POLITECNICO DI TORINO

Engineering, Dept. DIATI –Transport Systems
Italy

Rail transport systems

Tilting and high speed trains

for Degree, M.Sc. and Ph.D. programmes at the

MOSCOW STATE UNIVERSITY OF RAILWAY ENGINEERING (MIIT)

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POLITECNICO DI TORINO

TILTING AND HIGH SPEED TRAINS

INNOVATIONS - FOR RAIL SPEED, ENERGY CONSUMPTION AND OPERATION - BASED ON ADVANCED TECHNOLOGIES

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October 2015

Textbook: Dalla Chiara B., ENGINEERING AND DESIGN OF RAILWAY SYSTEMS - trains, lines, operation, innovation and telematics, POLITECNICO DI TORINO, Ed. CLUT, pages 1-366 (UK), Oct. 2012, ISBN 9788879923231
http://www.clut.it/eng/architecture-civil-engineering-urban-planning-museography/-/engineering-and-design-of-railway-systems/218.html

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Rail transport systems:

premise, their role and relevance of speed

Garibaldi and Cavour (I) building the **Italian boot**, in a cartoon of **1861**: ***sewing the boot with railways***

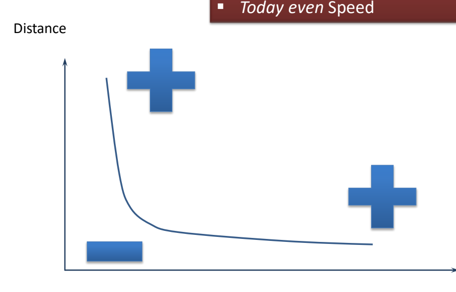
→ Railways for unification and connection

1st steam train in **Russia** appeared in 1834 (Yefim Cherepanov and son Myron, Urals).
1st initiative in developing railways by **Tsar Nicholas I** held on 13.1.1842 when he announced the St. Petersburg-Moscow railway.

He proceeded with determination, aiming at overcoming problems relating a capital distant from areas of the Empire; he envisaged that railways would have provided a more reliable method of transport, particularly during the climatic extreme conditions.
Influenced by military considerations, yet railways would have helped to bring food from South to the less fertile northern areas, creating a network which could extend to the Lower Volga and the Black Sea, developing Moscow as a railway hub.
By the early 1880s all railroads were of private companies, then a mixed system of private and government railways.

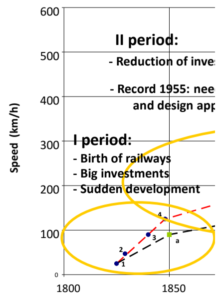
Total length used today by the Russian Railways is 85,500 km, one of the largest in the world.
Russia, the largest country in the world, has a geography making railroads suitable as basic mode of transportation.
[Elaboration on Wikipedia and other Sources, Russian Railways]

