



An Overview of Railway Transportation Systems for High and Medium Steep Gradients in Operation and Under-construction Worldwide (2019 Data)

Prof. Christos Pyrgidis, Aristotle University of Thessaloniki, Greece



The railway as a transport system

The “railway” is a terrestrial mass transport system. Trains move on their own (diesel traction) or remotely transmitted power (electric traction) on a dedicated steel way corridor defined by two parallel rails

Passengers and goods

- Transportation of passengers : 1500 km (2439 km, China)
- Transportation of goods > 3000 km (10000-12000 km, Europe-China)

It serves **different distance transfers in all kinds of environment** (urban, suburban, peri-urban, regional, interurban)

The railway is the only technology that reached its peak, then dropped to nadir and peaked again



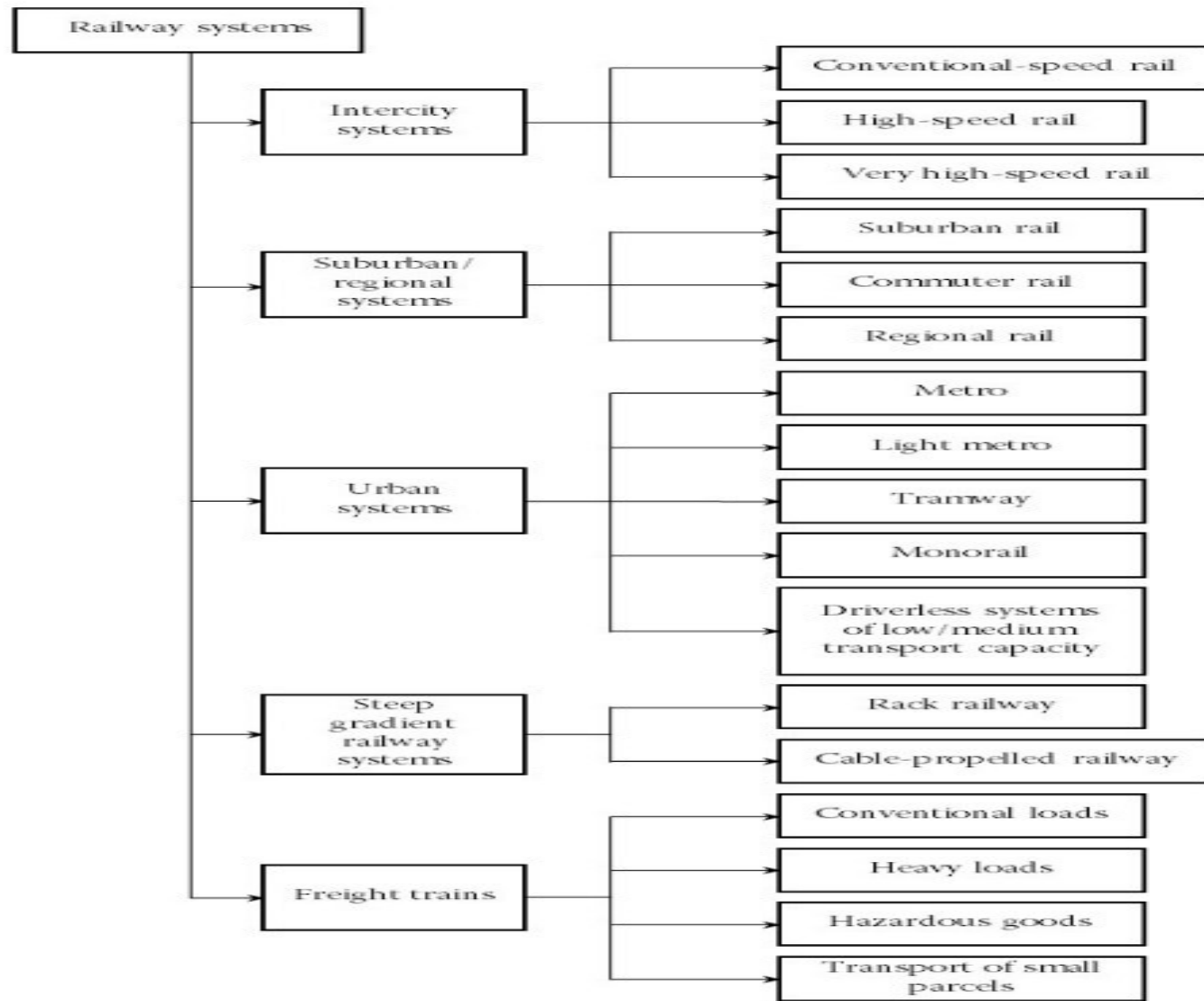
1830 - 1950



1960 - 1980



The railway was the means of transport that set the basis for the development of the inland in all continents





