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Evolution and Diffusion of ICTs in the Indian Railways: A Historical Analysis

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Cover Page Footnote

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ABSTRACT

The Indian Railway system is one of the largest socio-technical systems in the world. It has existed for over 160 years, starting from the British Colonial times. It continues to play a critical role in present-day India. It's continued functioning is dependent not only on the personnel who are employed in the railways, but also the technologies that go into the system. A critical technology in the functioning of the railway system is information and communications technologies (ICTs). ICTs are deployed in almost every facet of the railway system. But these ICTs did not manifest themselves recently. They have been continuously deployed in some form or other since the inception of the railways. The systems and technologies have evolved, and there has been continuous diffusion of these technologies over the entire system. Their evolution has been based on the political economy, societal needs and pressures, and have thus been socially constructed. The technologies developed within one area of the railway system have been diffused and adapted into other areas. In this paper we study and analyze the adoption, adaptation, evolution, and diffusion of ICTs within the Indian Railway system over a period of 160 years. Our study shows that ICT evolution and diffusion in large socio-technical system is continuous and cyclical, and dictated by political exigencies, societal needs, regional politics, as well as resistance and public-relations considerations. The flow of power was often, if not always, bi-directional. These considerations have affected ICT evolution in Indian railways even more than the sophistication of the technologies themselves. Our study also shows how the adoption of ICTs follow cycles of rise and fall, even as they continue to grow in size overall, and offers lessons for other emerging economies on issues related to ICTs in large socio-technical systems.

Key words: ICT adoption, ICT evolution, ICT Diffusion, socio-technical system, India, history of technology, political economy

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INTRODUCTION

The Indian Railways is one of the largest socio-technical systems in the world. It is the fourth largest rail system, with total tracks measuring 80,000 miles, covering a total route of 40,000 miles. It ranks highest in terms of the number of passengers served per day and per year. In 2012-2013 alone it served about 8.5 billion passengers, which is about 23 million passengers every day (Indian Railways, 2014b). It also carried 1.01 million metric tons of freight that year. It operates 19,000 trains a day, of which 12,000 are passenger trains, and the rest freight trains. It is India's largest single employer, employing about 1.6 million people (Indian Railways, 2014a). The system provides a critical and indispensable link to a majority of India's varied population. In its 165 years of operation, it has become deeply enmeshed with the fabric of Indian society.

DIFFUSION OF ICTs IN THE INDIAN RAILWAYS: MOTIVATION AND PRIOR WORK

The Indian Railway system as a whole has been a fascinating subject of study for various authors and researchers. Much of these have focused on Indian Railways history, early construction, and subsequent impact on Indian society. Canadian researcher and historian Ian Kerr has written extensively on how the early railroads were built in India, and the social changes that they brought (Kerr, 1995). H. H. Bhandari, an ex-Indian Railways employee and historian, has detailed the history of railways in India, with special focus on regional railways (Bhandari, 2005). Bagchi et al have looked at railway construction in India by compiling select historical documents such as Indian Railways Acts and Rules (Bagchi et al., 2009).

Historian Daniel Headrick studied the "technology transfers" that were engineered by the British during Indian railway construction (Headrick, 1988). More recently, historians Manu Goswami and Ritika Prasad have studied the effects of the railways on everyday life and the socio-cultural transformations that railways brought to the native Indians in the Colonial period (Goswami, 2004).

However, there has been no study that has exclusively examined (a) the evolution and diffusion of ICTs in the Indian Railways, and (b) what factors have shaped the evolution, diffusion, and adaptation of ICTs in the Indian Railways. "ICTs" in this context is broadly considered to include signaling, telecommunications, and customer-facing and organizational computing systems. This paper addresses this gap. It studies the evolution and diffusion of ICTs over a period extending over 160 years, from the 1850s to 2015 – a period which has also seen revolutionary political and technological changes in India. During this period, ICTs have played big roles in shaping the railway system, and the technologies themselves have been determined by the larger society in which the railway system operates.

During this period, a plethora of technologies have been used, adapted, and improved, much of them to suit Indian conditions. There was contingency at every step of their evolution and diffusion, and have been steeped in various power plays, politics, and sociological effects and consequences – between

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colonizer and colonized, the lay citizen and security establishments, societal needs and business imperatives. This paper is important because it takes a very different, post-colonial approach to view the evolution, diffusion, and adaptation of ICTs in a large socio-technical system. We believe that this is an important contribution to the study of ICT adoption, diffusion, and evolution, especially in countries with a colonial history.

USING THE HISTORICAL APPROACH: JUSTIFICATION

History is a legitimate area of research in Management. As noted by Daniel Wren, management historian, history is especially important in understanding the intersection of organizations, information systems, and society (Wren, 2004). Yet, there is a shortage of historical research in the area of Information Systems Management. The historical approach, while well established in other fields of management such as Economics, Accounting, Marketing, Business and Finance, is strikingly underused as a research methodology in research on Information Systems. This is despite the clear, documented importance of historical methods in MIS research by Mason, McKenney and Copeland in three articles describing the importance and use of historical methods in MIS research that appeared in the MIS Quarterly in 1997 (Mason et al, 1997a, Mason et al, 1997b, McKenney et al, 1997). As stated by Mason et al in the abstract of the paper titled "An Historical Method of MIS Research: Steps and Assumptions,"

> "Historical research offers perspectives on phenomena that are unavailable by any other methodological means. They reflect the cultural circumstances and idealogical assumptions that underlie phenomena and the role played by key decision makers together with long-term economic, social and political forces in creating them…"

An analysis of the contents of leading IS research journals such as MISQ, ISR and ISJ since the publication of the above articles reveals a paucity of historical studies in the broader IS field. If any historical treatment is considered at all, it is done in a mostly indirect and backhanded manner. For example, there are numerous longitudinal studies of systems' usage and adoption, and a few papers that examine the development of different IS research paradigms over the last thirty years or so. But no serious historical research has been undertaken, perhaps because of the notion that the IT and IS fields have changed dramatically over a very short period of time.

This study of ICT adoption, diffusion, and evolution in a large national system is clearly historical in nature. It is a long-term case-study of India and its relationship with IT, and hence warrants the use of the historical approach.

RESEARCH QUESTIONS

The main questions addressed in this study are (In the following, "technology" primarily refers to "Information and Communications Technology.")

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1 How did the power interactions and politics of colonization affect the development and adoption of railway technology in India?
2 How did the political economy and power equations of post-independent India affect technological development in the railways?
3 How has the post-liberalization economy affected technological development of the railways?

