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Urban Rail Implementation in Emerging Economies: An Opportunity for Industrial Development and Technological Learning?

Report for the "Inclusive and sustainable smart cities in the framework of the 2030 Agenda for Sustainable Development" Project

Emmanuel Theodore Asimeng

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Draft version

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Abbreviations

BEML	Bharat Earth Movers Limited
BEL	Bharat Electronics Limited
BJTU	Beijing Jiaotong University
CARS	Chinese Academy of Railway Services
CNR	China North Railway Co.
CSR	China South Railway Co.
CRRC	China Railway Rolling stock Company
DMRC	Delhi Metro Rail Corporation
EMU	Electric Motor Unit
GOI	Government of India
ICF	Integral Coach Factory
JICA	Japanese International Cooperation Agency
NAIR	National Academy of Indian Railways
NCMC	National Common Mobile Card
NDRC	National Development and Reform Commission
NITI Aayog	National Institute for Transforming India
SATCO	Shanghai Alstom Transport Company
SATEE	Shanghai Alstom Transport Electric Equipment
SWJT	Southwest Jiaotong University
TU	Tongji University

1 Introduction

The socio-economic well-being of urban areas depends on a well-functioning transportation system that makes it easier for people to access goods and services. Most urban areas in emerging economies are expanding in size and human population, resulting in increased demand for transportation and mobility. But urban areas of most emerging economies are characterised by high motorisation and inadequate public transportation resulting in traffic congestion, accidents and increasing greenhouse gas emissions (GHGs) (Pojani & Stead, 2017). There is an urgent need to ensure a sustainable mass transit system to move the growing urban population to address the current socio-economic and environmental problems associated with the transportation system in emerging economies. Urban rail (metro, tram, suburban) can be the solution.

Urban rail has many advantages; trains can move a large number of people at high speed, provide reliable services because of its spatial isolation, less GHGs when the source of energy is renewable and has a low accident rate. There has been a consistent increase of 3.5% per year in urban rail lines in emerging and low-income countries over the past decade (IEA, 2020) because of the need to efficiently transport the growing urban population. In 2018, 907.1 km of metro lines were constructed in emerging and low-income countries representing 94.5% of global new metro lines (UITP, 2019). Despite the benefits it offers, urban rail is capital intensive. For instance, the infrastructure cost of implementing light rail is about three times more expensive than a bus of similar passenger capacity (ITDP, 2017). Another major challenge for emerging economies when introducing urban rail is the many technical capabilities required for rolling stock, infrastructure, public works and IT solutions. Because they are technology latecomers, they do not possess these essential capabilities.

To facilitate urban rail introduction in emerging economies, they can either import or combine public tenders with pro-active industrial policy to gradually increase value-added. But the latter is not easy as the leaders in rail technology are unwilling to share their intellectual property. The option of domestically developing rail technology may translate into inferior products and service quality and perhaps higher transportation costs.

This report examines how emerging economies can build the required urban rail capabilities while ensuring good service quality and affordable prices for users. To explore this question, the report relies on secondary data and adopts a case study approach as this enables a better understanding of the context and processes, causes and outcomes (Flyvbjerg, 2011). Two countries are selected for the case study – (mainland) China and India. Both countries have large markets for urban rail development and have adopted an industrial policy to indigenise rail technology. Whereas China has successfully managed the transition from importation to indigenising urban rail technology, India is currently pursuing an explicit “Make in India” strategy to increase local manufacturing and offers one of the most dynamic markets for urban rail development. The lessons from these two countries can be useful for other emerging economies that seek to indigenise urban rail implementation through an industrial policy to address their transportation problems.

The following Section introduces the rail transport system focusing on types of urban rail, the components of rail systems and the technical barriers to its adoption to demonstrate the level of expertise required for rail technology indigenisation. Chapter three briefly discusses the concept of industrial policy and provides information on how it can be adopted. Chapter four describes how China has become a role model for urban rail development among emerging economies. How India is implementing urban rail transportation is then described in chapter five. Chapter six highlights lessons from the experiences of China and India, and then chapter seven concludes with the limitations of the study and an outlook for policy makers in other emerging economies.

This study is one of the knowledge products from the research project Inclusive and sustainable smart cities in the framework of the 2030 Agenda for Sustainable Development carried out by the German Institute of Development and Sustainability (IDOS) and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). Within the framework of the Big Push for Sustainability, this paper will introduce the challenges and co-benefits of the manufacturing of railway systems in emerging economies. IDOS would like to acknowledge the financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ).

2 Rail Transportation Systems

Rail transportation is useful for transporting goods (freight) and people. But, because rail tracks are fixed and do not primarily offer last-mile services, they are not the preferred transport service for goods within urban areas. Therefore, rail transport in this report solely refers to passenger transport.

2.1 Types of urban rail transport

Although there are different types of urban rail transport, they can be broadly categorised based on passenger capacity, speed and number of tracks. Within this categorisation, there are four main types.

Suburban rail

This type of rail transport covers medium to long distances with a maximum speed of 150 km/h. They mainly connect urban centres with surrounding areas for work and school purposes. This allows people living in the suburbs outside the city to commute via mass transit to the urban centre where jobs and services are located. Suburban trains usually have a higher comfort level than other urban trains because of the relative long route. The transport capacity of the trains can vary between 250 and 1,500 passengers and can reach about 60,000 passengers/ hour/direction depending on the frequency of services, speed and number of vehicles. The trucks are usually double to achieve sufficient track capacity and reduce travel time (Pyrgidis, 2016).

Metro rail

This refers to high-frequency services within the city with standing passenger options and wide doors for rapid boarding and exit. They are mainly designed as underground and elevated networks. There are two types of metro rail transport i.e. light and heavy metro. While the heavy metro is appropriate for conveying a larger number of people (about 45,000 passengers/hour/ direction), the light metro is characterised by lower capacity (about 35,000 passengers/hour/ direction) and a shorter distance between intermediate stops. Therefore, the heavy metro may have more vehicles per train and train length than the light metro. The light metro can be considered as a compromise between the heavy metro and tram. Metros have a maximum speed of 50-90 km/h depending on the location and distance to the next station in the city. Metros often operate on double tracks.

Tram

Trams or tramways are transport systems, most often at street level and offering less capacity (about 15,000 passengers /hour/direction) than metros. It usually serves distances between 5-20 km with commercial speeds of about 15-25 km/h. It uses double tracks constructed either with grooved rails embedded in the pavement or with conventional flat bottom rails.

Monorail

These are usually electrified light rail. It moves via rubber-tyred wheels on an elevated beam which serves as the guideway. Thus, this rail has one track, not two, like other rail types. It can develop a maximum speed of 60-90 km/h and is specially offered for short-distance transportation services within leisure places due to the panoramic view it allows (Pyrgidis, 2016). Because monorails are elevated, they also serve to circumvent land scarcity in congested cities and mountainous landscapes. Magnetic levitation (Maglev) is a type of monorail technology. With Maglev, the coaches of the rail float on a four-inch cushion above the track using the Meissner effect of superconducting magnets (W. W. Clark & Cooke, 2015; Mahmoud, 2018). Maglevs can attain higher speeds than other monorails.

