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# Indian Railway System as a Hub and Spoke: Opportunities & Challenges

**Krunal Hareshkumar Rajyaguru[1*] Prof. Dr. Pratapsinh Chauhan [2]**
*[1*] Research Scholar, Department of Business Management Saurashtra University, Rajkot, Gujarat, India.*
*[2] Hon'ble Vice Chancellor, Govind Guru University – Godhra, Gujarat, India*

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***Corresponding Author:***
Krunal H. Rajyaguru

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**ABSTRACT**

To achieve the modal shift projected by public transport policies, intermodal rail transport needs to improve its performance in order to become more attractive. Hub and spoke bundling is an option to improve its performance. Railway transit hub as an important part of urban railway transit has great impacts on urban traffic system. But there are severe traffic problems in road network due to the complex traffic characteristics of urban railway transit hub areas. To solve the traffic problems in network structure in urban railway transit hub areas. The hub-and-spoke network problem for railroad freight, where a central planner is to find transport routes, frequency of service, length of trains to be used, and transportation volume. Hub-and-spoke networks, often found in air freight, have not been favored by railways in the past. Such a structure could be profitable, however, if there exist concentrated freight flows on some service links. We suggest opportunities and challenges whose objective includes not only the typical operational cost, but also cost due to the transit time spent by freight in the network.

## 1. Introduction

Indian Railways (IR) is a statutory body under the ownership of the Ministry of Railways of the Government of India that operates India's national railway system. As of 2023, it manages the fourth largest national railway system by size with a running track length of 104,647 km (65,025 mi) and route length of 68,426 km (42,518 mi) of which 60,451 km (37,563 mi) is electrified. With more than 1.2 million employees, it is the world's ninth-largest employer and India's second largest employer. The first steam operated railway operated in 1837 in Madras with the first passenger operating in 1853 between Bombay and Thane. In 1925, the first electric train ran in Bombay on DC traction. The first locomotive manufacturing unit was commissioned in 1950 at Chittaranjan with the first coach manufacturing unit set-up at Madras in 1955. Various companies operating railways across the country were re-organized into six regional zones in 1951, which were gradually expanded to 19 zones.

Indian Railways runs various classes of express, passengers and suburban trains. In 2018–19, it operated 13,523 trains on average daily covering 7,325 stations and carried 8.44 billion passengers. Indian Railways also operates different classes of rail freight transport. In 2022–23, it operated 8,479 trains on average daily and transported 1418.1 million tons of freight.

* Author can be contacted at: *Research Scholar, Department of Business Manager Saurashtra University, Rajkot, Gujarat, India*

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Indian Railways operates multiple classes of rolling stock, manufactured by self-owned coach-production facilities. As of March 2022, Indian Railways' rolling stock consisted of 318,196 freight wagons and 84,863 passenger coaches. As of December 2023, Indian Railways had 10,238 electric and 4,543 diesel locomotives amongst others. Indian Railways (IR) is a governmental entity under the Ministry of Railways which operates India's national railway system. It is run by the government as a public good and manages the third-largest railway network in the world by size, with a route length of 68,155 km (42,350 mi) as of March 2019. 40,576 km (25,213 mi) or 64% of all the broad-gauge routes are electrified with 25 kV 50 Hz AC electric traction as of August 2020. In the fiscal year ending March 2019, IR carried 844 crore (8.44 billion) passengers and transported 123 crore (1.23 billion) tons of freight. IR runs 13,523 passenger trains daily, on both long-distance and suburban routes, covering 7,321 stations across India. Mail or Express trains, the most common types, run at an average speed of 50.6 km/h (31.4 mph). Suburban EMUs run at an average speed of 37.5 km/h (23.3 mph). Ordinary Passenger Trains (incl. mixed) run at an average speed of 33.5 km/h (20.8 mph). The maximum speed of passenger trains varies, with the Vande Bharat Express running at a peak speed of 180 km/h (110 mph).

In the freight segment, IR runs more than 9,146 trains daily. The average speed of freight trains is around 24 km/h (15 mph). The maximum speed of freight trains varies from 60 to 75 km/h (37 to 47 mph) depending on their axle load with 'container special' trains running at a peak speed of 100 km/h (62 mph). The government has committed to electrifying India's entire rail network by 2023–24, and become a "net-zero (carbon emissions) railway" by 2030.