Railways - Characteristic speeds

<i>Characteristic speeds</i>	<i>Maximum value (km/h)</i>	<i>Country</i>
Rolling stock design speed	400	China
Commercial speed	304.1	China
Cruiser (forward) speed	350 (320)	China (Japan, Europe)
Track design speed	400	Spain
Speed record	574.8	France (2007)



Objective of the work and application field

Railway systems that (can) operate, in a great part of their route, on gradients higher than 5%

- Definition and classification of the systems
 - Identification and recording of the systems that are operational at a global level
 - Registration in databases, of their constructional and operational characteristics
 - Analysis and statistical elaboration of the data
 - Future trends
 - Reference date: End 2019
- Rack Railways
 - Cable-propelled Railways
 - *Monorails (medium slopes)*

Rack Railways

Two conventional rails plus a toothed rack rail in-between

Classification according to:

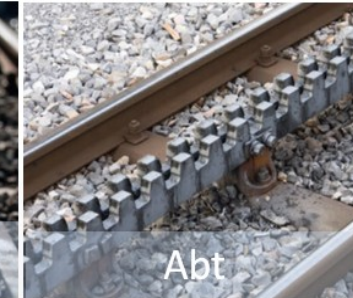
- Rack system
Riggenbach, Abt, Strub, Locher, Marsh or Lamella
- Type of adhesion along the line
Purely racked, Mixed adhesion