2.2 The components of rail transport system

All rail transport can be grouped into three main components from a transport system point of view. These are; the railway infrastructure, rolling stock, and railway operations. This subsection generally describes the components that enable rail transportation.

2.2.1 Railway infrastructure

Railway infrastructure refers to the railway track, all the civil engineering structures, and the systems and premises that ensure safe railway traffic (Pyrgidis, 2016). The railway tracks are long, large structures designed to support the movement of heavy rolling stock on soft ground. The railway track comprises different sub-components. The components are of varying stiffness that transfer the static and dynamic traffic loads to the foundation. The lower part of the superstructure, called track bed layers, are of different types, which may be used variably on the track because of advantages in cost savings and low maintenance requirements. For example, a ballasted track may be used at above-ground areas where low train speeds are required. In contrast, the non-ballasted track may be preferred for underground track sections where maintenance requirements are restricted and stability and durability are required.

The civil engineering structures comprising tunnels, bridges, overpasses and underpasses, drainage systems, noise barriers, and fences ensure that the railway tracks are not intruded or obstructed by external objects. Some engineering structures may be complex and challenging, requiring specialised knowledge in various engineering disciplines such as soil mechanics and structural mechanics. These skills are particularly essential for metros where underground rail is required.

The system and premises comprise level crossings and electrification, signalling and telecommunication systems collectively referred to as line side systems. This complex area requires diverse specialised knowledge in power supply systems, low voltage telecommunication systems, and automated control systems. The premises are mainly the stations to protect passengers from inclement weather, depots and warehouses to keep coaches for repairs and other purposes and administration buildings.

2.2.2 The rolling stock

The rolling stock is the term used for all railway vehicles. There are four types of rolling stock. These are power vehicles, single rail vehicles, trailer vehicles and engineering vehicles. The power vehicles are self-propelled and may be used for hauling trailer vehicles, transporting several passengers or used for shunting purposes. Power vehicles used for hauling are called locomotives.

Locomotives may be steam, diesel, gas, or electric powered, depending on the traction power. The single rail vehicles may be diesel, gas or electric powered. Trams, monorails, and metros may be single vehicles, while suburban trains may have locomotive sections to haul trailer vehicles. Most urban trains are connected single cars depending on the required passenger capacity. The number of connected single car units distinguishes heavy metro from the light metro.

Whereas steam technology is old and not used anymore because of its inefficiency, onboard storage technology such as hydrogen and battery or fuel-cell are becoming the new fuel technology for rail transport because of the low greenhouse emissions and mobile usage. These alternative propulsion technologies are useful for urban rail services because of the relative short distances and lower speed. They are considered as the future technology for rail transportation (Hein & Ott, 2018). The trailer cars are either for passenger or freight purposes. The engineering vehicles carry out track panel installations and various track inspection and maintenance work. The locomotive is an essential part of the rolling stock since it powers the movement of the trailer vehicles. The design and engineering of the locomotive and single cars require high expertise because they embody the main traction motor with the power to move the train.

Every rolling stock consists of two essential parts: the vehicle body (the part where passengers sit or stand) and the bogies (trucks) that support the car body and provide traction and braking. The bogies consist of several small components and can be found at the bottom near the vehicle ends. The bogies also contain the wheelsets which move on the rails. The bogies enable the movement of the wheelsets as the traction motor is built within it.

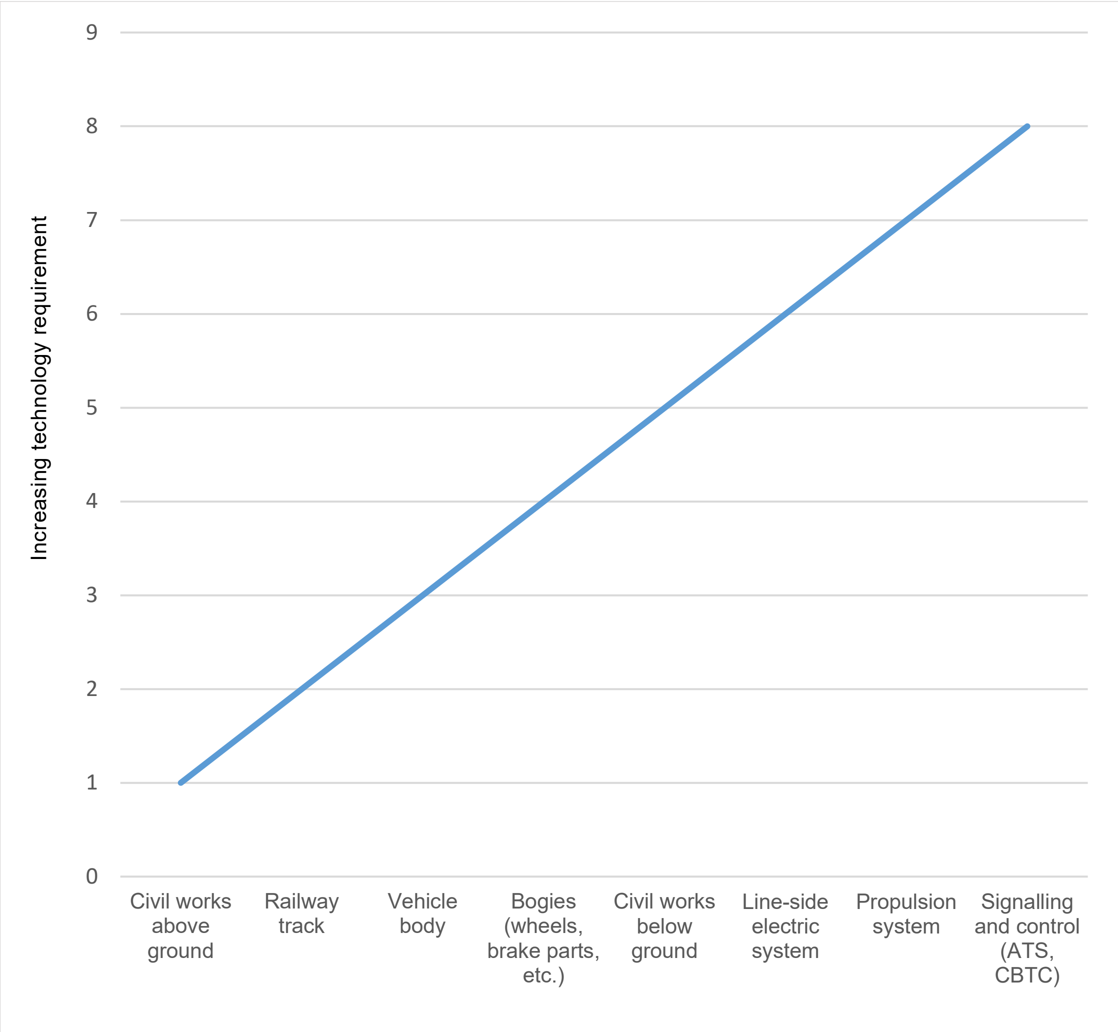
2.2.3 Railway operation

The railway operation brings together the infrastructure and rolling stock to ensure movement from origin to destination. Railways require technical, commercial and maintenance components to ensure delivery of services. The commercial component usually consist of pricing policy, marketing and organisation and management subcomponents that ensure that rail services generate enough revenue to cover the expenditure and profit for reinvestments for improving the service. The technical component comprising of scheduling, regulation and traffic control, traffic safety and staffing of stations enables safe and reliable services. The maintenance component address issues that may affect the safety and reliable services. Without the assurance of safety and reliable services, lower number of passengers may result in higher costs and collapse of the service.

