Journal of Civil Engineering and Architecture 17 (2023) 605-615
doi: 10.17265/1934-7359/2023.12.001

IoT: Understanding from a Management Perspective for the Railway Sector

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Abstract: The railway industry is a key part of any country's transportation infrastructure. The railway industry supports the competitive advantage of the country's economy, providing a vital link in the supply chain of most manufacturing, agriculture, and other allied industries. However, in many countries, the railway needs an upgrade, concerning maintenance. In most countries their railways still run on old architecture and are in vital need of improvement into the 21st century technological marvels. To meet the myriad of the industry's problems, it is proposed in this paper that it is ripe to introduce IoT (Internet of Things) for the competitive advantage of the industry. A qualitative analysis of the issues was conducted through a thematic approach. The results obtained have shown that there is a gap within the industry's knowhow and modern forms of management perspectives using assisted smart technological. From the findings of the analysis, it is proposed that a rethink of how issues of moving forward should include aspects of smart technology that include IoT and smart systems using some form of AI (artificial intelligence) approach. The proposed approach in this paper will help modernise the railway sector and finally set it on a better roadmap for future improvement to the entire rail network and its trains.

Key words: IoT, railway, management, data.

1. Introduction

Rail transport has been considered as the core mode of transport for goods and people since a steam train began to run in the 19th Century. Since then, the railway went through different stages in technology development after the discovery of oil and invention of diesel engine, improved design methods, as well as understanding of the strength of materials. All these technological advancement and innovations most recently enable a high-speed railway system which satisfies the public demand on traveling a far distance. Many governments in different countries support and encourage the railway transport sector because of its key characteristics of high level of safety, high capacity, and energy efficiency [1].

During this decade, there are substantial advances of wireless sensors based on technologies that allow for machine-to-machine interaction and communication, this technology is known as IoT (Internet of Things). IoT applications are increasingly getting recognised by different industries. This technology has been incorporated into various industries and services to deliver decent services to the community and improve the overall experience for all. One of the key features of IoT is that it allows people and things to integrate virtually to information systems via wireless data capturers [2]. These information systems analyse these data and may help in decision making based on the accurate, up to date information collected without human intervention. Each piece of information can be captured regardless how it is small or big in short time. In general, IoT provides a platform for integrating local infrastructures into a global architecture that exploits the paradigm of traditional Internet "every time and everywhere" [3].

One of the key requirements to have an efficient operation of the railway network is the maintenance of

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the whole of its infrastructure including rail tracks, signals, coaches, tunnels, and bridges. This requires checking the rail system regularly and keeping it in a good working condition, renewing worn or damaged components. To overcome these challenges and issues of the railway sector, this research will propose incorporating the modern technique of IoT to improve the performance of rail network infrastructure and to resolve the discussed challenges.

The aim of this paper is therefore to raise the awareness that there are technologies that are now available that can assist to alleviate the railway industry's problems, while creating better value for the clients, and the users. Such technology can be found on IoT. If the railway sector is to be effective and efficient, and highly productive, it is essential that practitioners involved in the creation, training, and running of the trains, and maintenance of the tracks and allied infrastructure, have the requisite skills, knowledge, awareness of the latest advances in technologies and training in their respective areas as a start.

2. IoT Research Techniques

At the start of this research presented in the paper, the key words in the title of the paper were used as the starting themes that were developed into sub-level areas for the analysis of the papers that were used in the study. Synthesisation and comparison of evidence overview the research topic and tracking of developments over specific period of critique and synthesise [4] of IoT in the railway system has been conducted. The traditional literature review approach was developed within thematic areas concerning the topic in question. The central question behind this research work:

"Is there an optimised approach that would enhance the utilisation and application of archival, existing, and simulating future data from the rail sector effortlessly, for the benefits of client and rail users?"