MODEL AND METHODOLOGY

We study the evolution and diffusion of ICTs in the Indian Railways in conjunction with the policies of the British government during the colonial period, as well as the policies adopted by the Indian government post-independence. Thus government policies and the political economy play a big role on the ICTs that have prevailed in the Indian Railways. Jason Dedrick and Kenneth Kraemer provide a useful framework for this. Their model (Figure 1):

> "posits that environmental factors constitute independent variables that affect technology diffusion in two ways: directly, and indirectly through the mediation of policy (shown by bold, straight lines). This is a static view, however, because we know over time the consequences of policy will affect the environment (shown by thin curved lines). In fact this is precisely the assumption of arguments in favor of industrial and technology policy: that the outcomes of the policy will bring environmental changes in the forms of improved economic and social welfare."(Dedrick & Kraemer, 1993)

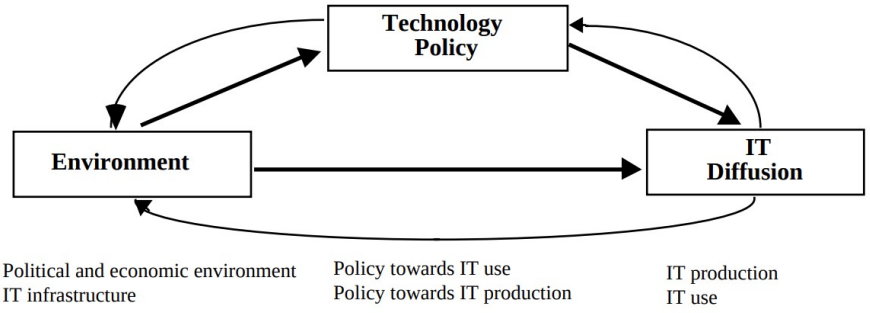

Figure 1

We use this model broadly. This model presumes existence of "agency" in the actors, which is not the case among the colonized. Agency encompasses all aspects of the model as we focus on both the colonial period and post-colonial periods in India. We also believe that IT Diffusion naturally leads to IT Evolution. Within the context of the Indian Railways, we view the infusion and adoption of ICTs by focusing on the interactions among technology policy, the social, political and economic environments, and the notion of IT diffusion – how IT was used, adopted and adapted within the railways.

Given our history focus, we follow the historical approach elucidated by Barbara Hahn (Hahn, 2019). It strongly focuses on the *causation, linearity,* as well as the *teleological* aspects that inform the history of technology, which inform our study of the Indian Railways. For our research we analyzed published documents in archives, books, academic journals as well as mass media. We interviewed managers, technicians, workers, and ex-employees that have been involved in the development, evolution, and continued operations of ICTs in the railway system. We examined government documents, especially from the Ministry of Railways, as well as Laws and Acts pertaining to the technologies in use in Indian Railways.

ORGANIZATION

The rest of the paper is thematically organized as follows: The section immediately following traces the historical origins of the Indian Railways – the justification (of the British) for building it, and the business deliberations that resulted in its eventual funding and creation. Following that, technical communications, education and training of the personnel, and power-plays during the process are discussed. In analyzing communications technologies in the railways, it is also important to recognize that railways always played a big role in society and became a metaphor for communication. This eventually resulted in mobilizing the Indians in their struggle for independence from the British. The section that follows addresses this development. Following that discussion, the paper gets into the details of the evolution of ICTs in the railway system. After that the paper examines the post-independence period and how ICTs continued to evolve after India gained independence, and follows that with the newer ICT enhancements leading up to the present. At the end of each major section, a brief summary-cum-analysis of the section is presented, vis-à-vis the research questions listed above.

HISTORICAL ORIGINS OF THE INDIAN RAILWAYS

Building a railway system in India was conceived by British businessmen starting in1844. R.W. Stephenson, as well as Messrs. White and Borrett wrote to The Court of Directors of the East India Company suggesting a 5 per cent minimum dividend to railway shareholders in two companies they proposed respectively: The East India Railway Company and The Great India Railway Company. Indian railway historian R. R. Bhandari notes that the reason was trade enhancement for the East India Company (Bhandari, 2005). As he notes, the company had been granted a charter in 1600 by Queen Elizabeth I to conduct trade with India. But by the early 1800s merchants of the East India Company found that trade with British India was meager. They felt that shipping and railway lines could facilitate and enhance trade. In 1843 Governor General Lord Hardinge argued that railways in India would be beneficial “to the commerce, government and military control of the country” (Bhandari, 2005). The proposal by the railway promoters led to many debates and discussions in the ensuing years. Stephenson’s sustained efforts from 1844 to 1849 bore fruit in 1849.

They found support in the Select Committee appointed by the House of Commons to look into the functioning of East India Company and trade between (British) India and Great Britain. This Committee came up with a proposal for constructing rail-roads in India (Bhandari, 2005). But this did not mean that India in the early 1800s was devoid of transportation. Canadian historian Ian Kerr notes

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that in the early 1800s bullock carts provided short-range transport, while long range transportation and trade was carried out through caravan trains - long convoys of pack animals – as well as through boats plying along India's rivers and coastal waters (Kerr, 2007). The Select Committee's Report led to many debates and discussions in England, culminating in the assurance of financial support and government guarantees to two private ventures, the East Indian Railway (EIR) company and the Great Indian Peninsula Railway (GIPR) in 1849. Construction began on the GIPR at Bombay (now Mumbai) in 1850 and on the EIR near Calcutta (now Kolkata) in 1851.

The first operational railway line opened in 1853 and connected Boribundar in Bombay and Thane, in the Western sector of the Great Indian Peninsula Railway (Khan, 2002). Within ten years, the 21 miles of tracks had expanded to 552 miles. By 1870, the system was complete. From no railway in 1850, trains were steaming through most parts of India in 1900. Trunk and branch lines extended over 25,000 miles (including double tracks) (Kerr, 1995).

Building a railway system in India was not an easy proposition. It needed sustained push from political benefactors. Lord Dalhousie, then Governor-General of India, saw the benefits of a railway system. It could be used to move raw materials and goods quickly to ports for shipment to England, and bring back return shipments of finished goods to the Indian heartland. Moreover, the railways could be used to deploy British military personnel quickly to various regions, to quell any uprising in any part of South Asia (Marshman, 1867). But the East India Company had to initiate the project. On April 20 1853, Lord Dalhousie wrote a 231-page "minute" to the East India Company's Court of Directors, providing detailed plans for a railway system connecting the three Presidencies of India (namely Madras, Bengal and Bombay) through trunk lines. He detailed the trade and military benefits, and urged the Court of Directors to "engage in the introduction of a system of railways into this India empire, upon a scale commensurate with the magnitude of the interests that are involved, and with the vast and various benefits, political, commercial and social, which that great measure of public improvement would unquestionably produce" (Lord Dalhousie, 1853). But as author and historian Shashi Tharoor notes, "public improvement" was meant to extend only to the British, and not native Indians (Tharoor, 2016),pp180-184.

The Indian railway system that evolved in the late 1800s almost entirely operated under British supervision. It consisted of several "classes" of lines or sub-systems:

1 Lines constructed and managed by "guaranteed" railway companies (private British-owned companies that raised capital which were guaranteed 5% interest by the British government)
2 Lines constructed and managed by State (Owned by the British Government of India)
3 Lines constructed and managed by "assisted" companies (private companies assisted by the British Government of India with limited-time, guaranteed low interest rate of return on investment)
4 State Railways worked by guaranteed companies
5 Lines owned by native (princely) states but worked by the British Government
6 Lines owned and managed by the native States

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7 Lines owned by the native States and worked by private companies, and Foreign lines (such as lines in Pondicherry which was under French rule) (Bhandari, 2005; Hunter, 1886; Misra (Ed.) et al., 1999)

In 1905, the Railway Board Act was passed, and the entire railway system was placed under the control of one single entity, the Railway Board. After Independence in 1947, the entire Indian Railways were nationalized by the government to create a single large entity under one management that exists at present.