- Mass
- Distance
- High frequency on short distances
- *Today even* Speed

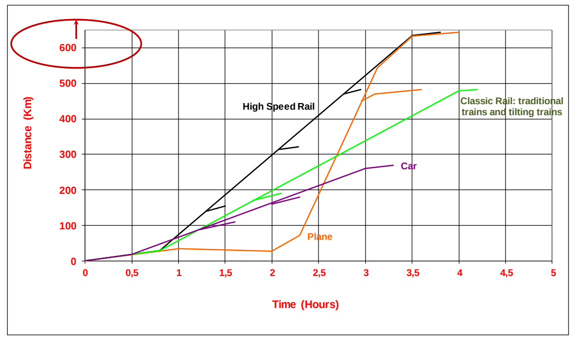


Records and maximum speeds on railways

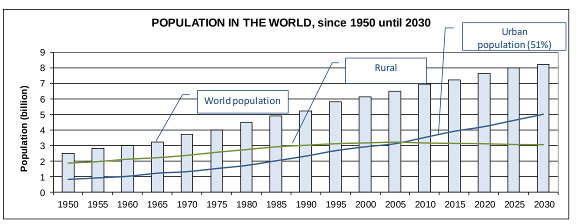
Territories



Door-to-door travel time



The demand



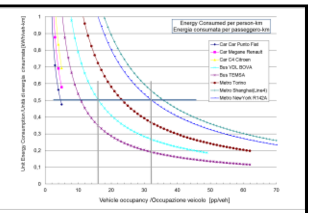
Hypothesis

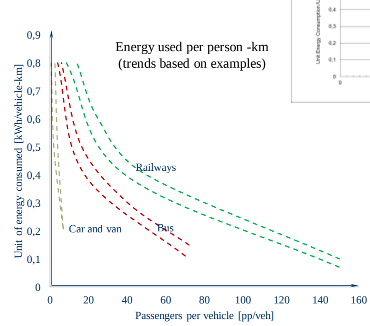
Urban population EU-27

73% of the whole population in 2008

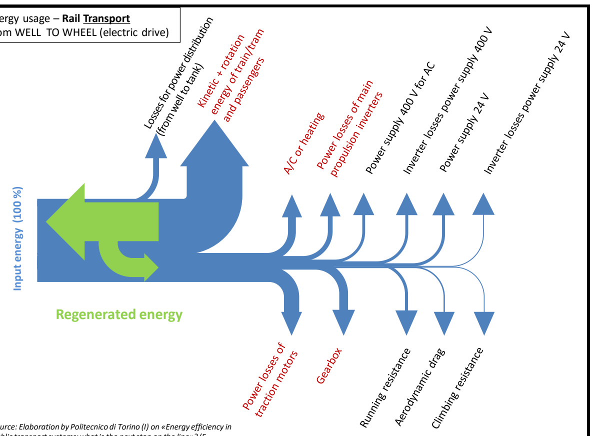
[Source: EU energy and transport in figures, Statistical Pocketbook 2010, p. 18]

Passenger transport
Graphs as examples
(various sources, Politecnico di Torino -I)

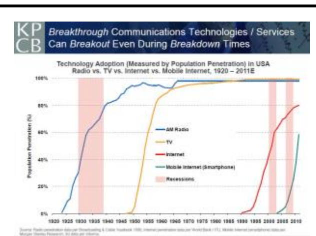


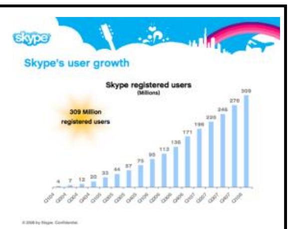


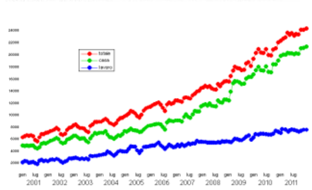
Energy usage – **Rail Transport**
From WELL TO WHEEL (electric drive)



Source: Elaboration by Politecnico di Torino (I) on «Energy efficiency in public transport systems: what is the next stop on the line»? (F. Burkhart), Public Transport International n° 5, Sept-Oct 2012







Motionless communications

Sources : Internet users in Italy, Jan. 2001-Nov 2009 [source : SeoAdv, 2012]

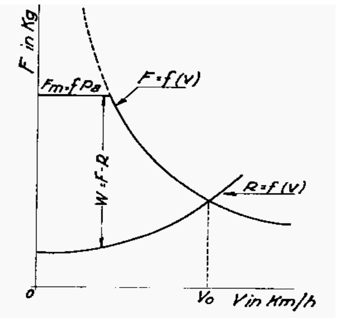
Rail transport systems :

Tilting trains

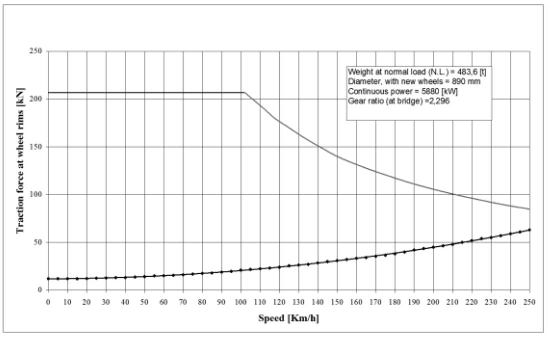
CANT, ROUTE GROUPS OR CIRCULATION (OPERATION) RANKS,

SAFETY IN CURVES,

TILTING TRAINS



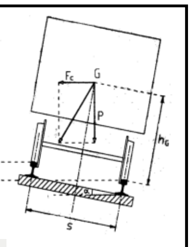
Curves for the traction forces (F) at wheels (from the electric motor) and resistances (R)

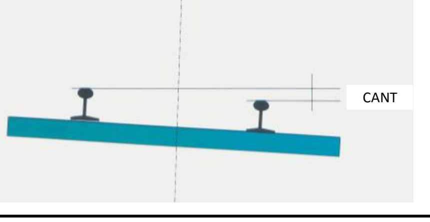


ETR *Pendolino: F* and *R*

Cant (superelevation)

DEFINITION: Difference in quote between the outer (external) rail and the inner (internal) one of a curve.