*1.1 Structure*

Indian Railways is a legally mandated entity that operates under the government's ownership, specifically the Ministry of Railways. The Railway Board, consisting of four members, is led by a chairman who is accountable to the government of Railways and acts on behalf of the government. The organizational structure consists of distinct verticals, namely traction, engineering, traffic, rollingstock, signaling, materials, personnel, RPF, finance, and health and safety.

Indian Railways is divided into 18 administrative zones (17 operational), headed by general managers which are further subdivided into 71 operating divisions, headed by divisional railway managers (DRM). The divisional officers of the respective operating verticals report to the DRMs and divisional heads and are tasked with the operation and maintenance of assets. Station master’s control individual stations and train movements through their stations' territory. In addition, there are a number of manufacturing units, training establishments, PSUs and other undertakings under the purview of the Indian Railways.

Indian Railways is headed by a seven-member Railway Board whose chairman reports to the Ministry of Railways. The Railway Board also acts as the Ministry of Railways. The officers manning the office of Railway Board are mostly from organized Group A Railway Services and Railway Board Secretariat Service. IR is divided into 18 zones, headed by general managers who report to the Railway Board. The zones are further subdivided into 68 operating divisions, headed by divisional railway managers (DRM). The divisional officers of the engineering, mechanical, electrical, signal and telecommunication, stores, accounts, personnel, operating, commercial, security and safety branches report to their respective DRMs and are tasked with the operation and maintenance of assets. Station master’s control individual stations and train movements through their stations' territory. In addition, there are several production units, training establishments, public sector enterprises and other offices working under the control of the Railway Board.


**Fig. 1** Close-up of a locomotive with the classification and number; WDM3A indicates a Broad gauge (W), Diesel (D), Mixed use (M), 3100 HP (3A) locomotive

## 2. Locomotives of India

The first trains in the 1800s were hauled by imported steam locomotives. In 1877, the first locomotive was built in India. Electric locomotives were introduced in 1925 and diesel locomotives later in 1954. By 1990s, steam locomotives were phased out and are currently operated only on mountain and on heritage trains. Locomotives are classified by track gauge (broad/meter/narrow/narrower), motive power (electric/diesel/battery), function (passenger/goods/mixed), power rating (x1000 HP) and model in a four or five letter code. The locomotives may be Longer Hood Front (LHF), where the driver cabin is behind the hood of the engine or Short Hood Front (SHF), where the cabin is located towards the front. Multiple units (MU) are propelled by locomotives integrated with train-sets. In 2015, the first Compressed Natural Gas (CNG) powered MUs were rolled out by ICF. In 2018, the semi-high speed self-propelled Vande Bharat train-set was rolled out from ICF. Locomotives are manufactured by five owned manufacturing units of the Indian Railways and BHEL. As of 2021, 37% of the trains are operated by diesel locomotives and rest mostly by electric locomotives. As of December 2023, Indian Railways had 10,238 electric and 4,543 diesel locomotives amongst others.

*2.1 Passenger coaches*

**Fig. 2 a** ICH Coach

**Fig. 2** b LHB Coach

The early rail coaches were based on a prototype by a Swiss company and were termed as ICF coaches after Integral coach factory (ICF), the first coach manufacturing unit in India. These coaches, manufactured from 1955 to 2018, were largely in use till the early 2010s. From the late 1990s, the ICF coaches were replaced by safer and newer LHB coaches designed by Linke-Hofmann-Busch of Germany. In the late 2010s, Indian railways started upgrading the coaches of select trains from LHB to new Tejas coaches with enhanced features. As of March 2022, Indian Railways' had 84,863 passenger coaches. Coaches are manufactured by five manufacturing units of the Indian Railways and public sector companies BEML and BHEL. The coaching stock have unique five or six digit identifiers. Till 2018, the first two digits indicating the year of manufacture and the last three digits indicating the class. In 2018, the numbering system was changed with the first two digits indicating the year of manufacture and the last four digits indicating the sequence number.

*2.2 Multiple units*

In the 1960s, Electric multiple units (EMU) were developed for short-haul and suburban rail transit. On regional short-distance routes, Mainline electrical multiple unit (MEMU) and Diesel electrical multiple unit (DEMU) trains are run. These train sets run in formation of 6, 9, 12 or 15 coaches and a three-car set is typified by a motor coach and two passenger coaches. These trainsets are self-propelled with capability for faster acceleration or deceleration. In 2018, Indian Railways also rolled out semi-high speed self-propelled train sets with modified coaches for intercity trains.

