# "Inertia and Change in Indian Railways' Sleeper Technology: A Multi-Level Perspective"

Dissertation submitted to the Jawaharlal Nehru University
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**MASTER OF PHILOSOPHY**

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## DECLARATION

This is to certify that dissertation entitled **"Inertia and Change in Indian Railways' Sleeper Technology: A Multi-Level Perspective"** submitted by **Mukesh Kumar,** Centre for Studies in Science Policy, School of Social Sciences, Jawaharlal Nehru University, New Delhi – 110067, India, in partial fulfilment of the requirements for the award of the degree of **Master of Philosophy** is his original work and has not been previously submitted for any other Degree of this or any other University.

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## CERTIFICATE

We recommend that this dissertation be placed before the examiners for evaluation.

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# Contents

# Abbreviations

**IR:** Indian Railways

**PSC:** Pre-stressed Concrete

**BIS:** Bureau of Indian Standard

**MLP:** Multi-Level Perspective

**FRI:** Forest Research Institute

**NAI:** National Archive of India

**NPTEL:** National Program on Technology Enhanced Learning

**RDSO:** Research Design and Standard Organization

**CST:** Central Standard Trial

# List of Tables and Figure

Tables



Figure:

# Chapter One

# Introduction

## 1.1. Background and Motivation

Systemic studies on technology have made a big inroad in Science, Technology and Society (STS) scholarship these days (Geels, 2010). Geels (2004) states that these studies have opened up a new strand of study, in which the scope of analysis has been broadened from artifacts to systems and from individual organizations to networks of organizations. Systemic changes are labeled as socio-technical because they do entail not only new technologies, but also changes in markets, user practices, policies and cultural meanings (Geels, 2002). However, the technical transition in socio-technical systems such as energy, transport systems do not come about easily, because existing systems are stabilized by lock-in mechanism that relates to sunk investments, behavioral patterns, vested interests, infrastructure, market structure and regulations (Unruh, 2000). The Multi-Level Perspective (MLP) is a framework for understanding technological change that provides an overall view of multi dimensional complexity of changes in socio-technical systems.

Geels (2002, 2007, 2014) understands technological change as arising from the interplay between multi-dimensional developments at three analytical levels: niches (the development of competing variants), socio-technical regimes (the locus of established practices and associated rules that enable incumbent actors in relation to existing systems), and an exogenous socio-technical landscape. In other words, the argument is that niche-innovations build up internal momentum through performance improvements; changes at the landscape level create pressures on the regime, and destabilization of the regime creates windows of opportunity for the diffusion of niche-innovations. The alignment of these processes enables the emergence of competing variant in the existing technological system where they struggle with the existing regime on multiple dimensions such as economic, political, infrastructural, etc.

Geels (2002, 2004, 2007) argues that the adoption of new technology in a complex technological system is influenced by various technical, economic, and political factors operating at multiple levels. Moreover, the multiple dimensions of a socio-technical system such as product specifications, research programs, policy goals, market rules, and user behavior, operating at the same level, coordinate with each other and define a regime. Though, studies have been conducted using MLP approach in the private sector (Geels, 2004, 2011), scholars not explored the application of MLP in studying the technological change in public sector. Since government directly intervenes in the operations of public sector firms, then it may be problematic to understand the relations between government and public sector firm on the same level as it is often practiced while using MLP approach.

For our study we take up a large public sector organization- Indian Railways (IR). Indian Railways offer various examples where government economic policies influenced the working of Indian Railways. For example, Hurd and Kerr (2012) argue that the Policy of self-sufficiency led to import substitution of railway equipment. New locomotives, coaches were manufactured in large workshops of IR. But this does not mean that IR stopped looking for new technology from the international market. Rather new technology transfer agreements such as for integrated coach factory technology were signed in a manner to facilitate the manufacturing of new technologies in India. It seems that public sector nature of Indian Railways might have influenced the process of technical change in the railway system. To be precise, in this study we want to understand the process of technological change in the monopolistic public sector firm using MLP approach. In this sense, the monopolistic character of IR poses a unique case of technological change where different functions of industry are managed under the single management of the Railway Board.

Unfortunately, very little has been discussed on technological changes happened in Indian Railways. Though there is no dearth of studies on Indian Railways, studies mainly are concerned with its organizational issues, financial modeling, and operational efficiency. In these studies, technology is often understood as an exogenous factor without much discussion on its origin and emergence in Indian Railway network (Saxena, 1991). The objective of this research is to explore the changes in track technology in Indian railways using Multi Level Perspective.

### 1.2. Track Infrastructure of Indian Railways

Indian Railways (IR) plays a significant role in inland freight and passengers transport in India. IR's position in the inland transport is further bolstered by its monopoly on the railway sector (NTDPC, 2013[1]). However, Indian Railways confronting some major issues such as capacity constraints, the conflict between social and commercial objectives, inadequate R&D, technology up gradation, energy conservation, etc. (Rakesh Mohan Committee report, 2001). Though all of these issues are interrelated, this research work explores more on the issues of capacity constraint and technological up gradation of railway tracks.

Since Independence, the share of IR in inland freight transport is declining, from 86% in 1950-51 to 38% in 2004-05 (Indian railways statistics, 2010). The issue of falling freight shares has been discussed in various reports of Planning Commission, Government's white papers on Indian railways. Track capacity augmentation is often cited as the solution to arrest the fall in rail transport shares (Rakesh Mohan committee report, 2001; Planning Commission, 2013[2]). Technically, there are two prominent ways to increase the network capacity. One is by improving the utilization of track infrastructure which can be achieved by increasing the speed and the capacity of the traction system[3]. More examples of this strategy include track electrification, dieselization of traction power, containerizations, etc. However, IR is already utilizing track infrastructure to the extent of 130%, at least on high traffic density routes (White Paper on Indian Railways, 2015[4]). Therefore, it becomes crucial for railways to considering the alternatives for increasing the network capacity.

The other method for increasing the network capacity is increasing the track capacity itself. Various projects were undertaken to increase the track capacity, particularly after Independence. For example, unit gauge project, conceptualized in 1950's, is meant for converting meter gauge

[1] National Transport Development Policy Committee on Railways. (2013) (Vol. 03). Retrieved from http://planningcommission.nic.in/sectors/NTDPC/volume3_p1/railways_v3_p1.pdf on June 30, 2016

[2] Planning commission report on Trends in the growth and development of transport (2013). Retrived from http://planningcommission.nic.in/sectors/NTDPC/volume2_p1/trends_v2_p1.pdf on June 30, 2016.

[3] For example, Block signaling system, which replaced the manual signaling system in 1970's on major routes, allows to run more trains per track km, thus more volume of freight could be transported on a given track (Agarwal, 2007).

[4] Indian Railways Lifeline of the nation - A White paper on Indian Railways (2015) http://www.indianrailways.gov.in/railwayboard/uploads/directorate/finance_budget/Budget_2015-16/White_Paper-_English.pdf accessed on June 30, 2016

tracks into broad gauge tracks[5]. Doubling of existing routes is another such major efforts for increasing the network capacity. In 2006, IR announced another major capacity augmentation by developing dedicated freight corridor connecting all four major cities. Despite these initiatives, in last three decades, capacity augmentation remained disappointing considering the sheer size of railway network (Rakesh Mohan Committee report, 2001; Planning Commission, 2013).

Increasing the track capacity is not only laying new lines or constructing new routes, but it also involves the up gradation of existing track with better technology. Up gradation of track components, which is less capital intensive than installing new routes altogether, remained an important aspect of IR strategy for capacity augmentation (World Bank modernization plans, 1949 to 1982[6]; 83rd track committee report, 2012).

As a matter of practice in Indian railways, track rehabilitation projects are taken as an opportunity to introduce new technology. World Bank drafted successive rehabilitation and modernization plans for Indian railways and suggested various technological changes in track infrastructure. For example, World Bank in its modernization plans, conceived in 1950's and 1960's, suggested for the adoption of Prestressed concrete (PSC) sleepers[7] by replacing wooden and metallic sleepers. However, it took 40 years, since its first mention in the IR Budget speech of 1956 to IR formal announcement in 1996 to accept concretization of tracks as a full-fledged policy, to happen this technological change from wooden sleepers to PSC sleepers[8].

In this study, we focus on track and sleepers because we find IR to continue with wooden sleeper despite many hue and cry wood scarcities, and finally changing to concrete, but never really taking up metallic in any significant manner, at least in main corridors.

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[5] Under project unigauge, share of broad gauge routes increased from 47% to 85% of total track length (http://www.irfca.org/faq/faq-gauge.html accessed on June 30, 2016).

[6] World Bank made 16 loans programs of value $ 1.5 billion to the Indian Railways from 1949 to 1980's. These programs were mostly for purchasing new locomotives, technological up gradation, track renewals, electrification, etc. (Kapur, Lewis, and Webb, 2011)

[7] A concrete sleeper is a type of railway sleeper made out of steel reinforced concrete.

[8] We fixed the period by assuming the first field trials of PSC sleepers in 1956 as starting date and Railways' announcement of track concretization policy as the end of period.

## 1.3. Research Objectives

This research work has the following objectives:

1. To understand how various technological, scientific, economic and political factors that shaped the process of technological change in railway tracks.
2. To understand how different types of rules governing the technological regime are aligned with each other to sustain the dominance of a particular technology in public sector.
3. Analytically distinguishing the operating levels of various factors, which have influenced the technological change in sleeper technology at multiple levels.

## 1.4. Methodology

This research is based on both primary and secondary sources. Extensive literature review, review of many technical reports, policy documents, parliamentary proceedings, railway budgets, archived documents of Indian Railways, forestry journals related with railway tracks have been carried out. For example, review of annual budget speeches of railway ministers, from 1950 to 1990 have been carried out. Also, various websites, blogs, and newspaper reports are also referred.

A field work comprising six semi-structured interviews with engineers, subject experts, and labor union representative at Delhi and Baroda for understanding the issues concerning Indian railway tracks and their views on the modernization of track technology. The data obtained from the fieldwork along with archival data have been analyzed using methods of logical deduction and archival data interpretation techniques.

## 1.5. Limitation of Study

The unavailability of organized official communications notes exchanged among engineers from 1970 to 2000 is a serious limiting factor. Official communications could have helped to understand the engineer's conceptualization of track problems. To an extent we tried to offset this limitation by using technical manuals and reports. Though, Technical reports often are a good source of knowledge about formal regulations surrounding technology, cognitive and normative rules are not discussed in much detail. Finally, time and resources were the other two serious constraints which restrained from carrying out an extensive field survey and interviewing IR engineers and policymakers related to tracking maintenance problems.

### 1.6. Chapter Plans

This research work is divided into six chapters. Chapter one introduces the problem, the motivation for research, research objectives and methodology. This chapter also discusses the limitations of this study.

Chapter two deals with the analytical and theoretical framework that has been employed for carrying out the present research work. In this chapter, we will discuss how some technologies become dominant and how the dominance of a technology develops a host of network externalities, which create inertia for technological changes in the system.

Chapter three is the historical analysis of railway sleeper technology and its origin as an industry. Further, it discusses how wooden sleepers evolved over the period with a special focus on the evolution of technical standards, market structure of wooden sleepers, procurement mechanism and physical infrastructure.  This chapter also traces the technology import of PSC sleepers and their adoption in Indian tracks.

Chapter four engages with the research questions and methods used to answer those question. This chapter also covers the reasons for selecting sleeper technology for a case study.

Chapter five deals with the analysis and interpretation of the historical evolution of different competing variants of sleeper technology. It identifies various factors that influenced technological change in railway sleeper technology. Also, it engages with these factors using the theoretical framework and explores relations among them.

Chapter six concludes and summarizes the various research findings and attempts to give suggestions for further research on technological changes in Indian Railways.

# Chapter Two

# Theoretical and Analytical Overview

## 2.1. Introduction

Hurd and Kerr (2012) consider railways as the primary source from which all modern engineering branches in India emerged. Throughout the history of railways, heavy technology transfer took place from Britain and Europe. After Independence, Railways workshops are credited with significant achievements in indigenization of imported technology. Historians have discussed technological changes in Indian railways but for them, railways as a technology remain a blackbox. In this chapter, we discuss the theoretical and conceptual framework of Multi-level Perspective (MLP) on technological change. MLP approach states that technological change in a system is influenced by various factors; and these factors operate at multiple levels-niche, regime, and landscape level. MLP approach sees complex technological systems as a set of rule (e.g. formal, normative, and cognitive). The stability or strength of a system depends on the coordination of these rules (Geels, 2004). Once a technology stabilizes in the system, many network externalities such as organizational expansion, the growth of physical infrastructure, the codification of technical standards develop. Network externalities associated with a technology generates increasing returns as the user base of that technology grows (Tushman, 1986). However, the coordination of rules is not always perfect rather coordination is often semi-coherent. Lack of coordination among rules creates a kind of misalignment, which creates instability at the regime level. When a "Window of opportunity" opens such as war, climate change, technologies at niche level could benefit from the instability at regime level and may develop a user base in existing technological regime (Geels, 2002).

This chapter is divided into four sections. We present in section 2.2 the brief overview of the major themes in studies of Indian Railways. We define technology in next section 2.3. Then, section 2.4 deals with the theoretical concepts of Multi-level perspective. This section further discusses the factors, which stabilize a technological regime. Next section 2.5 engages with the meaning of technological discontinuities and competencies in a complex technical system.

Section 2.6 accounts an integrative framework on technological change. This section discusses how the rules in a regime improve the performance characteristics of a particular variant over other competing variants. Section 2.7 describes the types of network externalities develop with the expansion of user base of technology. It further explores how network externalities generate increasing returns.

**2.2. Brief Overview of studies in Indian Railways**

Indian Railways have been studied from various dimensions, and a significant volume of literature has been produced. Major themes undertaken by scholars in their writings are the political economy, labor issues, cultural representation, urban development, financial management of IR, and environmental impact. Very brief overview of major themes is discussed here.

*Political Economy:* Thorner (1955) discusses the political economy of railway under colonial period. He argues that railway could have been a better tool for modernization of India. But railway was predominately used for three main purposes: military, social and economic. Extraction of coals, manganese, and iron ore increased. Export of agricultural raw material for industrial use increased. Import of manufactured produced increased and so on. It happened along with a heavy burden of guarantee system[1]. Irfan Habib (2006), understand railways as a tool of exploitation in the hands of the colonial government. He argues that railway, on the one hand, introduced modern engineering practices in India, and on the other hand, it accentuated the process of deindustrialization by facilitating the availability of cheap imported goods in the interior parts of India. The literature on the political economy of Indian railways helps to locate IR in the larger context of socio-political conditions (Kerr, 2004).

*Labor:* Railway workforce was half million in 1905, one million in 1947, and 1.7 million in 1990. There is no room for doubt that Indian Railways introduced modern industrial processes in India and off course modern labor processes with heavy usage of machines in the production. Railway as a battleground for working class movements is well portrayed in literature. Labor

[1] Under the guarantee system, colonial government promised to pay 5% guaranteed returns on the capital investment made by private investors on developing railway infrastructure in India (Bhandari, 2005).

unions and their general strike of 1974 have been discussed in the political context of Indian history (Hurd and Kerr, 2012).

*Health and Environment:* Some studies were carried out focusing on railways, pilgrimage, and cholera. For example, one such study discusses malaria spread in construction camps populated by a strong labor force of 15000 (Kerr, 1995a). These studies exploring public health issues and design of railway tracks attempt to establish the role of railways on public health issues in colonial time.

*Urban Development:* Complicated, often profoundly consequential relationships between the railways and South Asia's urban places have received little direct attention. Hurd and Kerr (2012) write that "*in urban areas, the relationships are intense. The palpable presence of lines and trains in India's cities: lines and trains are immediately abutting dwellings and businesses; lines to be crossed, sometimes hazardously on a daily basis; rights-of-way to be used as toilets areas by slum dwellers; suburban trains that carry the crush of commuters"*. Some writing by geographers and transport specialists touches on the railways and the processes of urbanization (Kerr, 2012). For example, Gumperz (1974) examined City-hinterland Relations in Western India in the 19th century with considerable discussion of the effects of railways. Arora (1985) provides a history of Bombay Suburban Railways, 1853–1985. Mrinal Basu (1999) examined "Railways and Municipalities in Western Bengal".

*Technology Transfer:* All themes we discussed often consider railways as a blackbox and technological changes in railways are exogenous. Railway technology since its inception in 1850' to 1947 has been mostly imported from Europe and USA. Primarily maintenance work was conducted in workshops built in India. Heavy technology transfer took place especially in traction system. Even after independence, technology transfer took place but in a strategic manner to fulfill the goal of self-reliance. One such study carried out by Walker (1987), which involves the ICF (Integrated coach factory) technology transfer from Swiss company to IR explores the many dimensions of successful technology transfers: from the absorptive capacity of the IR, skill levels of the workforce, R&D support, responsible foreign collaborators, and institutional structure. But Railway's workshops, which are now 42 but in colonial time they were 145, remains a black box. And not much has been discussed. Particularly, workshops are the primary source from which all branches of engineering emerged. However, very little is written on the modernization of workshops.

Other themes discussed by scholars are travel writings, history of a line, and crime and policing along the railway routes, social and cultural representation of IR (Hurd & Kerr, 2012). One Book (Nilakant and Ramnarayan, 2009 ) discusses Indian Railways' turnaround (from 2004-08) as the outcome of specific policies adopted that time such as increasing the capacity of the wagons, commercial approach for operations, fostering "positive emotions" by improving site safety conditions. Though the book understands IR from multiple dimensions, systemic perspective of IR is not explored.

During the development in railway technology, various factors such as political, social, economic, technical might have influenced the process of technological change. In this study, we tried to understand the technological change in an integrative technological framework.

### 2.3. Defining Technology

Efforts to define "technology" face at least two difficulties. First, there is a problem to assign technology a general "nature" at all. Any attempt to define technology faces the problem of explaining away the already numerous competing alternatives. Second, there is widely popular but the problematic characterization of technology as applied science or equipment (Scharff & Dusek, 2003, p.208).

Stephen Kline (1985) suggests technology first and foremost as involving both "socio-technical system of manufacturers" and "socio-technical systems of users." He argues that technology is often understood in terms of its product (e.g. artifacts, equipment) and its facilitating knowledge and techniques, but technology is best understood in terms of "purposes" furthered by those socio-technical systems of manufacture and use. The socio-technical system of manufacture denotes all the elements needed to manufacture particular kinds of artifacts. The system includes people, machinery, resources, processes, and legal, economic, political and physical environment (Scharff & Dusek, 2003, p.210). A socio-technical system of use is a system *using a combination of hardware and people to accomplish tasks that human cannot perform unaided by such systems to extend human capacities* (Scharff & Dusek, 2003, p.211). Without a socio-technical system of use, the manufacture of artifacts would have no purpose. Taken together both socio-technical system of manufacture and use, form the physical basis of all human societies past and present (Kline, 1985).

Kline (1985) discusses that pattern of creating hardware in the socio-technical system of manufacture and diffusing the hardware into another socio-technical system in order to use it. For example, we manufacture automobiles and embody them in a system of roads, laws of ownership, rules of the road etc (Scharff & Dusek, 2003, p.211). And, we do this in order to perform tasks which individual human cannot perform without such systems. To perform these tasks, we need information, skills, processes, and procedures necessary for functioning in socio-technical systems of manufacture and use.

In summary, Kline (1985) proposes the definition of technology, which is characterized by following four elements- hardware, the socio-technical system of manufacture, socio-technical system of use, and information, processes, procedures and skills. In order to fulfill the "purpose" of the socio-technical system, these four elements operate in consonance with each other. In the next section, we will discuss how these four elements of a technology align or misalign with each other and create the conditions for "selection" or "rejection" of a particular competing variant of that technology.

## 2.4. Multi-level Perspective (MLP)

Scholars dealing with MLP have been mainly concerned with two broad research agenda, which were- improving the understanding of long-term technological change, and generating and refining the perspectives on tools used in technology analysis. In both research areas multi-level perspective (MLP) has been invoked to enhance the understanding of the complex relationship between technology and society (Genus and Coles, 2008). MLP represents an integration of various strands of evolutionary economics, innovation studies and technology studies. Geels (2004) conceptualize the aggregation of different factors, which affect technological change, at three levels- landscape (macro level), regime (meso level) and niche (micro level). When there opens a "window of opportunity" at landscape levels such as war or climate changes, it challenges the stability of the existing regime. If a competing variant of that technology exists, it may enter into the existing regime and comes into the competition with it and eventually may replace it, and this is a period of flux, restructuring when wider changes (political, infrastructure, user practices, etc.) happen (Geels, 2004).