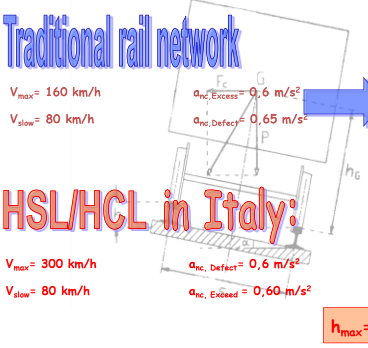




Cant: to counteract the effect of centrifugal force on curves the level of outer rail is raised above the inner rail by a certain amount and this raising of outer rail over inner rail is known as cant.

Cant Deficiency: the equilibrium cant is provided on the basis of the average speed of different trains on the track. This equilibrium cant (or super-elevation) will fall short of that required for higher speeds and this shortage of cant is known as cant deficiency.

Cant



Source: FS Group - Italy, 2005

Route groups: circulation or operation ranks

Railway lines can be ranked into route groups* on the basis of four factors:

- *Maximum* permissible *speed*;
- Train *speed on curves*;
- *Jerk* on transitions;
- *Non-compensated centrifugal acceleration*.

*Which might also be identified as “circulation ranks” or “operation ranks”.

Roll velocity (rolling)

Roll velocity is defined as the angular velocity or speed with which a vehicle regarded as being rigid and of negligible length rotates in the plane perpendicular to the direction of motion and around the point of contact with the lower rail as a result of the gradual raising of the outer rail on a parabolic transition curve.

ω

We have

$$\omega = \frac{h \cdot v}{S \cdot L} = \frac{P \cdot v}{S}$$

Where :
h = cant of outer/external rail [m]
v = velocity or speed [m/s]
P = lateral grade
S = rail gauge [m]
L = length of transition curve [m]

or, in transitions between a curve with cant h_1 and a curve with cant h_2 (poli/multi-centres):

$$\omega = \frac{(h_1 - h_2) \cdot v}{S \cdot L} = \frac{P \cdot v}{S}$$

Jerk or counter-blow

Jerk (ε) is defined as the rate of change in non-compensated acceleration: in a parabolic transition curve of length L negotiated at a constant speed V, non-compensated acceleration increases linearly from zero to the maximum value *a* in the time 3,6 L / V that the vehicle takes to travel through the transition curve.

$$\psi = \frac{v \cdot a_{nc}}{L} \qquad \psi = \frac{v \cdot \Delta a_{nc}}{L}$$

where:
ψ = jerk
a_{nc} = non compensated lateral acceleration [m/s²]
v = velocity or speed [m/s]
L = length of the considered line stretch [m]
Δa_{nc} = variation of acceleration

Limit speed in curve

That speed which determines a limit non compensated lateral acceleration (e.g. 0.6 m/s²) with a cant *h* (real o hypothesised) of 160 mm.

$$a_{nc} \cong \frac{v^2}{R} - \frac{g \cdot h}{S}$$

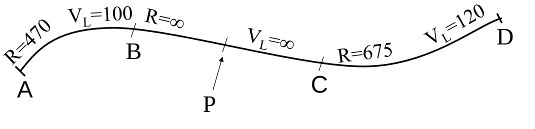
In calculations: 1500 mm

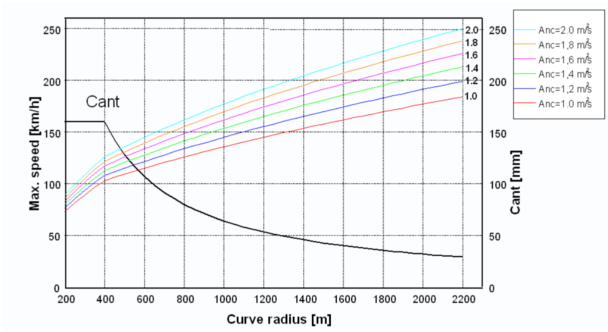
where : *R* is the radius of the curve [m], *h* is the cant of the outer rail with respect to the inner one [mm], *v* is the speed [m/s] and S track gauge [mm]