Analysis: The railways was a massive communications system, within which are embedded several communications subsystems. The British are often credited with building and bequeathing to India what is arguably one of the largest and long-standing "communication systems" in the world. But this communications infrastructure was motivated by the desire to profit – to enhance the movement of valuable raw materials from the interior regions to the ports, from where they could be shipped to England for manufacture. The effects of this system on native Indian commerce was not a consideration. Another motive was the railways as a means to exercise control by being able to move military personnel quickly to control native Indians at times of unrest. The main actors were the British parliament, the (British) Indian government, East India Company, the railway business promoters, and the venture capitalists/financiers. If the railways did not make profit, the plan was simply to make up the loss by taxing the native Indians who did not have agency. Thus the initial motivation for this massive communication system was purely profit.

BUILDING THE "COMMUNICATIONS NETWORK" (RAILWAYS)

The common narrative holds that the British engineers planned and directed the construction, and also taught the Indians the skills specific to railroad construction. But reality was more nuanced. The British designed, planned, and supervised the construction of the Indian railway system, but it was Indians themselves who actually built the Indian railways. "They did most of the work and most of the dying" (Kerr, 2007). The British presence was typically small, with just a few hundred supervisors. The labor was contracted out and was entirely Indian. They did the toughest jobs, such as earth removal, working under very inhospitable and unsanitary conditions. While there was readily available British technology for earth removal, those technologies were not deployed. Only Indian manual labor was used. The Indian workers did not employ any sophisticated construction tools such as tilt wagons, mechanical excavators, etc. Instead, earth moving was done by hand, using small implements and hand carried baskets. The British companies found this method more expedient and cheaper than using wheel barrows.

Cost-saving was the motive. Hundreds of thousands of Indian men, women, boys and girls were employed, as labor was cheap. The workers had to endure extremely harsh working conditions, and tens of thousands of Indians lost their lives in building the Indian railway system (Kerr, 1995).
Historian Arnold Pacey notes that the British kept the transfer of technology "in its crudest form (Pacey, 1990,pp147)."

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Technology Transfer and Diffusion

A certain level of nuanced technology transfer did take place. Railway construction required skilled workers such as blacksmiths, carpenters, masons, brick-makers, mechanics, riveters, etc. When British personnel with those skills were in short supply, Indian workers were sought and taught those skills. Also, the technology and skills transfer was not always uni-directional (i.e. from the British to the Indians). Over time, Indian traditional technologies also came to play. The British realized that their traditional permanent-way and track construction, as well as pier based bridge foundations were not able to withstand the fury of Indian rivers. Indians had a rich history of bridge building, and some of the technologies, such as well foundation techniques used for centuries, began to be adopted by the British in constructing railway bridges. This knowledge was communicated through journals and manuals. The Indian workers also preserved and transmitted the new knowledge gained among themselves. This evolving knowledge and body of practices came to be known as the "new syncretic 'Indian approach' to railroad building (Derbyshire, 1995). This was an early example of technology diffusion. Several of the technology adaptations are listed by Bandyopadhyay Madhumita (Madhumita, 2013). Some adaptations were novel, but effective. An example is the 'Bezwada' (Vijayawada) bridge built over the 'Kistna' (Krishna) river. The bridge has twelve spans of 300 feet. The foundation wells were sunk using bullock-powered dredges, where each dredge required four bullocks, a bullock man, and two men working in the well (Railway Board, n.d.). Other examples of indigenous methods and technologies used included the 'jham' dredge device for dredging the soil inside the foundation wells (Kerr, 2007), as well as the 'piccotah' pump which was traditionally used in the Southern India for pumping water from wells (Forrest, 1866). The Indian workers also improvised a sling and bamboo combination to move and position the heavy rail tracks.

The notion that all technologies relating to railway infrastructure was transferred by the British to India can be contested. The British transferred the most rudimentary technologies and used many indigenous foundational technologies such as bridge-building, and building strong foundations under ferocious and fast changing rivers. The native knowledge gained by the British in this manner was used later put to use in other colonies such as Uganda (Tharoor, 2016, pp45).

COMMUNICATING AND DIFFUSING TECHNOLOGY

Railway Technology Training Institutes

Once the railway infrastructure was built, trains had to be operated and maintained. Railway operations was strictly restricted to the British, and Anglo-Indians. Non-technical, low level jobs were contracted out to Indian subcontractors. Native Indians were declared either unsafe or inept to handle critical operations. The British set up several civil engineering colleges to train engineers on railway technology. Institutes for Civil Engineering were set up all over India in places such as Roorkee (1847), Madras (1862), Calcutta (1856), Bombay (1888), Jamalpur (1888), etc. Training for the higher levels of railway jobs were reserved for British citizens, while Indians received training only for mid-level and lower-level positions, so that they could eventually take up jobs as assistants under a British engineer

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or Chief engineer. Their role was to function merely as intermediaries between the British supervisor and the Indian subcontractor. However, it was these mid-level engineers who would eventually accumulate enough knowledge for running the Indian railway system after independence.
The British thus unintentionally aided in the diffusion of technologies to Indians.

Railways as a Metaphor for Communications Technologies

One way to consider the railway system is to view it as a large-scale, dynamic, communications system, comprised of many sub-systems and feedback loops. The system was designed with two main purposes: (a) to efficiently transport goods and (b) to quickly transport critical manpower across geographies for maintaining security. In addition to moving raw materials from interio lands to the coast was the prime purpose of the railways, another stated intent was that rapid movement of staple foods would alleviate food insecurity in rural areas. However, in practice, the rail system accelerated rural food insecurity. While the traditional system of slow transport along river routes ensured that the staples at least reached the intended populations, where a culture of saving for the future existed, the rail system resulted in rapidly moving staples away from rural to urban areas and ports. The old pattern of food distribution and storage was rendered defunct. This loss of the traditional communication and distribution system had disastrous consequences and resulted in major famines during the colonial period, as noted by Tharoor (Tharoor, 2016, pp184-185). Looking at the system now, it is apparent that the colonial government did not have, or simply neglected to deploy adequate and timely feedback mechanisms that could trigger appropriate remedial action. This argument has been proposed by Amartya Sen in his study of poverty and famines (Sen, 1983). Thus, again, the basic premise that colonial railways was beneficial to efficient communications and movement of goods can be contested.

The Colonial railway system practiced racial segregation by creating three main classes of coaches for passengers. The first class was reserved only for Europeans, a majority of whom were British administrators and military personnel. The second class was reserved for upper class Indians. It was also known as the *transient class.* The rest of the Indian natives were relegated to travel only on third class. Historians Ian Kerr and Manu Goswami have noted the indignities and insults that the second class and third class passengers had to endure (Goswami, 2004; Kerr, 1995).