2.3 Rail implementation technical barriers

The components of rail systems described above show the diverse technical expertise that must come together for implementation and operational services. Expertise in architecture, transportation engineering, power supply systems, structural mechanics, soil mechanics, ICT, planning, low voltage communication systems, automated control systems, rolling stock technologies, and more are required. Rail transportation has undergone an evolutionary process in its development over the decades. The firms that have invested in research and development (R&D) have enabled rail technology to evolve in speed, safety, efficiency and comfort for passengers. Most of these firms are located in countries with a long history of rail transport services, such as Germany, Japan, France, the USA, and the United Kingdom (SCI Verkehr, 2018). Thus, the specialised expertise for rail transport has been developed by international rail firms over a long period at a particular regions of the world. Whereas there are international firms such as Alstom, Bombardier and Siemens Mobility that are specialised in all aspects of rail technology, other firms such as ABB and Mitsubishi Electric are specialised in aspects of rail technology such as propulsion systems for the rolling stock, signalling and electric systems.

Figure 1: Urban rail technology subsystems requirements



Source: Author.

The level of technology required for urban rail subsystems, as depicted in Figure 1, demonstrates the technical barriers to indigenisation. The subsystems that require higher technology have evolved to improve commuters' safety, comfort, and reliability. It is difficult for new firms or technology latecomer firms in emerging economies to develop the current rail technology and compete with already established firms. As a result the rolling stock subsystems, have been dominated by firms in the countries mentioned above. The China Railway Rolling Stock Corporation (CRRC) has recently broken into this exclusive group and has become the largest producer of rolling stock.

Rail technology indigenisation in emerging economies could follow a gradual process to overcome the technical barriers. The “indigenisation ladder” could start from the point where (a) countries import everything, tender out turnkey projects; (b) international firms are encouraged to produce locally; (c) international fims enter into joint ventures with local firms; (d) local manufacturers produce under licensing agreements with international firms; (e) local firms produce with own intellectual property. Although cost is an essential barrier to rail implementation, the lack of technical expertise as stated earlier is a key reason for its low adoption in emerging economies. This sub-section discusses three significant technical barriers to urban rail introduction.

2.3.1 The rolling stock

Since the trailer functions as a moving vehicle but does not contain the rolling stock's traction motor and other engineering aspects for suburban trains, this Section focuses on connected single rail car units and locomotives. As indicated above the rolling stock consists of the car body and the bogies. The vehicle body usually has a zone for the technological equipment and a zone for equipment needed to control the operation of the rolling stock which also serves as the driver's location. The body also contains the main structural frame that transmits traction and dynamic forces, the central power plant units and various units for movement of the wheels, monitoring and managing the locomotive’s performance (Spiryagin et al., 2016). It includes several components such as traction transmission control, braking, cooling, ventilation, and other safety devices.

The rolling stock has specific systems that require electric power to function. These systems include air-conditioning, lighting, battery chargers, monitoring, onboard signalling and communication equipment. In addition to the auxiliary electric power, the train monitoring systems collect, record and present information on functions of the train for efficient operation and maintenance. The monitoring systems perform several support functions, including ensuring doors open and close properly, the brakes function accordingly, executing test-run measurements, and recording faults. These systems require high skills and years of R&D. Thus, countries operating trains for more extended periods often have firms that have invested in rolling stock technology R&D.

Additionally, the energy generated (regenerative power) when an electric train is slowing down can be transformed into electricity that can be fed into the grid for use by other trains. But electricity powered trains have extra technology requirements as they require lineside infrastructure to transmit the electricity as explained in the subsection infrastructure and digitisation. In recent times, train personnel and passengers expect improved ventilation, air-conditioning systems, information and entertainment systems, and power sockets for laptops and phones on trains requiring more technological innovations to keep up with these demands. These further require onboard electric and electronic devices to meet the demand, which means that the locomotive designs must keep improving beyond speed and safety on the rails.

The weight of rolling stock has increased over the years due to the demand for onboard equipments such as heating and aircondition. These heavy rolling stock increase damage to the rail tracks, increasing infrastructure maintenance costs. The heavyweight also increases the energy required to operate the trains and the requirement of higher traction and braking systems (Mistry & Johnson, 2020). This means R&D for the lightweight rolling stock has become essential.

2.3.2 Signalling and communication systems

Trains cannot run safely without signalling systems. The purpose of signalling systems is to ensure the safe movement of trains on the railway through locking movable track elements, checking the clearance of track sections, locking out conflicting movements, and generally controlling train movements to keep them safely apart (Pachl, 2020). Signalling thus ensure separation between trains and control points of movement in order for trains to get to their destination safely. There are different types of signalling, and the methods differ for each country.

Because the distance needed for trains to come to a complete halt after brakes are applied is longer for trains than road vehicles, only one train can occupy a specific section of rail at one time for safety purposes. A section of the rail occupied by a train is called a block. Signals in rail transport enable information on the position of a train for it to stop, slow down, or proceed with its movement. Signals have evolved from signallers raising optics, pulling levers, to lineside electrical signalling and the contemporary communication-based technology. The present signalling technology enable real-time train-to-train and train-to-network communication and infrastructure components for autonomous driving technology (S. Clark, 2012; Hein & Ott, 2018).

Therefore, signalling and communication have become a high technology-based area for ensuring the safety of trains. The high technology enables many trains to operate in blocks at safe distances from each other to convey more people on the same rail line. For a long time, many firms in countries that have operated trains have developed capacity for signalling using current and upcoming technology to ensure safe and efficient movement of trains. It is difficult for new firms who have not gone through the evolution of rail signalling and communication to develop the technology for commercial purposes quickly. Thus, it has become a significant drawback for emerging economies that do not already have local firms with signalling technology. Over the years, purchasing the signalling and communication systems has been the main means of ensuring urban rail service safety for most emerging economies.

2.3.3 Infrastructure and digitisation

Because the advantages of electric-powered trains exceed that of diesel-powered trains, most of the recent urban trains are electric-powered. But electric trains come with the construction of additional electric infrastructure. Electric-powered trains require third-rail or overhead transmission systems (also known as catenary system) as part of the lineside systems. Power components such as transformers, rectifiers, inverters and switching circuits have to be constructed to provide power to the traction system of the locomotive. These involve expertise in power supply and electronics systems specific to rail traction.