In MLP approach, the stability of regime plays an important role in explaining the technological transition[2]. If there is instability at regime level, then it is possible that competing variant may get entry into the existing regime. The concept of regime stability has a significant role for our study as it helped to determine the conditions for the emergence of concrete sleeper technology.

Geels (2002, 2004, 2007) define regime as:

"*A technological regime is the rule set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, way of handling relevant artifacts and persons, way of defining problems; all of them embedded in Institutions and Infrastructures"* (Rip and Kemp, 1998, p.340)

Geels (2004) argues that technological regime can be stabilized by aligning different rules. He distinguished three kinds of rules which stabilize the technical systems as cognitive rules, normative rules, and regulative or formal rules.

First, cognitive rules make engineers and designers look into a particular direction and not in others. 'Cognitive capital' such as competencies, skills, and knowledge are 'sunk investments.' Cognitive capital builds upon the existing knowledge base, and its takes much to acquire new knowledge and build competencies. Core capabilities can turn into core rigidities. It is often difficult for organizations and firms to switch or develop competency destroying innovations (Tushman and Anderson, 1986; Christensen, 2006). Cognitive rules are shared belief systems among a social group, which orients the perceptions of the future and hence steer actions in the present. As long as the firms and organization believe that certain problems can be solved within the existing regime, they will not invest in radical innovations and continue along the existing paths and "technical trajectories.'

Second, Geels (2004) discusses normative rules are the mutual role perceptions and expectation of 'proper' behavior across the social and organizational networks. In some relationships, it is

[2] Technological transitions are defined as the major technological changes in the way societal functions are served. Technological transitions includes changes in technology, user practices, regulations, infrastructure, etc (Geels, 2002).

not seen 'proper' to raise certain issues. Normative rules encompass the values, norms, role expectations, authority system, duty and codes of conduct (Scott, 1995).

Third, Geels (2004) discusses regulative and formal rules as established systems, which may be stabilized by legally binding contracts. Walker (2000) describes the case of nuclear technology, about how a particular nuclear reprocessing plant was locked in because of contracts between British nuclear fuels and its foreign customers. In such scenario, contracts are the standards, and treaties can be observed as formal rules. He argues that complex technical systems place an emphasis on the persistence of change along well-defined pathways because of the creation of novelty are bounded by working procedures inherent in that regime, technical constraints, and an institutional barrier for switching from one regime to another. Examples of regulative rule other than legal contracts are technical standards, market regulations.

These three different types of rules proposed by Geels (2004) are analytically distinguished into five different regimes. Table 2.1 tabulates examples of rules in a different regime such as technological/product regime, science regime, policy regime, socio-cultural regime, and user regime. The analytical separation of regime helps us distinguish different kinds of interest groups exist within a socio-technical system, but rules operate across analytical boundaries. For example, technical standards may be categorized analytically in technological/product regime, and at the same time, same technical standards defining a technology also operates in policy regime. In other words, analytical segregation of rules in different regimes is not our main concern; rather how these rules align with each other to stabilize the existing regime is our prime objective. Also, Table 2.1 offers an integrative framework for analyzing the rules operating in a socio-technical regime. This framework is particularly important for our research work, as it provides an opportunity to integrate different views of policymakers, engineers, and forest conservators on sleeper technology.

Geels (2004) argue that stability of a regime depends on the coordination of these rules. Rules do not exist as single autonomous entities. Instead, they are linked together and organized into rule systems. Theoretically, it is similar to social rule system, which regulates and structure social transactions. He understands regime as a semi-coherent set of rules coordinating with each other. The alignment between rules gives regime the stability and strength to coordinate activities in a socio-technical system (Geels, 2004).

**Table 2.1: Examples of rules in different regime**

| | Formal/regulative | Normative | Cognitive |
|---|---|---|---|
| Technological and product regimes (research, development production) | Technical standards, product specifications (e.g. emissions, weight), functional requirements (articulated by customers or marketing departments), accounting rules to establish profitability for R&D projects (Christensen, 1997), expected capital return rate for investments, R&D subsidies. | Companies own sense of itself (what company are we? what business are we in?), authority structures in technical communities or firms, testing procedures. | Search heuristics, routines, exemplars) (Dosi, 1982; Nelson and Winter, 1982), guiding principles (Elzen et al., 1990), expectations (Van Lente, 1993; Van Lente and Rip, 1998), technological guideposts (Sahal, 1985), technical problem agenda, presumptive anomalies (Constant, 1980), problem solving strategies, technical recipes, 'user representations' (Akrich, 1995), interpretative flexibility and technological frame (Bijker, 1995), classifications (Bowker and Star, 2000). |
| Science regimes | Formal research programmes (in research groups, governments), professional boundaries, rules for government subsidies. | Review procedures for publication, norms for citation, academic values and norms (Merton, 1973). | Paradigms (Kuhn, 1962), exemplars, criteria and methods of knowledge production. |
| Policy regimes | Administrative regulations and procedures which structure the legislative process, formal regulations of technology (e.g. safety standards, emission norms), subsidy programs, procurement programs. | Policy goals, interaction patterns between industry and government (e.g. corporatism), institutional commitment to existing systems (Walker, 2000), role perceptions of government. | Ideas about the effectiveness of instruments, guiding principles (e.g. liberalisation), problem-agendas. |
| Socio-cultural regimes (societal groups, media) | Rules which structure the spread of information production of cultural symbols (e.g. media laws). | Cultural values in society or sectors, ways in which users interact with firms (Lundvall, 1988). | Symbolic meanings of technologies, ideas about impacts, cultural categories. |
| Users, markets and distribution networks | Construction of markets through laws and rules (Callon, 1998, 1999; Green, 1992; Spar, 2001); property rights, product quality laws, liability rules, market subsidies, tax credits to users, competition rules, safety requirements. | Interlocking role relationships between users and firms, mutual perceptions and expectations (White, 1981, 1988; Swedberg, 1994). | User practices, user preferences, user competencies, interpretation of functionalities of technologies, beliefs about the efficiency of (free)markets, perceptions of what 'the market' wants (i.e. selection criteria, user preferences). |

Source: Geels (2004)

Stability of existing regime is also important as it helps to define technological niches (micro level). Niches are the location where it is possible to deviate from the rules in the existing regime and niches provide a location for these deviations. It means that rules in technological niches are less articulate and not defined clearly. There may be uncertainty about the technical design, standards, etc. but niches stay close to existing rules with regards to user behavior. As the performance of novelties is initially low, they emerge in "protected spaces" to shield them from the mainstream market selection. Protection is often in the form of subsidies, a strategic investment by firms (Levinthal, 1998).

### 2.5. Innovation and Technological Competency

Various scholars (Tushman 1986, Utterback and Suarez 1975) understand the stability of a technical regime in terms of competencies. They argue that incompetency destroying innovation existing firms have to adapt or face competition by increasing the performance of the existing technology. But in a monopolistic firm, existing organizational structure either suppresses the internal innovation or accepts new technology partially despite higher performance and competent pricing.

Tushman (1986) sees technological discontinuities as either competence-destroying or competence-enhancing, and the former discontinuity render old skills obsolete whereas later is built and nurtured by accumulated knowledge. This ontology of new emergent technologies assumes that producing firms and user group are two distinct identities. New entrants bring new ideas or technologies, which force the incumbent firms either to adopt the new technology or to improve the performance of old technologies to the extent of the newly set benchmark. However, it is difficult to frame IR in Tushman's theory of technological discontinuities. Since IR virtually has a monopoly over railway industry in India; producers of new technology, as well as the user of that technology, co-exist in the same organizational structure however loosely defined. When producers and users happen to be in the same organization, then it might be possible that introduction of new technology exhibit both competency destroying and enhancing tendencies in different domains of its production and use. We will examine this hypothesis in chapter 5.

Tushman (1986) argues that selection environment is shaped by legal, political, and technological factors and interplay between them. While other socio-economic institutions affect the evolution of an organization, technology has been argued to be a major force which defines the evolution path of the environment and ultimately organization (Tushman, 1986). As we discussed major technological shifts are either competency destroying of competency enhancing. The former requires new skills, knowledge and operational practices and alter the set of relevant competencies within a product or process class. Tushman (1986) also argues that competence-enhancing innovations are built on old knowledge and skills, having significant improvement in price or performance. Old skills are not rendered obsolete rather contribute towards the dominance of new technology. The dominance of technology is a function of market, legal, political and social factors, which could be studied only in retrospect. For instance, the technological shift from steam engines to diesel engines demand new technical and engineering skills, which are qualitatively different from those necessary to manufacture and operate steam engines. Competence-destroying discontinuities either substitute an existing product (e.g. steam engine substituted by a diesel engine) or creates new product altogether (e.g. automobiles) (Noble, 1984). These discontinuities are fundamentally different from the previous dominant technology in terms of skills and knowledge required to manufacture and operate the new products. The introduction to the new skills and competencies alter the control and power mechanism in an organization (Chandler, 1977).

### 2.6. Technological dominance: an integrative framework

The emergence of dominant technological trajectory among several competing ones has multiple facets and scholars have conceptualized it in varied ways. The labels used by the scholars to conceptualize the emergence of niche technologies in a technological system are: "Dominant design" (Utterback and Abernathy, 1975; Anderson and Tushman, 1990; Utterback and Suarez, 1993), "technological trajectories" (Dosi, 1982), "standards" in network industries (Katz and Shapiro, 1985; David and Greenstein, 1990), "technology cycles and organizations" (Tushman and Murmann, 1998); Murmann and Franken, 2006). Scholars put most efforts on identifying the factors, which affects the emergence of a dominant design, such as firm resources, technological performance, institutional roles, etc. (Suarez and Utterback 1995; Schilling, 1998; Scherer, 1992). In addition, few studies attempted to develop an integrative framework, by incorporating environmental factors and firm-specific indicators, to explain the process of dominance (Suarez, 2003; Murmann and Frenken, 2006). However, these studies including technology-specific case studies and integrative frameworks are based on the dynamics of industry where independent firms compete. New entrants with new technology enter the market and then start the period of ferment when alternative technologies battle for dominance. However, these frameworks remain silent on the source and origin of new technology. In other words, the focus of research remained on explaining the process of dominance mainly. But what set the platform for the emergence of new technologies, are not touched upon in details by scholars.

A technology broadly defined as a set of pieces of knowledge, some of which are embodied in physical devices and equipment-become dominant as the result of a complex process by which several competing alternatives and versions are de-selected until a preferred technological hierarchy becomes evident; a particular design then emerges (Clark, 1985). Indeed, the whole concept of technological dominance is borrowed from the sociology of science and technology, which purported that science and technology evolve through periods of incremental changes and punctuated by the paradigm shifts (Unruh, 2000).

Scholars dealing with technological change have highlighted that in the early stages of technology's history, some variants compete with other (Utterback 1994). In the early history of automobiles, three competing technologies emerged-internal combustion engines, steam engines, and battery driven automobiles. Among these variants, internal combustion engine came to dominate, and the other two possibilities were negated. One explanation is that internal combustion engines were superiors and were selected. In their explanation, potentially superior technology requires some development before it could establish itself as superior technology. During this development phase, a lot of organizational and technical learning happens. However, in some cases, technology fails to manifest its superiority and get rejected at a later stage. But, according to Dosi 1982, mostly better technology will win.

Arthur (1989) and David (1985) propose another explanation for the selection of a particular technology among multiple variants. According to them, it is not necessary to be superior in order to emerge as dominant technology. In their models, increasing returns are set in motion once a particular technology is employed. The greater the technology is in use, the more its attractiveness relative to its competitors and this starts a rolling snowball mechanism.

Since technological change happens at multiple levels, evolutionary theories are better equipped to conceptualize this change. One such theory by Nelson (1995) on dominant design formulate the basic building block for the establishment of the technological system. Nelson's theory begins when inventions and innovations create several variants of technical solutions to fulfill the demand of a certain social group (Abernathy and Utterback, 1978). A period of uncertainty arises when variants compete, ensures for performance improvement and market share (Anderson and Tushman, 1990). The competition ends when one particular technology captures a critical mass and becomes the de-facto standards of the industry. Once a particular design gets ascendency, a shift occurs from product innovations to incremental process improvements (Ayers, 1991). In pure economics argument, choices are made by optimizing agents under the conditions of a perfect market. It is presumed that optimizing agents select superior technology with better performance. However, this approach could not explain the selection of inferior technology, regarding performance (Arthur, 1989). Unruh (2000) argues that increasing returns associated with technology with its development and commercialization accelerates improvements compared to competing variants. Increasing returns are more explicit during the competition period when favorable historical circumstances could give a fillip one technology over others, which can lead to market domination (Arthur, 1994). Many empirical studies focused on increasing returns such as the QWERTY keyboards, light water reactors, VHS technology (David 1985; Cowan, 1990).

We identified three causal mechanisms to explain why a particular design emerges as the dominant design rather than other ones in the competition. They can be classified into three types- scale economies, technological compromise, and Network externalities. In the following section, we will explain these three types of causal mechanism.

**Scale economies** is an economic logic, which states that unit production cost declined as fixed cost are spread over increasing production volume (Case and Ray, 2006). It is one of the most straightforward explanations put for explaining the emergence of dominant design. Economies of scale that can be realized with the standardized product. Based on this logic, the design, which acquires an initial lead among the competing variants, will emerge as the dominant design. Murmann and Frenken (2006) argue it as a consequence of first mover advantage. Kelpper (2002) emphasizes more on learning to do rather than on scale economy, which explains why often experienced firm survive a shakeout than do less experienced entrants.

Following are the examples, which show that scale economies are not always available for firms. Christensen and Greene (1976) discuss the case of economies of scale in USA electric power generation. They analyzed the data of electricity generation firms in the USA from 1955 to 1970 and causes for the decline in the average cost of production. They found that in 1955, economies of scale was available to nearly all the electricity generating firms, however, by 1970's most firms in the business exhausted the scale economies. The explanation for this finding is that the firm's size requires exhausting the scale economies increased by only 60% whereas the output per firm tripled. They concluded that the decrease in unit cost of electricity production, for the period under study, could not be attributed to the economies of scale. In fact, there is very little correlation exists between economies of scale and decrease in production cost in that period.

Christensen et. al (1998) argue that dominant design becomes dominant because it represents the best **technological compromise** among the different functional characteristics of the technology. Here, elements of dominant design that are most salient to the firm are architectural in nature. They are the concepts that define how the components within the product interact or relate to one another. In this explanation dominant design is a cause that settles that debate among designers and further R&D is guided by the framework set around dominant design. For example, in the case of Disk drive industry (Christensen et al., 1998), the dominant design of disk drive was defined by certain architectural concepts, which came to be used by all surviving firms engaged in manufacturing. Within this architecture framework, component level innovation continued at a fast pace and some of these components became standardized as well. Thus they concluded that the most salient feature of the dominant design is that how different components within the product interact and relate to each other.

### 2.7. Network Externalities

Network externalities are identified as an important driver for the emergence of the dominant design. Network externalities define a condition where the selection of a technology depends on the number of users who are using the technology (Unruh, 2000). The condition of technological lock-in, which occurs at firm level as well as industry level, arises from the systemic interaction among technologies, infrastructure, interdependent industries, and user. As physical infrastructure and informational networks grow, they become more valuable for the users. These increasing value for users are defined as positive externalities.

There are many products for which the utility derives increases with the increase in the number of consumers. Kartz and Shapiro (1985), identifies three possible sources of positive consumption externalities. First, the externalities may be generated through the direct physical effect of the number of consumers on the utility of the product. For example, the utility that a consumer derives from a telephone depends on the numbers of other agents are using the telephone networks. Second, there may be indirect effects that arise from the consumption externalities. For instance, a consumer buying a computer will be concerned with the number of other agents buying similar hardware because the amount and variety of software supplied will depend on the number of hardware units sold. Third, positive external externalities occur for durable goods when the postpurchase service depends on the size and experience of the network, which in turn may depend on the number of units of goods sold. In the USA automobile market, the sales of foreign manufacturers initially were retarded due to the less experience and less dense network of after sale services. If a particular model of automobile requires customized parts or specialized service skills, then the buyer of the model will find a less dense network of repair service. This smaller network will reduce the initial willingness of the consumer to pay for the model.

In interdependent technical systems, network externalities are multiplied among the many subsystems, which grows in tandem with the primary network (Frankel, 1955). Frankel argues that as an industry grows to increasingly complex production methods, interconnections develop among its technological components such as among machines, plant, transport, raw material, etc. Interconnections among technological components make it difficult to introduce the new and cost-saving technology in the system.

Tushman and Anderson (1986) propose two cost categories associated with the replacement of old techniques with the new one: sunk cost and future outlays. Sunk costs are expenditure already made, which are allocable to future production period and which must be recovered from future revenues. Future outlays include outlays for replacement of technology. The new firm will utilize the latest, cheapest method when it starts its operations and when it expands. If firm's profit fall short of an excess of revenue over future costs for the older technique, will be one which replacement criteria deny to the older firm until it must replace its equipment. Further, he argues that a new technology will be introduced sooner in a competitive than a monopolized industry. In the former, entry of new firm or expansion of old firms will lead to the introduction of new technology irrespective of how slight the cost saving. But in the monopolized industry, there will be little tendency to change until the old equipment are worn out (Unruh, 2000; Arrow, 1961).

If a new machine is developed, then two possibilities arise, either the new machine will replace the old one immediately, or the old machine will continue to be used until it exhausted its service life, then there will be a delay in a replacement until the existing plant wears out. However, probably the durability of each of these machines in the production process will differ. If a new machine is not compatible with the rest of the production system, the replacement of a worn out component of the old plant with the new component would require the discarding of those components which are still serviceable. Unless all the components are worn out simultaneously at a later stage, the cycle would repeat itself and modernization would be indefinitely postponed.

Unruh (2000) argues Networks effect manifests by the creation of industry and inter-industry forces of coordination such as establishing standards and developing design specific supply networks. The growth of interconnected industry network requires a high degree of coordination that can be achieved through codified conventions and standards. Examples of codified conventions and standards include 110/220 V power supply[3], octane standards[4], etc. These standards reduce the uncertainties that can hinder the investment and tends institutionally to lock in key characteristics of the dominant design. Dominant designs are often the strategic sources for creating the lock in conditions because the new technology requires new standards and elimination of existing standards, which were set around dominant design. However, changing the existing standards require inter-industry coordination. Those firms which are uncertain about the preferences and potential responses of the other firms may not invest in the new technology. Unless firms are confident that new technology will become dominant design, it may be judged risky to invest in new technology. Same network effects which inhibit new technology apply to all the firms bounded by the industry standards. A firm will face barriers or "excess inertia" to new technology if it requires new standards to operate in the system.

[3] Electricity is transmitted and distributed at a particular voltage. For example, in India households are supplied electricity at 220 V, which is also a standard for electric home appliance.
[4] Octane number is a numeric figure indicating the anti-knock properties of a fuel.

The way complex technological systems are financed can also create conditions for technological lock-in. From 1952 to 1995, for example, the 90% of the investment capital in the USA funded by companies internal cash or retained earnings. Profitable firms generating their investment, capital tended to invest in the dominant design based core competencies (Unruh, 2000). This continued re-investment of profits in dominant design creates a self-reinforcing positive feedback mechanism, which locks in the existing technological solutions.

It is often thought that design initially gaining the lead in the market will often become the dominant design because of above-discussed self-reinforcing forces (Murmann and Frenk 2006). However, some scholars (Leibowitz and Margolis, 1995) counter this view by emphasizing firm level strategic maneuvering as the major reason for the emergence of the dominant design. These strategies include coalitions, R&D collaborations, pricing and licensing. In his history of video cassettes recorder (VCR), Arthur (1990) argues that the history of VCR represents a simple example of positive feedback. It deals with the diffusion and standardization rivalry between two similar but incompatible formats for VCR- Betamax and VHS( Video home system). The Betamax introduced by the Sony Corporation in 1975 and VHS was introduced by Japan Victor (JVC) in 1976. Both products were introduced around the same time and captured roughly equal market shares. Those shares fluctuated early because of external circumstances, "luck", and corporate maneuvering; increasing returns on early gains eventually tilted the competition in favor of VHS. Furthermore, if the technical performance of Betamax was better compared to the performance of VHS, then the market choose the inferior model. Leibowitz et al. (1995) reexamined the case study and concluded that the dominance of VHS resulted from the random association of VHS with a more aggressive licensing and pricing strategy, and adopter's foresight played a crucial role in the dominance of VHS. The ability of VHS to attract partners such as Hitachi indicates the market participants' ability to recognize the large potential gains from promoting superior standards. Consumers could identify a preferred standard and predict that an adequate number of others would do the same. Thus, according to Leibowitz etc al (1995), there is no evidence that the market choice was due to blunders, unlucky promotional choices, or insufficient investment of the beta format.