Railways as Communications Amplifier to the Independence and Protest Movement

In an ironic twist, the rail system was used to maximum benefit by Indian independence activists. It was initially thought that Indians, steeped in their caste system, would never use the railway system for fear of mingling with people of other castes. Indeed, higher caste Hindus initially demanded separation of space from Muslims and lower caste travelers. However, the nascent Indian Independence movement put an end to such calls for separation. Indian nationalists and freedom fighters led by Mohandas Gandhi emphasized that there should be no differentiation during travel (Prasad, 2016). Gandhi traveled extensively on third class coaches spreading the ideas of peaceful protests. Over time it became fairly common for Indians from various backgrounds to travel together in the same railway coaches. Indians used trains for pilgrimages, for which they traveled the length and breadth of the country. By 1902, Indians constituted 90% of the train passengers, and almost all of them traveled by

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third class. Through the railways, Indians learned about the Independence and Protest movements across the sub-continent. They became familiar with the notion of time and punctuality – that the trains waited for nobody. By 1947, the number of passengers had reached one billion. The train travel figures however underestimate the number of passengers, as countless numbers of people traveled without tickets – which was considered to be a form of anti-colonial protest.

Also for the first time, Indians from different states and speaking different languages were able to go to other states and learn more about India. The railways played a big role in national integration – giving the Indians a sense of unity based on the Hindu culture despite their different languages, diets and customs. Indians used the system the most, and thereby gained a better understanding of the sub-continent. Thus, as noted by Christian Wolmar, the railways became a "double-edged sword." It was at once an instrument of control, as well as a symbol of national integration and communication, and ultimately played a big role in Indians' freedom struggle (Wolmar, 2017).

Analysis: Railways is undoubtedly a huge communication system, which required old and new skills, as well as adoption of old and new technologies belonging to the British and Indians. During this phase of building the system, older, analog systems of information transfer and diffusion, namely journals, field notes and manuals, maintained by both the Indians and the British, became useful information repositories. But power and politics were ever-present in developing and enhancing this massive communications system. When the British needed more trained workers for the Indian railways, they opened up several training centers, purportedly to train mostly British and some Indian technicians. Indians were to be trained only for lower level jobs, while the British citizens were trained in the top level technical jobs. Native Indians were forced to travel in crowded third-class carriages without any facility or comfort. However, this forced mixing of various classes of Indians into a low-comfort zone only enhanced inter-class communication more than any technology could. It increased camaraderie, and eventually the railways and the coaches became the main communication medium for the Indians in their struggle for independence. Mahatma Gandhi, as well as leaders of the Indian independence movement used the train coaches with their captive audience to deliver lectures on independence and build the movement (Prasad, 2016). Unfortunately, native Indians still lacked agency when it came to railway operations and planning. Thus, the gains did not help prevent famines that were exacerbated by the introduction of trains to move staples quickly from the rural areas to the ports.

DEVELOPMENT OF ELECTRIC SIGNALING IN THE INDIAN RAILWAYS

As rail traffic increased in India in the late 1800s, train accidents also began to increase, resulting in fatalities. Train travel in India did have one common aspect for all passengers despite the different classes in which they traveled: the specter of railways accidents. One major railway accident occurred on May 7, 1868, when a mail trail derailed near Shyamnagar, killing 10 people and injuring 35. By 1905, train accidents were occurring with regularity. That year, 143 passengers were killed or injured in train accidents. According to O. Lloyd, rapid expansion of the railroads (and the resulting influx of passengers) led to the hiring of incompetent people and also resulted in overwork for the staff (Lloyd, 1911). Other causes included weather-related issues such as collapsed embankments, mechanical failures, animal encounters, broken equipment, as well as human errors, such as failure to obey human

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hand signals.

The need to keep safe distances between trains became important. Many questions needed to be addressed: How was the railway staff to know, before they sent off a train from a station, that the previous train was a safe distance away? How were the staff to know that no train was approaching another train on the same line? Initially, there were no means of communication between any two points. There was only human hand signaling. Clearly communications technologies needed to be incorporated to ensure safety of passengers as well as railway assets. As a result, electro-magnetic railway signaling technologies and regulations began to be introduced in the late 1800s. These signaling technologies were supported by the telegraph network that had been introduced in India during the 1850s.

The first telegraph lines in India were laid in 1851 by the British government. These were mostly installed near Calcutta, which was then the headquarters of the British government in India. The early telegraph network was laid with the support of James Andrew Broun Ramsay, Marquee of Dalhousie (1812 – 1860), also known as Lord Dalhousie, who was appointed the governor - general of India by the East India Company in 1848. His reasoning for a telegraph network was simple: to unify India, a land of numerous kingdoms, and control it. Over time, the telegraph was used by the British as a law-and-order maintenance tool (Headrick, 1988). This became apparent in 1857, when the telegraph became the primary communications technology that was used by the British army in its successful effort to quell an Indian rebellion.

When the railways were built, the telegraph lines used the railways' right of way to extend the network. In the absence of a standardized set of guidelines and rules, several railways created their own laws and Acts. The next step was to provide strict guidelines that governed the operations of trains. The different rules were harmonized through the Indian Railway Act of 1990. As an example, the Rules and Regulations of the Rajputana Railway (1873) stated (Excerpted from (Bagchi et al., 2009)):

1 "Every Line of Railway intended to be worked by Engine power, for the conveyance of Passengers, shall be provided with an Electric Telegraph."
2 "Trains moving on a single line, shall invariably pass each other at the Stations, and no Engine, with or without a Train, shall be permitted to leave one Station for another until it shall have been ascertained, by means of the Electric Telegraph, that the Line between those two Stations is clear of Engines and Trains, and of all impediments, so far as can be known."

The Role of Telegraph in Early Railway Communications

According to Bhandari, the early railway companies initially did not see the use of the telegraph as a vital communication system to aid railway safety, even though a fairly elaborate telegraph system was being developed in parallel to developments in the railway system by William Shaughnessy (Bhandari, 2005). The telegraph lines ran alongside railway lines. All railways in India were able to use the telegraph from day one (Ghose, 1994). Later the telegraph was used for dispatching trains, as well as in cases of emergency. Telegraph also played other roles in the railways. Ian Kerr notes that first class

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passengers in the late 1800s could place meal orders with a carriage attendant, which would be telegraphed to a future station. When the train reached that station, the meal would be ready. But, apart from these uses, the railway companies in colonial India did not immediately use telegraph for safety purposes (Kerr, 2007).