The civil engineering requirements within urban areas for rail transport is enormous. Underground tunnels, drainage systems, overpasses and others may be difficult to develop if the expertise does not already exist. The civil works such as tunnelling and laying of electric cables for electric trains may not require very high specialised skills but experience in successful execution of such projects ensure safety and value for money. Civil works may require several high expertise for underground construction which is very useful for already densely populated areas.

Furthermore, digital infrastructure has enabled efficient transportation through pre-board booking and payment in recent times. Cumbersome payment systems may turn away potential passengers, whereas ease of payment is associated with modernity. The introduction of urban rails requires an easy payment system linked to other transport systems to enable transfers, increasing passenger usage of mass public transportation. The many infrastructure requirements for urban rail, mainly metros, contribute to their long construction duration.

3 Industrial policy pathways for latecomer development

Markets sometimes fail to adapt to changes for comparative advantage or efficiently allocate resources. Therefore, governments can step in and stimulate firms to undertake investment decisions in another direction, do more of the same, or implement plans at a higher speed (Groenewegen, 2000). Industrial policy is about the situation where governments opt to intervene in markets. But there are several instances where government interventions through industrial policy have failed miserably, leading to the situation where it was virtually banned from official economic discourse in most countries. This led to the ideology that the best industrial policy is no industrial policy; industrial policy should be restricted to horizontal policies such that it should not consider policies that discriminate explicitly by favouring some industries than others (Moreno-Brid, 2013). There is no substantiation that implementing an industrial policy would ensure the transformation of the productive structure that would lead to sustained economic growth (Moreno-Brid, 2013).

But in reality, all nations use industrial policy, but some are more successful and others more openly than others (Ciuriak & Curtis, 2013). Indeed, industrial policy has become a common term for economic policies since the global credit crunch in 2008-2009 and how the Asian tigers of Korea and Taiwan, and now Chinese government have utilised it for their economic development (Andreoni, Chang, & Scazzieri, 2018; Ciuriak & Curtis, 2013). There are numerous benefits of industrial policy. Firstly, it serves as a tool to protect jobs and stimulate local demand. Secondly, It can be used to push for cleaner technologies and more efficient energy use for green economy purposes.

Thus, the critical question is not whether to adopt an industrial policy but rather how it is done. Altenburg & Lütkenhorst (2015) identified 7 key lessons on how industrial policies could be successfully implemented in latecomer economies. These lessons are:

- Political leaders must have the firm will to implement national transformational projects aimed at diversifying the economy and developing new competitive advantages in higher value activities
- The transformational projects need to build on existing or anticipated comparative advantages and define upgrading pathways
- The transformational projects need to balance economic, social and environmental objectives
- The industrial policy should be devised as a collaborative process of experimental learning involving stakeholders and ensuring feedback loops between learning, implementation and impact measurement.
- The focus of the industrial policy should be on supporting innovative ideas and encouraging experimentation
- The policy should strengthen the linkages between firms and segments of the business community
- The policy should promote and gradually increase international and regional trade and investment links.

Through industrial policy, China opted for purchasing rail technology from established international firms with the option of technology transfer. India is also using the Make in India initiative to increase local manufacturing of rail technology. Recently, China has moved from purchasing and relying on foreign firms to locally producing and competing with those same international firms in the rail technology market. India has also started shifting from wholly purchasing rail technology to locally manufacturing specific components. Mexico, Indonesia and other emerging economies that still rely on complete importation of rail technology are keenly observing rail development in China and India. The following Section discusses how China and India are implementing urban rail in their growing urban agglomerations.

4 Urban rail development in China

4.1 Growth in rail implementation

The Chinese government expects to migrate 20 million people to urban areas each year until 2035 (McKinsey and Company, 2009). China is deliberately concentrating people in urban areas to maximise the benefits of urban expansion. There are already six cities with a population above 10 million, 12 cities with population between 5-10 million, 21 cities with population between 3-5 million, and 164 cities with population between 1-3 million (Bao, 2018). Overall, China expects to have 221 cities with a population above 1 million by 2035. The increasing urbanisation has implications for transportation and mobility. The Chinese government has focused on urban rail development as one of the primary means of addressing the current and future transport demand. As a result, since the beginning of the 13th 5-year development plan (2016-2020), 100 cities have formulated plans for urban rail transit (Bao, 2018).

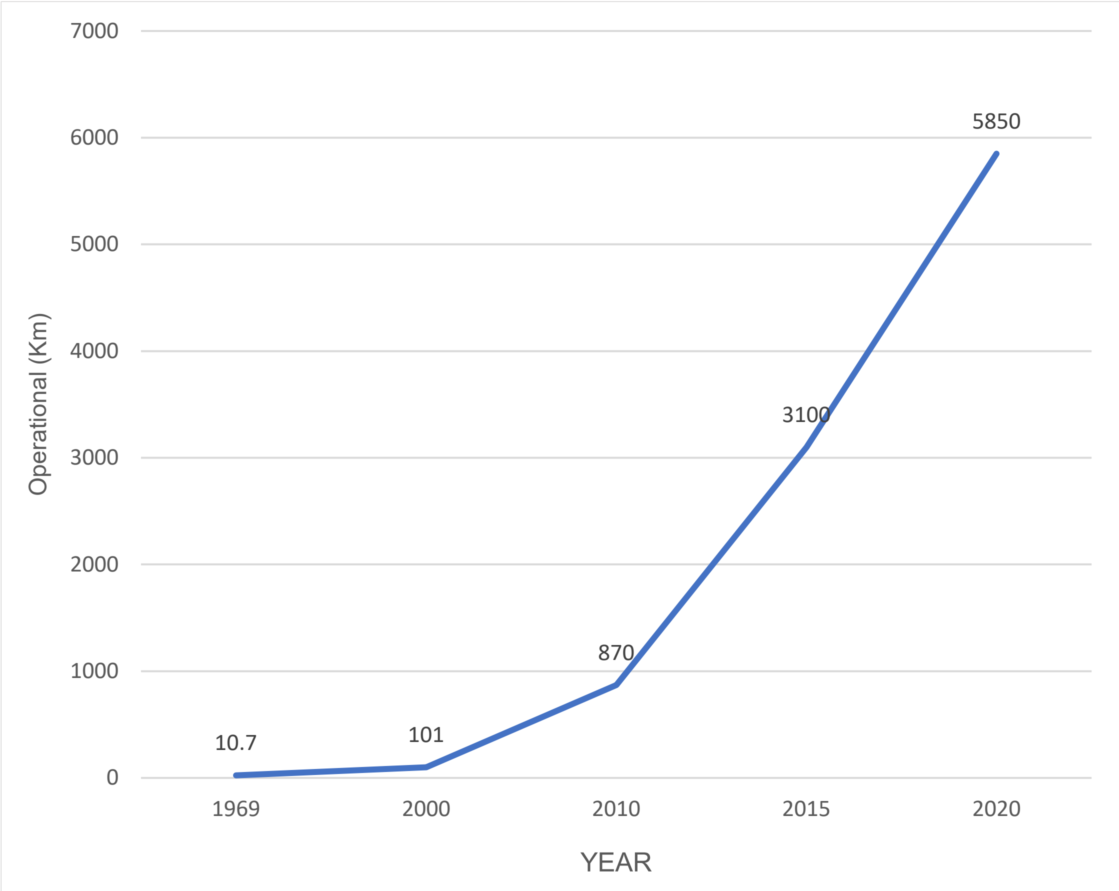
However, urban rail development in mainland China can be categorised into three stages. The first stage was initiated by opening a 10.7 km metro line in 1969 in Beijing. Tianjin, Guangzhou, and Shanghai followed with metro construction in the 1980s and 1990s (Ding & Xu, 2017; Klinge, Xuelian, & Kuizhong, 2020). The technology for the rolling stock, signalling and automatic ticketing were primarily imported. Subsequently, trains were seen as symbol of modernisation, and therefore many regions and cities submitted metro proposals to the central government for approval. But because of the high cost of importing rail technology, maintenance and the long construction period, in 1995 the government suspended all metro projects except ongoing projects in Beijing, Guangzhou and Shanghai (Liu, 2020).

