, J. D., & Easton, J. M. (2019b). *Blockchain technology as a mechanism for digital railway ticketing,* 3599–3606.
22. Sharma, M. G., & Kumar, S. (2020). The implications of blockchain as a disruptive technology for construction industry. *IIM Kozikhode Society and Management Review, 9*, 177–188.

23. Tata, C. S. (2019). *Blockchain for a robust and efficient supply chain.* Tata Consultancy Services Limited, Mumbai.
24. Sivarajah, U., Kamal, M. M., Irani, Z., & Weerakkody, V. (n.d). Critical analysis of big data challenges and analytical methods. *Journal of Business Research*, *70*, 263–286.

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