### 2.8. Summary

In this chapter we took a brief overview of studies on Indian Railways. Various themes-political economy, urban studies, operation management, technology transfer- are discussed briefly. We took an exception to these studies and understand IR as a socio-technical system of user and manufacture. Subsequently, we discuss the analytical representation of a socio-technical system by segregating regime level into product, science, policy, culture, and user regimes. Thereafter, the question of dominant technology in a system is discussed and how network externalities associated with increasing returns strengthen the dominance of that technology.

# Chapter Three

# Railway Sleeper Technology in India: An Overview of Its Origin, Growth, and Technological Development

## 3.1. Introduction

In the previous chapter we discussed that a complex technical system is itself made up of various distinct technologies categorized in terms of function, compatibility, organization, technical performance, standards, R&D efforts, environmental concerns, etc. For a particular function in the technical system, sometimes multiple technical choices are available; while at times only one choice is available there. Available technical choices compete within the historical context of their development. Many factors such as availability of raw material, competitive environment, physical environment, ownership patterns (public, private, and monopoly), and technological capabilities influence the growth and development of technology. These conditions set the context for the early adoption or rejection of a particular variant. If multiple variants of technology are in competition, then technical performance may play a significant role in the selection of a particular variant. However, it is also perfectly possible that initially, only one technological solution is available. Therefore no question of comparative technical performance arises. The literature review further suggests that the once a particular variant gets a first mover advantage, it starts exhibiting increasing returns associated with network externalities (Tushman, 1986). These increasing returns further favor a particular variant, thus creates the conditions for the dominance of that variant. The historical context plays a significant role in the adoption or rejection of a particular variant in the early period of fermentation when no technology is clearly emerging as the dominant technology (Unruh, 2000). The objective of this chapter is to explore the context in which multiple variants of sleeper technology grew and developed.

Further, literature on technology studies delineates the conditions of a dominant design on the basis of market share. As we have discussed in Chapter 2 that design is considered dominant once it acquires more than 50% of the total user base (Tushman, 1986). This chapter will discuss the types and sizes of user base each variant of sleeper technology enjoyed over a period in India.

In the previous chapter, we have discussed the definition of technology (proposed by Kline, 1985), which sees “hardware” or artifacts as one of its basic element. Therefore, we discuss in section 3.2 the technical function and engineering fundamentals of sleepers in the track system. Section 3.3 discusses the historical overview of wooden sleeper technology and its relationship with Forest Department. This section also covers the problems associated with the sustained use of wooden sleeper in Indian tracks. Thereby the sections 3.4, 3.5, and 3.6, give a detailed description of the IR’s responses in the wake of problems emerging with the wooden sleepers. We present the debate, in section 3.7, surrounding the import of PSC (Prestressed concrete) sleeper technology. Then in section 3.8 we discuss the very brief description of a composite sleeper.

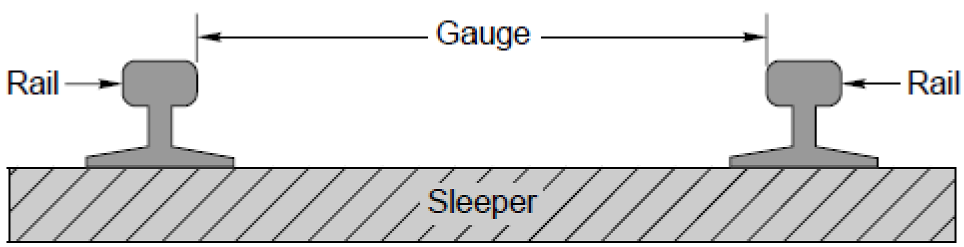
### 3.2. Fundamentals of railway track engineering

Railway track is a fixed structure consisting of two parallel lines of iron rails tied up with cross sleepers with necessary fittings and a fastening mechanism to provide a guided path for traction system. There are two fundamental elements in the design of any type of railway track system. First, reducing the friction between wheel and road and second, guiding the movement of traction system. Railway track system was first introduced in the middle of 18$^{th}$ century in Britain using the stone slabs and wooden beams, particularly in mines. However, later stone slabs were replaced with wooden sleepers and wooden beams were substituted by cast iron rails. Stephenson’s moving steam engine ran first time on cast iron rails with wooden sleepers as cross ties. Though, modern track structure are capable of carrying transports of heavy loads with increased speeds, but still, the basic structure remained the same since it first came into existence in India (Mundrey, 2010).

The engineering of railway tracks constitutes following components: earth embankment (base), rails, sleepers, ballast, and fastenings (fig 3.1). Figure 3.1 depicts the architectural arrangement of iron rails and sleepers in a track system. Two iron rails are held at the opposite ends of the sleeper, and the distance between two rails is known as a gauge. For instance, in broad gauge line the distance between two iron rails is 5 ft 6 inches and in meter gauge, this distance reduces to 3 ft 3 inches. Gauge value plays an important role in the design of railway sleepers. For example, broad gauge lines need high strength sleepers whereas meter gauge sleepers owing to less traffic can be operated with non durable sleepers also.

Technological changes in railway track technology primarily revolved around two major problems: first how to increase the capacity (measured in terms of gross metric tons-GMT) and second regarding improving the reliability of the track system (measured by failure rate[1] of components and track utilization ratio[2]). However, technological changes in track technology are not the only way to increase the GMT, there are other methods too. For example, by reducing the number of crossing, reducing the block length in signaling, etc. can increase the carrying capacity of the track. Though there are methods for altering the capacity of a track other than conventional methods of strengthening track structure, these methods were largely introduced after 1970's when new signaling technologies came up using electric communications (Agarwal, 2007).

**Figure 3.1 – Track structure**




Source: Agarwal 2007, p.31

Technically, track strength could be augmented either by introducing new construction material or improving the design and quality of the existing construction materials. For instance, in the case of rails, the material remained the same that is cast iron, since the inception of railway technology, at least in India. The main technical changes in rails pertained to the improvement in the design and quality. The first design of iron rails had dumb-bell shape[3], then moved to bull

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[1] Failure rate is the frequency with which an engineered system or component fails, expressed in failures per unit of time.

[2] Track utilization ratio is defined as the ratio between demand for railway services and available track capacity (http://www.wctrs-society.com/wp/wp-content/uploads/abstracts/rio/selected/1358.pdf accessed on July 18, 2016).

[3] Dumb bell shape iron rail profile (Chandra and Agarwal, 2007, p. 82)

head shape[4], then changed to flat bottom rails[5]. Parallel to this design change, the weight of the rails has increased in proportion to increase in axle load[6] of traction system. Earlier the weight of the rails was in the range of 12 kilograms per meter; it increased progressively to 52 kg/meter. After Independence, section weight[7] of a rail was standardized, in high traffic density routes, at 60 kg/meter (M M Agarwal, 2007, p.84).

Technical changes in sleeper technology happened not only in design and quality concerns of the existing construction material but also introduced radically different construction materials. Three different categories of materials-wood, metal, concrete- are used for making sleepers. Railway tracks in Europe first used wooden sleeper for laying tracks and keep using it till 1950's. Various factors such as easy accessibility of quality timber, good physical properties of wood and absence of alternative construction material, prompted railways in Europe to adopt wood as the de facto material for sleepers. This design of track based on the wood as a construction material was also introduced in India, despite knowing that wood rapidly decays in tropical countries (Parkin, 1836). The search for alternative material led to the development of

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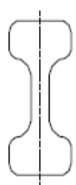
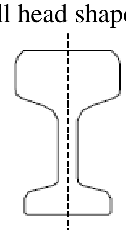
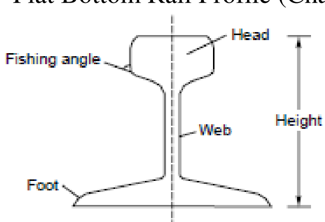


[4] Bull head shape iron rail profile (Chandra and Agarwal, 2007, p.82)



[5] Flat Bottom Rail Profile (Chandra and Agarwal, 2007, p.82)




[6] The axle load of a wheeled vehicle is the total weight felt by the roadway for all wheels connected to a given axle. Viewed another way, it is the fraction of total vehicle weight resting on a given axle. Axle load is an important design consideration in the engineering of roadways and railways, as both are designed to tolerate a maximum weight-per-axle (axle load); exceeding the maximum rated axle load will cause damage to the roadway or rail tracks (https://en.wikipedia.org/wiki/Axle_load accessed on June 18, 2016)

[7] Section weight is defined as the weight of a unit length of iron rail. It is usually measured in terms of kg/meter.

metallic and concrete sleepers. However, a concrete sleeper could not gain serious consideration until the start of World War II. Metallic sleepers, because of high strength of iron, soon gained the ascendancy as an alternative construction material. Metallic sleepers, however, were subject to the problem of metal rusting, which made it impossible to use those sleepers in the coastal area due to high moisture content in the air[8]. So, technically, metallic sleepers have serious technical limitation due to rusting problems. In addition to this, metallic sleepers have poor vibration absorption capacity. Combining poor capacity to absorb vibration and susceptible to rusting increased the consumption and maintenance frequency to a great extent, which limited its absorption[9]. However, many new designs were tested and tried but failed to offset the weakness of a metallic sleeper. The consideration of metallic sleeper or in other words, the incompatibility of metallic sleepers manifested completely when modern electric signaling was invented. Since metal is a good conductor of electricity, a metallic sleeper could not insulate the track, which is a must for implementing electric signaling methods. These inherent deficiencies of metal distanced engineers from the use of metallic sleeper as a substitute for a wooden sleeper (M M Agarwal, 2007).

### 3.3. Origin of the timber "scarcity."

Expansion of railway infrastructure in the second half of the nineteenth century disturbed the ecological equilibrium to a great extent in India (Guha, 1983). One reason for this disturbance was the wood requirements of the private and state-owned railways in the British controlled Punjab region. Till 1860's railways were mostly in construction phase, therefore, timber was required primarily for manufacturing wooden sleepers only. But as soon as railways commenced

[8]**Heaviest rusting take place between rail and sleeper when both components are of iron** ; the acid water being introduced by capillary attraction, forms layers of rust which by continual accretion attains a thickness of 0.39 to 0.59 inch. Wooden sleepers, on the other hand, protect the iron on account of their low conductivity, which prevents the precipitation of the acid gases (https://archive.org/stream/gri_33125001413166/gri_33125001413166_djvu.txt accessed on June 18, 2016)

[9] North-Western Railways of India laid 300 miles of railway tracks in 1896 in the Sindh Sagar District using metallic sleeper. One stretch of the rail line run in the dry land of the district and other section run between the salt range and right bank of Jhelum, which for months every year remained expose to inundation. In second portion, sleepers weighing 148 lbs each in 1886 averaged only 87 Lbs in 1890, or a loss of 41 weight in four years. Metallic sleeper could not withstand the deteriorating effects of saline moisture in the air. Wooden sleepers were then substituted for steel sleepers. Later, authorities decided not to use metallic sleeper in those areas where moisture content is high. It has been considered that steel sleepers should not be adopted in brackish soil and within 10 miles of coastal area (John Newman, 1896, p.67 https://archive.org/stream/gri_33125001413166/gri_33125001413166_djvu.txt accessed on June 18, 2016)

their operations in Punjab region, timber demand patterns changed to a great extent. In the early years of railways operations, wood was used as a fuel to compensate for the limited supply of coal. Imported coal from Britain was four times the price of fuelwood, thus was prohibitively expensive. The only nearby coal in Salt Lake range was not only less in quantity but also was low in quality. The total demand for fuelwood could be estimated from the fact that the regular operations of one-mile tracks in 1870's needed 20-acre timber plantations. As new lines from Delhi to Multan were planned, total demand for wood was expected to grow. In British Punjab alone, total track mileage grew from nothing in 1860's to 1824 miles in 1884, adding the total requirement of 37680-acre timber plantation. (Pallavi Das, 2013)

Initially, measures were taken to increase the supply of timber by designating an officer especially for maximizing the supply from forest areas. Potential supply areas were identified and protected exclusively for railway use. Considering the mounting demand for fuel wood, which could hurt the future investment in railway infrastructure, British government undertook timber plantation itself. As Guha (1983) rightly argues that Colonial government intended to 'exploit' the forest not to 'conserve' them. Plantation activities in the Punjab region promoted British government to create Imperial Forest Department for promoting scientific forestry (Rodger, 1925). Under the scientific forestry, thousands of acres area was declared protected for timber plantation, considering the average yielding time (15-20 years) in the arid region of Punjab. However, in the second half of 1880's, private railway companies connected the eastern coal field with the northern plains, which eventually reduced the demand for fuel wood. After, 1890's railways needed timber mainly for sleepers. In 1870's in British Punjab, 50% of annual timber consumption by railway was for fueling steam engines (Pallavi Das, 2013).

As the process of colonialism advanced, natural resources came to be increasingly commoditized. Some timber species such as Indian Teak were highly valuable, notably at times of conflict, such as the Napoleonic war, and facilitated maritime expansion (Gadgil and Guha, 1992). The most notable resource-intensive use of timber undertaken by colonial government was for the construction of Indian Railways system. In the fifty years between 1860 and 1910, railway track length increased from 1349 kilometers to 51658 kilometers (Bhandari, 2005). One mile of track required approximately 860 sleepers, which had an expected lifespan of approximately 12-14 years. In 1870's, it was calculated that Railways needed one million sleepers every year. Indian species of durable timber, particularly Sal, Deodar, and Teak were most preferred as sleepers, for their perceived strength over other Indian timbers, so it was these three species that were intensively exploited. Much of Sal was exploited from the forests of Jungle Mahal in West Bengal and Bihar for the construction of Bengal-Nagpur railways in 1898 (Poffenberger, 1995). While Sal was initially found to occur in abundance near the sites of railway construction in Indian Peninsular, its overharvesting necessitated procuring other species, notably deodar from the forests of the northwest Himalaya (Gadgil and Guha, 1992). The timber demand for railway expansion was seen to intensify timber extraction much further afield, while also stimulated and facilitated commercial demand. In some Zamindaries, such as Midnapore in West Bengal, timber merchants rushed to purchase and lease large tracts of forest lands, reflecting the increasing values of forests (Poffenberger, 1995). Later, these methods of scientific forestry became a well established institution. Even these methods of cultivation for fulfilling railway’s need remained functional at least till 1970’s (Sharma, 1972)

As we discussed, railways since their inception were closely interrelated with the introduction of scientific forestry for commercial exploitation of timber resources. However, the nature of timber demand shifted its focus from fuel wood to durable species of timber needed for manufacturing wooden sleepers. Within the first two decades of railways’ operations, concerned engineers started to raise the issue of “timber scarcity”. This perceived scarcity of timber has two important characteristics. First is that the scarcity was for durable timber of sleeper quality only. Timber for other purposes in Indian railways, which was the major user of timber resources that time, was quite abundant. Second, the notion of scarcity was raised in a relative term. For example, in the early years of railways’ development, often wood for fuel and track construction was taken from the nearby forests of the proposed lines. Massive use of wood fuel by railways exhausted the nearby forest to a great extent. Owing to the growing needs of railways, forest department was forced to explore deep in the forest for securing timber supply (Pallavi Das, 2013). The whole notion of timber scarcity gained moment with the concerns that timber sources are moving deep from forest in plain areas to the forest in Himalayan range and problems associated with the deep forest explorations.

As the theory (Katz and Shaprio, 1985) argues that once a technology gets initial leads to its competitors, network externalities in the form of the user base and physical infrastructure grow at a pace faster than the growth of network externalities of other competing variants. Since wooden sleeper were the only technical options available to Indian Railways for the first 50 years of its operation, wooden sleeper had an initial lead, which eventually led to the growth of infrastructure such as R&D facilities for wooden sleepers, transport infrastructure in difficult terrain, etc. For example, Metallic sleepers were introduced in 1870's, twenty years after the first use of wooden sleeper, but R&D of metallic sleepers could not be undertaken by IR till the 1920's; whereas Forest department started to build R&D infrastructure focusing on wooden sleepers by the end of 19th century.

Forest department in conjunction with railways responded to the condition of timber scarcity by adopting three-fold approaches-expansion of forest geography, increasing the service life of wooden sleepers, and building a procurement mechanism, coordinating production and distribution of wooden sleepers in India.

Two chief railway gauges in British India and Burma were the broad gauge (5"ft-6'in) and meter gauge (3"ft-3'in) with total track miles of 30,000 miles and 20,000 miles respectively, in 1920's. In a broad gauge track, roughly half sleepers were of wooden and half metal. The following table 3.1 gives the position of sleeper use in Indian tracks in 1928-29 and 1929-30 (Marriott, 1928).

**Table 3.1- Category wise sleeper use in Broad Gauge and Meter Gauge tracks**

| | *Wood.* | *Cast Iron.* | *Steel.* | *Other Material (Concrete, etc.).* |
|---|---|---|---|---|
| | | *Broad Gauge* (5*ft.* 6*in.*). | | |
| 1928-29 .. .. | 45.8 | 38.7 | 15.1 | 0.4 |
| 1929.30 .. .. | 44.2 | 38.6 | 16.8 | 0.4 |
| | | *Metre Gauge* (3*ft.* 3⅜*in.*). | | |
| 1928-29 .. .. | 74.5 | 6.7 | 18.6 | 0.2 |
| 1929-30 .. .. | 73.3 | 6.5 | 20.0 | 0.2 |

Source: Empire forestry journal, 1930

As Table 3.1 shows the use of wooden sleeper is more prevalent in meter gauge while Broad gauge is laid with a metallic[10] and wooden sleeper in almost equal proportion. It also reflects that

[10] Here metallic sleepers include both cast iron sleepers and steel sleepers.

use of concrete sleepers was almost absent in India in 1920's. Since, in America and Britain, wood was relatively cheap and working conditions for sleepers were not as severe as were in India, wooden sleeper gained ascendency. It is worth noting that best of American sleepers could not survive in Indian conditions for more than two years whereas Indian species such as Sal, Deodar were delivering sleepers of 8-12 years service life. Some specific quality of sleepers could work in Indian climatic conditions without any treatment (Marriott, 1928). It was the prime reason that seasoning and preservation technologies for sleepers became a key concern in India unlike in America where most of the sleepers were untreated. In India, where the ground conditions for sleeper use are far more severe, owing to sudden changes from extreme dryness to extreme humidity and ravage of white ants, experiments with various types of cast iron and steel sleepers have been going on since 1870's (IRFC[11]). In reply to a question asked in the Legislative Assembly at Delhi in 1930, it was announced that a policy of keeping the three variants of sleeper technology-wooden, cast iron, and steel- in competition would be pursued in the best interests of railways, with price as the governing factor. It was also stressed, however, that no matter how favorably the price of one kind of sleeper may compare with another, changes in any direction must in practice be very gradual. The major portion of the annual supply of sleepers was devoted to the renewals works, as distinct from replacements of one kind of sleeper by another kind. The life of best quality wood is generally less than half that of metal. As different kind of sleepers can never be mixed in a track, the demand for wood for renewals remained fairly constant. The extensive conversion was chiefly undertaken along with relaying on heavier rails, and every time it is decided to convert 100 miles-sleepers cost around one-third of the total conversion cost. The cost of best durable timber such as Sal sleeper in 1930 was around Rs 8, which is approximately the cost of works of the cheapest type of cast iron sleeper in India. Further by the 1930s, India started to manufacture steel and cast iron sleepers indigenously and no longer were dependent on imported one.

### 3.4. Expansion of forest geography

Imperial forest department strived in two dimensions for managing the demand of wooden sleepers. One is identifying the plants varieties, which could be used for sleeper productions, and other is improving the service life of timber by using preservation techniques.

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[11] Indian Railway Fan Club Association http://www.irfca.org/ accessed on June 30, 2016.

In the Proceedings of Journal of Royal Society of Arts (Pearson, 1917), forest wood was classified into three types based on their use-value. For example, Hardwood for the production of valuable products such as wooden sleeper and construction materials, pulp wood for the production of paper pulp, and others for use in distillation process producing wood charcoal.

Colonial government of Punjab and India opened forest areas as a source of raw material for the development of railways. Since wooden sleepers were made of hard wood, hard wood related activities became one of the major focus areas of Forest Department. However, some business person feared that railways in India would soon replace the wooden sleepers with the newly designed concrete sleepers. The reason for their fear was an order placed by a railway company in India to get the supply of 750,000 concrete sleepers before WWI, and only the war had prevented it's being carried out. After this failed attempt, concrete sleepers were never tried till 1950's (Pearson, 1917).