Rack systems



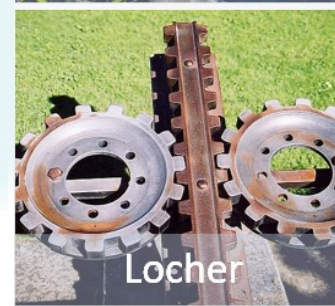
Riggenbach



Abt



Strub



Locher



Marsh

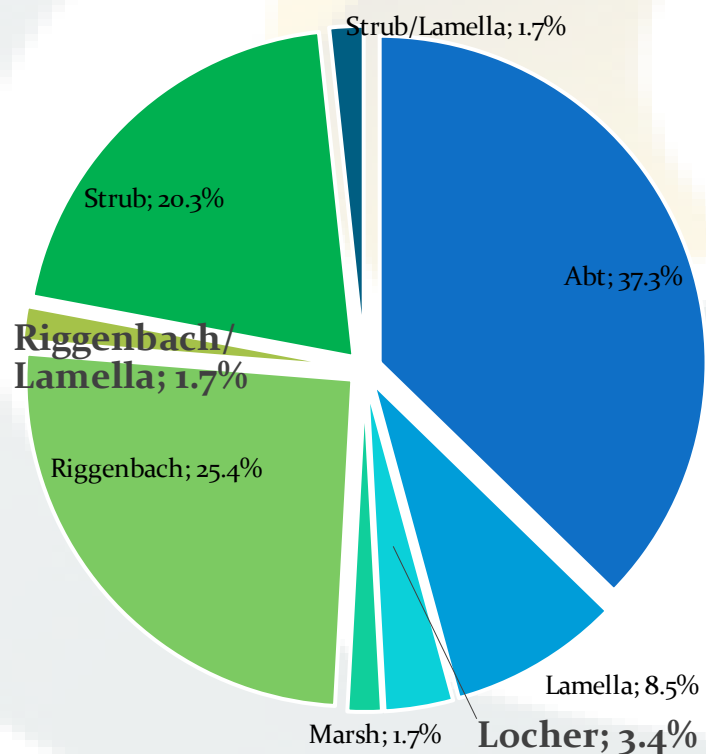


Lamella



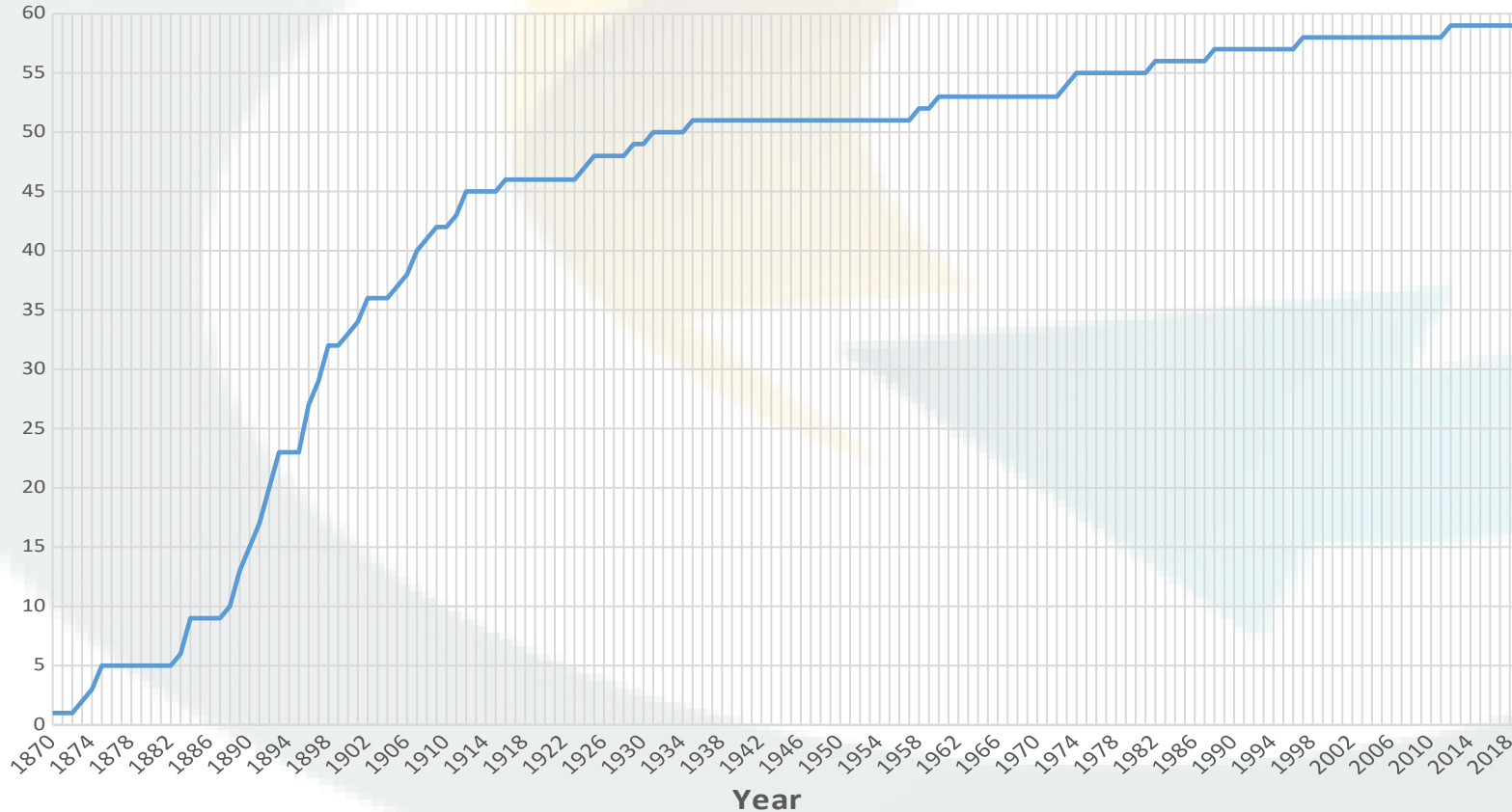
Rack Railways

59 Systems in operation
(2019 data)



CONTINENT	COUNTRY	PURELY RACKED SYSTEMS	MIXED ADHESION SYSTEMS	TOTAL
EUROPE(48)	Austria	2	1	3
	France	3	2	5
	Germany	2	2	4
	Switzerland	13	11	24
	Greece	0	1	1
	United Kingdom	1	0	1
	Spain	0	2	2
	Italy	2	1	3
	Hungary	1	0	1
	Russia	1	0	1
	Slovakia	1	1	2
	Czech Republic	0	1	1
AMERICA (6)	Brazil	1	1	2
	United States	3	0	3
	Panama	0	1	1
ASIA (3)	India	0	1	1
	Indonesia	1	0	1
	Japan	0	1	1
AUSTRALIA (2)	Australia	1	1	2
TOTAL		32	27	59

Rack Railways



- First rack railway opened in 1868 on Mount Washington, USA
- Only 3 new rack railways during the last 35 years
- No systems under construction



Rack Railways

Constructional & Operational Features

Route length	Usually 4.5-6km, $S_{\max} = 19,09\text{km}$
Track gauge	Usually metric gauge (1000mm or 1067mm)
Longitudinal gradient	>5%, usually $i = 20\text{-}25\%$, $i_{\max} = 48\%$
Traction system	Diesel, bio-diesel, steam, usually electric (67.2%).
Commercial speed	7.5–20km/h, $V_{\max} = 40\text{km/h}$
Transportation system capacity	Low/medium transportation system capacity

- Infrastructure cost: 10-15 million €/km (single track)
- Mostly used for passenger transport
- Mainly directed towards leisure activities, mountainous areas

Cable-propelled Railways

Moving with the aid of a cable that rolls over pulleys mounted on track



Classification:

- Funiculars (non-detachable cable-propelled vehicles for steep gradients)
- Cable cars (detachable cable-propelled vehicles for steep gradients)
- Inclined elevators