Goods wagons

**Fig. 3 a.** covered wagon **b.** tanker

Indian Railways hauls variety of cargo to cater to various requirements and have specialized rolling stock corresponding to the cargo hauled. There are 243 types of rolling stock used for cargo operations. These include covered wagons, boxcars, flat wagons, flatbeds, open wagons, hoppers, containers, automobile carriers, defense vehicle carriers and tankers. The freight cars can often carry loads from 10 to 80 tons per car depending on the configuration. A new wagon numbering system was adopted in Indian Railways in 2003. The requirement of wagons was previously met by Bharat wagon and engineering with the procurement and manufacturing now done by both in public and private sector. Apart from standard passenger classes, the Indian Railways has other specialized coach types used for dedicated functions. These include accident relief medical vans, brake vans, generator cars, inspection carriages, military cars, pantry car and parcel vans. These may be dedicated self-propelled units or attached to train-sets.

*2.3 Manufacturing*

Indian Railways operates various manufacturing units. Chittaranjan Locomotive Works (CLW), commissioned in 1950, was the first locomotive manufacturing unit in India. The first rail coache manufacturing unit, the Integral Coach Factory (ICF) was established at Madras in 1956. Banaras Locomotive Works (BLW), commissioned in 1961, is the second locomotive manufacturing unit operated by Indian Railways. BHEL, Patiala Locomotive Works, Diesel Locomotive Factory, Marhowrah and Electric Locomotive Factory, Madhepura also manufacture locomotives in India. Railway coaches are also manufactured at coach factories at Karputhala, Raebareli, Sonipat and Latur. Indian Railways also operates two rail wheel manufacturing factories at Bangalore and Chhpra.

## 3. Network

*3.1 Tracks*

As of March 2*023, Indian railway network spanned 104,647 km (65,025 mi) of running track length and 68,426 km (42,518 mi) of* route length. Track sections are rated for speeds ranging from 80 to 200 km/h (50 to 124 mph), though the maximum speed attained by passenger trains is 160 km/h (99 mph). Spanning 65,093 km (40,447 mi) 1,676 mm (5 ft 6 in) broad gauge is the most used gauge with 1,000 mm (3 ft 3+$^3/_8$ in) metre gauge metre gauge and 762 mm (2 ft 6 in) narrowguage and 610 mm (2 ft) narrower gauge tracks limited to certain routes. The broad-gauge network is equipped with long-welded, high-tensile 52kg/60kg 90 UTS rails with pre-stressed concrete (PSC) sleepers and elastic fastenings. As of 31 March 2019, IR network spans 1, 23,542 km (76,765 mi) of track length, while the route length is 67,415 km (41,890 mi). Track sections are rated for speeds ranging from 80 to 200 km/h (50 to 124 mph), though the maximum speed attained by passenger trains is 180 km/h (110 mph) during trial runs. Almost all the broad-gauge network is equipped with long-welded, high-tensile strength 52kg/60kg 90 UTS rails and pre-stressed concrete (PSC) sleepers with elastic fastenings. 1,676 mm (5 ft 6 in) broad gauge is the predominant gauge used by IR and spans 62,891 km (39,079 mi) of route (93.29% of total route network), as of 31 March 2019. It is the broadest gauge in use across the world for regular passenger movement. Broad gauge generated 100% of the freight output (net tonne-kilometres) and more than 99% of the passenger output (passenger kilometers) in the fiscal year 2018–19.

The 1,000 mm (3 ft 3 $^3/_8$ in) meter gauge tracks and 762 mm (2 ft 6 in) and 610 mm (2 ft) narrow gauge tracks are present on fewer routes. All these routes, except the heritage routes, are being converted to broad gauge. The meter gauge tracks were 2,839 kilometers (1,764 mi) (4.21% of total route network) and narrow gauges tracks were 1,685 km (1,047 mi) (2.50% of total route network) as of 31 March 2019.

*3.2 Electrification*

The first electric train ran in Bombay in 1925 on DC traction. In 1928, DC traction was introduced on the suburban of Bombay by the Bombay, Baroda and Central India Railway between Colaba and Borivali and between Madras beach and Tambaram by the Madras and Southern Mahratta Railway in 1931. In 1957, Indian Railways decided to adopt 25 kV AC as its standard. The first 25 kV AC EMUs operated in Calcutta in 1962 and Madras in 1968. In 2017, Indian Railways announced a plan to electrify the country's entire broad gauge rail network by 2023. Post electrification, 30 billion units of electricity will be required on an annual basis for Indian Railways. As of October 2023, IR has electrified 60,453 km (37,564 mi) of the total broad-gauge route length. Indian Railway uses 25 kV AC traction on all its electrified tracks.