The first phase of agenda focused on the identification of the geographical and physical characteristics of timber species in India. Forest Department in 1925 published a detailed list (Table 3.1) classifying timber on the basis of natural durability. During the first phase of research, FRI graded 8 species of durable timber and 17 species of non-durable timber, which could be treated for use in railways. Table 3.1 reflects that forests producing timber for sleepers were mainly concentrated into few geographical areas such as Burma, Bengal, Assam and Lower Himalayas. In addition to this classification of the forest was based on the natural durability of timber rather than on the natural mechanical strength of the timber. Since, the natural durability of timber, which is often measured in terms of longevity when exposed to ground conditions, is not sufficient criteria to determine the suitability of timber for use in railway tracks. A more comprehensive method, which accounts for both durability and mechanical strength while grading timber for sleeper use, Comprehensive Index (Composite Index) was not in use till the first half of 20$^{th}$ century. This method of classification, based on the only durability, reflects that the prime concern of Forest department was not to determine the suitability or actual properties of the timber for sleeper use but to only ascertain the potential of Indian forests to supply the quantum of sleepers.

**Table 3.2- Geographical distribution of timber species in Colonial India**

TIMBERS SUITABLE FOR USE AS RAILWAY SLEEPERS UNTREATED.

| *Species.* | *Where found.* |
|---|---|
| *Shorea robusta* (sal) .. | .. Nepal, United Provinces, Himalayan slopes from Jumna eastwards, Central Provinces, Chota Nagpur. |
| *Tectona grandis* (teak) | .. Burma, Central Provinces, Madras, Bombay, Travancore. |
| *Xylia dolabriformis* (pyinkado) | Burma. |
| That found in S. Kanara and Malabar is said to be *Xylia Xylocarpa*, an inferior species not nearly so durable. | |
| *Cedrus Deodara* (deodar) | .. Western Himalayas. |
| *Mesua ferrea* (nahor) .. | .. Assam, West and South India, Burma, Ceylon. |
| *Michelia Champaca* .. | .. Eastern Himalayas, Assam, Burma. |
| *Pterocarpus dalbergioides* (padauk) | Andamans. |
| *Shorea obtusa* .. .. | .. Burma. |

TIMBERS SUITABLE FOR USE AS RAILWAY SLEEPERS WHEN TREATED. OUT-TURN NOT KNOWN.

| *Species.* | *Where found.* |
|---|---|
| *Abies Webbiana* (silver fir) | . Himalayas. |
| ,, *Pindrow* ( ,, ,, ) . | ,, |
| This timber would probably give better service if incised before treatment. | |
| *Altingia ex* p. 241 jutli) | .. Assam, Burma. |
| *Anogeissus acuminata* | .. Burma, Chanda, Hyderabad, Chittagong. |
| *Artocarpus Chaplasha* (sam) | .. Assam, Burma, Andamans, Lower Himalayas from Nepal eastwards. |
| *Cynometra polyandra* (ping) | .. Assam. |
| *Dillenia indica* (otenga) | .. Assam, Bengal, Burma, Malabar, Kanara. |
| *Dillenia pentagyna* (karmal) | .. Bengal, Burma, Deccan, Western Ghats. |
| The *Dipterocarpus* family | .. Widely distributed throughout India and Burma. |
| *Lagerstroemia parviflora* (sida) | Assam, Central India. |
| *Picea Morinda* (spruce) | .. *See* Silver Fir. |
| *Pinus longifolia* (Chir) | .. Western Himalayas. |
| *Pinus excelsa* (kail) .. | .. ,, ,, |
| *Planchonia Andamanica* | .. Andamans. |
| *Shorea assamica* .. | .. Assam, Burma. |
| *Terminalia* family, especially *Terminalia tomentosa, Terminalia Manii, Terminalia myrio-* | |

Source: Warr, J.H. "Sleeper's problem in India" (1926)

Gradually, Forest department was bringing new geographical terrain under its ambit for exploring and exploiting the resources. Table 3.2 shows the mapping of timber species and potential source in 1926. The categorization of timber species on the basis of chemical treatment required or not shows the influence of Indian Railways on forest exploration process. Moreover, Table 3.2 reflects that every geographical area listed in the untreated category is also the source of treated type timbers. Therefore it is probable that considering railways' preference for durable timber, forest exploration for durable timber led to the identification of various non-durable timbers species. Since, Sal and Teak being the most used timber species for track construction, Nepal, Burma, and United Provinces emerged as the major forests supplying durable timber to railways. But the conditions of exploitation for Forest department and railways did not remain favorable always. For example, Forest department included Nepal under its control with commencing its operations in 1924 which laid the foundations for woodworking industries in Nepal. However, by 1960's Nepalese forests were marred by the excessive exploitation of resources, particularly due to construction works and ever rising demand for wooden sleepers which led to the promulgation of the forest protection act, 1967. This act was aimed at controlling the excessive damage of Terrai forest due to the extraction of timber for railway sleepers (APFSOS II, 2009; Wallace, 1987). Under this act, the ownership rights of forest were transferred from private entities or individuals to the government of Nepal. However, this act did not have much impact on the forests of Nepal. This act was further strengthened with another law, forest production, and distribution, in 1971. Under the new law, the permits were allotted for forest's exploitation along with a fixed price structure. Since, Nepal was the leading suppliers of durable timber for railways sleepers, subsequent changes in the procurement mechanism and price system distorted the sleepers market and altered the supply-demand equation to an extent. Nepal, which supplied the significant share of total supplies of durable sleepers, gradually after 1970's either cut down its annual production of sleepers or diverted durable timber to other purposes in construction works (Wallace, 1988).

Largely by 1920's, Forest Research Institute (FRI) at Dehra Dun developed a substantial knowledge base about timber production and utilization. Many volumes of forest data such as quantity and variety of timber were published in order to attract capital investment in forests for resource exploitation. President of FRI commented (Rodger, 1925; Stebbing, 1925) that Indian forests are a great mixture of species. With few exceptions, important timber trees of India do not grow in large pure strands. Though there are good qualities of timber trees in Indian forests but mostly are placed in remote and difficult terrain, which make extraction on a large scale infeasible. Forests under British India constituted one fourth of the total forest area in British Empire. Indian forests contributed greatly in the doubling of total forest revenue in 1906, which signify the progress in forestry made in India which was partly the results of the FRI, which collected and published the estimation of resources in a forest.

Subsequently, other geographical areas were brought under the ambit of forest department for the production of durable timber. For example, forest department took control of forests in J&K in 1910, forests in Nepal commenced timber exploitation for sleeper production in 1924, and forests in Burma, which emerged as the largest source of durable timber, started to supply sleepers in 1940's.

With the end of British colonial rule, India and Burma became two different nations. Since, Burma being the major source of timber supplies, Indian Forest Department was left with two choices for compensating lost forest area to Burma, either increase domestic production or import timber. Consequently, Forest department keep exploring new species within India. To tap new resources, Forest Department even considered some timber species, which were previously found unsatisfactory or commercially unviable, for manufacturing sleepers. The introduction of new species for wooden sleepers also supported by the similar opinion of Food and Agriculture Organization (Unasylva FAO, 1953[12]). FAO was of the opinion, as mentioned in 1953 Commodity Report, that railways strict standards set for wooden sleepers creating the scarcity of durable species. Report recommended that Railways should consider the lower grade timbers for track purposes in order to ease the high demand for durable species. The figure for India's sleeper production data shows the annual shortage of 56,000-meter cube timber. To bridge this gap in 1950's forest department came up with a new list of 36 non-durable species, which could be used for Indian tracks.

However, this process of acquiring new avenues of timber resources kept moving after Independence but with limited choices. In fact, old sources of timber supply, which were the part of the erstwhile British India, were gradually phasing out from the list of timber suppliers which

[12] http://www.fao.org/docrep/x5366e/x5366e0a.htm#railway%20sleepers accessed on June 30, 2016.

may be partly due to the tight restrictions on foreign exchange necessary for timber import (NAI, Annual Timber Conference, 1969). The addition of new geographies in timber promoted the use of wooden sleepers in railway tracks whereas the elimination of various geographies after 1950's such as Myanmar led to the discussions for an alternative.

### 3.5. Development of life cycle improving techniques

Hardwood was difficult to get because of lack of transport infrastructure in difficult terrains, improving the service life of soft wood by using preservation techniques became a research agenda of the forest department. By 1920's, at least, nineteen different methods of timber preservation were known to the forest department, particularly for sleeper timber (Pearson, 1917)

Unasylva (1968) reports that the importance of wood preservation in tropical countries stemmed not only that large quantity of timber is involved but also because the rate of timber consumption in tropical countries in 1960's was more than three times that prevailed in the rest of the world. Two major geographical conditions made it more important to preserve timber for longer service life- first, hot and humid weather and numerous species of insects in tropics facilitates the decomposition of wood, second, only a few out of a great variety are naturally durable. For example, in the Philippines, only 10% species out of total 3500 timber species are reported to be naturally durable. The economic value of timber preservation reflects an increase in service life. For example, in India in 1960s preservation treatment cost 20% more compared to non-durable untreated sleeper with a 400% increase in service life, which reduced annual expenses by 2 to 3 times.

FAO in Unasylva (1968) argues that it is surprising that despite visible and feasible economic benefits railways in tropical countries were generally reluctant in using treated[13] non-durable species. Moreover, existing capacities of treatment plants were not fully utilized. For example, In Argentina, only 40% of total installed capacity of treatment plants was utilized. Similarly, only a fraction of total capacity was under operations in Malaysia and Indonesia and India.

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[13] Sleeper treatment is a process in which sleeper is protected by a layer of heavy oil or creosote. The fibers of wood contain millions of minute cells containing juices. When these juices ferment, they lead to decay of timber. In the treatment process these juices are removed as much as cells are filled with some preserving solution. The preserving solutions may be oil or some salt solution. The treatment processes can be categories as- treatment by creosote oil, treatment by salt solutions, treatment heating under pressure, painting (http://www.engineeringarticles.org/treatment-of-wooden-sleepers/ accessed on June 19, 2016).

It is important to note that railways and forest department both had a different opinion on the perceived benefits of the life-enhancing techniques. Railways were of the opinion that forest department should focus more on acquiring the durable species of the timber whereas forest department was propagating the use of treated non-durable species. The difference in the perception of the sleeper problems could be explained by the fact that both railways and forest department were acting on different assumptions. IR was assuming that treated sleepers could not provide the same level of reliability in its operations compared to the naturally durable sleepers. Whereas Forest department's motivation was influenced by the economic exploitation of forests feasible only when both durable and non-durable species are demanded by railways.

IR concerns for preservation techniques were stems from its dependence on wooden sleepers itself. First, since the standards of railway track varied considerably regionally in India, often sleepers were made to fit for tracks by altering it according to specific site conditions. The treated sleepers have a layer of creosote over it. However, at the time of altering at the site, some portion of the sleeper's surface will be without creosote protection, thus become vulnerable to the natural environment, making it as good as an untreated sleeper. Further, untreated non-durable sleepers were often purchased from the regional forests, which were easily accessible (Track committee report). In other words, railways' engineer had a preference for wooden sleepers in order of- durable, and then untreated non-durable and at last treated non-durable types. Railways preference for durable timber delayed IRs' investment in treatment plants for decades. As we had mentioned that despite having know-how of sleeper treatment process, Forest department could not convince IR till 1923, when first sleeper treatment plant came into existence at Dhilwan, Punjab.

Another logic put forward by IR's for its reluctance to adopt treated sleepers was that timber species in Indian forests varied greatly in terms of their technical characteristics. Because of these varied features, it was difficult to impregnate each variety with a uniform layer of creosote with the same process. Non-uniform layer of creosote could alter the maintenance schedule greatly as the service life of each sleeper varying with the different degree of impregnation[14].

[14] Impregnation is a process of infusing creosote in the fine fabric of wood. The selected wood is introduced in vacuum pressure vessels, called autoclaves, at high temperature (+85°C) initially under vacuum (-10psi) in order to extract water, and later on under pressure to inject creosote. Creosote is a fungicide and insecticide oil that

Combine these logics IR exhibited very reluctant efforts for improving preservation infrastructure. IR's response to preservation techniques reflects from the repeated insistence, through various official communications to IR, of Forest department for sharing the economic cost of R&D (Pearson 1917; Rodger, 1925; Stebbing, 1925).

However, Forest department, working on different assumptions, pushed forward research work on preservation techniques. In fact, Wood preservation constitutes an important place in forest conservation policy of forest department. The increased penetration of treated timber made good sense for forest department because with the help of preservation techniques previously non-usable species became valuable which increased in forest value attracted the forest department for pushing the agenda of using treated sleeper in railways. Thus the promotion of wood preservation attracted not only wood based industries but also forest departments.

Timber preservation methods witnessed improvements in many practical and commercial challenges. In the early decades of 20th century, treatment of timber sleeper was a tedious task because of the varied rate of creosote absorption. This problem was solved by using a machine with steel rollers. The rollers set apart the wooden fibers and made a cavity for creosote incisions. This incised treatment of timber increased the numbers of sleepers could be treated per plant by reducing treatment time. In addition to this, new techniques facilitated the uniform spread of creosote for reliable prediction of service life (Kynoch, 1923).

Pertaining to the FRI's (Forest Research Institute, Dehradun) efforts for increasing the service life of wooden sleepers; R&D was focused on three dimensions mainly- timber testing for developing standards for known species, timber seasoning timber impregnation techniques. These three areas of research were crucial for the development of wooden sleeper technology.

FRI invested its resources primarily on developing testing standards for measuring the relative timber strength data. This database of relative strength became the starting point for the necessary deliberation required to determine the suitability of Indian timber for specific uses. More than twelve electrically fitted testing machines have been installed at FRI, which was

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immunizes the wood and protects it from wood-eating organisms. The complete process can last from 24 to 36 hours, depending on the previous condition of the wood (AWPA Standards; www.awpa.com).

possibly the only such large-scale facility in the British colonies (Editorial notes, Empire Forestry Journal, 1930).

Similar advances are noted in timber seasoning by air, Tiemann, and Sturtevant processes[15]. Researchers at Dehra Dun proved that timber service life could be double if timber is exposed to the specific amount of moisture and sunlight. These seasoning methods proved useful for increasing the utility of once not so useful soft timber. Besides climatic conditions, Indian timber was subjected to the destructive attacks of white ants, termites. There are a number of timber species in India, which last for years in the open such as Sal, Teak, deodar. But there are others, which are mechanically strong enough for use as a sleeper but do not contain any natural oil which will protect them from destructive agencies of white ants and termites. The direction of the preservation research was to find out the application of creosote and heavy oil on non-durable timber so that it becomes as durable as it is mechanically strong. In fact, FRI research on preservation of sleepers for railways yielded valuable results. They developed economic methods of applying costly preservative on non-durable species and kept the prices of treated sleepers competitive with those of durable types (Rodgers, 1925).

The proceedings of the Royal Academy on Indian forestry, in 1925, noted that "*FRI has rendered a great service to the railways and kept the supply and prices of wooden sleeper affordable. The separation of general finances and railway finances laid the onus of adequate return on investment on the Railway Board. Railways required an agency to conduct the scientific experiments on timber, which was necessary for the track operations. The lack of knowledge about timber species has put a significant cost on the operations and maintenance of tracks. Thus, it would be in railways' interest to invest in the research activities related to timber sleepers. With an abundant supply of timber species, railways were confining themselves to only*

[15] Air drying: Air drying is the drying of timber by exposing it to the air. The technique of air drying consists mainly of making a stack of sawn timber on raised foundations, in a clean, cool, dry and shady place. Rate of drying largely depends on climatic conditions, and on the air movement (exposure to the wind). For successful air drying, a continuous and uniform flow of air throughout the pile of the timber needs to be arranged (Desch and Dinwoodie, 1996)
Tiemann and Sturtevant Process: In this process humidity and temperature inside a drying kiln are controlled rather than depending on external weather as is the case with air drying (http://trove.nla.gov.au/newspaper/article/1745573 accessed on June 19, 2016)..

*a few species of Sal, Deodar, and teak and sometimes have to choose artificial sleepers. Scientific research on timber species can enlarge the species available for exploitation."*

By 1926, the attention of sleeper problem started to shift from the geographical mapping to the tapping of known resources. It became established that except hard wood-Sal, Deodar, Teak-no other easy accessible species could provide durable sleepers. However, FRI identified abundant timber resources in lower Himalayas, which could be exploited for use in railway tracks after treatment. Thus, the FRI decided to direct their research efforts for developing the treatments methods of non-durable timber species.

The second phase of FRI sleeper research was directed in two directions-improving the mechanical methods for spiking and drilling[16], and developing the seasoning and oil impregnation techniques.

There was no standard practice in Indian railways about the use of mechanical means, for instance, bearing plates, for fasting sleepers and rails; nor there any uniformity in the working procedure. Some engineers were in favor of adopting them with all types of sleepers; other considers that they are only warranted with certain species of timber (Warr, 1926).

The impregnation techniques developed in Europe were low-pressure techniques, suitable for timber species found in Europe. Indian timber species, because of varying creosote absorption capacity[17], needed different pressure and temperature conditions compared to the process conditions practiced in Europe. Since, tropical timber often needs high-pressure treatment, modified version of European Pressure Treatment Plants were installed in India. Even these plants were catering to the needs of only a few specific species. Lack of uniformity in impregnation techniques created difficulties in interpreting results and no standards mechanism evolved for determining the mechanical age of a sleeper (Warr, 1926). Moreover, continuous

[16] A rail spike is a large nail with an offset head that is used to secure rails and base plates to sleepers in the track. Robert Livingston Stevens is credited with the invention of the railroad spike in 1832. In 1982, the spike was still the most common rail fastening in North America. Common sizes are from 9 to 10/16 inch square and ~5.5 to 6 inch long. Originally spikes were driven into wooden sleepers by hammering them with a heavy hammer by hand. This manual work has been replaced by machines, commonly called "spike drivers (https://en.wikipedia.org/wiki/Rail_fastening_system accessed on June 19, 2016).

[17] Creosote absorption capacity is defined as the total volume of creosote absorbed by a unit volume of wood under the specific conditions of process parameters of pressure and temperature.

operations of trains leading to the mechanical loosening of the spike and consequent enlargement of spiked holes, with the results of moisture got into the hole and deteriorated the wood fiber. In Europe, this problem of hole enlargement was dealt with drilling the sleeper before treatment. However, in India, there was not any uniformity in the weight and patterns of iron rail, engineers always demanded that hole should be drilled at the site so to make sleepers compatible with iron rails and track geography. This problem of loosening of spiked holed remained unresolved even after Independence. Engineers and labor force working in Indian Railways were accustomed to the readjustment of sleepers at the site, thus were more inclined to purchase new sleepers without any holes drilled. This lack of uniformity in the use of new sleeper at site discouraged the development of mechanical means of strengthening wooden sleepers.

On the other hand, seasoning and preservation techniques yielded significant results. With proper stacking, drying, and steaming[18], FRI increased the service life of non-durable sleepers by more than doubled. The first sleeper treatment plant was installed in United Provinces[19], who supplied about three hundred thousand Chir pine sleepers, by Forest department for Indian state Railways in 1915-17. On the whole, these sleepers have given quite a satisfactory service. In 1920's (Stebbing, 1925), the North Western Railways installed their own pressure plant at Dhilwan in the Punjab to creosote Himalayan pine, fir, and spruce sleepers with an annual output of 400,000 sleepers. One of the smallest railways in India, the Dibru-Sadiya, using pressure treated hardwood sleepers from Assam, planned to expand the practices and use of seasoned sleepers. For this FRI and Railways scheduled to install seasoning kilns at five locations in British India-Burma, Calcutta, Punjab, Bombay, and Dehra Dun. A detailed procedure including timber grading, the degree of seasoning required, moisture control determination, grading of defects,

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[18] *Stacking* is one of the most important factors in satisfactory air seasoning of timber. Proper stacking of timber ensures uniform drying and reduces seasoning degrade, particularly warping and biological deterioration through mould and stain. The drying rate in air seasoning is influenced by rate of air circulation, stack size, width and height of the stacks and crossers and their spacing. Two types of stacking, horizontal and vertical, are widely used for sleepers ( http://www.forestrynepal.org/article/rajendra-kc/2411 accessed on June 20, 2016).
*Drying*: When wood is dried, surface zones dry in advance of the interior because of direct evaporation of the moisture at the surface. As a result, a moisture gradient is set-up which causes the moisture to move from the interior to the surface.
*Steaming* is a process in which steam is passed through the kiln for vaporizing the moisture trapped in the wooden sleepers (BIS Standards, 1993 https://law.resource.org/pub/in/bis/S03/is.1141.1993.pdf accessed on June 20, 2016).

[19] The United Provinces of British India was a province of British India, which came into existence in 1921. It corresponded approximately to the combined regions of the present-day Indian states of Uttar Pradesh and Uttarakhand (https://en.wikipedia.org/wiki/United_Provinces_of_British_India accessed on June 20, 2016)..

and record keeping was laid out and made it as a standard format for collection and analysis of seasoning and preservation data.