Towards the end of 1997, the National Development and Reformation Commission (NDRC) allowed metro implementation. But the policy pushed for the localisation of rail technology in China after studying the rail implementation plans of the cities. Percentage of local manufacturing of rail sub-components were introduced. This marked the beginning of the second stage of rail development in China. The national plan was to further establish cooperation between international and local firms to achieve the localisation strategy (Liu, 2020). As a result, Alstom formed a joint venture with Shanghai Electric group joined to form Shanghai Alstom Transport Electric Equipment (SATEE) in 1999 to mainly produce traction equipment. In the same year, Alstom and Shanghai Rail Traffic Equipment Development formed SATCO for manufacturing and maintaining rolling stock (Alstom, 2016). The Chinese firms that participated in the joint ventures either belong to the China South Rail Company (CSR) or the China North Rail Company (CNR).

Besides the local manufacturing mandate and the push for joint ventures, the ministry of railways opted to open up to the leaders in rail technology in a quid-pro-quo. Thus, they offered the Chinese rail market to four rail technology giants (Alstom, Bombardier, Siemens Mobility and Kawasaki Heavy Industries) in exchange for high-speed and metro rail technology transfer in 2004 (C. Li, 2014; Lin, Qin, & Xie, 2021). As a result of these policies, although 4 cities had metro lines operating on a track length of 101 km in 2000, this increased to 10 cities with a track length of 870 km in 2010 (Salzberg, Mehndiratta, & Liu, 2012).

These policies ensured that international firms locally manufactured rolling stocks and locomotives through joint ventures, while developing local capacity for rail subsystems. The rate of approval of new rail proposals and the extension of existing systems increased, ushering in the third stage of rail implementation boom. As a result, the metro rail lines increased to 3,100 Km in 25 cities by 2015 (S. Li, 2018), and then in 2020, 30 cities had metros with 5,850 km (Urban Transport Magazine, 2021) (Figure 2). Since 2016, the length of newly operational metro lines has exceeded 500 km per year.

Figure 2: Metro rail expansion in China from 1969 to 2020



Source: Author

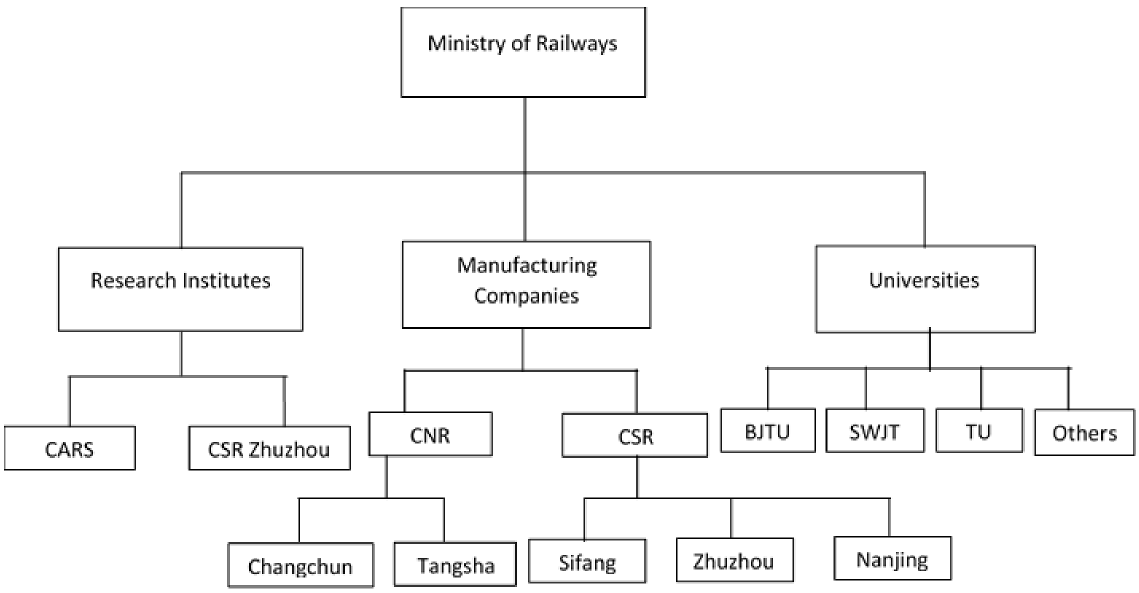
4.2 Rail technology indigenisation

Following the high demand for rail transportation in China, a number of indigenous electric-powered trains were developed till the early 2000s but these were considered to have technological deficiencies and were therefore not moved into mass production (Chen & Haynes, 2016). Despite the development of rail technology that did not meet the Chinese demand, local institutions and firms had developed the capacity for rolling stock production and other essential rail technology capabilities through continuous R&D. China needed to answer the question of whether to rely entirely on local production of rail technology or purchase the technology. Relying on local technology meant that China would produce trains with outdated technology, missing out on the speed, reliability, low CO2 emissions and other benefits of modern rail.

As stated earlier, the first step was to push for percentage mandates on local manufacturing and joint ventures between Chinese and international firms. Before these joint ventures in the late 1990s, Alstom and the Chinese Railway Signal and Communication Corporation had formed a joint venture in 1986 called CASCO, which currently provides signalling services to metros across Chinese cities. The second step was to open up to the leaders in rail technology in exchange for rail technology transfer. According to Lin, Qin, and Xie (2021), the technology transfer had the following components:

- Joint design of train modes based on foreign prototypes but with adaptation to the local Chinese conditions
- Access to the blueprints
- Instructions on manufacturing procedures
- Training of engineers

Figure 3: Organisational structure of rail manufacturing, research and universities in China



Source: Chen & Haynes (2016).

To achieve assimilation of the rolling stock technology, the task of R&D and manufacturing of 9 critical subsystems were given to the local institutions in Figure 3. These technologies included electric motor units (EMU), bogies, traction control, traction transformers, converters, traction motors, braking systems, network control systems and EMU system integration (Chen & Haynes, 2016). Local institutions such as Zhuzhou electric locomotive research institute and the rolling stock institute of the Chinese Academy of Railway Services (CARS) researched the AC traction system, network control systems, and braking systems. At the same time, the CSR Nanjing Rolling Stock Manufacturing developed braking systems.