Early Signaling Technologies

By the late 1800s, increase in rail traffic in the second led to the establishment of stations in towns and villages. Some stations became junctions, where the railway lines merged or diverged. In the absence of any formal method of communication between stations to tell when a train was departing or arriving, a system had to be developed. The first system that was devised to address this problem was the *time-interval* system. This system assumed that the trains were all proceeding according to schedule. Thus, after the first train left, the next train waited for a fixed time before proceeding in the same direction on the same line. Trains were also run using *messages* (most probably conveyed through telegram), *hand signals* and *candle light signals.*

The early signaling technologies were all analog. In most stations, hand-held green and red flags were used to signal trains. Mechanical "semaphore" signals gradually took the place of hand or flag signals. These were two-position lower quadrant semaphore signals. Each signal had an assembly with an arm mounted on a mast. If the arm was horizontal, it indicated "danger" or "stop." If the arm was inclined downwards at 45 degrees, it indicated that the line was clear. Block section interlocking was introduced in India after the serious accident that occurred when a train derailed near Shyamnagar on the Eastern Bengal Railway on May 7, 1868 (noted earlier). Initial reports from the British authorities acknowledged the signalman's negligence. This was when the need to interlock signals and points was realized. Interlocking is an arrangement of signals connected through electrical means so that a signal for a train to proceed on a section cannot be granted until that section is declared to be safe. Interlocking systems were initially manual mechanical systems. Soon the purely mechanical interlocking systems were succeeded by electro-mechanical interlocking systems, which require that the signal boxes and stations are connected by electricity.

INDIA- A CENTER FOR INNOVATIONS IN SIGNALING TECHNOLOGIES

Many innovations in railway signaling technology were made in India during this period. The first electro-mechanical interlocking system used in Indian railways seems to have been in operation since 1872, according to R.R. Bhandari (Bhandari, 2005). This system was designed by Messrs. Saxby and Farmer in the UK. However, others note that the first interlocking system used was that by G.H. List and A. Morse (hence known as the List and Morse system), working in the Northwestern Railway in India, and that the Saxby and Farmer system was not introduced until 1893 (Hinson, n.d.). G. K. Winter, a telegraph engineer working in the Madras Railway, is credited with developing an electrical block ticket apparatus. Winter received a patent for his system in 1878 (*Obituary of G. K. Winter, The Electrical Review, Volume 42*, 1898; Patent Office, 1879). Several token and key systems were developed in the late 1800s for working the interlocking system. An electric block key instrument by C. D. Theobald, Chief Telegraph Inspector of Madras Railway is described by H. Raynar Wilson (Wilson,

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1909). Another electric key system was Hepper's electric key transmitter, patented in May, 1901 (Saunders & Blundstone, 1902). J. E. Neale, telegraph superintendent of the Great Indian Peninsular Railway developed the Neale's Ball Token instrument around the same time. This signaling instrument was very popular at the time, and was used in many sections of Southern Railways as recently as 2016 (Radhakrishnan, 2016). As can be seen, numerous signaling and communications systems were developed and introduced to the Indian railways system from 1868 onward. These are all credited to British engineers, many of whom were working in India. It can however be conjectured that there were native Indians working in these same offices, who also played some role in the development of these innovations, but remained in the background, unacknowledged.

*Comment: The preceding section discusses the steady increase in the introduction of information and communications technologies during the late 1800s and early 1900s. Many historians have noted that the railway companies themselves were not very eager to adopt or install the expensive telecommunications systems required for safe operations, but were forced to do so due to the increase in the number of accidents and the resulting deaths. An illustration of the importance given to accidents is seen by reviewing the "*Summary Of The Administration Of The Earl Of Minto Viceroy And Governor Of India In The Railway Department Nov 1905- July 1910*," noted earlier. The detailing of accidents is relegated to page 87 of the 90-page report. Many new signaling technologies were invented and patented in India by British engineers. No Indian name is ever mentioned in these patents.*

INDEPENDENCE AND FURTHER DEVELOPMENTS IN ICTs IN THE RAILWAYS

India gained independence on August 15, 1947. The development of the Indian railways after independence in 1947 has been "decidedly post-colonial" (Kerr, 2007). It has been shaped by the developments moored in the colonial period, but has been responsive to changes in society, technology and political economy, and has consciously attempted to shed the vestiges of its colonial legacy and has developed a uniquely Indian character. India's first Prime Minister was Jawaharlal Nehru. He was greatly influenced by the philosophy of Karl Marx and Vladimir Lenin, as well as the Clement Richard Attlee, the British Labor Party leader. Nehru conceptualized a formula for India's development that was distinctly socialist, focused on heavy industries, power generation and scientific research institutes. He adopted the Soviet model of a planned economy and five-year plans and actively promoted those ideas. His idea was to integrate technology-development and with central planning. The railways were a very important component in Nehru's plans for India's development.

At the time of independence, there were almost 41 different railway systems, operated by various princely states (controlled by the British), private companies, and a few that were government-run. The new Indian government decided to consolidate all of these into a single, giant, state-run entity, called the Indian Railways (theevandi, 2013). The Indian Railways played a critical role in India's economy. In the initial years after independence, almost 75% of the country's budget was focused on the railways (HT Correspondent, 2012). As a result, a separate Ministry of Railways was created, with John Mathai as the first railway minister of India. In a practice that has continued for almost 100 years, a separate

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railway budget is presented to the Indian Parliament every year.

At the time of independence, India also lacked the facility to manufacture train locomotives indigenously. As noted by Shashi Tharoor, when railway institutes were set up by the British in places like Jamalpur and Ajmer in 1862, the Indians had been quick to learn locomotive manufacturing technologies, despite being denied higher level training and relegated to the level of maintenance technicians by the British. Alarmed at this ability of the Indians, and the threat to their hegemony, the British banned all locomotive manufacture in India, through at Act of Parliament in 1912. This forced the railways to import all locomotives from Britain, US, Canada and Germany. Thus, at the time of independence, India had to go back to England to acquire locomotive manufacturing know-how. There were other major challenges. By 1930, when the British realized that Indian independence was imminent, it decided to stop investing on the railways, and neglected maintenance of the railway rolling stock. By the time of independence, the railway rolling stock was widely considered to be a pile of rust. Another major challenge was the partition of the erstwhile Indian subcontinent into India and Pakistan. The sudden and arbitrary nature of this partition cut of several railways systems, with workshops, maintenance centers, and personnel, stuck on different sides of the partition. Enormous amounts of information had to be exchanged between the borders, especially during the terrible communal strife and dislocation that was engineered by the partition (R. Rao, 2020), (theevandi, 2013). Thus the nascent Indian Railways had to start from scratch and re-engineer its path to growth.

Tharoor provides what he calls a “fitting postscript” to this event in history: In 2016, sixty-nine years after independence, the principle technology consultants of the British Railways, Rendel Palmer and Tritton, depend almost entirely on Indian technical expertise, provided by RITES Ltd., a transportation infrastructure consulting subsidiary of the Indian Railways (Tharoor, 2016) – which shows the rapid growth of railway expertise in India after independence.

After independence, the Indian government raced to improve and enhance the railways. The government saw the benefits of railways to commerce, nation-building, as well as the greater society. Specialized institutes for engineering and railway administration were set up by the Indian government to train Indians to enhance and run the railway system. Among them was the Indian Railway Institute of Signal and Telecommunications Engineering, Secunderabad.