### 3.6. Institutionalization of procurement mechanism

Firms or Indian contractors holding forest leases in state or private forests provided the major chunk of wooden sleepers to Indian railways. However, the sleeper treatment plants were installed and operated by Indian Railways, not by forest department or contractors. The procurement system of a wooden sleeper in India was introduced by Peter H. Clutterbuck when he was a conservator of forests in Northern India. He designed the sleeper procurement mechanism to ensure that the railways get a regular supply of sleepers at a fixed price. A number of sleepers and prices were fixed before awarding the forest lease to the contractor. Forest lessees in India were of all types ranging from the very small lease for a single working season supplying only few hundred sleepers to big holdings comprising of several long-term forest leases supplying thousands of sleeper per annum. In some parts of British India, usually, where forest exploitation was in infancy or more than usually difficult, the forest department or other forest owners exploited their forest themselves (Marriott, 1928).

Railways in India constituted a sleeper purchasing agency known as the sleeper pool of Indian railways. Most of the railways in India were members of this sleeper purchasing pool consisting of five groups of railways, each of which purchases sleepers only in the territory allotted to it. In each of these groups, centralized authority, usually headed by one of the Chief Engineer in that group, was enshrined the job of pricing, inspection, and distribution of total produced sleepers. This overarching management of whole supply chain improved the standards of passing sleepers by making it economical to employ well paid, whole time passing officers. It has prevented reckless competition among the railways for sleepers in the year when the supply is deficient, and it had facilitated the co-operation between railways and forest owners. The general policy of the pool, the allotment and distribution of the available supplies of sleepers in accordance with the requirements of the different railways and the specification to be used for the different kinds of sleepers, are controlled by a general pool committee[20], which meets periodically at Shimla (National Archive of India (NAI), 1957).

This kind of procurement mechanism, where a single overarching management looked after the function of sleeper market, allowed railways to fix the prices of wooden sleepers. This arrangement created a disincentive for forest contractors to do business with railways, especially when prices in open market were comparatively high. For instance, in 1957, one timber advisor noted that it is very difficult to improve timber suppliers for sleeper by accepting high prices and diverting timber intended for other industries (NAI, 1957). In order to enforce forest contractors for increasing timber supplies, the government reserved a certain proportion of total timber production exclusively for use in railways. In other words, fixed price and fixed supply quota were the hallmarks of sleepers' procurement mechanism (Sharma, 1972).

However, there was some competition in sleeper market, usually arise from the need of wooden sleeper for river valley projects, port commissioning, and light railways and they were buying sleepers at a higher price. This competition was not augmenting sleeper supply; in fact, it was merely diverting the use of sleepers for track infrastructure to other infrastructure projects. Considering timber advisor argument, IR suggested to check this internal competition and to promote the use of second class sleepers in those projects (NAI, 1964).

Another reason that has turned in favor of IR was that most of the species used for sleepers from theses three states have no other alternative sustainable market. And in addition to this IR policy of advancing finances for sleeper operations to state forest department strengthened its monopoly. But the situation in other states was different in one sense that other industries- defense, building, steel plants, ports, etc. - were competing with railways for getting a share of timber production. Timber advisors noted that increase in price in non-monopoly states would force railways to raise fixed price agreed upon with monopoly states. Though railway tried to outbid other buyers in the non-monopoly state, this had a spiral effect and some buyers such as Hindustan Steel, Bhakra Dam, Hoogly Port Authorities, practiced aggressive pricing. For instance, the prices of non-durable Matti sleepers were more in Madhya Pradesh and Bombay

[20] The secretary of this committee was a forest officer, whose services were placed by the forest department at the disposal of the railways in order to carry out this and certain duties, and generally to act in an advisory capacity in connection with the railway's timber requirements.

state compared to those in Durable Sal sleepers in Uttar Pradesh and West Bengal. The ever-mounting pressure of timber demand, state forest departments were hard to meet it. Even the contractors of forest departments found it profitable to pay the penalty than to fulfill the contractual obligation of supply quantity (NAI, 1957).

Indian railway consumed around one million sleepers every year to fulfill its demand for expansion of its networks and replacement of depreciated assets in which year. Since, most of the forests, which could produce wood for sleepers, were under the control of forest department of respective states, IR established procurement mechanism with them. For the purpose of sleeper procurement, IR divided India into 7 zones according to their supply potential and geographic location. However, IR tied up with almost with every state, Jammu & Kashmir, Uttar Pradesh, and Mysore region emerged as the biggest suppliers. Some states, particularly, in North-Western and Western regions such as Rajasthan, Gujarat, and Maharashtra either had no potential for production of wooden sleeper or had very marginal production capacity; and that little supply was usually not of as good quality as desired for high capacity track in 1960's (NAI, 1961).

For procurement purposes, IR designated one Timber advisor for each zone. Timber advisor's jobs were to liaison with state forest department for fixating the sleeper's price and ensure maximum supply of hardwood sleepers. Table 3.3 shows the Railways' categorization of State forests based on their timber potential. Railway's had a predefined quota, usually 12%, in the total annual wood produced by the forest, as mandated at central planning level (NAI, Timber advisor report, 1961). The prices varied from state to state depending upon the quality of wood and accessibility in the deep forest. Specifications of sleepers demanded by IR were often very clear in terms of size, quality, and preservation. Sleepers were specified with a list of visible features to determine such as cracked ends, brown circular rings, etc. in order to ensure that whether a particular sleeper is acceptable or not.

The issue of tight quality inspections was discussed in various annual sleeper conferences, which was held annually on zonal rotations basis. Each zone has its own inspectors ensuring the quality of sleepers. The inspection was normally done in batches, and if the defective sleepers are less than 2% of the total batch, then whole lots get accepted. IR's engineers often complained about the poor quality and improper methods of stacking and preservation. In other words, high demand with stringent quality norms with a fixed cost mechanism was the central feature of procurement mechanism of wooden sleepers. Most of the annual sleeper conferences held between 1950's to 1970's often revolved around two issue- state forest department's failure to meet the production target of hard wood sleepers and high rejection rate of sleepers for their failure to meet IR quality standards.

**Table 3.3- Source of Timber Supply**

| Wooden sleeper- Sources of supply (Extracted from the office note written by Timber Advisor on April 1961) | | |
|---|---|---|
| **Zone** | **States** | **Remarks** |
| Northen | J&K, Himachal Pradesh, Punjab | Punjab is making no supplies on Govt to Govt Basis |
| North Eastern | Uttar Pradesh, Nepal | |
| North East Frontier | Assam, Sikkim, Bhutan, NEFA, Manipur, Tripura | |
| South Eastern | West Bengal, Bihar, Orissa, Madhya Pradesh | Madhya Pradesh is making no supplies on govt to govt basis |
| Southern | Andhra Pradesh (Old Hyderabad State), Madras, Kerala, Mysore, Andamans | |
| Western | Rajasthan, Gujarat | Both states have no potential for sleeper supply. |
| Central | Maharastra | Maharastra is making no supplies on govt to govt basis |

Source: Office note written by Timber Advisor on April 1961 (NAI, 1961)

Many supply augmentation steps were taken to bridge the supply-demand gap. For instance, in case of J&K state, IR agreed upon to pay 12% developmental charges for improving the infrastructure for cutting and staking wooden sleeper. These developmental charges were used as an incentive for increasing supply by state forest department (NAI, Timber advisor report, 1965). In addition to this, IR provided special rail service for transporting sleepers to the warehouse.

**3.7. Import of Pre Stressed Concrete Sleeper Technology**:

During WWII, another construction material, pre stressed concrete, started to gain prominence. The first main production system in pre-stressed concrete was introduced by Hoyer, who in 1939 established a factory in Germany. The Hoyer system, which was an adaptation of Freyssiner's work, used very thing (2mm) steel wires The wires were held in position bench through templates, and moulds are placed along the production bench to receive concrete. In this way, quite large numbers of units having similar cross-section and identical reinforcement can be produced. A numbers of production plants were installed in UK to produce a variety of products such as railway sleepers, power transmission poles and fence posts. (ACI manual of concrete practice, 1980[21])

In UK, National economic stringency resulting from the immediate post war country has given boost to the development of PSC sleepers. Two world wars tighten the building restrictions, tightened economy and short supply of steel accelerated the development and improvement of PSC. After the war anyone needing to construct has to seek alternative material to the materials in short supply, and steel was one of those most affected (ACI manual of concrete practice, 1980).

A continued development of PSC was ensured when the Ministry of Public Works in UK advocated its use and did much in publicizing the new structural medium. The Ministry of Works published a number of documents showing the advantages to be obtained from the use of PSC. The first International congress, organized by Federation Internationale de la Precontrainte, on PSC was held in London during WWII. An international organization was set up to act as a link between the various bodies concerned with the development of PSC and to encourage the formation of such groups in all countries. In 1958, the University of California organized and held a successful world conference on pre stressed concrete in San Francisco, which was attended by more than 1000 delegates from all over the world. Intensive research was being

[21] https://law.resource.org/pub/us/cfr/ibr/001/aci.manual.1.1980.pdf accessed on June 30, 2016)

undertaken by some regions of British Railways on Concrete sleepers, this was linked with the development of continuous welded rails (TRADA, 1963).

Two fundamental improvements in the design of PSC sleepers distinctly marked its departure from the earlier design. First, the design fundamental reversed from post stressed concrete slabs to pre-stressed concrete, which made sleepers suitable for sustaining the cyclic load of running trains. Second, the use of steel wires in the concrete slabs provided it with an immense tensile strength, which distinguished it from the wooden sleepers in technical performance (Ghosh, 2008).

The first attempt to develop concrete sleeper technology in India was made during the first five years plan. However, the results of the experiments conducted on PSC were not satisfactory. Subsequently, it was decided to supplement indigenous efforts of developing PSC with the technological assistant from European railways. For this purpose, a special directorate was constituted in IR in 1962 to select one or more design of concrete sleepers suitable for Indian conditions. Four designs, which were most successful in Europe that time, were chosen for deliberations and experiments (NAI, 1962; NAI, 1965).

Considering the technical superiority of PSC sleepers, Board has decided to first install 100,000 sleepers (on Tundla-Ghaziabad Section) to generate reliable statistics of actual cost of the various operations and attendant problems in the labor conditions, which are different from those in India. The solutions of these problems and collection of realistic statistics on a practical scale were necessary for the introduction of concrete sleepers in large numbers in India (World Bank IR Modernization plan, 1970).

At first proposal of four different designs- German B-58, British F type, French RS, Swedish SJ-101, were considered and it was decided to produce 25000 numbers of each type near Delhi by Indian firm with Indian Collaboration. It was proposed to invite to invite open tenders for the manufacturing of PSC sleepers with a stated objective to use components and machinery produced in India to the maximum and reduce to the absolute minimum the import of components such as high tensile steel rods with the anchors, dowels, clips and special steel tube, high tensile moulds and pre-stressing jacks. Considering the restriction on the use of foreign exchange for importing technology, in this case it was estimated Rs. 17 lakhs, Finance ministry contended for the further reduction of import. Finally, French RS design was adopted for trail field trials (NAI, 1962).

### 3.8. Composite Sleeper Technology

Most of Indian tracks, today, are laid with concrete sleepers. Though, Indian Railways banned on use of wooden sleepers in 1996, PSC sleepers could not replace wooden sleepers in bridges (Supreme Court Judgment, 1996)[22]. Partially complying with ban, Indian Railways reduced the use of wooden sleepers at bridges by replacing them with specially designed steel sleepers with insulation pads. RDSO in collaboration with Defense Research and Development Organization (DRDO) had developed sleepers of synthetic material (fiberglass-reinforced plastic), which were put on trial on some bridges. However, trails were not successful and later this project was abandoned (IRFC)[23].

Another experimental version involved sleepers made of composite material consisting of regrind resin, recycled automobile tires. Composite sleepers were developed by a private firm, Patil Group, with technology import from a US firm, Tie Tek. These sleepers have been deployed for trails on some bridges of Northern Railways and Eastern Railways. Composite sleeper technology is in embryonic stage and not much in use in Indian tracks (Patil Group Website)[24].

### 3.9. Summary and Salient Points

The discussion in this chapter outlines the complexities involved in understanding technological change. Various factors influence technological change, and these factors are aggregated at multiple levels-niche, regime, and landscape. MLP approach integrates these factors, operating at multiple levels, into a coherent framework but in an abstract manner. Geels (2004) framework integrates different strands of literature-evolutionary, innovation, and technology studies. MLP sees the stability or instability of a regime as the core concept to explain the emergence of new technologies in the existing systems. Tushman (1986) defines regime as the set of rules coordinating with each other. Coordination of these rules determines the stability or instability of

[22] Supreme Court Judgment on "T.N. Godavarman Thirumulkpad vs Union Of India & Ors on 12 December, 1996" (https://indiankanoon.org/doc/298957/ accessed on June 29, 2016)
[23] Indian Railways Fan Club (http://www.irfca.org/faq/faq-pway.html accessed on June 29, 2016)
[24] Patil Rail Infrastructure Pvt Ltd (http://www.patilgroup.com/composite-sleepers.html accessed on June 29, 2016)

a regime. Unruh (2000) argues that once a technology stabilizes in the existing regime, increasing returns associated with network externalities exhibits inertia for technical change. Network externalities could manifest in the form of physical infrastructure, user base, technical standards, user practices, etc. In other words, first mover advantages precipitate in the dominance of a particular variant of technology. Consequently, increasing returns associated with a dominant variant of technology, improve the performance of dominant variant at a pace faster than that of other competing variants. Considering the theoretical framework, uniqueness of our study stems from two facts- one is that it discusses the process of dominance of a technology in a monopolistic firm and another is that it attempts to explain the emergence of new technology out of the process of dominance itself.

It is already discussed that rules play a significant role in determining the stability or instability of a regime. Geels (2004), in order to analyze these rules and their interrelation, categorize rules operating into five analytical different regime- technological/product regime, science regime, policy regime, socio-cultural regime and user networks. However, mere stability or instability of existing regime is not the sufficient condition for the successful emergence of new technology replace existing one, other factors operating at niche and landscape levels plays a crucial role. When there is "opportunity of window" at landscape level coupled with the instability of existing regime, new technologies could emerge and substitute the existing one.

Surveying the literature three hypotheses are emerging:

1. The emergence of technology is followed by the period of ferment when negotiation happens among actors involved in the production, operations, and maintenance activities related to that technology. Often, performance criteria are developed out of this negotiation, against which the performance of competing variants is determined.

2. Various factors other than the performance characteristics influence the process of technology selection. These externalities grow in strength as a particular variant take lead in the market and expand its network of suppliers, users, physical infrastructure. However, these externalities associated with the growth of network may prefer inferior variants or superior technology,

3. Once a technology becomes dominant in the market, it inhibits the emergence of new technologies in its domain by those very same mechanisms, which set the increasing returns.

# Chapter Four

# Research Questions and Methodology

## 4.1. Introduction

The theory suggests that often a technology get selected and become dominant, which is an inferior one in terms of performance, because of increasing returns associated with that technology. However, the criteria set for comparing the performance of competing variants of a technology are problematic in one sense that different variants may have different performance characteristics when subjected to use in different set of conditions. Furthermore, criteria for measuring the performance level of a technology changes with time. Literature on dominant technology states that increasing returns associated with a particular variant of the technology strengthen its position in the market. Increasing returns create inertia in the form of physical infrastructure, technical standards etc; and hinder the emergence of alternatives. However, no technology remains dominant for indefinite time. New technologies, which have the potential to compete with dominant design, render existing dominant technology obsolete. In other words, the improved performance of new technology is seen as the possible reason for its ability to replace existing dominant technology. Then, is it only performance characteristic of new technology that makes it winner or loser; if not, then what factors influence the emergence of a new technology.

It is clear from the previous chapter that not many studies have been done on technological changes in India Railways. This research intends to explore some of these dimensions.

## 4.2. Area of Research

For the purpose of this study, we have chosen to study technological change in sleeper technology. We have chosen sleeper technology for following reasons.

First, sleeper technology is unique in at least two aspects. One is that various competing variants of sleeper technology remained in use for more than a century, each finding its base in a particular type of track. Generally in Dominant design literature, the same principles of performance measurements are applied on all the competing variants of a technology; and on the basis of those performance indicators such as carbon equivalents, interrelatedness, a technology is decided to be "superior" or "inferior". However, these measures of performance are not static but changes as the technology evolves. Study of sleeper technology offers a long period for analyzing such changes.

Second, changes in sleeper technology happened not in isolation rather, these changes were greatly influenced by the changes in other regimes such as forest policy regime, national development policy regime, user regime. Significant infrastructure was installed both by Forest department and IR relating to manufacturing and distributions of wooden sleepers, which supported the choice of a particular variant and influenced the performance criteria to a great extent. Sleeper technology provides an excellent case study where an analytically different forest policy regime had a direct bearing on the technological choices of Indian Railways. Through this case study of sleeper technology we intend to know how IR aligned its rules-formal, normative, cognitive- governing tracks operations while connecting with an analytically different regime that is forest policy regime.

Third, it is not that with the concretization of Indian tracks the debate on sleeper technology is over. The search of Indian Railways for "perfect" material for railway sleepers is still going on. As the days of wooden sleepers are over now, engineers consider environmental impact and weight of sleeper as the important performance parameters. Considering the environmental impact of concrete sleepers, IR is developing composite sleepers using regrind resin and recycled automobile tyres. However, this technology is in infancy now with few experimental trials have been conducted in Konkan Railways. As IR is planning to replace concrete sleepers with composite sleepers in the future, lessons from the history on technological transition from wooden sleepers to PSC sleepers could provide some policy insights.

Fourth, Rakesh Mohan Committee (2001) constituted for initiating reforms in Indian Railways. For example, this committee suggests the unbundling of track operations and train operations businesses of Indian Railways. The logic put forward behind this reform is that the monopoly of Indian Railways on all aspects of train operations is the prime reason for the underdevelopment of Indian tracks vis a vis European tracks. Unbundling of tracks operations from rest of the railways' businesses would allow efficient use of tracks and boost modernization efforts. In order to understand the merits or demerits of this argument, it is important to understand the influence of monopolistic structure on the rules governing the product/technological regime of railway tracks, of which sleepers are a major technological component.

### 4.3. Research Questions

In order to answer these questions we have explored three questions:

1. How did IR manage the sustained use of wooden sleeper in the wake of technological changes in sleeper technology in Europe and changing transport demand patterns in India?
2. What factors shaped the transition from wooden sleeper to PSC sleeper technology in IR?
3. Forest department greatly influenced the sustained use of wooden sleeper technology. However, the forest department operates itself in a different regime. Then the question is that at what level in MLP approach, the influence of forest department on sleeper technology is to be understood?

### 4.4. Methodology

In order to answer the questions mentioned above, we used both primary and secondary data. For data analysis we employed logical deduction methods[1] and archival data interpretation techniques. In the following section we will elaborate the types of data, sources of data, and techniques of analysis that we have used in our research.

#### 4.4.1. Data Collection

The approach that we used to collect data is discussed below.

##### 4.4.1.1. Administrative and Technical Records

Since the nature of our research question is qualitative, nature of our data collected is primarily qualitative. We also used quantitative data to substantiate our arguments. For our analysis, we have used both primary and secondary data.

The operation and maintenance methods of track maintenance were specific to the local geography and traffic patterns. Thus it is crucial to understand the opinions of engineers at zonal

[1] http://www.socialresearchmethods.net/kb/dedind.php accessed on July 18, 2016.

level. For knowing the opinion of railway's engineers, we have studied the official communications, among engineers regarding sleepers and track issues, ranging from colonial to post colonial era. Official communication from the last decade of 19th century to 1970's are accessed at National Achieve of India. For records of official notes from 1970 to 2000, documents are kept in abeyance in a store room at Rail Bhawan without proper catalogues. It is the limitation of this study in the absence of primary data. However, various proceedings of conferences and reports were used to offset this deficiency to some extent. For example, we studied Modernization Plans of Indian Railways drafted by World Bank from 1970 to 1998. These plans provided a perspective different than those purported by policy makers.

The evolutions of track standards and various other incremental technical changes are best documented in the technical literature on railway track technology. These technical documents, committee reports and operation manuals are accessed at National Academy of Indian Railways, Baroda during one week visit in the month of February, 2016.

Since, Forest department was primarily responsible for meeting the production target of wooden sleepers, its views on the nature of sleeper problems in India hold a great significance for this research. Though opinions of forest department on railway sleepers are not documented systematically, proceedings of colonial forestry journals (Empire forestry journal, Royal society of Arts and manufactures) are studied for analyzing their role in the development of wooden sleepers.