As part of the technology transfer scheme, Alstom received 60 orders for high-speed rolling stock. Among the 60 orders, Chinese engineers were allowed to observe the design and manufacture of three; six orders were imported as parts and later assembled by Chinese engineers under guidance from the foreign partners; the rest of the 51 orders were manufactured by gradually replacing the foreign parts with domestically produced parts, which facilitated the absorption of the transferred technologies (Chen & Haynes, 2016; Lin et al., 2021).

Besides receiving rail technology for whole rolling stock companies, the Chinese companies also received technology for traction motors, braking systems and series pantographs from specialised international firms such as ABB, Mitsubishi and Hitachi (Lin et al., 2021). In general, the two leading manufacturing companies with facilities all over China -the China South Rail (CSR) and China North Rail (CNR), rapidly absorbed rail technology and made substantial indigenous innovations (C. Li, 2014). These two rolling stock companies were merged in 2015 to form the China Railway Rolling Stock Company (CRCC). The CRRC is now the largest manufacturer of rolling stock globally. The joint ventures formed between international and Chinese firms (table 1) locally manufacture and provide urban rail technology within China through the CRRC. Chinese firms mainly undertake rail infrastructure construction.

Table 1: Selected joint ventures in China

Selected joint ventures in China	Rail technology	Year of establishment
CASCO (Alstom + Chinese Railway Signal and Communication Corporation)	Signalling and control	1986
Changchun Bombardier Railway vehicles Company ltd. – CBRC (Bombardier + CSR Changchun Railway vehicles Co. ltd.)	Rolling stock manufacturing (also approved as Designated Localisation Enterprise)	1997
Bombardier Sifang Power (Qingdao) Transportation Ltd (Bombardier + CSR Sifang Locomotive and Rolling stock Co. Ltd)	Rolling stock manufacturing	1998
Shanghai Alstom Transport Electric Equipment – SATEE (Alstom + Shanghai Electric Group)	Traction equipment supply	1999
SATCO (Alstom + Shanghai Rail Traffic Equipment Dev. Com. Ltd.)	Manufacturing and maintenance of rolling stock	1999
Bombardier CPC Propulsion System Company Ltd. (Bombardier Power ltd + Changzhou Railcar Propulsion Engineering and R&D Center	Production, marketing and maintenance of propulsion equipments	2003

Source: Author.

4.3 Current urban rail development in China

Because there is a large demand for urban rail transportation due to the increasing urban population, the Chinese government has been investing in local urban rail development since attaining the capability of locally developing rail with current technology. Different cities have different kinds of urban rail, mainly locally developed. Trams, metro, monorails, and suburban rail serve the increasing urban population at lower implementation costs because they are locally produced.

The Chinese had a clear learning strategy as part of the technology transfer from the large international companies. As shown in Figure 1, research institutions and universities have been part of China's rail technology development, facilitating technology assimilation and absorption. After receiving rail technology from the leading international rail companies. It was important for the research institutions to figure out why the rail technology functioned the way it did. They could innovate and improve the received technology and not just reproduce it. The goal of the Chinese government is to produce through import substitution.

Rolling stock

The CRRC with manufacturing sites in 25 cities has been responsible for rolling stock manufacturing in China. The CRRC has been utilising current rail technology to develop modern urban rail in Chinese cities. Beijing opened its first Maglev line in 2017, and then a modern tram in Guangzhou with 70% low vehicle to allow access for passengers with prams and wheelchairs (S. Li, 2018). BYD, a private Chinese manufacturing firm established in 1995 has also been engaged in urban rail transit. The company produced a monorail in China at 1/5 construction cost and 1/3 construction time of subways in 2017 for the city of Yinchuan (Ju, 2017).

China has also developed suspended light rail. Recently, the CRCC launched an autonomous metro in Shenzen. This self-driving train has a maximum speed of 80 km/h. The train is supported by an in-built multi-dimensional safety detection system which aids the train to precisely check the rail conditions and provide information on obstacles in a precise manner than humans. The CRRC Datong and the State Power Investment have developed China's first hydrogen fuel-cell hybrid locomotive. The hydrogen-fuelled locomotive has a maximum speed of 80 km/h, can operate continuously for 24 hours, and would be used for shunting, fetching and delivery services (CRRC, 2021).

Despite the increased capabilities of Chinese firms for rolling stock manufacturing, some of the traction and electrical equipments are provided by foreign firms such as Hitachi, Mitsubishi, ABB and others (Shaoxuan et al., 2008). Joint venture companies like SATEE have also been providing traction systems for metro rolling stock. The CRRC continues to corporate with international firms such as Knorr-Bremse for the provision of brake controls, sliding door and HVAC systems (Railway Technology, 2020)

Signalling and control

The Chinese telecommunication company Huawei has been providing urban rail communication support. Their services allow multiple uses such as train control, dispatching, and video surveillance. Two other core services that ensure safety and efficient travel are the cloud-based traffic control integrated automation system and urban rail data communication system. CASCO, a joint venture between Chinese Railway Signal and Communication and Alstom established in 1986 provides signalling services to many metros across China.