Cable-propelled Railways-Funiculars

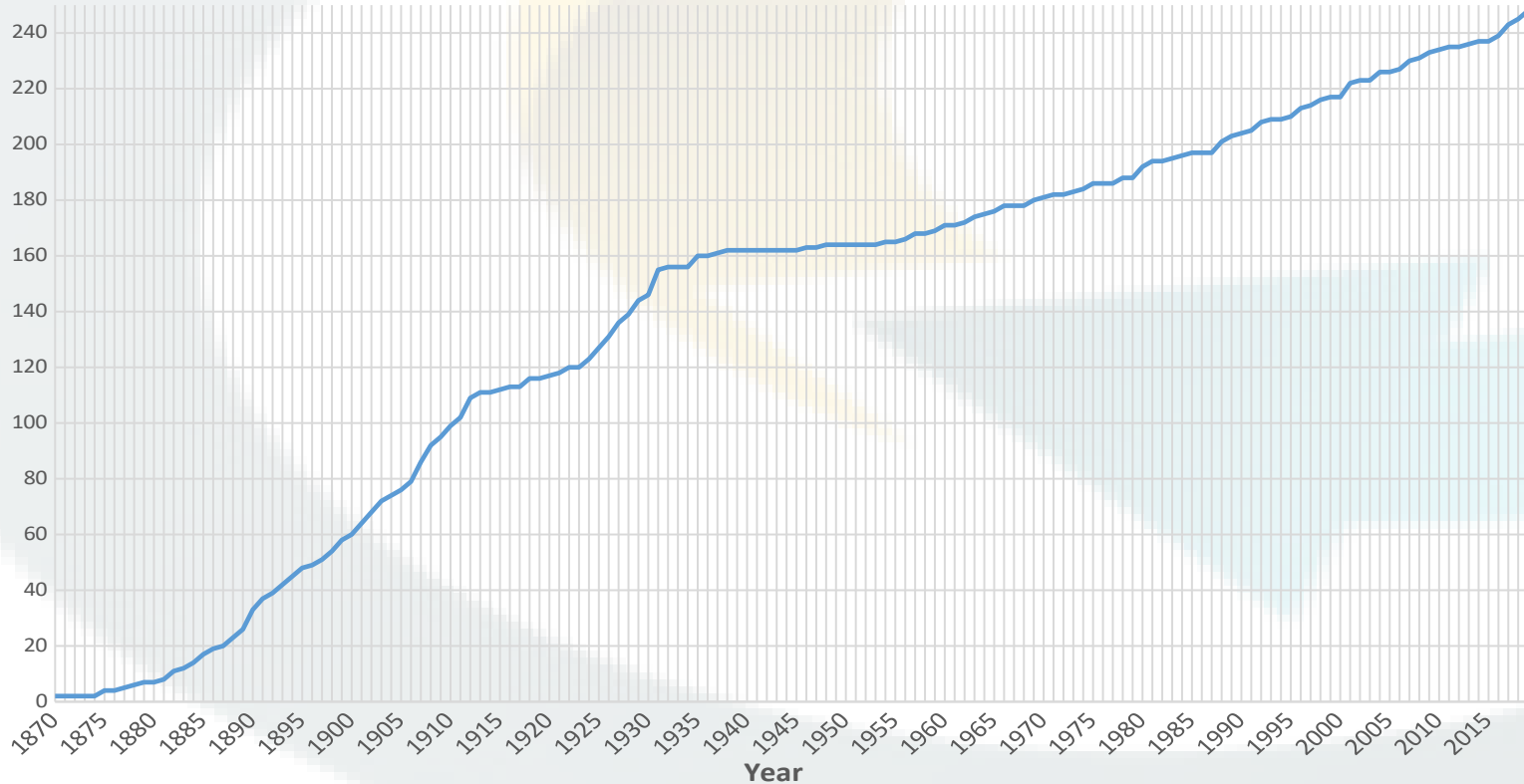
248 funiculars in operation
(2019 data)

50 of them in Switzerland

CONTINENT	COUNTRY	FUNICULARS
EUROPE (175)	ENGLAND	13
	AZERBAIJAN	1
	AUSTRIA	11
	FRANCE	16
	GERMANY	14
	GEORGIA	1
	SWITZERLAND	50
	GREECE	1
	SPAIN	11
	ITALY	21
	CROATIA	1
	LITHOUANIA	2
	LUXEMBURG	1
	NORWAY	2
	WALES	5
	HUNGARY	1
	UKRAINE	1
	POLAND	3
	PORTUGAL	8
	ROMANIA	1
	RUSSIA	2
	SLOVAKIA	1
	SWEDEN	2
	TURKEY	3
	CZECH REPUBLIC	3
NORTH AMERICA (14)	UNITED STATES	12
SOUTH AMERICA (18)	CANADA	2
	ARGENTINA	1
	BRAZIL	6
	COLOMBIA	1
	MEXICO	1
	CHILE	10
ASIA (39)	VIETNAM	2
	JAPAN	22
	INDIA	2
	ISRAEL	1
	CHINA	4
	LEBANON	1
	MALAYSIA	1
	THAILAND	3
	HONG KONG	2
	SOUTH AFRICA	1
AFRICA (1)	NEW ZEALAND	1
AUSTRALIA (1)		
TOTAL		248