*As of 1 April 2020, IR has electrified 58.49% or 39,866 km (24,772 mi) of the total route kilometers. Indian Railway uses* 25 kV 50 Hz AC traction on all its electrified tracks. Railway electrification in India began with the first electric train, between Chhatrapati Shivaji and Kurla on the Harbor Line, on 3 February 1925 on the Great Indian Peninsula Railway (GIPR) at 1500 V DC. Heavy gradients in the Western Ghats necessitated the introduction of electric traction on the GIPR to Igatpuri on the North East line and Pune on the South East line. On 5 January 1928 1500 V DC traction was introduced on the suburban section of the Bombay, Baroda and Central India Railway between Colaba and Borivili, and between Madras Beach and Tambaram of the Madras and Southern Mahratta Railway on 11 May 1931, to meet growing traffic needs. The 3000 V DC electrification of the Howrah-Burdwan section of the Eastern Railway was completed in 1958. The first 3000 V DC EMU service began on the Howrah-Sheoraphuli section on 14 December 1957.

Research and trials in Europe, particularly on French Railways (SNCF), indicated that 25 kV AC was an economical electrification system. Indian Railways decided in 1957 to adopt 25 kV AC as its standard, with SNCF their consultant in the early stages. The first 25 kV AC section was Raj Kharswan–Dongoaposi on the South Eastern Railway in 1960. The first 25 kV

AC EMUs, for Kolkata suburban service, began service in September 1962. For continuity, the Howrah–Burdwan section of the Eastern Railway and the Madras Beach–Tambaram section of the Southern Railway were converted to 25 kV AC by 1968. Because of limitations in the DC traction system, a decision was made to convert the electric traction system of the Mumbai suburban rail network of WR and CR from 1.5kV DC to 25 kV AC in 1996–97. The conversion from DC to AC traction was completed in 2012 by Western Railway, and in 2016 by Central Railway. Since then, the entire electrified mainline rail network in India uses 25 kV AC, and DC traction is used only for metros and trams.

Indian Railways announced on 31 March 2017 that the country's entire rail network would be electrified by 2022. Though not a nascent concept, the electrification in India now has been committed with a fresh investment of 35,000 crore (US$4.9 billion) to electrify the entire network and eliminate the cost of fuel under transportation which will amount to a massive savings of 10,500 crore (US$1.5 billion) overall. This will be a boon for savings for the Government to channelize the investments in modernization of the railway infrastructure. Close to 30 billion units of electricity will be required for railway electrification on an annual basis by 2022, leading to excellent opportunities for IPPs of conventional power.

*3.3 Stations*

As of March 2022, Indian Railways manages and operates 7,308 stations. Prior to 2017, the stations were classified based on of its earnings into seven categories. Since 2017, Indian Railways categorizes the stations by commercial importance into three different categories namely Non Suburban Group (NSG), Suburban Group (SG) and Halt Group (HG). These are further subdivided into subcategories based on their commercial importance (NSG 1–6, SG 1-3 and from HG 1–3). The commercial importance of a station is determined by taking into account its passenger footfall, earnings and strategic importance and these categories are used to determine the minimum essential amenities required by each station.

## 4. Passenger trains

*4. 1 Express trains of India*

**Fig. 4 a** Rajdhani Express **b.** *Shatabdi Express*

Indian Railways operates various classes of passenger and express trains. The trains are classified as a basis average speed and facilities with express trains having fewer halts, priority on rail network and faster average speed. The trains are identified by five digit numbers with train-pairs traveling in opposite directions usually labelled with consecutive numbers. Express trains often have specific unique names for easy identification. In 2018–19, Indian Railways operated 13,523 passenger trains on average daily and carried 8.44 billion passengers. India Railways operates various categories of express trains including Rajdhani Express, Shatabdi Express, Garib Rath Express, Double Decker Express, Tejas Express, Gatimaan Express, Humsafar Express, Duronto Express, Yuva Express, Uday Express, Jan Shatabdi Express, Sampark Kranti Express, Vivek Express, Rajya Rani Express, Mahamana Express, Antyodaya Express, Jan Sadharan Express, Suvidha Express and Intercity Express.