5 Urban rail development in India

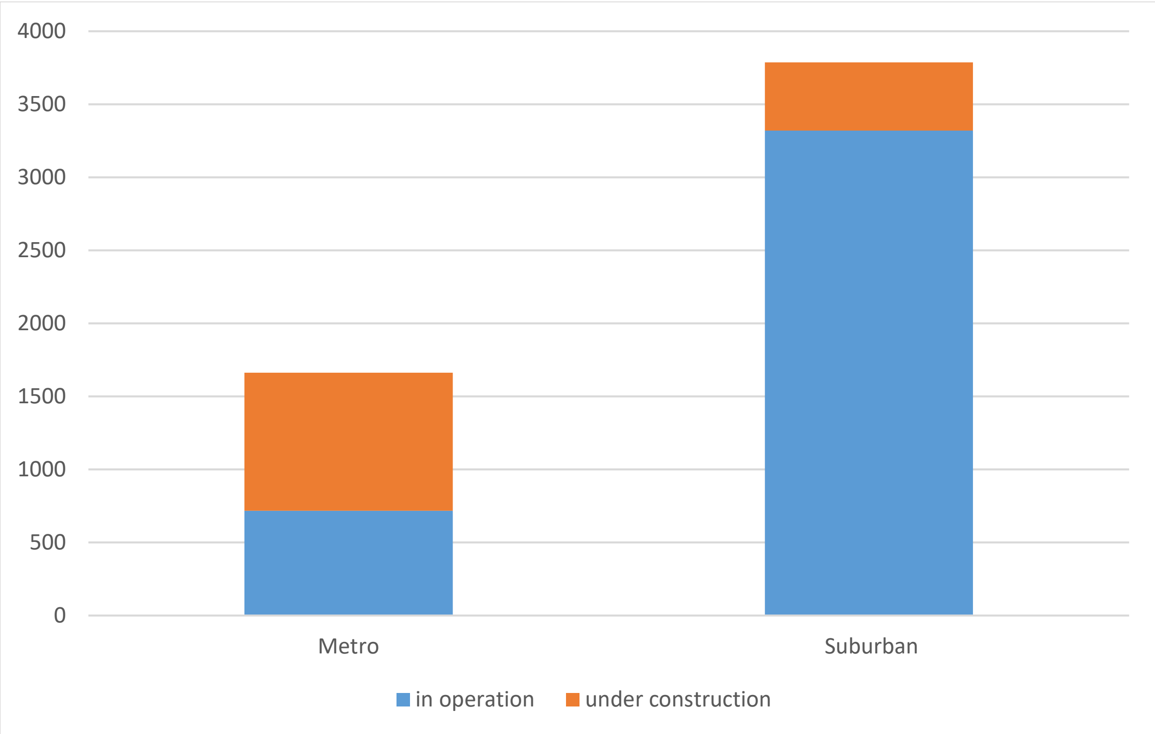
5.1 Growth in rail implementation

India is rapidly urbanising. The Indian urban population in 2011 was 377.1 million representing 31% of the population. This represents a 3.1% increase compared to the 2001 urban population (Ministry of Housing and Urban Affairs, 2019). Whereas there is a natural population growth by a higher ratio of birth to death, the is also a high rural-urban migration trend in the country. The trend would continue as urban growth is expected to contribute to 73% of the total population by 2036 (NITI Aayog, 2021). The growth in the urban population should correspond with growth in urban transport options.

But government of India's (GOI) focus over the period has been on road transportation favouring private car ownership as the investments in road transport have been higher than public transportation. However, this is changing as the focus is shifting to promoting public transportation. In this context, rail-based transit systems have resulted in several cities developing rail transportation plans to meet the growing urban population. The national urban transport policies (2006 and 2014) have strengthened this, particularly the "Make in India" initiative.

The first urban transport in the form of horse-drawn tram commenced operations in the 1870s in colonial India. Since then, other modes of urban transportation have been implemented. Until recently, suburban trains and buses were the main means of public transportation in Indian urban agglomerations. Suburban trains were introduced in Mumbai in 1928, Chennai in 1931 and Kolkata in 1957 without improving service quality until recently (IUT India, 2013). The first metro (mainly underground) in India commenced operations in Kolkata in 1984 and then another one (above ground) in Chennai later. The first phase of the largest metro was completed in 2007 in Delhi, covering 65 km. The second phase of the Delhi metro covering 125 km was completed in 2010. Subsequently, several cities have implemented urban rail to ensure efficient transportation of their growing urban population. Mishra (2019) reported that 17 other cities had implemented metro rail besides Delhi and its suburban areas. These cities include Bangalore (42 km), Hyderabad (56 km), Kolkata (27 km), Chennai (45 km), Jaipur (9 km), Kochi (18 km), Lucknow (23 km), Mumbai (20 km), Ahmedabad (6.5 km) and Nagpur (13.5 km). In total, there are 718 km of operational metro rail in 14 cities, whereas 945 km are under construction in 18 cities, of which some are extensions in the already mentioned cities. Additionally, 3,319 km of suburban trains are in operation whereas 468 are under construction. In 2014, a monorail of length 19.5 km commenced operations in Mumbai.

Figure 4: Metro and suburban trains in operation and under construction (km) in 2021



Source: Author

5.2 The policy and implementation strategy

The rising urban population has resulted in a focus on urban transport issues in India. The urban population is expected to increase to about 590 million by 2030, requiring a rethink of urban policies, particularly transportation, because urban activities thrive on efficient mobility. The Ministry of Urban Development (MoUD) came up with a national urban transport policy in 2006. The policy recognised the deteriorating and inadequate public transport availability in urban India and sought to push for reforms with transport technologies that ensure efficient mass mobility (Ministry of Urban Development, 2006). Early 2014, the MoUD developed an update to the policy stressing public transportation a need to create a low emission pathway for the transport sector (Ministry of Urban Development, 2014).

The most significant policy yet is the Make in India initiative. The initiative seeks to facilitate investments, innovation, enhance skill development, job creation and manufacturing (Mishra, 2019). It encourages indigenous manufacturing and production of goods. The make in India initiative has technically replaced the five-year plans that have existed since independence from 1947 by the planning commission. The National Institute for Transformation of India (NITI Aayorg) is the newly formed institution tasked with coordinating the national reforms in India. To grow the manufacturing sector in India, infrastructure development is seen a significant part (Mehta & Rajan, 2017). Because urban rail is expected to address the transport demand of the growing urban population, the GOI has further developed a metro rail policy to shape the implementation of metros in Indian cities. The metro rail policy (Government of India, 2017) provides a framework for rail implementation including justification, funding options and planning, to integrate with other forms of mass transportation services within urban areas. Urban transport is also seen as an option for India to reduce its GHG emissions by promoting varied mass transportation that uses minimal fossil fuel-based energy sources (Verma, Harsha, & Subramanian, 2021).

The implementation of rail within the Make in India framework has been about the deliberate inclusion of indigenous firms in a phased manufacturing plan. The plan seeks to increase the participation of Indian firms by 50% in rolling stock, telecom and signalling to 50% by 2023 in a phased manner (Mishra, 2019). It further seeks to ensure that 80% of civil works and 50% of electrical items are procured locally. Since the initiative seeks to attract international finances and firms to make their products in India as part of the package, a standard eligible criterion for procurement has been developed to ensure local firms do not lose out. This ensures that a minimum of 75% tendered quantity of products is manufactured in India by international firms establishing facilities in India or partnering with established local firms (Mishra, 2019). Furthermore, rail components such as rolling stock, telecommunication and signalling systems, electrical and civil engineering systems have been standardised in India to facilitate the establishment of international firms that want to participate in providing rail infrastructure for the fast-urbanising economy.

5.3 Rail technology indigenisation

Rolling stock

In 1961, India had 10,624 locomotives of which 10,312 were powered by steam, 181 by diesel and 131 by electric (Indian Railways, 2006). However, in 2006, the Indian Railways reported having 8,025 locomotives, of which 44 were powered by steam, 4,793 by diesel and 3,188 by electricity. This shows how rail technology in India has changed over the period in favour of modern technology. The report further elaborates on how the GOI procured Linke Hofmann Busch (LHB) coaches from Alstom-Germany on a technology transfer basis in the early 2000s. The Indian rolling stock company, Integral Coach Factory (ICF), which was established in 1955, currently produces about 2000 coaches per year based on the LHB technology in India.

During the first phase of the Delhi metro, BEML, an Indian government firm established in 1948 signed a technical collaboration agreement with Rotem (now Hyundai Rotem) to manufacture rolling stock for the Delhi Metro Rail Company (DMRC). BEML became the first indigenous firm to produce metro rolling stock in India. Nevertheless, metro rolling stock was imported by DMRC and other cities because of limited capabilities in India. For instance, the DMRC in 2009 imported metro coaches from Bombardier-Germany. The coaches were airlifted from Germany to India to ensure they arrived early for commissioning and quickly commenced services to ease travel as there had been a 30% increase in ridership (DMRC, 2009).