Cable-propelled Railways- Funiculars

Funiculars in operation



- First funicular opened in 1862 in Lyon, France
- 14 new funiculars during the last decade
- 1 funicular under construction (Qiddiya Project, Saudi Arabia)

Cable-propelled Railways- Funiculars

Three main superstructure types:

Two-rail superstructure with passing loop



Three-rail superstructure with passing loop



Four-rail superstructure configuration



Cable-propelled Railways- Funiculars

Constructional & Operational Features

Route length	Usually $S < 1000\text{m}$, $S_{\min} = 39\text{m}$, $S_{\max} = 4827\text{m}$
Track gauge	Usually metric gauge (1000mm or 1067mm)
Longitudinal gradient	usually $i = 30\text{-}50\%$, $i_{\max} = 110\%$
Commercial speed	7.2–14.4km/h, $V_{\max} = 50.4\text{km/h}$
Transportation system capacity	1000-2000 passengers/hour/direction

- Implementation cost: 20-30million €/km (infrastructure & rolling stock)
- Used for passenger transport
- Short distances with continuous gradients

Cable-propelled Railways- Inclined Elevators

- Uses a single vehicle, balanced by a counterweight
- Ideal for large continuous and very high gradients (50%-70%)
- Private use in residences (hotels, beach houses, cabins, etc.)
- Low transport system capacity (200–700 passengers/hour/direction)



Monorails

The monorail is an electrified light rail passenger transport system. This transport mode (in a typical manner, an articulated train) is formed of a small number of vehicles (2-6 and rarely 8) and in most cases it moves via rubber-tired wheels, on an elevated permanent way (guideway). The guideway is essentially a beam, which takes over the traffic loads and guides and supports the vehicles (guide - beam)