Post-independence saw robust increases in rail traffic as the newly independent nation sought to enhance its economic growth. As rail traffic increased, so did the number of accidents, many of which involved human fatalities, and led to interruptions in rail traffic. To address this, the government set up several committees over the years. Notable among them were the Railway Accident Committee under H. N. Kunzru in 1962, the Wanshoo Committee in 1968, the Sikri Committee in 1978, and the Khanna Committee in 1998 (Sahay, 2002). These committees recommended safety plans and procedures. Analyses of accidents by Parvakar Sahoo in 2002 (Sahoo, 2011), and Mukesh Mehrotra in 2017 (Mehrotra, 2017) have indicated that the main causes of accidents and fatalities were due to human error. But looking more deeply, it is clear that the human intervention occurred because of signal equipment failures and malfunctions. Based on the various committee recommendations, more resources began to be directed towards enhancing ICTs in the railways, especially Signaling systems,

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starting from India's Fifth 5-year Plan (Planning Commission, Govt. of India, 1974). Since then, signaling and telecommunications systems gradually improved and increased in sophistication, in keeping with technological advances in electrical engineering and communications technology. Over time, many other techniques, such as Tokenless Block working, multi-aspect light signaling, microwave networks, Ultra High Frequency/Very High Frequency communication links, solid state interlocking, etc. came to be used in railway signaling.

POLITICAL ECONOMY AND COMPUTERIZATION IN INDIAN RAILWAYS

As the Indian Railway system continued its growth, its complexity increased. In addition to passengers, it also managed very large freight operations. The freight operations emanated from 7000 stations, handling about 600 commodity groups with a daily loading of 30,000 wagons. To deal with this level of complexity, the railways resorted to mechanization for managing and recording its operations. Unit Record Machines (IBM Corporation, 1950) with punched card systems were introduced even prior to Independence, and were in operation until the 1960s (B. V. R. Rao, 1973). By 1964, the continued growth in rail traffic necessitated the aging unit record machines to be replaced with electronic computers. At the time, it was found that Traffic Accounts and Stores Accounts were very tedious to compute manually, and thus were potential areas to be computerized.
A senior officer was assigned to study and recommend an approach for the computerization process. As noted by Rao, this resulted in the first Management Information Systems for the Railways.

Computerization of the Indian Railways started in the early 1960s. Each of the nine Zonal Railways offices got its own computer. So did five production and operating units. Totally 14 computers were inducted, all of them being IBM 1401 Series computers. The computers were used mainly for accounting and freight billing. The data-processing applications planned at the time were: Passenger and freight traffic revenues, fuel accounting, operations statistics, payroll, stores, accounting, inventory control, production control, and scheduling. Many Operations Research (O/R) applications were also added during the 1970s, some of them being Linear Programming for production scheduling, simulations, network analysis by CPM/PERT for project scheduling and control, Monte Carlo simulations for marshaling yard operations, and multiple regression analysis for manpower planning and scheduling. While this appears to be a comprehensive list, Rao notes that many of these applications were used only occasionally, and not as an established way of tackling the multifarious problems encountered by the railways. Rao notes that in this regard, the computerization in the Indian Railways was at a "primitive phase" – basically automating what was already done manually with just a few marginal improvements in systems design.

Computerization in India was affected by political events in the 1970s. This was also the period when India gradually shed its dependence on foreign computer companies and started developing indigenous computing skills. In 1973, the Indian government enacted the Foreign Exchange Regulation Act (FERA) to conserve foreign exchange. Under this act, most foreign companies were required to dilute their holdings and take on an Indian partner with majority stakes. IBM refused to agree to these new conditions of operation and chose to leave India completely in 1978. In its place, and Indian-government owned company, Computer Maintenance Corporation (CMC), was set up to maintain IBM

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computers, including those at the Indian Railways.

INDIGENOUS RAILWAYS COMPUTER APPLICATIONS DEVELOPMENT: FOIS AND CRIS

The first major indigenous computer application developed by the Indian Railways is the Freight Operations Information System (FOIS). As noted by the Ministry of Railways, freight constitutes two-thirds of the Railways' revenues, and tracking various aspects of freight movement is a very complex operation. Currently the Indian Railways carries about 1100 tons of freight in a year. This requires an average of 5000 freight trains every day. Freight trains also do not run according to a fixed schedule, which makes scheduling very complex. To make freight operations more manageable and efficient, the Railways Ministry approved the development of the FOIS in 1984. In 1986, the Ministry also created a semi-autonomous "society" for overseeing all information systems developments in the Indian Railways, the Center for Railway Information Systems (CRIS). This new organization took over the development of FOIS. The system initially helped in tracking and monitoring the movement of wagons and locomotives. Eventually, it became a complete freight management tool, handling freight movements as well as billing and revenue collections. The next important milestone for Indian Railways and CRIS was the development of the passenger reservation system.

PASSENGER – FOCUSED IT SERVICES

The focus of computer applications during the 1970s was on improving the railways' organizational information management. It was not passenger-focused (i.e. aimed at providing better services to the passengers using the system). Providing ease of use to the millions of passengers was not high on the list. One of the biggest problems that rail passengers encountered and dealt with, was the manual ticket reservation system. As noted by V. Rajaraman, in 1984 alone, the railways handled over 5 million passengers (Rajaraman, 2012). They travelled in over 600 trains, and there were over 50,000 reservation requests. The reservation process was complex and tedious not just to the passengers but also the reservation clerks. Reservations were generally issued on the basis of fixed quotas for each station. Onward reservations, reservations from other stations, and return reservations required telegrams to be sent to those stations, and awaiting telegraphic confirmations from those stations.

In the early 1980s, booking a railway ticket would often take the majority of a day for a passenger. Author Dinesh Sharma writes in detail about the travails of booking a railway ticket in the 1980 (Sharma, 2015). There were numerous passenger complaints about the difficulty of buying a railway ticket. (The author recollects standing in queues for hours to buy railway tickets in the 1980s). Ticket booking in the Indian Railways became a political talking point and the butt of jokes. This process was clearly unsustainable, given the projected growth of rail travel in India. Computerization of ticketing and reservations was the solution.

Passenger Reservation System

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Today the computerized reservation system is a source of pride to the Indian Railways. However, as is typical in the Railways' long history, the development was not without hiccups. Dinesh Sharma notes on how the Indian Railways was initially not very keen on improving or computerizing the ticketing system until the World Bank tied an "efficiency through modernization and computerization" criterion as a precondition to providing a large loan. Moved to finally act, the Indian Railways sent two teams to various countries including the US and Canada to study and recommend a suitable ticket reservation system. The teams came up with recommendations, and the Directorate of Operations and Information Systems developed a plan. But again the Indian Railways Board did not act. Indeed many officials of the Indian Railways were opposed to computerization, and came up with various excuses not to move forward. Some of the opposition was a general resistance to chance, whereas some were due to fears of job losses that computerization could cause. Finally, out of frustration, N. C. Gupta, head of the Directorate directly approached the Railways Minister and convinced him of the benefits of computerizing the passenger reservation system (Sharma, 2015,pp90-91).