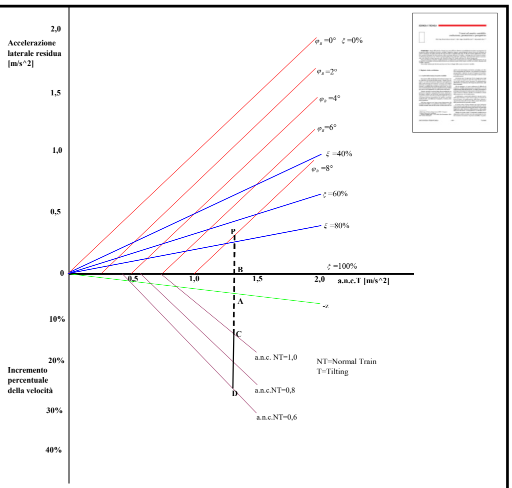
Velocity or speed of the track layout (Vt)

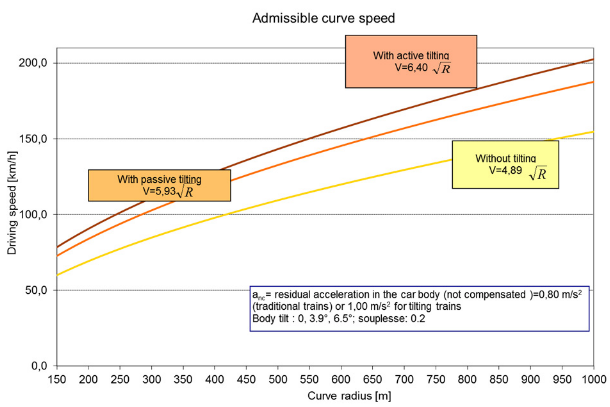
Given a track layout the limit speed is that on the minimum radius.

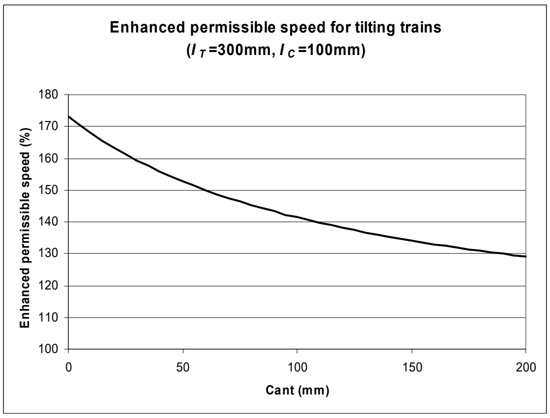
If in the considered line curves do not exist, the speed is theoretically unlimited.











Rail transport systems :

HST

HSL (high speed lines): GENERAL FEATURES FOR NEW LINES

Solutions	Speed that has to be allowed	Power supply	Kind of operation	Kind of operation and timetable	Kind of material	Freight service
New lines close to the existing historical ones	≥ 200 km/h	DC or AC, e.g. 3000 V D.C. (interoperability of rolling stock)	Promiscuous	Operation of lines with dissimilar (heterogeneous) train speeds	Heterogeneous	Allowed/ admitted
New HSL	≥ 250 km/h	D.C. / 25 kV - 50 Hz A.C.	“”	Operation of lines with dissimilar train speeds	“”	“ “
New HSL	≥ 300 km/h	25 kV - 50 Hz A.C.	Specialised	Operation of lines with homogeneous train speeds	Homogenous	Not allowed

GEOMETRICAL FEATURES OF HSL

	Unit	AGC (European agreement on the main international railway lines)	FS RM-FI	FS *TAV* (HSR)	SNCF TGV South East	SNCF TGV At.l/North	DB	RENFE (E)	JP Tokaido
Curve radius	m	---	3000	5450	3200	4000	5100	2300	2500
			4000	8000	4000	6000	7000	4000	4000
Rail gauge	mm	1435	1435	1435	1435	1435	1435	1435	1435
Max. grade	‰	---	8.5	15 - 21	35	25 - 35	12.5	25	20
Max. cant	mm	---	125	105	180	180	80	nd.	180
Distance between axles of tracks	m	4 - 4.2	4 - 4.2	5	4.2	4.2	4.7	4.3	4.2
Max. load per axle	t	22.5	22.5	22.5	17	17	22.5	17	nd.
Sleepers		Reinforced or pre-stressed concrete							
Tunnels: width	m	---	9.44 - 10.6	14	---	10	12.5	10	nd.
natural section	m^2	---	54	82	---	71	82	75	62