A systematic review of literature was utilised as a methodological approach to explore useful findings into the existing literature on IoT application in industries, especially in the railway sector and to identify knowledge gaps for future research. For this paper, an understanding of the railway industry was also done, to get a richer appreciation of the current state of the railway industry. Systematic review adopted helped to identify, select, and appraise all the literature of a specific pre-defined level of quality that is related to a research topic to be investigated [5]. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were applied in conducting this systematic literature review [6]. ScienceDirect, Scopus and the WoS (Web of Science) databases were used as sources for the literature review. The period studied ranges from 2010-2022 and the search was carried out using the "Title/Abstract/Keyword" field of the databases. The full search is "Title/Abstract/Keyword IoT, Railway, rail" or "Title/Abstract/Keyword internet of things, railway, rail".

3. Railway Sector

In most developed nations, the railway sector has undergone structural changes, especially in their management and due to economic challenges since they started as a commercial success. In many countries, the sector has gone from being privately owned by several pioneers of railways, through being nationalised by the government and most recently privatised into several franchise and enterprises. Such privatisation was carried out in the name of efficiency, effectiveness, higher productivity, and value creation in the industry. However, not all these current private organisations are profitable or workable in the commercial sense [7]. These organisations are increasingly passing on their liabilities to the users of the rail network through perennial increase of rail fares. Such burden is creating problems for the seating government. Finding a solution to such perennial issues will make a substantial change to government liabilities in the positive sense. Recently, the main problems encountered within this sector at a strategic level include the processes that are involved in the supply chain to run an effective and

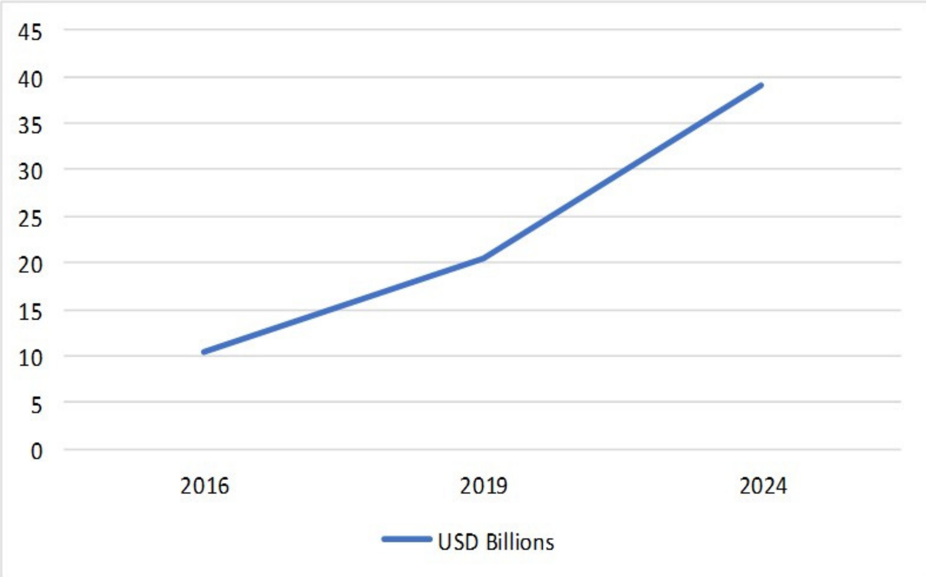

Fig. 1 Smart railway growth.

efficient rail industry; the competencies of the organisations and its people in dealing with the day-to-day workflows of the railway sector; and lastly the integration of technology and its knowledge.

Integration of technology involves issues of using sensors, radio-frequency identification (RFID) and other smart systems. However, smart systems in railway industry are in a dominant state for a quite a while. Recently, the smart railway market is in increase (see Fig. 1) as it is estimated to reach up to USD 20 billion in 2021 [8] and it is expected to reach USD 39.0 billion by 2024 [9].

The railway has historically created massive quantities of records, and the operation and development of the railway infrastructure in the twenty first century is no exception. The earliest record collections from the railway sector in the form of data include, construction of bridges, tunnels and stations which are designed and built by the nineteenth century's most dynamic and innovative engineers and are still very much part of today's operational railway. Every day the sector is also creating records and managing data that use and develop innovative engineering technology to improve and support the modern railway.