In 1984, the CMC proposed developing such a system to the Ministry of Railways, and its proposal was accepted. So in the end, the reservation system was developed from scratch, locally. In 1986, CMC implemented its computerized train reservation system. The CMC system proved to be incredibly sophisticated, complex, and successful. It had to address the following requirements: It had to handle a projected volume of over 600,000 seat and berth reservations a day, on 7 passenger train categories, 72 types of coaches, 7 classes of accommodations, over 40 "quotas", and around 80 types of concessional fares (IRFCA, 2010). The system, simply known as "Passenger Reservation System (PRS)," was initially implemented in New Delhi in 1986. It had 50 counters, and customers could go to any counter and get a reservation for any train. The system was implemented on a DEC VAX 11/750 cluster, and FORTRAN was used as the programming language. Access was through VT220 terminals (Sharma, 2009,pp144-156). This achievement by Indian engineers was considered to be nothing short of a miracle by railway passengers, and was an eye-opener to Indian citizens who clearly perceived the benefits of computerization. Thus, the railway passenger reservation system holds a very pivotal position in India's computing history. In the next few years the PRS was extended to four other major cities. Initially the five nodes operated independently. They maintained localized databases, and could not exchange information. This problems was rectified in 1999 when the PRS evolved into a much larger, "Country-wide Network for Computerized Enhanced Reservation and Ticketing (CONCERT)."

Over time, CRIS has overseen the development of many other passenger-focused systems such as the "National Train Enquiry System (NTES)," the "Passenger Operated Enquiry Terminal (POET)," and the "Unreserved Ticketing System (UTS)." In addition, CRIS has also developed the "Interactive Voice Response System (IVRS)," which can be used by passengers to get status information over the telephone. CRIS is currently working on other passenger-focused applications such as: Ticketing on Mobile Phones, linking tickets to Aadhaar (India's Unique Identification Number), tracking of trains in real time through GPS, tracking of rolling stock using radio frequency identification, and setting up a geo-spatial database for the Railways (Ministry of Railways, 2017).

Analysis: It is important to note that the initial computerized reservation system resulted due to interactions among various actors: From the World Bank, as a precondition to issuing loans; from the

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citizens, who were fed up with the delays (and resulting corruption) that occurred during ticketing; through direct intervention from political parties (i.e. the Railways minister); from the workers' unions, which were co-opted early in the process, and were able to provide useful inputs to enhance the process; and from the unorthodox efforts of the head of the Directorate of Operations and Information Systems. The availability of local computing talent was also a critical factor in the success of the effort.

WEB- BASED PASSENGER – FOCUSED APPLICATIONS: IRCTC

The next major intervention came due to the emergence of the Internet and World-wide Web. A big leap in providing better experience to the Indian railway passenger occurred on September 27, 1999, when the Indian Railways created a new subsidiary, the "Indian Railway Catering and Tourism Department (IRCTC)." The IRCTC handles railway catering, tourism and online ticketing operations for the Indian Railways. The IRCTC operated on-board pantry cars in long distance trains, which enabled passengers to buy and consume fresh meals of their choice without being restricted to limited meal options at station stops. Most importantly, the customer-facing part of the IRCTC was designed as an e-commerce storefront. Customers could plan vacations and travel, book tickets online, and also buy on-board meals using a web browser. The IRCTC claims to have more than 30 million registered users, and processes over 500,000 ticket bookings per day, making it one of the busiest e-commerce portals.

In addition to the web portal, IRCTC has developed many mobile apps that allows a user to track trains between stations, look up train schedules, real-time seat availability in trains, inquire about fares, look at live train status, order food on trains, and even file a live report on the sanitary conditions on board a moving train. A recently added "Food on Track" app allows passengers to order restaurant food of their choice to be delivered to their seats at specified station halts. These new-fangled applications have enjoyed big successes with the customers. By the end of 2019, the ICTs in the Indian Railways continue to evolve and grow, expanding into newer applications horizons focused on all the stakeholders – the customers, end-user railway employees, businesses, and the government.

160 YEARS OF ICT EVOLUTION AND DIFFUSION

Historians have investigated the phenomenon of the Indian railways in a variety of ways, for a variety of objectives. Some have focused on the construction of the railways system by the British, some have focused on the technologies transferred, and others have focused on the social changes that the railways brought to India. We investigate the history of the railways by focusing on evolution and adoption of the technologies, specifically the information and communications technologies (ICTs) that form the backbone of operations of the railways.

Our objectives in this study was to answer three main research questions.

The first question was: How did the politics of colonization affect the development of railway technology in India?

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We show that the politics of colonization played a significant role in the way the railways were constructed and enhanced during the colonial period. Our study reveals the politics among the main players involved in bringing the railways to India. It is clear that the British introduced the railway system to India primarily to further their interests and control India through the vast communications network that the railways created. But this was not accomplished without much debate and political shenanigans, such as guaranteed rates of return to British investors. The colonial rulers initially envisaged the railway system as an instrument of control as well as a driver of commerce. Technologies were steadily added to the railway infrastructure, but only when absolutely necessary, and when faced with strong protests from the native Indians, or when press reports caused negative public relations. Electronic signaling and telecommunications systems were installed in the Indian Railways in the 1920s, but only after the rate of technology-related accidents increased considerably, and there was intense pressure to take action. Thus over time, analog signals and telecom systems evolved into electronic signaling and digital communications systems.

The British rulers wanted to project power and control the native Indians while simultaneously extracting revenues from them. They devised the system of different classes of service in the railways, wherein the best available customer service and technologies were provided in the first class coach to the "higher class" British, while relegating the Indians to spartan, often humiliating third class coaches. However, leaders of the Indian independence movement used this to their advantage, by spreading their message to the "captive" audiences in the third class coaches and recruit more supporters in their struggle to gain political power. We see that even at the height of colonial rule and control, native Indians were not completely without agency. At critical junctures, they were able to push back and resist British control. Thus, the railways and the trains became a vehicles of resistance, rather than a vehicle of control.

The second question was: How did the political economy of post-independent India affect the technological development in the railways?

By the time India got independence, the British-built railways was very much in decline. Much of the railway system had been neglected for years after the First World War, and also by the end of the Second World War, when it became apparent that the Indians were going to gain independence. The British no longer had any political or financial incentive to care for the railways. The Indians inherited this massive system, but did not possess some critical technologies, such as locomotive manufacture know-how. This inability was due to British colonial policy, which banned India from manufacturing locomotives, as noted by Shashi Tharoor (Tharoor, 2016), and discussed earlier. Starting immediately after independence, the Indian government slowly began to bring up the railways to acceptable standards. New lines were added, and new services were provided. As the largest employer in India, the railways became a public good in the eyes of the Indians. The performance and well-being of the railways and its passengers became hot political issues. Elections were won and lost on the issues of employment, ticket tariffs, and convenience provided to passengers (Mashru, 2014). Numerous classes of tickets and concessions were introduced depending upon the lobbying power of various interest groups. When the railway management sought to gain control over its voluminous, manual, records, and provide quicker ticketing services to passengers, it realized that massive computerization was

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necessary. However there was much opposition to the introduction of computers, as people feared job losses.