International development agencies remained at the forefront of providing technical and financial suggestions for the rehabilitation and modernization of railway system in India after Independence. Successive modernization plans after Independence headed by World Bank are taken as a valuable source for examining railways decision from the perspective of an International agency. Similarly, the annual publication of FAO (Food and Agriculture organization, UN)- Unasylva, has been included in the data source, which offers valuable information on the comparative trends prevailing regarding timber trade that time in different parts of the world.

#### 4.4.1.2. Interview with Semi Structured Questions

Nature of our primary research questions prompted us to have opinions of railway engineers and labor union representatives. The central question that this study asks is about the process of decision making and criteria of decision making in a monopolistic public sector organization. As we have discussed in chapter 2 that rules define a regime and their coordination level decides the stability or instability of that regime. User practice, which is understood as cognitive rule, greatly influences the selection and adoption of a particular variant of a technology. Therefore, it is imperative for us to interview engineers for understanding the prevalent user practices in maintenance of track sleepers. In addition to this, Engineers' view on track maintenance helped us to reconstruct the modalities of track maintenance prevalent in colonial time by comparing extent of use of mechanical tools for maintenance works. The questionnaire consisted of following two types of questions.

**a) Track Maintenance Practices**

The questions that we asked in this category were intended to understand how engineers interpret formal technical norms as coded in technical manuals while practicing maintenance works. The objectives of these questions were first to analytically separate the cognitive rules, as practiced while doing maintenance, from formal technical standards, as preached in technical manuals; and second to trace out misalignment, if any, between cognitive rules of user practices and formal technical rules. In order to answer these questions we have interviewed three Section Engineers, engaged in track maintenance, Chief Engineer, involved in track design and engineering, Procurement Engineer, looking after procurement of track components, and, labor union representative. Care has been taken to develop a multi-dimensional view on track maintenance by including different aspects of sleeper engineering such as design, maintenance, and procurement.

**b) Indian Railways as a Monopolistic Public Sector**

Indian Railways is a monopolistic Public sector organization. The objective of this set of questions was to see whether the monopolistic public sector setup of Indian Railways has got anything to do with the adoption of concrete sleeper technology. We discussed in chapter 2 that monopoly retards the emergence of alternative technologies, which challenges the dominance of existing one. We ask interviewers their opinion on modernization of railway tracks and does decision making process hinders or encourage them to adopt innovative solutions. To answer these questions we choose to have experts' opinion of faculty members at National Academy of Indian Railways (NAIR), Baroda. We interviewed Deputy Director General, Library and Information Officer, and Professor of Information Technology. Further, we Interviewed labor union representatives to understand their perspectives on modernization of Indian tracks.

#### 4.4.1.3. Parliamentary Proceedings

Indian Railways is a public sector organization under the Railway Ministry. Government is accountable to public for its operations and activities. Every year Railway Minister delivers a speech on Railway Budget Year. These speeches enable us to gauge the views of Policy makers on railways' operations. The data enables us to track the government's response on the modernization of Indian tracks.

### 4.4.2. Techniques of Analysis

In order to answer these questions we have relied on primary sources and their analysis. However, to substantiate and support our analysis, we have used secondary data wherever necessary. For the purpose of analysis we have relied heavily on the interpretation and deduction methods[2]. The interpretation has been done in the context of theoretical work discussed in the literature review. Similarly, deductions have been made by following the standard assumptions of firm's behavior and public sector operations. In this process, we have not taken the opinions of IR policy documents at face value. We analyzed railway's opinions by juxtaposing them against the opinions of other agencies such as forest department and International development agencies. The selection of sources is done in such a way that the differences of opinions among relevant actors- railways, forest department, World Bank, FAO get representation in the research work.

[2] http://www.ssr.org/sites/ssr.org/files/uploads/attachments/node/16/rothchild_scimethod.pdf accessed on July 18, 2016.

### a) Techniques for Interpretation of Archival Records

Archival research methods include a broad range of activities applied to facilitate the investigation of documents and textual materials by and about organizations (Ventresca & Mohr, 2001). There are mainly three methods to study archival records- historiography, ecological, and new archivalists. For the purpose of our research, we have used new archivalist[3] tradition for analyzing archival records of Indian Railways with following set of principles.

1. We treated archival records of Indian Railways as data to be analyzed. We relied on formal methods of logical deduction to reveal features of railways' sleeper business activities and put analytical findings up front, at the core of our interpretative endeavor.
2. Archival records of an organization could be studies in two ways. One is the organization centered approach and other is studying relations rather than objects or attributes. Organization centered approach assumes organization as independent objects, thus does not reflect on the linkage of an organization with its ecology (Ventresca & Mohr, 2001). We, thus, focused on studying the institutional linkages of Indian Railways in order to build arguments about the nature and consequence of the monopoly of Indian Railways on wooden sleeper manufacturing and distribution. We constructed a relational system that operates to produce forms of social organization, including the forms of knowing (codified or tacit), and sets of shared belief that constitute organizational activity.
3. An important concern in handling archival records for research is how the data are put into the service of a particular analytical agenda, a distinction that a scholar brings to the material. Foucault (1980) describes this as the difference between a "descending model of analysis" and "ascending model of analysis". In the former case, macro patterns of social organization are expected to explain more micro processes, and for later case, local practices and logics of action are presumed to develop in their own fashion after which they are incorporated at macro level of social organization. We preferred later approach for our research, which helped to identify and specify the practices prevalent among IRs' engineers, the relational network of India railways and Forest Departments that tie the elements of organizational life of sleeper technology.

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[3] New archivalist method comprise of a set of principles, which emphasize on the understanding of relations between objects rather than studying the objects itself (Ventresca & Mohr, 2001).

# Chapter Five

# Analysis and Interpretation

## 5.1. Introduction

In this chapter we analyze our research findings on the development of sleeper technology in India, mentioned in the last chapter. We discuss our three research questions in this chapter.

Our first research question is how Indian railways managed to sustain use of wooden sleepers in the wake of competition from metallic and concrete sleepers, scarcity of durable timber, and changing traffic patterns after Independence. To answer this question we have used Geels's (2002, 2004) framework for understanding the stability of technical regime of wooden sleepers. We understand stability or sustain use of a particular variant in terms of rules such as legal contracts, formal technical regulations, problem solving approaches, market rules etc. We have explored those rules, which could have stabilized the existing technological system.

Our second research question explores the factors that have influenced the emergence of PSC sleepers in India. We identified factors at three levels- niche, regime, and landscape-based on the abstract conceptualization of levels, as proposed by Geels (2004). Geels (2002, 2004) argues that for the successful emergence of competing variant in the existing regime dominated by another variant, three conditions are necessary- development of a competing variant at niche, misalignment of rules at regime level, and a landscape opportunity. In order to answer this question, we have explored and identify those factors, which might have influenced the emergence of concrete sleeper technology

Our third research question deals with the role played by Forest department in the sustained use of wooden sleepers. As we have discussed in chapter 3 how Forest department actively engaged with the wooden sleeper technology. In this question we attempt to conceptualize the role of Forest Department in the growth and development of wooden sleeper technology.

For the purpose of analysis, we have categorized rules into four analytically different regimes- product regime, science regime, policy regime, and user networks. In section 5.2 of this chapter we will conceptualize the different rules governing the technological regime of wooden sleeper technology. Subsequently, rules are discussed in the context of changing policy dimension after Independence. In the last parts of this section we explored how these rules contributed to the stability of the technical regime. Section 5.3 discusses our second research question on the emergence of PSC sleeper technology. We have analyzed the various factors, which influenced the use of concrete sleepers in Indian tracks. Analytically, these factors are understood to operate at niche, regime, and landscape level. As we have discussed in chapter 2 that change in landscape conditions might open "window of opportunity" for a newly developed technology to emerge. But the conditions, which make transition possible, emerge from the instability of a technical regime. In sections we also discussed how negative feedbacks are generated in the technical regime of wooden sleepers due to either landscape changes or alignment of existing rules. The section 5.4 of this chapter discusses our last research question understanding the intervention of FRI in technological change in sleeper technology.

### 5.2. Analysis of Sustained use of Wooden Sleepers

In chapter 3, we discussed the history of sleeper technology with special emphasis on wooden sleepers. Wooden sleeper was the first variant[1] of sleeper technology used in Indian Railways. Within four decades, perceiving the scarcity of timber for manufacturing railways sleepers, Indian Railways started to import cast iron sleepers. Though, metallic sleepers soon got popularity as a substitute for wooden sleepers, but for the engineers' first preference remained wooden sleepers only. If in case, engineers' could not get wooden sleepers for construction and maintenance of tracks, only then they opted for metallic sleepers (IR reports, 1882, 1891, 1924). In other words, metallic sleepers were effectively procured to bridge the supply-demand gap of wooden sleepers. This arrangement of co-existence of wooden and metallic sleepers in Indian tracks remained in practice from 1880's to 1990's[2]. With the emergence of electric signaling,

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[1] In the very beginning of railways in Britain, engineers used stone block providing support for holding iron rails. Later it was found that it was hard to maintain the correct gauge on stone blocks. Also the heavy weight of stone bocks was unsuitable on soft ground (https://en.wikipedia.org/wiki/Railroad_tie accessed on July 12, 2016).

[2] We decided chronological dates of metallic sleepers use in India by comparing administrative reports of Indian Railways published in 1882, 1891, and 1999. Report published in 1882 barely mentions the use of iron sleepers in state railways whereas multiple instances of cast iron sleepers' use in track construction are cited in 1891 reports. Thus we concluded that metallic sleepers might have been imported first time in between 1880 and 1890. Indian Railways set up a committee in 1999 on "System Improvement on Indian Railways". Committee report reiterates the railways' contemporary policy of track concretization and stop using metallic sleepers to pave the way for electric signaling of railway tracks. Based on this report, we marked 1990's as the end date of metal sleepers' use in Indian tracks.

serious concerns[3] were raised regarding metallic sleeper's compatibility with new signaling methods. Thereafter, Indian Railways imported PSC sleeper technology as a substitute to metallic sleepers. First field trials of concrete sleepers were carried out in 1950's but concrete sleepers were not prominent in use till 1990's[4] In 1989 Supreme Court of India (SC) banned use of wooden sleepers; we consider this year as the end of use of wooden sleepers in Indian tracks . We think the point is that wooden sleepers did not continue automatically, rather agencies of technical change facilitated its continued use. Various other factors such as competition from metallic sleepers, development of concrete technology in Europe during World War II, investment in heavy industries by Government of India under Five Year Plans influenced the sleeper technology.

During World War II engineers in Britain were working on the development of alternative construction materials for replacing wood, which was in great demand. In 1944, engineers developed pre-stressed concrete with better technical performance[5] than that of post stressed concrete. Subsequently, railways in Italy and France developed pre-stressed concrete sleepers. By 1960's, it became the norm in Europe (excluding United Kingdom) to replace wooden sleepers with concrete sleepers (Unasylva, 1968). Strictly speaking concrete sleepers also offered an alternative to the sleeper problems of Indian Railways.

After Independence India unveiled her Five Years Plans for development. Under first and second Five Year Plans, Government invested in heavy industries such as steel production, coal mining etc, which needed higher capacity tracks for transportation. Indian Railways being a Public sector organization, government policies had direct bearings on railways' development plans. Increased demand of track capacity prompted railways to look for technological up gradation. Study of modernization plans[6], drafted by World Bank for Indian Railways, mentions various technological up gradation projects undertaken under Five Years Plans. Sleeper technology was

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[3] Since metallic sleepers are good conductor of electricity, track insulation necessary for electric signaling could not be achieved with them. RDSO developed insulation pad to be used with metallic sleepers in order to solve track insulation problem. But these pad were never used at large scale (Chandra & Agarwal, 2007).

[4] First field trials of concrete sleepers were carried out in 1954, but were not successful (IR Annual Report, 1954; National Archive of India, Railway Department, 1957, file no. 57-W6-RWT-26/1-44).

[5] Refer

[6] World Bank drafted "Rehabilitation" and "Modernization" plans for Indian Railways from 1950's to 1990's. During this period Railway imported improved locomotives, signaling system, coach designing etc.

one of the focus areas of World Bank's modernization plans, which envisaged development of high strength metallic sleepers and concrete sleepers in 1950's and 1960's.

Though, availability of alternative technology to wooden sleeper and national polices demanding high capacity tracks created favorable conditions for the emergence of concrete sleeper, but it could not become dominant in use. Here we are asking a question that how did Indian Railways manage to sustain the use of wooden sleepers in the wake of competition from metallic sleepers, emerging PSC technology in Europe, and increasing demand for higher capacity of tracks.

In next section we discuss metallic sleepers as a competing variant for wooden sleepers in Indian tracks.

### 5.2.1. Metallic Sleeper Technology As a "competing variant"

East India Railways introduced wooden sleepers in India for railway tracks in 1850's. Subsequently, all other railways operating in India that time followed suit and adopted wooden sleepers for track construction (Bhandari, 2005). The reasons for selecting wood as a sleeping material for supporting iron rails were obvious- easy availability of timber near construction site, wood could be modified architecturally with simple machines[7], excellent material properties such as light weight, and tested and tried compatibility with the other components of the track system[8] (M M agarwal, 2007). Wooden sleepers were operating successfully in European railways for at least two decades before their use in India. However, as the quality timber near railway track exhausted, engineers started to clamor about timber shortage. Engineers' concern for timber shortage was further intensified by the reckless use of wood for fueling steam engines and massive expansion of railway track infrastructure (Pallavi, 2012). Growing debate of timber "scarcity" challenged the notion of wood as a "perfect material" for manufacturing sleepers. In response to the "timber scarcity", as claimed by engineers, railways decided to import cast iron sleepers from Britain. During 1880's the idea of cast iron sleepers for Indian tracks was mooted.

[7] In the early phase of railway construction, track alignment, the practice of maintaining uniform gap between two rails throughout the track length, was done manually, which is a hit and trail method. This method needs considerable flexibility in the use of technical components, suited to the site conditions. Since, wood as a construction material provided this flexibility to change its shape and size at site, railway engineers could mould the architectural dimensions of wooden sleepers for alignment work easily.

[8] Wooden sleepers for railway tracks were operating successfully in European and American railways for at least two decades before their use in India.

Since, then gradually Cast iron sleepers' share in market increased up to the level of 50%, almost same as that of wooden sleepers by 1920's (Marriott, 1928).

Metallic sleepers were in more use than wooden sleepers on broad gauge tracks. But still metallic sleepers could not substitute wooden sleepers completely; in fact proportion of metallic sleepers on broad gauge remained fairly constant. The most straightforward explanation for the selection or rejection of a technology is its comparative technical and economic performance with other competing variants. Therefore, one could argue that metallic sleepers could not replace wooden sleepers simply because of their high cost compared to that of wooden sleepers. In the next section we will evaluate the validity of this argument.

### 5.2.2. Comparative Economic Performance of Wooden Sleepers and Metallic Sleepers

In contrast to wooden sleepers, cast iron sleepers were mostly imported until 1920's. Though, cast iron sleepers were in use since last decade of 19th century, indigenous production could not take place until 1924. As far as design of cast iron sleepers is concerned, first indigenous design came only after 1956 after the birth of Research Development and Standard Organization (RDSO). However, one could argue that the high cost of metallic sleepers offsets their economic feasibility, which caused the reluctance of railways to improve metallic sleepers. But this argument is not feasible on following grounds.

Throughout the 20th century Indian tracks could be categorized broadly into two main types- Broad gauge, meant for high traffic and Meter gauge, designed for low traffic flow. Metallic sleepers were uneconomical for meter gauge lines, where traffic flow was low to justify high cost of imported cast iron sleepers. But long service life, high mechanical strength made, and high scrape value made them competitive for Broad gauge routes. In 1928 railways were using metallic sleepers on more than 55% of the broad gauge lines (total length 30,000 miles) and 25% of meter gauge tracks (total length 20,000 miles) were laid with metallic sleepers (Marriott, 1928). Since, a broad gauge sleeper often consume twice the material used for manufacturing a sleeper for meter gauge, normalizing two different gauges on one scale leads that metallic sleepers were on use in 19000 Broad gauge equivalent track miles whereas wooden sleepers were in use on 21000 Broad gauge equivalent track miles[9]. And if we see the sleepers' depreciation funds[10] for the budget 1925-26, we observe that the budget estimates for wooden sleepers and metallic sleepers were 12,08,000 and 9,87,000 Rs respectively (Railway Budget, 1925-26). Since, depreciation funds were supposed to represent a fraction of total product value, we can assume railways' expenditure on wooden and metallic sleepers would be in the ratio of depreciation funds. We estimate railway's expenditure on one mile of metallic sleepers was 52 Rs whereas for wooden sleepers this value was 57 Rs[11], after normalizing broad gauge and meter gauge route length on broad gauge equivalent length. Therefore, we conclude, from economic point of view, that metallic sleepers were performing better than wooden sleepers. Therefore the performance argument seems implausible for explaining sustained use of wooden sleepers on broad gauge routes. Despite 50% of Broad gauge tracks using metallic sleepers, metallic sleepers could not expand their infrastructure like wooden sleepers did. Thus, it seems reasonable to assume that comparative economic performance of cast iron sleepers and wooden sleepers could not explain the dominance of wooden sleepers on at least Broad gauge routes.

We observed in this section that metallic sleepers despite having better economic performance and equal user base compared with wooden sleepers could not get the attention of policy makers. In policy circle, as reflects from IR Annual Reports and Budget speeches, Wooden sleeper always remained the central point of discussion and all debates concerning sleeper problems revolved around development of wooden sleepers. In the wake of this discussion, it is important to analyze the definition of dominant design, which is based on criteria of user base for defining dominance, as proposed by Tushman (1986).

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[9] Depreciation Funds, as defined in IR annual budget, 1925-26, is the fraction of product value that has to be saved every year to accumulate sum equal to the product value once product's life span is over.

[10] Broad gauge sleeper consume twice the material required for meter gauge sleepers (Marriott, 1928). In other words, 2 miles of meter gauge track would need same quantity of sleeper material as much required for one mile of broad gauge track. On the basis of this, we conclude that total length of track laid with metallic sleepers, measured equivalent to broad gauge, would be 55% * 30,000 + 25%*20000/2= 19000 miles broad gauge tracks. Similarly for wooden sleepers 45%*30000+75*20000/2=2100 miles broad gauge tracks.

[11] For metallic sleepers 987000/19000= 51.94 Rs per broad gauge equivalent track miles
For Wooden sleepers 1208000/21000= 57.52 Rs per broad gauge equivalent track miles

### 5.2.3. Wooden Sleepers as Dominant Variant of Sleeper Technology

Tushman (1986) argues that a technology is considered dominant once it has acquired 50% of user base. In case of sleeper technology, wooden sleeper and metallic sleepers were in use on 45% and 55% of broad gauge tracks in first half of $20^{th}$ century. Tushman's definition suggests that metallic sleepers should be considered dominant on broad gauge tracks. But our discussion in chapter 3 reveals that before 1924 no significant efforts were made to indigenize metallic sleepers and in contrast considerable research programs were carried out by FRI for improving the performance of wooden sleepers. Then we ask a question, should we consider a competing variant dominant solely on the basis of its user base. Here we argue that the criteria for deciding a dominant variant should be expanded to include physical and technical infrastructure built for its functioning. Expanded meaning of dominance qualifies wooden sleeper technology as the dominant variant of railway sleeper technology.

In chapter 2 we discussed that once a variant of a technology become dominant, various rules, governing that technology, align with each other in such a manner that rules favor the stability of dominant variant. In our case, wooden sleepers were the dominant variant; therefore, in next section we will discuss the various rules that sustained the use of wooden sleepers in Indian tracks.

### 5.2.4. Technological Regime of Wooden Sleepers

Wooden sleepers remained in use for more than 130 years in Indian tracks. During this period, wooden sleepers emerged as dominant variant of sleeper technology. Many rules evolved and implemented over a period, which stabilize the technological regime of wooden sleepers.

We examined the factors, operating at multiple levels, which influenced the adoption or rejection of three competing variants of sleeper technology by IR. When technologies install a user base, it develops socio-technical systems of manufacture and use (Scharff and Dusek, 2003). These socio-technical systems are defined and characterized by rules (e.g. formal, normative, and cognitive) and as user base increases rules gradually harmonize with its economic, social, and political environment (Geels, 2004). Once rules become harmonized with their environment, socio-technical system of manufacture and use become stable. Geels (2004) define set of these rules, which determine the stability or instability of a socio-technical system of manufacture and use, as regime. For analytical purpose, we have segregated rules in four analytically distinct categories of a regime-technological/product regime, science regime, policy regime, and user regime.