By standardising rail technology and requiring 75% tendered production in India as part of the Make in India initiative, two international rolling stock firms - Bombardier and Alstom - have established production centres in India to take advantage of the growing rolling stock market. Japanese companies providing rolling stock as part of JICA financial support are also required to manufacture at least 75% of rolling stock in India through collaboration with Indian firms or by establishing independent manufacturing firms in India (Mishra, 2019). Recently, Indian firms such as BEML and Titagarh have been bidding for rolling stock manufacturing tenders because of their increased capacity for rolling stock production. For instance, BEML won a bid to produce 378 coaches for the Mumbai metro line (Mishra, 2019). The companies that participated in the bid included Bombardier-India, Alstom-India, China’s CRRC, Hyundai Rotem, CAF and Titagarh. Besides Mumbai and Delhi, BEML has manufactured metros for Kolkata, Bangalore and Jaipur (BEML, 2019). Titagarh recently acquired the Italian rolling stock firm Firema Transporti. This makes Titagarh the only Indian firm with high-end technology for carbon steel, stainless steel and aluminium for the rolling market.

The times of India reported that the railway ministry would from ending 2022 achieve 100% local manufacturing of LHB coaches. Whereas ICF manufacture the LHB locally, axels and wheels in the bogie are imported, local capacity is expected to increase to end the importation from the set date. ICF is reported as being part of the 10 largest rolling stock firms for the first time in 2020 owing to increased sales (SCI Verkehr, 2021).In support of the indigenisation of rolling stock manufacturing, the DMRC (2015) reported that 90% of rolling stock procured for use is locally manufactured. Besides the coaches, window glasses, brake blocks, bogie frames, and other subsystems were being manufactured in India.

Signalling and communication

Since signalling and communication are essential components for the safe movement of trains, especially metros which have high-density operations where services are scheduled just minutes apart. Mishra (2019) reported that Indian railways are entirely dependent on foreign firms for this vital technology. Mishra further stated that the DMRC, the Bharat Electronics Limited (BEL), and the Centre for Development of Advanced Computing (CDAC) have taken the initiative to develop the technology locally. It is believed that the indigenisation of signalling technology would reduce metro rail project costs by about 15%.

In September 2020, the DMRC released a press statement to inform the public that it had indigenously developed a communication-based train control signalling technology for Metro railways in India. This was through the joint effort of the BEL and CDAC. Because of this development, the DMRC would use the locally developed signalling technology while upgrading metro lines that do not use the locally developed technology (DMRC, 2020).

Infrastructure and digitisation

The growth in urban rail transportation and overall rail transportation demand has resulted in increased infrastructure for tracks, civil engineering structures, systems, and premises. Additionally, India’s target of 100% electrification of all rail transport in the country is expected to spur the growth of local firms to undertake most of the electrification within the Make in India initiative.

Generally, both indigenous firms and international firms in India are constructing the rail infrastructure. Whereas some of the indigenous firms have been in existence since India’s independence in 1947, some are young firms. For instance, ABNCO group, a major rail electrification company, was founded in 1997. Tata Projects formed in 1979 has been involved infrastructure development for the Delhi metro. Recently, it was reported that Afcons Infrastructure (an indigenous Indian firm founded in 1959) had been awarded a contract for Delhi metro phase 4 underground construction works (Shah, 2022). Three other indigenous firms contested the bid.

Digital payment is gradually replacing paper ticket and cash payment systems because of its flexibility to users. It also has the additional benefit of reducing financial losses from paper ticket sales. Users of the Delhi metro and others in India can pay digitally with a card based on an indigenous automated fare collection system by the CDAC and the national payments corporation of India (Mishra, 2019).

6 Lessons from indigenising rail technology

The cases have shown how China and India have adopted industrial policy to ensure the indigenisation of rail technology. After importing rail technology, both China and India’s first industrial policy focused on attracting international firms to set up joint ventures with local industries or manufacture locally. Local firms have also been producing under licensing agreements with international rail firms. China took another step by engaging in an open technology transfer with the leaders of rail technology. Through a clear learning strategy that further propelled its ability to quickly assimilate and re-engineer to the point where Chinese firms compete with the early rail technology developers on the international market. Thus, through the adoption and practical application of an industrial policy, China has moved from “a - e” of the “indigenisation ladder” mentioned in Section 2.3. This shows that indeed the adoption of industrial policy can improve technological indigenisation. Altenburg (2011) had earlier emphasised that countries that managed to catch up with traditionally industrialised and high-income countries are those whose governments proactively promoted structural change by encouraging channelling resources into promising and socially desirable activities. Thus, industrial policies in emerging economies are essential for unlocking the structural change required for sustainable rail transportation for the growing urban population. After all, there is a likelihood of a learning process that would not be attained without industrial policy.

Although urban population growth can be a problem due to the increased demand for infrastructure and services, it can also serve as an engine for economic growth by concentrating access to highly skilled personnel for manufacturing and service industries. The case studies have shown how the two countries have taken advantage of the growing urban population to develop their rail sector for mobility purposes and attracted international rail firms. The cases have further shown how existing and new local rail firms can utilise industrial policy to develop expertise that did not exist prior. This has enabled joint ventures and readjustment in local firms investment towards rail, leading to the acquisition of international firms by local firms like Titagarh in India. The prospect of growing urban rail demand and industrial policy encourages local firms while pulling in international firms for local manufacturing. Bombardier-India, is reported to now export metro coaches to Australia, Brazil, Saudi Arabia and Canada because it is relatively cheaper to produce in India (Industrial Automation, 2019). Bombardier-India also provides engineering services for the parent company in China, U.K, Switzerland and Germany.

These examples clearly show that locally developing rail technology from scratch does not work for latecomer technology countries. Instead, an industrial policy that seeks to grow local firms, expertise and incentives to attract international firms through joint ventures and opportunity to manufacture locally could be a way to grow local capabilities.

7 Conclusions

Despite the high technical expertise required for urban rail implementation, China and India show that emerging economies can develop these skills through an industrial policy. The two countries are increasing urban rail lines to ease mobility in the cities through an industrial policy that seeks to entice international firms to manufacture locally. The decision to indigenise rail technology enables the utilisation of local skills, further development of local skills, technology spillover, potential growth of local rail industries, lower cost of rail implementation and more urban rail transportation systems to ensure sustainable transportation. They both moved from “a to d” on the rail technology “indigenisation ladder” mentioned in Section 2.3. China is already at the “e” stage. This can be the path for other emerging economies that seek to improve local capabilities for urban rail transportation to improve the quality of transport services for the growing urban population.

The report has relied on secondary data in the form of reports, published scientific and newspaper articles and it is therefore limited in terms of primary data. The report is also limited to only English language published articles which means available secondary information, particularly for the case of China is missing although it might be available. Another limitation of the report is the choice of countries as a representative for emerging economies. Although these two are the ones that are foremost in their adoption of industrial policy for urban rail transport, their population size and number of cities provide economic advantages which are unavailable for other emerging economies. Other emerging economies without the population advantage of China and India can use their regional demand to leverage rail technology indigenisation other than as individual countries.

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