Small monorails



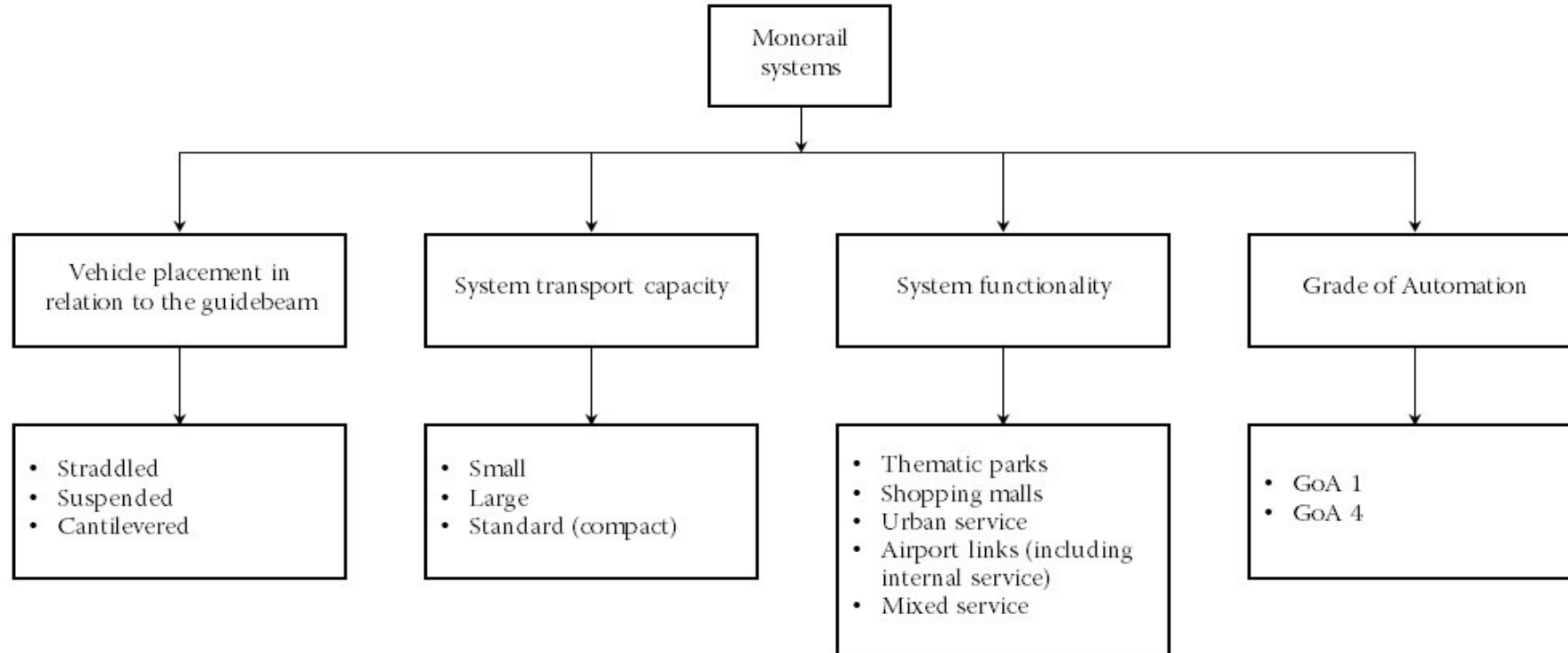
Large monorails



Standard monorails



Monorails-Classification

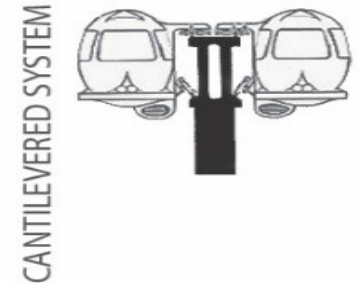
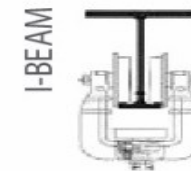


Monorails-Classification

Straddled



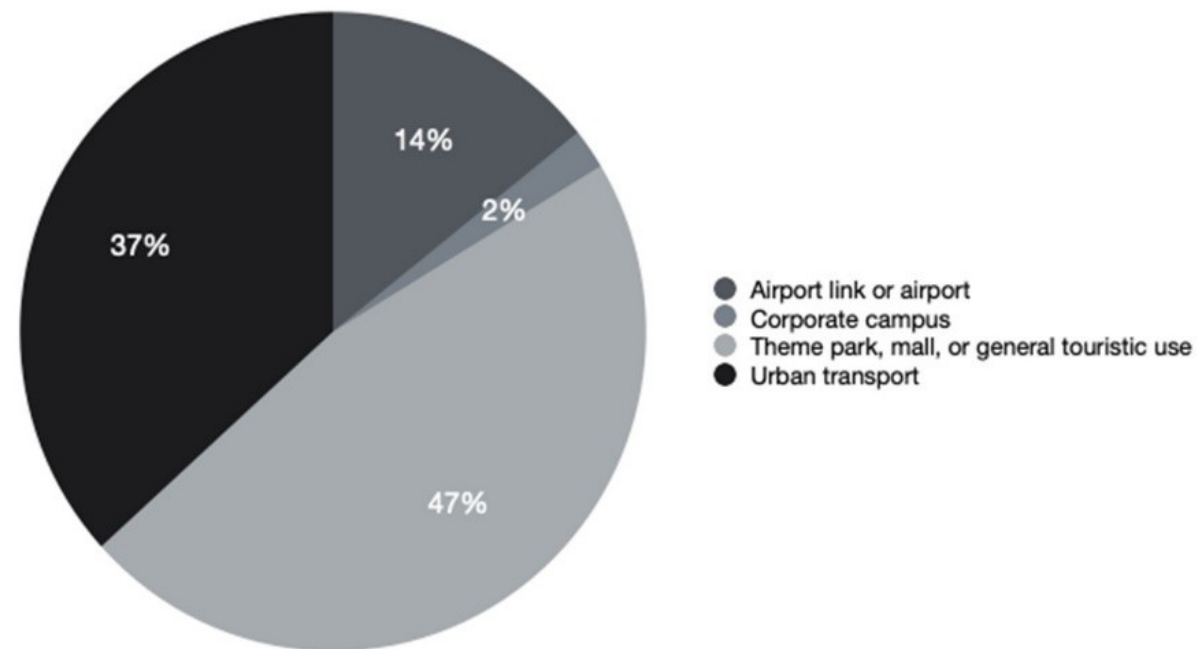
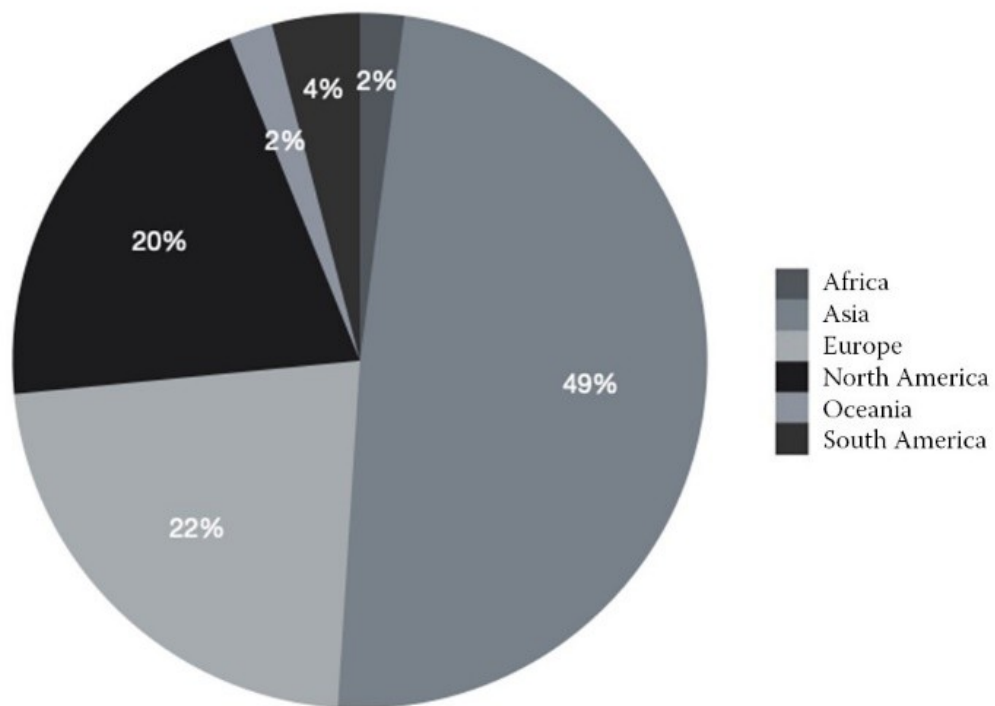
Suspended