Table 5.1 shows the different types of rules operating in the four analytical distinct categories of regimes. The coordination of these rules determines the stability or instability of technical regime of wooden sleepers. We have identified following five major rules, which sustained the use of wooden sleepers in Indian tracks-a) market rules and laws b) formal procurement program c) formal technical regulations d) formal research programs e) user practices.

**a) Monopoly of Wooden Sleeper Market**

Railways had monopoly on sleeper market especially on wooden sleeper business. Railways in collaboration with Forest Department dominated the domestic market of sleepers using fixed price contracts and quota system. These contracts, signed between railways and state forest departments, established a procurement mechanism for securing supplies of durable sleepers at below market price. For example, IR was paying approximate Rs 28 for one piece of Sal Sleeper against market price of Rs 32 in 1960's. This arrangement of market rules, where prices and quantities were fixed, favored the use of wooden sleeper in Indian tracks.

Railways monopolistic and Public sector characteristics influenced the sustained use of wooden sleepers in Indian tracks. Railways asserted their monopoly on sleeper market by enforcing fixed price contracts. Monopolistic behavior of railways suppressed attempts to raise the prices of wooden sleepers. Since, IR is under public sector management, government policies have direct bearings on its functioning and operations. For example, railways development plans were linked with the national Five Year Plans, which determined the growth targets for Indian Railways. Under national planning a fixed quantity of timber was reserved for use in Railways (NAI, 1957). Our analysis of procurement terms and conditions of wooden sleepers reflects that contractual arrangement between railways and state forest departments were strongly biased in favor of Indian Railways. The central features of these contracts were fixed price and fixed quantity.

### Table 5.1 - Technical Regime of Wooden Sleeper Technology[12].

| | Formal/Regulative Rules | Normative Rules | Cognitive Rules |
|---|---|---|---|
| Technological and Product regimes (Research Development production) | >Technical standards, product specifications (e.g., architectural dimensions, gauge size, Weight, chemical & physical treatment type)<br><br>>Functional requirements (architectural dimensions as decided by IR), expected capital return rate for investments. | >Testing procedures (e.g. Visual inspection method for wooden sleepers | >problem solving strategies (e.g. increasing sleeper density for track reinforcement)<br><br>>Classifications (e.g. durable and non durable wooden sleepers based on field experience) |
| Science Regime | >Formal research programs (e.g. FRI research wooden sleeper technology) | | |
| Policy Regime | >Formal regulations of Technology (e.g. Various track committees have defined the quality and quantity of wooden sleepers to be used in given traffic conditions)<br><br>>Procurement Programs (e.g. procurement programs were designed in such a way that a fraction of total sleeper budget was allocated for developing logistic and wood working infrastructure. | >Policy goals ( e.g. Railways plans were based on the annual transport demand projected by Planning Commission) | >Technical problem agenda (e.g. Priority of unigauge over track strengthening) |
| Users, Market and Distribution networks | >Construction of markets through law and rules (e.g. wooden sleeper market governed by fixed price and annual timber quota, as decided by IR and GOI).<br><br>>Product quality laws (e.g. wooden sleepers quality was determined by visual inspection, timber species type, mechanical strength, specific weight)<br><br>>Safety requirements (e.g. less stability of wooden sleepers could not hold axial weight beyond 25 GMT capacity, thus were unsafe on trunk routes) | | >User Practices (e.g. IR Engineers practices manual alignment of track, which needed flexibility in the use of sleepers) |

Source: Compiled by author based on Geels (2004).

[12] Based on the theoretical framework proposed by Geels, 2004

Railways dominated the trade with the “First Right to Refuse”, mentioned in the price contract signed with State Forest Departments. In one such case where IR used this clause is when IR refused 99% of the sleepers manufactured by Kerala Forest Department in a season (NAI, 1969). Furthermore, policies of Government secured a portion of annual timber production exclusively for Railways. In addition to this, Railways dictated the sleepers’ price with a separate fixed price contract with each State Forest Departments. It seems reasonable to assume that sleeper market was dominated by the Railways; and Forest Departments were operating under the norms, such as technical standards, fixed price structures, as set by the Railways. Monopoly of IR on the construction and maintenance of railway tracks made it the sole consumer of wooden sleepers. Therefore, it seems that the monopolistic public sector character of IR had a strong bearing on the development of sleeper technology. As we have discussed in chapter 3 that few infrastructure projects attempted to procure durable wooden sleepers by offering higher prices, but IR as a policy suppressed competition to keep the prices in check . As a matter of policy Railways always had a strong control over wooden sleeper market, which secured supplies of best timber available in Indian forests for sleeper manufacturing. Secured supplies at fixed price below market rate helped Indian Railways to sustain use of wooden sleeper in Indian tracks.

**b) Railway’s Procurement Programs for Wooden Sleepers**

In early period of railway development in India, Railways did not have any central procurement agency, which could control the prices at national level. But with the nationalization of railways and abolition of “guarantee system”, railways started to collaborate for securing the supplies of wooden sleepers. IR for the purpose of procurement and distribution of wooden sleepers established a central procurement group coordinating with the union and state forest departments. Tradition of organizing annual sleeper conference, which was attended by the General Managers of Indian Railways’ for reviewing and monitoring of sleeper situation, further highlights the importance of wooden sleeper procurement in Indian Railways (NAI 1957, 1965, 1966, 1968, 1969)). IR’s policy was first to satiate sleeper’s need first by procuring wooden sleeper and then bridging the supply-demand gap by using metallic sleeper (IR, 1957). Because of first priority accorded to wooden sleeper, annual sleeper conference commanded high importance for IR planners. Central procurement programs were designed to maximize supplies of durable timber. Through these programs railways invested in the development of those physical infrastructure, which could augment the supply of durable timber.

In chapter 3, we discussed about the geographical expansion of Forest department for acquiring new species for sleeper manufacturing. Exploitation of new sources of timber supplies needed logistic and wood working infrastructure. The quantum of expansion of logistic and wood working Infrastructure could be estimated by comparing the potential sources of timber supply in 1926 and actual forest area supplying timber in 1961 (Compare table 3.2 and 3.3). By 1961, almost all of the forests marked as "potential source" of timber in 1926 (table 3.2) start supplying timber for sleeper manufacturing. In fact by 1920's, mainly lower Himalayan forests in Punjab and United Province were supplying timber, whereas by 1960's many new forests such as Nepal, Assam, Mysore forests were included to increase supply base. This continued expansion of timber supply sources built physical infrastructure necessary for harvesting, seasoning, and logistics. Expansion of physical infrastructure created increasing returns for wooden sleeper by improving the timber supply.

The continuous demand of durable timber prompted Railways to push Forest Department to explore deep interiors of Lower Himalaya. To sustain their operations in deep forest, Railways and Forest Department built logistic infrastructure, treatment plants, and wood working and R&D laboratories. Railways was involved directly in building and managing the logistic infrastructure and treatment plants; other kinds of infrastructure such as wood working workshops at site, R&D laboratory were built and operated by Forest departments. Price contracts of wooden sleeper had a component named as "development charges", which were in the range of 10-12% of the total cost of wooden sleeper (NAI, 1957, 1965, 1966). These development charges in the price structure were intended for developing the wood working infrastructure at timber harvesting site. Railways at many occasion offered higher "development charges" as an incentive for luring Forest contractors to enhance the total output of durable timber.

Unruh (2000) argues that capital investment in physical infrastructure is "Sunk Investment". Firm, which has invested in infrastructure, intends to seek revenue from the future utilization of the assets. Expectations of future revenue from the infrastructure built for serving the production-consumption activities of a particular technology deters the chances of emergence of other competing variants.

Indian Railways, through procurement mechanism of wooden sleepers, invested substantially in logistics, wood working infrastructure, and treatment plants. Railways capital investment in building physical infrastructure created expectations for future returns on built infrastructure. These expectations of return on capital invested prompted railways to keep using wooden sleepers on railway tracks.

**c) Standardization of Technical Standards of Wooden Sleepers**

We discussed in chapter 2 that as user base of a technology increases, various technical standards regulating production, distribution, and consumption activities evolve, which ultimately contribute towards the stability of technical regime of that technology. Various technical standards of wooden sleepers regulating their physical dimensions, preservation techniques, maintenance schedules evolved over a period. These standards are considered as "technical infrastructure", which exhibits the inertia for technical change (Unruh, 2000).

Unruh (2000) defines formal regulations of technology as the inter-industry forces of coordination such as establishing standards and developing design specific supply networks Growth of interconnected industry network requires high degree of coordination that can be achieved by developing codified conventions and standards. These standards reduce the uncertainties that can hinder the investment and tends to institutionally lockin key characteristics of dominant variant. Katz and Shaprio (1985) argue that the dominant variant of a technology is often the strategic sources for creating the lock in conditions because new technology requires new standards and elimination of existing standards, which were set around dominant design.

We observed in previous section that how railways' monopsony in sleeper market evolved into a centralized procurement mechanism, which helped to sustain the use of wooden sleepers. Gradually, various technical specifications, quality norms, and testing methods evolved for high degree of coordination among railways and state forest departments. In 1982, Bureau of Indian Standards (BIS) published "Specification for wooden sleeper for railway tracks[13]", which mentions the types of defects, inspection methods, timber grading mechanism in great details.

[13] https://law.resource.org/pub/in/bis/S03/is.10394.1982.pdf accessed on July 18, 2016.

For example, BSI has developed a “composite sleeper index”, which takes various different material properties of wood such as elastic strength, moisture content, species type, visual defects etc into account for grading wooden sleepers. However, earlier mostly timber species and visual inspection were the key determinants for grading wooden sleepers. In other words, over the period, standardization of inspection and grading mechanism reduced the uncertainties in the behavior of wooden sleepers. Composition of “Timber Sectional Committee”, which drafted the 1982 BIS standards for wooden sleepers, shows that Indian Railways, FRI, and, Forest Departments participated in this standards setting exercise.

The activities of sleeper manufacturing process including species identification, cultivation, harvesting, wood working, seasoning, logistics, and procurement were divided between Railways and Forest Departments. For example, Railways was directly managing the logistics, procurement and distribution, operations of treatment plants, and formulation of technical standards, whereas Forest Department was responsible for timber species identification, cultivation, wood working, seasoning, and R&D on impregnation techniques. Owing to differential responsibilities, it reflects that manufacturing and R&D of wooden sleeper was managed by Forest Department whereas Railways was chiefly holding the financial and regulative aspects of the technology comprising safety and quality standards. However, the separation of responsibilities did not mean that either railways or forest department defined standards, rather both participated. For example, the physical dimensions of wooden sleepers were determined by gauge type and wood working capability of forest contractors. Since, selection of gauges was decided by Railways, Railways influenced the technical specification of manufactured wooden sleepers. Similarly, wood working capabilities determined the maximum length and thickness of wooden log that could be worked upon in a wood working machine. In other words, strong interconnection between Railways and Forest Departments developed various codified conventions and standards to reduce the uncertainty of transactions in sleeper market. As we have discussed in chapter 3 that Railways frequently had difference of opinions with State Forest Departments over the quality of wooden sleepers (NAI, 1967; Unasylva, 1949, 1953, 1968). Since, field quality inspection methods for wooden sleepers are mostly visual, inspection results are likely to be influenced by the experiences of Quality Inspectors. In this context, BSI standards for wooden sleeper (1982) codified these inspection methods with the involvement of more the one dozen organizations including Railways, Ministry of Agriculture, State Forest Departments, FRI, Wood based Industries, etc. These codified standards not only clearly articulate the inspection guidelines for Railways' inspectors but also provide detail list of instructions for Forest Departments to follow before and during inspection. As Unruh (2000) suggests that codified conventions and standards, evolved to reduce the uncertainty, tend to institutionally lock in the characteristics of dominant variant. Thus, we argue that the technical standards and conventions created lock in conditions, which sustained the use of wooden sleepers.

**d) Improving the Performance of Wooden Sleepers**

Geels (2004) argues that dominant variant of a technology gets preference in R&D budget and R&D efforts are directed for improving its technical and economic performance. In other words, R&D programs for a technology are often concentrated to increase the performance of its dominant variant. Forest Department as early as in 1880's started to map timber potential in colonial India. With the establishment of Forest Research Institute (FRI) Forest Department's research efforts on wooden sleepers got a boost. In chapter 3, we discussed various research initiatives, especially related to the development of seasoning and preservation techniques, undertaken by FRI. These research programs were mostly concentrated on improving the technical performance of wooden sleepers by increasing life cycle. As a matter of fact, FRI successfully improved wooden sleeper's life from 6-7 years in 1870 to 12-13 years in 1920's (Warr, 1926; NAI, 1968). Incremental innovations in wooden sleeper technology such as improving life cycle, providing mechanical means for increasing strength set higher standard of sleeper's performance in Indian tracks. Tushman (1986) discusses that higher standards of performance achieved due to incremental innovation make it difficult for new technology to emerge in the existing regime.

We observed that R&D efforts for improving the performance of wooden sleepers did not come from railways rather it was Forest Department which invested in R&D of wooden sleepers. Railways invested in the R&D of metallic sleepers and concrete sleepers but had not invested much in the R&D of wooden sleepers. It is interesting to note that the general hypothesis, which suggests dominant variant of a technology will get preference in the allocation of R&D budget, is not applicable on Indian Railways. As we can see that IR did not invest much in the R&D of dominant variant of sleeper technology, rather R&D on wooden sleepers was carried out mainly by Forest Department. FRI's research efforts on wooden sleepers improved their performance, which ultimately sustained the use of wooden sleepers despite facing challenges from metallic and concrete sleepers.

**e) User practices of Track Maintenance**

As we discussed in chapter 2 that major technological shifts are either competency destroying of competency enhancing. The former requires new skills, knowledge and operational practices and alter the set of relevant competencies within a product or process class. For instance, technological shift from wooden sleepers to metallic/concrete sleepers demand new technical and engineering skills, which are qualitatively different from those necessary to manufacture and operate wooden sleepers. For example, concrete sleepers are heavier and could not be handled manually and needed power equipment for laying and replacements. These discontinuities are fundamentally different from the existing dominant technology in terms of skills and knowledge required to manufacture and operate the new products. Tushman (1986) argues that competence-destroying innovations are not built on old knowledge and skills, thus old skills are rendered obsolete. Strictly speaking, dominant technologies resist the introduction of those competing variants, which are competencies destroying.

Geels (2002, 2004, and 2010) argues that user behavior is a determinant of whether competing variants would replace existing dominant variant or not. Three different variants of sleeper technology offer different degree of freedom[14] in use at site. All variants have different maintenance practices constrained by various technical factors such as weight, life cycle etc (NPTEL[15]). Wooden sleepers being the dominant variant of sleeper technology, railway engineers were accustomed to their use and maintenance practices. For example, Different Track maintenance methods in Indian railways were manual with almost no use of any mechanical powered machines since its inception to 1980's (Railway Budget, 1982). Manual method is essentially a hit and trial method, which needs considerable flexibility in use of sleepers at site (Agarwal, 2007). Railways' engineers were accustomed to the manual method of

[14] Degree of freedom in use indicates the flexibility that a component offers in its use. For example, wood as a construction material can be altered easily according to site requirement offers the higher degree of freedom in use than concrete could offer.

[15] National Programme on Technology Enhanced Learning (NPTEL) http://nptel.ac.in/reviewed_pdfs/105107123/lec11.pdf accessed on June 18, 2016.

track alignment. Wooden sleepers being the functionally technically best available material allowing flexibility in use became the preferred choice of engineers'. Concrete sleepers, which were heavier than wooden sleepers, could not be handled effectively at site with manual methods of track maintenance. Thus competency destroying nature of concrete sleepers inhibited its emergence in the existing technical regime of wooden sleepers and ultimately prolonged the use of wooden sleepers.

### 5.3. Emergence of PSC Sleepers

Railway infrastructure evolved through four different phases in India- construction phase, institutionalization, nationalization and railways in Independent India; each phase is characterized by the political economy of that time (Kerr, 2012). In other words, railway as a technical system operates within the boundary conditions set by the political, social, and economic conditions of the nation state prevalent that time. These boundary conditions greatly influence the rules that operate the Indian Railways. In the analysis of our first question we analytically distinguished these boundary conditions as technological regime, science regime, policy regime, and user networks. Rules governing railway track system evolve through the negotiation with each of these four analytically distinguished regimes. Coordination among these rules determines the "stability" or "instability" of the technological system of Indian Railways.

However, the mere stability or instability of a regime does not ensure the selection or rejection of an alternative technology in the existing technological regime. Geels (2004) highlights the two other conditions for the successful emergence of an alternative technology in order to replace the existing competing technology. First is the development of new technology at niche level, which determines the initial technical and economic performance of that technology. At this level, new technology is worked upon to make it compatible with the existing formal standards and competitive with existing performance parameters. Second condition is the opening of "window of opportunity" such as war, climate change at landscape level. It might be possible that a new technology had developed to an extent where it could compete with existing technologies. But in the absence of opportunity window successful emergence of new technology is unlikely. These three conditions-developments of a new technology, instability in existing technological system, and opportunity window-are analyzed at niche, regime, and landscape levels.

In the subsequent sections we discuss following factors, operating at multiple levels, which influenced the IR's decision of transition from wooden sleepers to PSC sleepers.

1. Technology import and development (niche level)
2. Supply-demand imbalances and lowering of quality standards for wooden sleepers (user regime)
3. Problem setting agenda for solving tracks' capacity constraints (Policy regime)
4. Increasing demand of high traffic (Policy regime)
5. Judicial Intervention (Landscape level)

### 5.3.1. Development of PSC sleepers at Niche level

Wooden sleepers, since their first use in Indian tracks, remained the first preference of railways' engineers. Though, metallic sleepers were in use in 49% of the Broad gauge tracks, but high traffic density routes[16] were laid with mostly wooden sleepers (Marriot 1928, NAI, 1966, 1968, 1969). After Independence, RDSO developed few successful designs of metallic sleepers such as CST-9 sleepers for heavy traffic routes also, but development of electric signaling in Europe rendered metallic sleepers obsolete (Agarwal, 2007). Electric signaling works on the principle of insulation between two parallel rails. Since, metal is a very good conductor of electricity, metallic sleepers were unable to insulate iron rails. Therefore, metallic sleepers were technically incompatible with the electric signaling system. From 1970 onwards the prospects of metallic sleepers in high traffic density routes diminished especially where electric signaling system was planned in near future[17]. Other limitations with metallic sleepers were severe import restrictions and inelastic supply of pig iron for sleepers' manufacturing. These limitations thwarted the possibilities of widespread use of metallic sleepers on Indian tracks. The only other technological solution available that time was PSC sleepers. As we have discussed that concrete sleeper technology was imported from Switzerland with the intensions for developing indigenous capabilities. Railways efforts for indigenizing concrete sleeper technology resulted in the annual production of a few lakh PSC sleepers annually by 1968. Though, the production capacity of PSC sleeper did not show significant increase from 1968 to 1985, incremental improvements

[16] High density routes include mainly trunk routes connecting Mumbai, Chennai, Kolkata, and Delhi.
[17] In order to solve the problem of incompatibility insulation pads were developed, but these pads did not prove effective in Indian weather.

kept happening in RDSO laboratories mainly focusing on reducing the weight and increasing the strength. Incremental improvements in the design of PSC sleepers increased their technical performance. From 1985 to 1990, annual production of concrete sleepers increased 10 times from 3.5 lakhs in 1985 (IR Budget Speech, 1990). Thus it seems that railways kept developing concrete sleeper technology for two decades and subsequently, could scale up the PSC production exponentially in couple of years.

Tushman (1986) defines niche as the early stage in the development of a technology when various R&D programs are run to improve its performance and compatibility with existing standards. When a competing variant of an existing dominant technology strives for securing larger user base, various incremental changes are necessary to improve the performance of niche technology to match performance of dominant variant by aligning characteristic of competing variant with existing formal standards of dominant technology. Various incremental innovation such as reducing weight, increasing vibration properties, improving ash content happened in PSC sleeper technology from 1950's to 1980's. Improvement in the performance level could be estimated from the evidence that Indian Railways had secured and executed various export contracts supplying concrete sleeper to railways of Saudi Arabia, and Iraq (IR Budget Speech, 1982). World Bank's reports (1988) on modernization of Indian Railways depicts that the technical and economic performance of concrete has improved to an extent that where it could substitute wooden sleepers.

It seems reasonable to locate analytically the development of PSC sleeper technology at niche level, which is the necessary condition for transition from wooden sleeper technology to PSC sleeper technology.