Recently, the main problems encountered within this sector at a strategic level include the integration of technology and knowledge; the processes that are involved in the supply chain to run an effective and efficient rail industry; and lastly the capabilities of the organisations and its people in dealing with the day-to-day workflows of the railway sector. All these challenges will be solved and assured with the introduction of IoT, although IoT technology is not considered as a "silver bullet".

4. Processes and Products

The processes in any business are constantly changing either through legislation or client demands such as sustainability issues. Companies with well documented, easily accessible end to end processes can assess the full impact of these changes to the processes quicker and more consistently. Areas of concern include:

- Processes tested and proven by teams can use and repeat them in terms of other similar project with some adaptation.
- Introducing mandatory work processes in the working patterns of the organisation.
- Lack of standard operating procedures.

- Evidential proof is needed on integrated processes for practitioners to be convinced
- Introducing clear auditing and gateway process.

The expanding level of rivalry portraying this market is likewise driving organizations to address cost-effectiveness objectives through the association of providers, and the normalization of materials and segments. It likewise requires collective connection between all stakeholder to share plans and development expenditure [10].

4.1 People and Organisations

The structure of the organisation and relationships in the railway sector is a product of their evolution. Beyond specialist niche markets, most rail projects are still rooted in regional contexts. The railway sector has experienced extensive structural changes over the last three decades. There has been a sustained proliferation of procurement methods to cater for the needs of different clients. There is a need to better understand the clients, user and different parties in the supply chain, which is paramount in achieving better integrated products. The emergence of management forms of contract offered clients a greater degree of engagement and resulting flexibility. At the same time design and build offered single point responsibility for clients who were able to pre-articulate their requirements. Both methods served to alleviate traditional process discontinuities and hence resulted in significant improvements in productivity. It is therefore concluded that the following are of relevance:

- Integration is not only technological but cultural.
- Remove the barriers to integration of teams. Integration should also be in technology as well as the processes.
- Start with the client who brings together integrated team.
- Include upfront risk management.
- Organise teams differently.
- Understanding engineering, architecture business processes by organisations should be long term than short term.
- However, the long-term approach will involve a lot of money that is contrary to the good business practice of profit making.

It is therefore necessary to find a way of meeting such issues which are highly management oriented by appreciating the benefits and barriers that new forms of technology will offer in these areas. One such technology is the IoT for short.

The railway network has a whole lot of physical technologies, but not so much asset concerning the ICTs (information and communication technologies), of the twenty first century. ICT will be the catalyst that will help kick start the IoT revolution, for without a robust and effective information technological infrastructure, the utilisation and application of these data will not be optimised for the benefit of railway network, and for the population [11].

4.2 Data Harvesting and Analytics

Data science is a set of fundamental principles that support and guide the principled extraction of information and knowledge from data, which is usually termed data analytics. These principles and techniques are applied broadly across functional areas in business, for example, marketing, online advertising, and recommendation for cross-setting. However, for data science to serve business effectively, it is important (i) to understand its relationships to these other important and related concepts (i.e. big data, data mining and DDD (data-driven decision) making), and (ii) to begin to understand what the fundamental principles are underlying data science.

A data science perspective provides practitioners with structure and principles, which give the data scientist a framework to systematically treat problems of extracting useful knowledge from data. One of the most critical aspects of data science is the support of data-analytic thinking. Data engineering and processing are critical to support data-science activities [12, 13].

It has been amply demonstrated that DDD making has advantages. Additionally, DDD is causally associated with greater returns on assets, returns on equity, asset utilisation, and market value [12], as such decision makers in this field need new devices, and coding (e.g. quantum computing) that will enhance faster results on classical computers that are available.

Furthermore, the requirement for such devices needs to be created to meet the requirements in costumer business case in terms of their usage patterns in any environment. New protocols will be needed for communication compatibility across heterogeneous things (i.e. living organisms, inanimate objects, vehicles, phones, appliances). Also, the current internet infrastructure needs to be upgraded to meet the IoT challenges in the future. Moreover, standardization of systems (i.e. technologies, protocols, applications) will be a backbone for the IoT to create a competitive environment for organisations to deliver quality products [14].