*4.2 High-speed rail*

Rajdhani express introduced in 1969 were the first trains to reach speeds of up to 120 km/h (75 mph). Shatabdi Express introduced in 1988, are capable of running at a maximum speed of 150 km/h (93 mph). In 2019, Vande Bharat Express was launched with self-propelled EMU train-sets capable of reaching maximum speed of 180 km/h (110 mph) with operational speeds restricted to 130–160 km/h (81–99 mph). A non-airconditioned semi-high speed train-set hauled by two modified WAP-5 locomotives was launched as Amrit Bharat Express. A high-speed rail line is under-construction between Mumbai and Ahmedabad which will become the first true high-speed rail line when completed in 2026.

*4.3 Freight service*

The first rail operational in Madras in 1837 was used for ferrying granite. The first dedicated commercial freight rail was operated between Bombay and Ahmedabad in 1966. Indian Railways ferries various commodities and cargo to cater to various industrial, consumer, and agricultural segments. Apart from dedicated freight trains, parcels, mail and small cargo are carried on specialized carriages attached to passenger trains. In 2022–23, Indian Railways operated 8,479 trains on average daily and transported 1418.1 million tons of freight. To counter this, Indian Railways established the Dedicated Freight Corridor Corporation of India in 2006 to construct dedicated freight corridors to reduce congestion, increase speed and reliability and proposed upgradation of existing goods sheds, attracting private capital to build multi-commodity multi-modal logistics terminals, changing container sizes, operating time-tabled freight trains and tweaking with the freight pricing/product mix. End-to-end integrated transport solutions such as roll-on, roll-off (RORO) service, a road-rail system pioneered *by Konkan Railway in 1999 to carry trucks on flatbed trailers is extended to other routes.*

In the freight segment, IR ferries various commodities and fuels in industrial, consumer, and agricultural segments across the length and breadth of India. IR has historically subsidized the passenger segment with income from the freight business. As a result, freight services are unable to compete with other modes of transport in terms of both cost and speed of delivery, leading to continuous erosion of market share. To counter this downward trend, IR has started new initiatives in freight segments including upgrading of existing goods sheds, attracting private capital to build multi-commodity multi-modal logistics terminals, changing container sizes, operating time-tabled freight trains, and tweaking with the freight pricing/product mix. Also, end-to-end integrated transport solutions such as roll-on, roll-off (RORO) service, a road-rail system pioneered by Konkan Railway Corporation in 1999 to carry trucks on flatbed trailers, is now being extended to other routes across India. Perhaps the game changer for IR in the freight segment are the new dedicated freight corridors that are expected to be completed by 2020. When fully implemented, the new corridors, spanning around 3300 km, could support hauling of trains up to 1.5 km in length with 32.5-ton axle-load at speeds of 100 kilometers per hour (62 mph). Also, they will free-up capacity on dense passenger routes and will allow IR to run more trains at higher speeds. Additional corridors are being planned to augment the freight infrastructure in the country.

## 5. Hub & Spoke Model

In the domestic arena as well, hub and spoke movements allow for a better utilization of transport potential and allow for long lead services to be generated based on short lead traffic collections using road and rail shuttle services. This service can be especially useful for big corporates for whom production centers are concentrated in a single location, but distribution needs are national in scale. Indian Railways has already successfully moved white cement as a commodity using this experiment, whereby the product has been distributed over various locations after being picked up from a single production center. The hub-and-spoke system is the best-known network system. The spokes in the network are liner services between regional terminals and the hubs. Hubs are terminals or, in railway systems, they may be marshalling yards. At the hub the transport units are transferred from one liner service to another connecting the hub with the destination terminal. Ideally, hubs are located near to the center of gravity of transport demand. In this way detour distances and trip times between origin and destination terminals can be minimized. The dotted arrow in the picture indicates that two services (spokes) are needed to connect different regions. The total terminal-to-terminal trip time is increased because of the extra distance for the call at the hub and the time spent in the hub itself. A hub-and-spoke system is designed to combine small flows arriving and departing in different directions. In the case of railways, the spokes can be of any type of liner service with any frequency.

The hub-and-spoke model allows railroad end points to release trains to the hub terminal with full railcars of mixed destination using any size railcar available. The hub combines small volumes for less populous destinations from the entire network, and builds large, full, pure railcars for delivery. This allows rail networks to pursue low-volume cargo because it is no longer necessarily high in cost. With every rise in the price of gasoline, a new market share is available to rail from trucking lines. The networks that can better reduce the costs of servicing smaller-volume customers stand to reap greater gains in market share. The opportunity exists for the rail network that can seize it.