### 5.3.2. Supply-Demand Imbalances

We discussed in chapter 3 how engineers defined the problem of timber "scarcity". The meaning of scarcity is not without qualification-first, short supply was of only durable timber, and second, for IR scarcity did not mean absolute dearth of timber but the relative difficulty in accessing durable timber. However, barring these qualifications, engineers framed the debate of timber scarcity in absolute term, even without knowing the timber potential of Indian Forests. This conceptualization of "timber scarcity" as absolute scarcity of all types of timber retained its meaning since its first use in 1880. As the problem of "timber scarcity" gained currency among railway operators in India, search for alternative sleeper material begun. First alternative that is metallic sleepers could not substitute wooden sleeper because of technical incompatibility with electric signaling. Consequently, the debate of timber scarcity resurfaced in railways' policy documents. Another search for alternative material has begun, which culminated with the import of PSC sleeper technology from Europe.

Study of annual Timber advisors' reports from 1960-1970, reflects that Forest department could supply only 50-70% of the target set for durable timber whereas for non durable timber there was no shortage. However, railways' engineers retained the colonial conceptualization of "timber scarcity" and kept highlighting the issue of timber scarcity. Engineers were so obsessed with the notion of scarcity that some of them even suggested the appropriation of timber at war level emergency[18] (NAI 1957). Since, wooden sleeper market was monopolized by Indian Railways, "scarcity of particular kinds of timber" translated into the general scarcity of timber with ease. This unqualified notion of "timber scarcity" played a role in framing the development of competing variants.

It is important to note that IR experimented with PSC sleeper technology in the wake of short supply of durable timber. IR has to import 5 lakhs cubic feet hard wood of worth Rs. 75 Lakhs in 1965 for various purposes, particularly for special sleepers to be used at bridges, turns etc (NAI, 1966). Since access to foreign reserve was restricted in Planning Years, finance ministry repeatedly denied railways to import timber for track sleepers. Therefore, railways were compelled to reduce sleeper quality norms to improve domestic sleeper supplies. Railways' official records (NAI, 1957, 1964, 1969), reveals that technical standards of wooden sleepers were very relaxed compared to those of American and European railways. Demand-supply imbalances of wooden sleepers were further exaggerated by IR's decision to increase the sleeper density on heavy traffic density routes from 1400 to 2100 sleepers per mile. Though, increase in sleeper density on high traffic routes strengthen the track but simultaneously increased the demand of durable timber per mile track kilometer. Increased demand worsens the supply situation of durable timber. This imposed a pressure on IR to lower its inspection standards in

[18] During WWII, Forest department was instructed to supply railway sleeper on emergency basis, as it was considered necessary to maintain tracks without interruption for transporting military supplies.

order to improve supply situation by allowing lower grade timber for manufacturing sleepers. This challenged the dominance of wooden sleeper as a dominant design in sleeper technology.

The first preference accorded to wooden sleepers by railways' engineers always kept durable timber in demand; and railways met this demand by lowering quality norms of wooden sleepers after 1960's. Lowering of quality standards in order to secure more supplies acted as an impediment for the further engineering improvements of wooden sleeper. If we take the technical performance parameter as a variable for measuring a positive feedback, we observe no significant changes in the performance characteristic of wooden sleeper after 1960's. Incremental innovations in sleeper technology kept happening but largely for improving life cycle of wooden sleepers. Increasing the thickness of wood for enhancing load capacity was not an illustrated method in sleeper design. For instance, for increasing the capacity of the track, designers were inclined to increasing the sleeper density in a track rather than increasing the size and weight of the sleeper. This stagnation in the possibilities for improving the strength of wooden sleepers allowed other competing technologies to emerge and expand in the technological system of railways. Thus wide use of wooden sleepers exhibited increasing returns whereas supply constraints of hard wood disrupted the incremental improvements of performance criteria, which is characterized by the lowering of the quality inspection norms for procurement. These counter currents, which limit the increasing return associated with a dominant design, generated a tension in the existing technological regime and open a window of opportunity for competing technologies to come out of niches.

### 5.3.3. Changes in the Technical Standards of Tracks

Technical specifications of the Railway system in India were influenced and sometime decided at the various levels of decision making body. For example, the map of a particular route between two stations was often decided at the level of chief engineer considering the local geography (Kerr, 2012). But that was not the case with every technical specification where engineers could enjoy the full autonomy. The debate on the selection of track gauge is the example where the decision was taken not by engineers but by a parliamentary committee. The gauge size 5’6” was chosen against the background of gauge debate in Britain[19]. Debate culminated with the adoption of 5’6” gauge for Indian railway system. However, colonial government in 1901 changed its regulations and allowed private companies to construct meter gauge (3’3’’) tracks also. Logic proposed for allowing multiple gauges was based on the construction cost of broad gauge. Construction cost for 5’6” gauge was 18000 British pounds, which was very high, and many regional or native states under the patronage of colonial government were unable to afford. Therefore, a more economical meter gauge (3’3”) was allowed to construct in 1880’s (Kerr, 2012). However, this decision of allowing multiple gauges was later reprimanded by many commissions, constituted in 1908 and 1921. After Independence, in 1971, issue of break of gauge was discussed again and uni-gauge was adopted (Commentary, EPW, 1994).

After Independence, policy makers thought of railways as medium for fulfilling the transport demands generated from the increased government investment in the economy. However, within one decade, Railways struggled to cope up with the growing transport demand, especially in bulk commodity transport. At this juncture, policy makers hypothesized that railway transport capacity is restricted due to break of gauge, and, consequently, invested more in gauge conversion than track strengthening.

As we have learned in chapter 3 that railways was using wooden sleepers on approximately 50% of broad gauge routes and 75% of meter gauge routes. In addition, FRI’s research programs on wooden sleepers were engaged in the development of treated sleepers for meter gauge sleepers mainly. Implementation of uni gauge policy gradually converted meter gauge tracks into broad gauge. Meter gauge tracks constituted 45% of total running length in 1970’s, which subsequently dropped to only 31% of total running kms in 1990’s (Saxena, 1991). These unigauge projects ultimately shrink the user base of wooden sleepers in meter gauge tracks. This reduced importance of meter gauge and consequently low demand of wooden sleepers for meter gauge might have reduced FRI’s research efforts on treatment processes. However, we do not have any data to support the hypothesis that with decreasing user base of wooden sleepers in meter gauge tracks led FRI to cut back on its research efforts on wooden sleepers. The decrease in user base

[19] In the middle of 19th century, there was a debate among British engineers over the selection of gauge for India. Some were in favor of 4’8” and others were arguing for 7 inches width of track, which led to a debate on size of track gauge (Kerr, 2012).

of wooden sleepers on meter gauges ceases the increasing returns associated with the use of wooden sleepers. We conclude that in the absence of increasing returns, dominance of wooden sleepers was soon challenged by emerging concrete sleeper technology and created instability in the existing technical regime of wooden sleepers.

### 5.3.4. High Traffic density

IR introduced Pre-stressed concrete sleepers (PSC) and conducted first successful trial on Delhi-Ghaziabad route in 1966. The production technique of PSC is completely different from that of wooden or cast iron (CI) sleepers in terms of raw material and production process. The competency developed in manufacturing of wooden sleepers rendered obsolete and does not contribute in the production process of wooden sleeper. However, the functionality and interconnection of sleeper in general with the other technologies in the track system is same for PSC, wooden and CI sleepers. Though, the performance of all three competing technologies may vary according to traffic density on a particular route. Largely PSC sleepers' performance in High density route (with carrying capacity more than 20 GMT) is better compared to those of wooden and CI sleepers (Track Committee report, 1982). The average life cycle of a concrete sleeper in 1970's was 40 years and that of a wooden sleeper was 15 years. In other words, approximately 3 times fewer efforts are required for maintain a track lay with PSC sleeper than efforts required for maintain wooden sleeper tracks. Since, high density routes are often busy with tight schedule for maintenance activities, less maintenance could yield in the better management of track asset. Gross metric tonnage in high traffic density routes increased by 140% from 1960 to 1990. Thus the same technological discontinuity, that is PSC, exhibits competency destroying in production of sleepers whereas competency-enhancing in track management and utilization. At the technological regime level, these two different feedbacks, one positively helping new technology to come out in dominant use and other holding its emergence by negative feedbacks, define the context of the emergence of a niche in a monopolistic public firm.

### 5.3.5. Judicial Intervention: Landscape factor

Series of legislations (e.g. conservation act 1980, forest policy 1988) passed in Parliament changed the preferences of Forest Department, as then new forest policy emphasized on the principle of conservation. Guha argues that National Forest policy 1988 set the new benchmark for Indian Environmental policy. It had conservation as its fundamental principle rather than focusing on resource exploitation as envisaged in previous policies. Niyati (2015[20]) argue that the outcome of these policy changes resulted in the outpour of environmental petitions. One such Public Interest Litigation (T.N. Godavarman Thirumulkpad vs Union of India) resulted in judicial intervention on the use of wooden sleepers in railway tracks. Supreme Court in its judgment banned on the manufacturing and use of wooden sleepers for track construction, which prompted railways to switch from wooden sleepers to concrete sleepers (IR Budget, 1990). Subsequently, railways in 1996 decided to adopt policy of track concretization.

### 5.4. Locating FRI in Transition Debate of Sleeper Technology

Our analysis of first and second questions categorizes factors influencing technical change at three abstract levels. The purpose of abstract classification of levels into niche, regime, and landscape is to segregate the factors according to their level of operations. Theoretical guidelines for determining which factor operates at what level are not very clear. Tushman (1986) defines niche as a “protected” environment where a competing variant improves its performance to the performance level of dominant variant through various formal research programs. For instance, development of CST-9 metallic sleepers and development of PSC sleepers are categorized at niche level because all three developments were carried out in the “protective” environment provided by Indian Railways and supported by formal research programs carried out by RDSO. Geels (2004) define regime as the set of rules governing the manufacture and use of a technology. For example, public investment in coal and steel industry during first three five year plans spurred the demand for railway infrastructure to facilitate bulk commodity transport. This increased demand opened a debate on the strength of Indian tracks. Subsequently, track modernization plans got attention among policy makers. Theory classifies this example operating at policy regime level which influences the technological change in track system. Landscape level is often attributed to those factors, which are either exogenous to the present socio-technical system or does not have any direct bearing on it. For instance, the impact of WWII on the development of concrete sleeper technology is categorized as landscape factor. MLP approach sees war as an external factor; and its relation with the existing technological regime

[20] http://www.isca.in/IJSS/Archive/v4/i4/2.ISCA-IRJSS-2014-327.pdf accessed on June 30, 2016

should be seen as an opportunity allowing conditions for the emergence of new technologies. Then we ask a question at what level the role played by Forest Department in sustained use of wooden sleepers on Indian tracks is understood.

Forest Department played a significant role in the development of sleeper technology for Indian tracks. Forest department was engaged in the R&D of wooden sleepers, setting up of technical standards for sleepers, and formulation of new forest policy. Various efforts of Forest Department may be considered analytically operating at multiple levels, niche, regime, and landscape. In following sections we will discuss the role of Forest Department to sustain the use of wooden sleepers.

### 5.4.1. Technical Standards of Wooden Sleepers

Before the advent of Forest Research Institute in the early decades of 20$^{th}$ century, sleeper performance was solely the function of quality of timber species used for manufacturing. In other words there were no measures for increasing the technical performance of wooden sleepers during their manufacturing process. The major criteria for categorizing sleepers were derived from the taxonomy of timber species used for wooden sleepers. Thus, the common names of timber species come into use for distinguishing sleeper types such as Sal sleepers, Teak sleepers, Deodar sleepers etc. However, the situation changed as Forest Department adopted seasoning techniques, which improved the quality of wooden sleepers. Subsequently, new categorization of wooden sleepers emerged, for example, *Green* sleepers and seasoned sleepers. Similarly, with the development of preservation techniques new words defining the quality of wooden sleeper added in the dictionary of railway engineers- treated and non treated sleepers. Forest Department by deploying new techniques for seasoning and preservation considerably improved the performance characteristics of many timber species. The Forest Department offered Railways with a wide range of products ranging from highest quality of treated durable sleepers to the lowest rung of untreated non durable sleepers. As we have discussed in chapter 2 that technical standards are tends to bring some sort of technical uniformity among multiple variants by defining the limits of acceptable performance. Competing variants are supposed to conform to this range for even being considered for serious competition to the existing dominant technology. Forest Department, thus, influenced sleeper standards by widening the possible performance characteristics of wooden sleepers.

The prominent role of Forest Department in formulating the technical standards of wooden sleepers and helped to sustain their use in railway tracks. Table 2.1 show that MLP approach assumes formal rules of technical standards to operate at the level of product regime. Thus, we consider that relation of Forest Department and Indian Railways formulating technical standards of wooden sleepers should be understood to operate at product regime of wooden sleepers.

### 5.4.2. Development of Treated Non Durable Wooden Sleepers at Niche Level

Indian forests are a great mixture of species. With few exceptions, important timber trees of India do not grow in large pure strands. Though, there are good qualities of timber tress in Indian forests, but most of them are placed in remote and difficult terrain, which make extraction on a large scale infeasible (Rodger, 1925; Stebbing, 1925). As a matter of practice in Forest Department, best of the timber was reserved for Railway sleepers. In other words, Railways demand for durable timber was a motivating factor for Forest Department to venture deep in forest for timber harvesting. Since, important timber trees in Indian Forests do not grow in pure large strands, harvesting in deep forest would be economical if whole plot including durable and non-durable timber is harvested rather than harvesting only few selected trees. In the earlier case fixed infrastructure cost would spread over high volume of timber harvested. However, the untreated non-durable sleepers hardly had any demand in railways. Forest Research Institute invested systematically in the development of preservation techniques (e.g. seasoning, creosote) for improving the performance of wooden sleepers, which yielded significant outcomes. More than 70% of tracks were laid with wooden sleepers of non-durable types in 1928. This pattern almost remained same till 1970's, when project unigauge was announced.

It seems that harvesting principles as practiced in Indian forestry had influence on the development of technical standards of meter gauge wooden sleepers by defining their treatment process. For example, the thickness of creosote on treated sleepers was developed and decided by FRI not IR, on the basis of laboratory experiments conducted at FRI, Dehradun. In this case, we have seen that how the economic logic of forestry influenced the technical standards of wooden sleepers in Indian Tracks at product regime level. As we discussed in chapter 2 that formal technical standards and quality norms are understood at product regime and policy regime level respectively.

In chapter 3, we have discussed the research programs of FRI on wooden sleepers in detail. FRI actively contributed in developing the taxonomy of timber species, designing mechanical means for improving sleepers' strength, learning seasoning techniques, installing chemical treatment plants for impregnation. Collective outcome of these efforts reflects in the generation of a reliable characteristic of manufactured wooden sleepers. Reliability of sleepers is very crucial for safe operations of railways. Failure of sleepers in holding together two parallel iron rails could result in catastrophic accidents (Agarwal, 2007). Without knowing the physical and chemical properties of Indian Timber, it would not have been possible to manufacture a range of reliable wooden sleepers. We argue in chapter 2 that when a competing variant of an existing dominant technology strives for securing larger user base, various incremental changes are necessary to improve the performance of niche technology to match performance of dominant variant by aligning characteristic of competing variant with existing formal standards of dominant technology. Forest Department especially FRI is credited with incubating treated sleepers at FRI, Dehradun, which find their application in meter gauge tracks.

In brief, Forest Department not only conceptualized the concept of sleeper treatment with creosote but also developed it in the competition period. Thus, it seems clear that Forest Department influence on the technological regime of wooden sleeper should be understood at niche level also.

### 5.4.3. National Forest Policy

We discussed in section 5.3.5 that in 1980's New Forest Policy shifted the fundamentals of forestry from exploitation to conservation (Guha, 1992). The advent of New Forest Policy coupled with other legislations altered the criteria for determining the performance of a wooden sleeper by adding environmental impact as criteria for comparing competing variants of sleeper technology. Our analysis of Railway Budget Speeches (from 1980 to 1990) reflects that railways' accepted the arguments of environmentalist that wooden sleepers should be re evaluated considering severe deforestation caused by them. Change in forest policy challenged the established performance criteria of wooden sleepers and proved them to be second to concrete sleepers at least in environmental performance.

In previous three sections, we discussed the role of Forest Department to sustain the use of wooden sleeper at two analytical levels-niche and regime levels. As we have discussed in chapter 2 on theoretical framework that influencing factors are classified in one of three abstract categories. But our analysis finds that it is perfectly possible that a particular factor may operate at multiple levels, similar to our case where Forest Department influenced sleeper technology on at least two levels of analysis-niche and regime.

Another important proposition that emerges out of this discussion is that the conceptualization of niche technology as something which replaces the existing technological regime is not valid in all cases. For example, development of treated sleepers, which we argue was a niche technology, was not meant for replacing the wooden sleepers rather it sustain the use of wooden sleepers in Indian tracks by increase the performance of wooden sleepers. On the other hand, development of PSC sleepers at niche level was clearly an effort for substituting wooden sleeper with more advanced technology. The present definition of niche as proposed by Tushman (1986) and Geels (2004) qualifies both development of treated sleepers by FRI and development of PSC sleepers by RDSO as niche, despite both having opposite purposes-former enhancing the existing technological regime of wooden sleepers and later competing with the existing technical regime of wooden sleepers.

# Chapter Six

# Conclusion

MLP has not been used in the context of a developing country, particularly in a planned economy where government coordinates between agencies. This was an attempt to use MLP in a complex technological system in a developing country context.

Wooden sleeper technology, being tested and tried in Europe for two decades before its introduction in India, was used for construction and maintenance of railway tracks in the early period of Railways development. However, perceived scarcity of durable timber pushed Railways in 1880's to import metallic sleeper for use in tracks. After that, till 1980's both metallic sleepers and wooden sleepers were in use in Indian Railways Though wooden and metallic sleepers both were in use on Indian tracks, former variant remained the dominant technology. Despite, globally railways shifting from wooden to concrete sleeper, which was highlighted by policymakers in repeated Railway Reports pointing for change, we find the reasons those restricted the adoption of PSC sleeper for 40 years. There was an alternative technological trajectory that sustained even in the face of a quality wood shortage. As the practice continued, it grew a system of physical and technical infrastructure around it to strengthen the dominance of wooden sleeper. This argument, we find, is quite in line with MLP. However, we identify the reasons for change could also be understood both in landscape factor and cognitive rules of track maintenance. The current study reveals that these factors reinforced each other and sustained wooden sleeper regime. As it is said in developing country context, coordination between agencies is done by government at a higher level, which helped to sustain the use of wooden sleeper. Here we observe government's role in technological change against MLP approach where government and technological regime operate at the same level.

After Independence, heavy investment in coal and steel sector changed traffic patterns on major routes which prompted Railways to develop PSC sleeper technology. However, the mere development of new technology does not guarantee its successful emergence in the existing technological system. Various other dimensions such as government regulations, user practices, formal research programs, etc. also influence the diffusion and adoption of new technologies in the existing technological system. Geels (2014) highlights that policymakers and MLP scholars dealing with technological transition are often tends to focus more on the development of new technology at niche level. Stability of an existing regime is often understood as "monolithic barrier," which has to be overcome. In our study, we observed that this conceptualization of stability of a regime is problematic. We understand the stability of regime as the active resistance of incumbent actors. For example, In the case of wooden sleeper technology, Forest Department kept investing in improving the performance of wooden sleepers for many decades, which increased the performance benchmark for niche technologies. Similarly, government policies reserved durable timber for railways despite consistent demand from the other sectors such as construction and woodworking sectors. Forest Department and Government Policies were actively improving the technical and economic performance of wooden sleepers. We argue that stability of existing regime should be understood as the active resistance to technological changes, supported by the government coordination of incumbent actors rather than a monolithic barrier resisting technical change.

The coordination by the government can allocate R&D activities and associated infrastructure in a unique way such as FRI conducted R&D activities for improving the performance of wooden sleeper for Indian Railways. Indian Railways was not investing in R&D of the wooden sleepers, therefore there was no burden on IR; and it made it easier for IR to change to PSC. It reduced inertia and sustenance were driven by FRI to make wooden technology more efficient.

MLP approach at regime level contains many dimensions such as technology, policy, science, user practices, etc. However, these dimensions explicitly bring in multiple actors in deciding the stability of regime but does not allow for a differentiated view of power, which spans over market rules, technical standards, investment plans, etc. For instance, IR, Forest Departments, and Government played a role to sustain the use of wooden sleepers, but Government's role cannot be understood in the same plane in which we understand the role of Forest Departments and IR. During Planning period, Government fixed a proportion of annual timber production for use in sleeper manufacturing. This intervention clearly indicates the overarching influence of government on sustaining the use of wooden sleeper by reducing supply uncertainties. In other words, the application of MLP approach for understanding the technical change in a public sector firm operating in an inward-looking economy needs further qualification. One such qualification, which is essential to the analysis, is whether the firms and government routines can be understood at the same level. In an inward-looking economy, the government has more control over the economy, subsequently become more authoritative on public sector firms, which makes firm-government relationship core to the stability of a regime.

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