4.3 IoT

The main concept of IoTs is integrating or interconnecting of things in our surrounding environment for exchanging information and services through interconnected sensors for creating an intelligent environment. The overall architecture of IoT is a communication paradigm in which microcontrollers, transceivers for digital communication, and suitable protocol stacks will be attached to our daily life objects to make them able to communicate with one another and with the users to become an integral part of the Internet [15]. The key elements of IoT are knowledge, smart sensors, RFID and Internet protocols.

IoT projects, by their very nature, tend to be complicated and time consuming, and certainly do not come cheap. Key factors in IoT deployment are security, data analysis, end-to-end support, user interface, scalability, agility, interoperability. However, as the IoT technology evolves there will be standard operating procedures that can be rolled out for most organisations.

In the UK, for example, the government white paper on IoT gave a range of ten recommendations of which there is one concerning transportation. The issues raised in the government review did not say much about transportation by the railway sector in the movement of goods and people [16]. The focus was more on roads, and autonomous vehicles, smart building, and smart cities, without appreciating the ubiquitous nature of the integrated IoT technology also relates to the rail sector. Already we have autonomous rails, from which others can learn, but at the same time improve and optimise massively with the arrival of the IoT technology. Most railway data can be transformed in such a way that smart technologies can access such data and make use of the repository efficiently for the benefit of all. By using the IoT technologies, the effect it will have for issues like training needs for working in 3D environment, upscaling skills, working patterns of professionals and mechanism for funding privatisation can be significant.

With IoT, employment organisations can connect to each other and their surroundings more easily to enhance collaboration and productivity, while all sides of the infrastructure they occupy become ripe for configuration to generate a more relevant and effective workspace, making significant cost-savings. A smart environment is one where technology works with people and continues to evolve in line with their needs [17], this is also true for the rail sector as it evolves over time into the twenty first century.

4.4 IoT Current Applications in the Railway Sector

In this section, related work with respect to IoT and the railway sector will critically be discussed. Railway network comprises of different components and systems including tracks, special trackwork (such as crossings and switches, loops, yards turnouts and sidings) overhead wiring structures, stations and platforms, signals, communication and control systems bridges and viaducts, tunnels, billboards and other infrastructure components [18]. To make sure these assets perform as required and safe, they required to be regularly checked and maintained. In this regard, several research studies have been conducted to address these issues and how IoT might help in making sure the rail network works efficiently and safe for the users, operators, and owners.

From Table 1, it can be deduced that most applications of IoT in the railway system focused on the health and safety issues that related to different components of the network. Other applications of IoT on components have been investigated, however, the missing research areas include billboards, bridges, embankment, overhead wiring structures, signals, special track work, tunnels, and viaducts. It is plain to see that most elements of the railway sector have not yet be considered for IoT supported management approach. IoT applications in the rail network have not yet been fully explored.

For an IoT to function effectively and efficiently, this must be done within a robust management system within the railway sector. The use and application of data for management using IoT should consider the three levels of management; that is, the strategic, the tactical as well as the operational management approach [19].

4.5 Management

The concepts, principles and practices of management have been influenced over centuries by the thinking and philosophies of prominent individuals and collective schools of thoughts, across the boundaries of many disciplines. In the context of organisations and a system approach to management, a management system is, simply put, a way of doing things—such systems arrange, develop, and apply protocols and sets of procedures which bring structure, order, and stability to the process of running a business. A system relates its business processes to the functions of management such that they are carried out systematically and consistently to the set standards of performance. Key features of any management system are that they are document based, standard based, process oriented, soft systems based and pursue continual improvement [20] in the business functions of the organisation. The basic management system approach of planning, organising, implementing, and review, can be applied when integrating the IoT architecture into the existing railway system. This should be reviewed in line with any conceptual IoT concerns in mind.

5. Towards an IoT Supported Management Systems Approach

The PDCA (plan, do, check, and act) [21, 22] railway IoT-supported management systems is shown in Fig. 2. The model has an IoT assisted support, which is made up of the IoT cloud area and the IoT-supported area. A brief description of the model follows in the next paragraph.