Monorails- Evolution

49 Systems in operation
(2019 data) + 1 (2020)



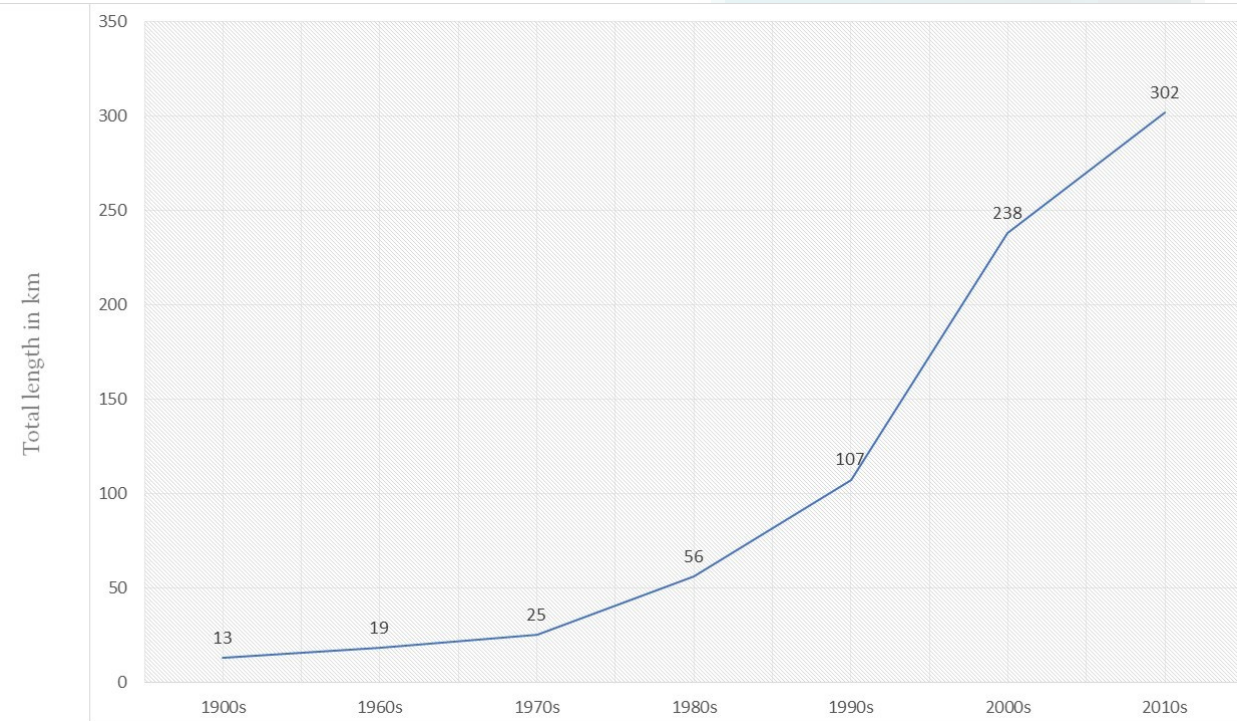
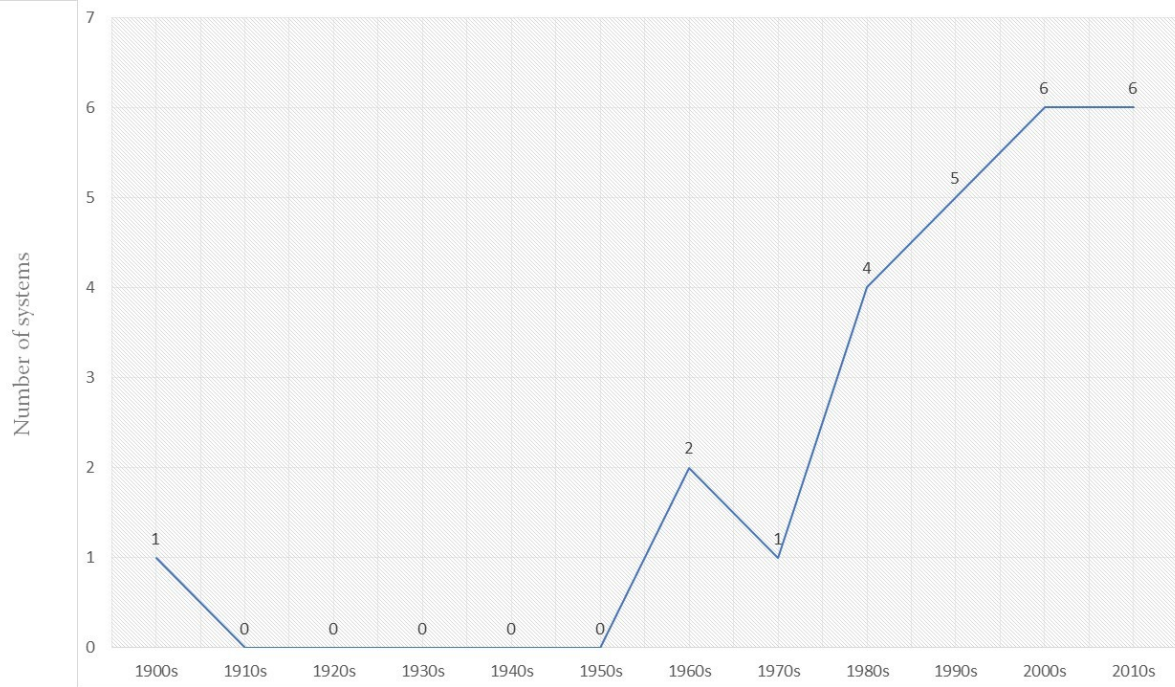
41(+1) straddled)