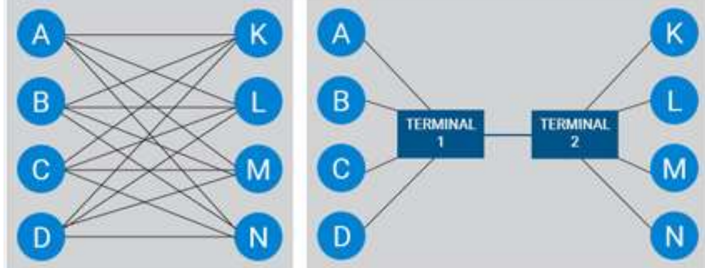


**Fig. 5** Hub & Spoke model

### 6. Maximize Freight Efficiencies

As part of the hub-and-spoke model, hubs are positioned no more than 300 miles apart from one another. Here's how it works: Driver A leaves from his original hub and meets Driver B at a switching point. They then exchange trailers. And while Driver B continues to the next switching point, Driver A heads back to his originating hub. This sequence of events keeps products in continuous motion and allows drivers to return home each night.

The hub-and-spoke model creates numerous benefits, including:

- Continuous movement for loads thanks to centralized handoffs.
- Reduced lengths-of-haul, which improve scheduling, reduce transit time and help drivers comply with hours-of-service regulations.
- Consistent on-time performance, which enhances service levels and ensures products arrive in the right place at the right time.
- Improved driver recruiting and retention. Drivers are able to return home each night, thus experiencing an improved quality of living. This produces additional benefits, including higher tenure, route consistency, increased transit dependability and performance, and improved safety.
- Reduced costs and enhanced productivity thanks to Penske's economies of scale (larger loads reduce per-unit costs) and the elimination of the need for team drivers.
- Lower carbon footprint, because few empty miles driven reduces wasted fuel and emissions.
- Consistent pricing mitigates the risk of third-party carrier price fluctuations.

Just-in-time doesn't have to mean high costs. By partnering with Penske and leveraging our hub-and-spoke system, you can strategically use your transportation resources and steer a course toward efficiency.

### 7. Opportunities

*7.1 Growth potential*

The hub-and-spoke system, developed after deregulation, has allowed a rapid growth in size, competition strategy and traffic demand in the transportation business. This had resulted in operational inefficiencies at periods of slow economy. As a result of this, some transportation companies restructure their business model to return to the point-to-point system and move out of the constant need for a large hub and utilize hubs in a more uniform matter in terms of arrivals and departures. This phenomenon is known as the rolling hubs.

*7.2 Optimization of available resources*

The system has a smaller number of routes connecting all spokes enabling a more efficient use of scarce transportation resources. This, however, had small stations and economies of smaller regions suffering as per the reduced capacity. As a result, this encouraged railways to agree with low-cost carriers to offer low transportation fees and commissions from local businesses to bring in traffic and passenger flow. The passenger market favored this type of airline business as lower fares were rolled out to the market from these smaller hubs, which caused great competition to full-service carriers that were operating with large amount of fees to use large hubs and can no longer return to these small hub markets as it is not cost efficient and are dominated by low cost carriers.

### 8. Challenges

*8.1 Congestion and delay management*

To limit waiting times and provide a large variety of possible connections for passengers at the hub station, it is essential for the hub station to schedule as many incoming and outgoing trains as possible during a short time frame. This results in high traffic peaks during these times and often causes delays due to scarce rail side facilities such as taxi- or runways. At the same time the hub-and-spokes-system however allows hub train to increase their benefit exponentially by adjoining an additional destination to the network compared to point-to-point-carriers. This implies for a hub train that usually the tradeoff between the costs due to congestion and the benefit of serving new markets is positive. Therefore, the train has an incentive for adding more traffic despite a rising congestion level. The point-to-point carriers at the railway station, which cannot capitalize on such an exponential benefit, however, suffer from the increasing number of flights.

Another reason for congestion stems from the fact that many stations do not limit the number of take-offs and landings. One possibility for trains to prevent further congestion and coevally increase the passenger count is the use of larger trains. However, doing so, new challenges occur if these trains with more passengers are delayed. More travelers will miss their connecting trains which would result in a poor utilization rate of the hub-hub connection and reduces the profitability of a train.

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