IoT data essential for strategic planning could be at the very high level of the systems, and projecting into the future scenarios of what the industry will be like, considering sustainable issues that are becoming prominent. IoT data for managerial or tactical level that come from development and implementation or the DO stage in Fig. 2, should include how the current rail system is working, in different environmental conditions, captured through IoT cloud technology, as well as distilled into manageable system information. IoT data synthesis for operational level involves the use of knowledge gained from such analysis, for operational deployment through technicians, and artisans in facilities management, corrective, and preventive maintenance of the railway system.

Table 1 Key research areas on the application of IoT in railway.

Author \ Function	Ballast	Billboard	Bridge	Communication	Control Systems	Embankment	HSE	Land for Railway	Level Crossing	Management	Maintenance	Overhead wiring structures	Signals	Special trackwork	Tracks	Tunnels	Viaducts	Floating Docks
Guo et al. [23]										✓								
Zhou et al. [24]															✓			
Takikawa [25]															✓			
Chandrappa et al. [26]					✓													
Chellaswamy et al. [27]															✓			
Fraga-Lamas et al. [8]	✓																	
Hatzivasilis et al. [28]							✓											
Kondratenko et al. [29]																		✓
Jo et al. [30]											✓							
Lei et al. [31]							✓											
Reddy et al. [32]					✓													
Yadav & Temkar [33]							✓											
Yang [34]							✓											
Khivsara et al. [35]							✓											
Kim et al. [36]							✓											
Uddin et al. [37]							✓								✓			
Ai et al. [38]				✓														
Al-Naimi & Qidwai [39]															✓			
Brezulianu et al. [40]										✓								
Hung et al. [41]								✓										
Rathore et al. [42]							✓											
Saki et al. [43]				✓														
Singh et al. [44]					✓													
Waghmare et al.[45]					✓													
Xu et al. [46]															✓			
Zhang et al. [47]							✓											
Gbadamosi et al. [48]											✓							
Iyer et al. [49]															✓			
Mangrule et al. [50]							✓											
Prasad & Madhumathy [51]				✓														
Shah et al. [52]															✓			
Wisultschew et al. [53]									✓									
Mishra et al. [54]						✓												
Chacon et al. [55]		✓																