Computers did not come into service in the railways until the 1960s, when they were used mostly for tabulating financial transactions. In the 1980s, with the advent of electronic computers, full-fledged efforts were made to computerize the accounting and financial functions of the Indian Railways.
Over years, as the Indian Railways continued to expand, the volumes of passengers and freight transported by the railways began to rise exponentially. By 2016, India's knowledge of railway technology had surpassed critical levels, and was sought after even by the British. This is a particularly important example of bi-directionality in India-British knowledge transfers.

The third question was: How did the post-liberalization economy affect technological development of the railways?

The services offered to passengers and freight-bookers were not improved until the 1980s, when India started to open up its economy. There were tremendous demands to improve passenger facilities, freight services, and ease of use. These became important political issues in India, as the railways carried almost all of India's people across places, and almost all of India's commercial freight. As a result, serious efforts were undertaken to computerize the passenger reservation system, and then the freight booking and tracking system. These efforts were slow and tedious. There was opposition from the unions who feared job losses. Compromises had to be made. However, computerization was eventually implemented.

Over the years, additional computing systems have been incorporated into the Indian Railways system. In 1986 a new organization, "Center for Railways Information Systems" (CRIS) was created to plan, design, implement and oversee all of the computerized operations of the Indian Railways.
The period from the 1980s to the present have seen further developments in the evolution of ICTs, such as those that incorporate customer relationship management, Web-based reservation systems, Web-based and social-media "apps" such as real-time GPS-based train tracking, apps for fare inquiry and seat availability, real-time food ordering apps, online complaints and suggestions systems, etc., to name a few. Some of the developments exceed those available in advanced economies with respect to their innovative aspects.

It has often been noted by numerous commentators, that when the British left India, they gifted it with a great railway system. This claim has been contested and debated by many historians. While it is true that the British "brought" railways to India, allocating credit should be more nuanced. It can be argued that the British government built the Indian railways purely to serve the interests of British capitalists and British industries. The railways were also used as a tool to project British dominance over Indians and to move troops quickly to quell unrest. When the British left India, India inherited a railway system that had suffered years of neglect, with crumbling infrastructure.
Given that, it can be argued that today the Indian railway system is comparatively healthy. It continues to serve millions of Indians, is safer, continues to improve its customer service and efficiency, and strives to keep up with new technologies. It exists within a deeply entrenched socialist-leaning political

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ideology which considers the railways as a tool for national and economic development. It remains focused on serving the public through subsidies garnered from its freight revenues, which constitute two-thirds of its revenues. Being a monopoly state-owned enterprise serving a core sector, Indian Railways' fortunes are vastly dictated by political needs rather than profitability. This has meant that the system does not operate at optimum levels of efficiency. For large sections of India's vast population, the railways form a lifeline that cannot be replicated by any other entity. It is also a vast employment engine that directly affects the lives of millions of Indians. There are major redundancies and inefficiencies in the number of people employed. To large sections of the people, getting a railway job means that one has achieved success and security in life. There is also undeniable corruption in the ways work contracts are awarded, which affects the health of the entire system. Thus, even though profitability through efficient deployment of resources is desirable, and successive governments have developed plans towards this, that goal remains elusive.

This situation has significantly impacted the amount of capital available to invest on new technologies and modernizing the system. Indeed, in several (off the record) interviews with top management, the author was told that many Indian customers simply cannot bear the costs that would result in modernizing the system (such as introducing high speed, fully air-conditioned, long distance trains).

However, despite these obvious shortcomings, the railways has succeeded in enhancing safety and operational efficiency over the years. Its technical cadre is acknowledged to be world class, and its ICT infrastructure has kept up with new developments in other developed countries. It continues to remain the most important economic lifeline to much of India. And its ICTs continue to evolve, driven by its users, their resistance, and their expectations.

Railways, Technology and Max Weber

While the above discussion tends towards viewing the Indian railway system, and the evolution of technologies from a historical (and post-colonial) perspective, there is arguably at least one other way of looking at the technology evolution in the Indian Railways – as a cultural phenomenon. Sociologist Ann Swidler notes that the sociology of culture contains two basic traditions, that deriving from sociologists Max Weber and another from Emile Durkheim (Swidler, 2005,pp25). We will focus on Max Weber here. Weber's fundamental unit in cultural analysis was always the individual actor. According to Weber, ideas developed and promoted by self-interested actors tend to constrain people by describing the world in a particular way and specifying what they can seek from it. This is akin to the early British rulers such as Lord Dalhousie creating the Indian railway system with a view to achieving their own self-interest, and constraining the Indians by allowing them limited say and participation in the endeavor. But, Weber notes that culture shapes the actions of people, by defining what they want and how they imagine they can get it. Cultural analysis focuses on complex systems of ideas that shape individuals' motives for action. Weber uses the "switchman" metaphor to explain this: "Not ideas, but material and ideal interests, directly govern men's conduct. Yet very frequently the 'world images' that have been created by ideas have, like switchmen, determined the tracks along which action has been pushed by the dynamic of interest (Weber, 2009,pp64)."

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Following Max Weber, it can be argued that while the British aimed to shape the Indians' views and govern them and push them into modes of the subaltern, some "switchmen" arrived to introduce new ideas and change the tracks laid out by the British. The (cultural) switchmen were enlightened leaders like M. K. Gandhi, as well as other leaders of the independence movement. These "switchmen" changed the views of the colonized. While they continued to enthusiastically use the rail system for pilgrimages and other social purposes, they also used trains as vehicles of protest and communication. They resisted and protested for better conditions. Gandhi reviled the dominance of trains, yet constantly used, traveling only in third class, where he and his fellow freedom fighters met and energized Indians all over the sub-continent to the ideals of freedom (Chatterjee, 2017). These "switchmen," thus determined the "tracks" of Indians in ways ("the dynamic of interest") that were not in accordance with the plans of the British, eventually resulting in the end of the British rule in India, while at the same time creating a railway system that is uniquely Indian in identity.

ICTS IN LARGE SOCIO-TECHNICAL SYSTEMS: LESSONS FROM THE INDIAN RAILWAY

Summarizing the above narrative, it becomes clear that the story of ICT adoption, adaptation, and evolution within the Indian Railways system is a story of IT diffusion in a large political economy, albeit one that has been tempered with colonialism. We learn that Dedrick's and Kraemer's model of information technology adoption, development, and evolution explains the Indian Railways case very well. The existing political and economic environment when the British colonized India led to the adoption of certain discriminatory and exploitative technology policies by the colonizers. However, they also led to IT diffusion, which the Indians capitalized on and improved upon after independence with newer technology policies that considered the Indian Railways as a vehicle for national development. Thus, the railways became a symbol of national integration and national development, rather than one of exploitation. The new policies arose from a new national and ethnographic identity, which led to policies for enhancing technology education and developing robust entrepreneurship environments. It can also be seen that newer, more liberal economic policies had to be adopted before the technical education and entrepreneurship to take roots and enhance the overall development of the Indian Railways. The narrative also shows, for the benefit of other emerging economies, that appropriate framing of technology policy is the most important aspect of technology development and diffusion. Policy is however tempered by agency and the economic, political, and social environment of a nation.

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