Total length approximately : 410km

Monorails- Evolution

25 urban use systems (300 km)

8 systems under construction



- **Route length** : 1.5-12 km (When used for public transport, its length may be significantly longer-55.5 km)
- **Maximum running speed** : 60-100km/h
- **Commercial speed** : 15-40 km/h
- **Distance between successive stops** : 800-1,500m
- **Longitudinal gradient** : 0-10% (20%)
- **Implementation cost** : 30-90 mil € / km (infrastructure + rolling stock)
- **Frequency** : 3-15 min (min 60 sec)
- **Maximum transportation work (pphpd)** : Small systems 2,000, Large systems: 12,500, Standard systems 4,800 (20,000-25,000 pphpd)
- **Driverless or not**
- **Axle load** : 8-11t

Area occupied on the ground by
the pylons : 1 - 1.5m x 1 - 1.5m
Usually pillars are constructed
inside a 2-3 m wide green zone





Monorails: Requirements for implementing the system

When there is a need for a transport mode that will serve movement within amusement parks, zoos, and so on

For the transportation of passengers over small distances, and in areas that are particularly interesting in terms of their view

For the connection of urban areas of the same altitude, where there is a natural barrier hindering their connection (e.g., water)

In recent years, monorails are increasingly used not only for recreational purposes but also for urban public transport, for serving connection with airports, movement within shopping malls and so on

Name	Continent	Country	City	Expected Date	Length	Placement	Type	GoA
Cairo Monorail	Africa	Egypt	Cairo	2023	96	Straddled	Urban Service	Driverless
Kai Tak monorail	Asia	China	Hong Kong	2023	9.0	Straddled	Urban service	n.d.
Wuhu Metro	Asia	China	Wuhu	2020	46.2	Straddled	Urban service	With Driver
Zunyi Rapid Transit System	Asia	China	Zunyi	n.d.	50.0	n.d.	Urban service	n.d.
QOM Monorail - Line M	Asia	Iran	Qom	n.d.	7.0	Straddled	Urban service	With Driver
Yellow Line	Asia	Thailand	Bangkok	2022	30.4	Straddled	Urban service	With Driver
MRTA Pink Line "2020"	Asia	Thailand	Bangkok	2021	34.5	Straddled	Urban service	Driverless
Marconi Express	Europe	Italy	Bologna	In operation from November 2020	5.0	Straddled	Airport service	Driverless
Krasnogorsk Monorail	Europe	Russian Federation	Krasnogorsk	2020	13.0	Suspended	Urban service	Driverless



Conclusions

- Construction of rack railways has virtually halted - Evolution of adhesion railways
- Funiculars remain in consideration as an alternative for cases of a complex landscape
- Inclined elevators remain a popular solution for very steep gradients and very short distances
- In recent years, monorails are increasingly used not only for recreational purposes but also for urban public transport, for serving connection with airports, movement within shopping malls and so on

The champions in gradient

Pilatusbahn—Rack (48%)



Stoosbahn—Funicular (110%)



Lotte World Monorail (20%)