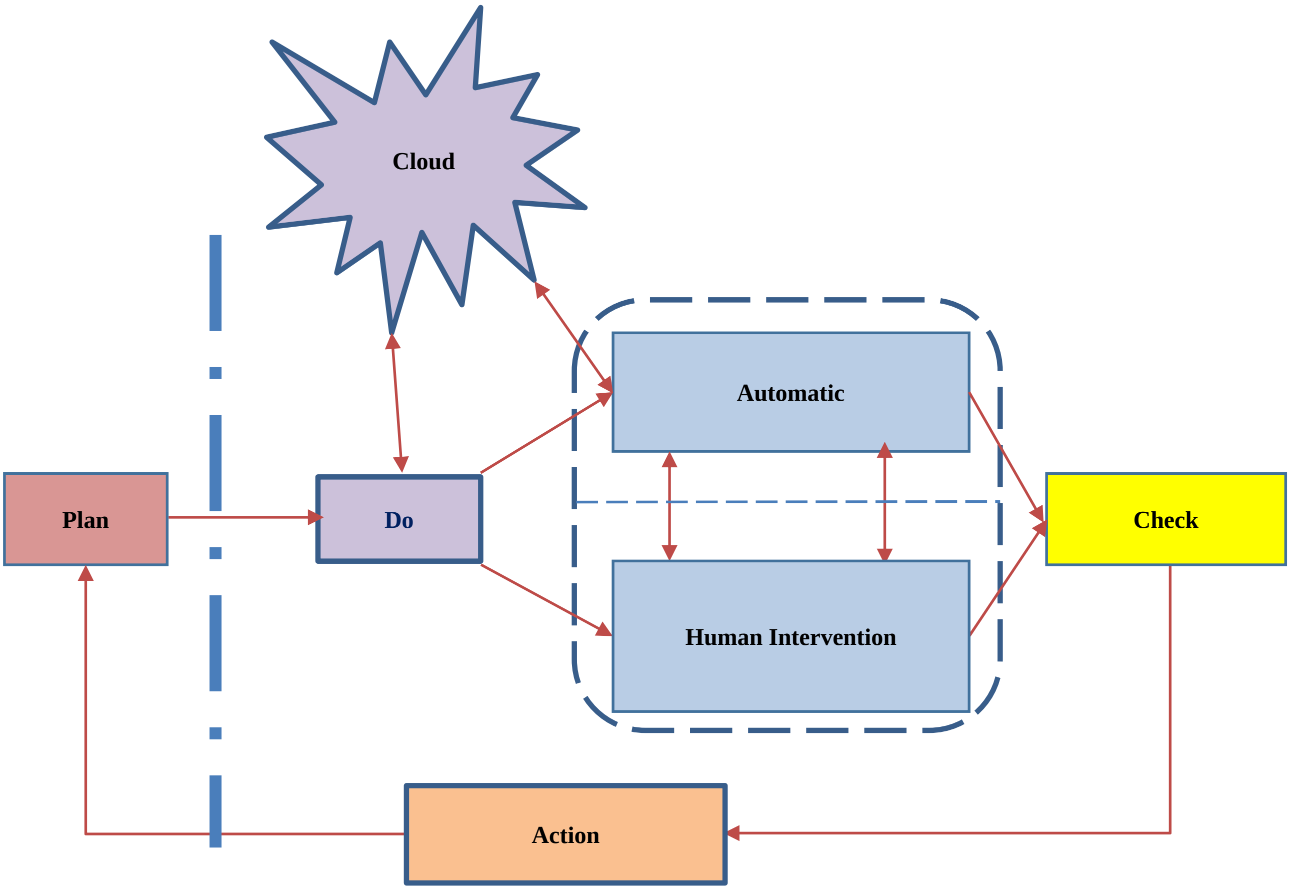

Fig. 2 Railway IoT-management perspective using PDCA Deming's approach.

The IoT-supported intervention can be either automated through software applications or humanly controlled depending on what the issues are that management is trying to contend with in the system. This phase is just a way of appreciating the data for management team or experts to discuss. Hence, this will lead to the check status for management to make decisions. Thus, going through the PDCA system as the data capture improves so the decision making of management will be enhanced continuously with updated reviews and technological innovations.

6. Discussion and Conclusion

Each industry with their many functions is making use of data engineer to organise their data, the information technology to organise their data processing capability, data scientists to translate business strategies and requirements of the organisation, not forgetting the industry expert. We can see that these professionals and technologies are not enough, as the digital domain is ever expanding, and automation is needed. Explicit knowledge is not enough concerning IoT, and it is therefore necessary for the tacit knowledge of the expert also to be captured. This is where the team of data professionals will come in, such as railway professionals, as IoT is considered automated, and do not need every data professional to intervene in the work process of the IoT.

Better understanding of the interaction of these technologies within their environment is essential to appreciate if any future maintenance is to be affected. The approach should be holistic by practitioners, not in isolation according to their respective professions. With technology improving at an alarming rate, it is also necessary that the competencies of the practitioners in the rail sector follow the same trend. However, the knowledge and experience of most practitioners' lag such technologies. The areas of knowledge improvement required by practitioners are work practice methods, sustainable issues, and procurement methods. From these areas, it is therefore clear that integration of technology, as well as that of people and the way organisations interact with each other is paramount.

In this paper a proposed IoT-supported framework is discussed, which gave a high-level understanding of the use and application of these new technologies. Since the approach is a system-oriented approach, it is envisaged that each sub-system will be developed in detail and then integrated seamlessly for management to be able to use such assisted IoT approach for all levels of management within a given railway organisational structure.

Once the subsystems are looked at it would be good to look at innovative emerging technologies that would assist such an approach in the areas of AI (artificial intelligence) and the "bots" that will be purely management oriented

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