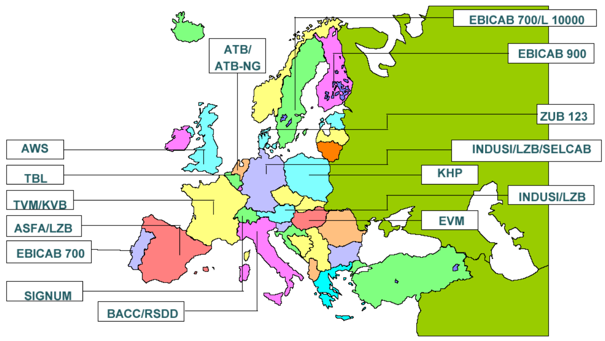
OPERATIONAL FEATURES OF HSL
ERTMS
25'000 V a.c. and 15'000 16 2/3 Hz

	Measure unit	AGC	FS RM-FI	FS TAV	SNCF TGV Sud Est	SNCF TGV Atl./Nord	DB	RENFE	JP Tokaido
Operation		---	Mixed	Mixed	Mixed	Passengers	Mixed	Passengers	Passengers.
Lenght of priority tracks	m	750	650	650	---	---	750	na.	na.
Max speed	km/h	250-300	250	250-300	270	300	250	300	220-270

ELECTRIC FEATURES OF NEW HSL

	Unit of measure	FS RM-FI	FS TAV	SNCF TGV South East	SNCF TGV Atl./North	DB	RENFE	JP Tokaido
Power supply	kV	3000 c.c.	25 kV c.a. 50 Hz	25 kV c.a. 50 Hz	25 kV c.a. 50 Hz	15 kV c.a. 16 2/3 Hz	25 kV c.a. 50 Hz	25 kV c.a. 60 Hz
Average distance between among substations	km	15	50	50	70	35	35	nd.
Kind of electric block		Automatic block	Mobile block radio	TVM 300	TVM 430	LZB	LZB	ATP-ATC
Transmission pf signals on board		Coded current block section with 9 codes	Continuous via radio + discontinuous with transponders	Coded current block section with 9 codes		Coded currents and punctual system		Coded current block section
		ERTMS						

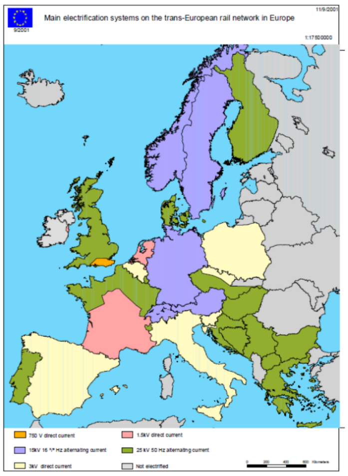
SIGNALLING SYSTEMS IN EUROPE

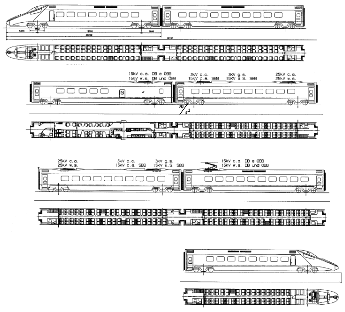


	ITALY* ETR 480	ITALY* ETR500 then ETR 610, 1000	GERMANY ICE	GERMANY ICE M	FRANCE TGV South East	FRANCE TGV Atl.	FRANCE TGV 2N
Length (m)	237	326	360	200	200	237	200
Number of places	458	588	648	412	324	485	547
Total weight (t)	426	652	850	---	418	479	425
Weight on the drive axle (t)	-	17.7	19.5	17.0	16.7	17.0	17.0
Installed power (MW)	5.9	8.8	9.6	7.2	6.6	8.8	8.8
Maximum speed (km/h)	250	300 (>300)	250	300	270	300	300
Power supply	3 kVdc 15 kVac	3 kVdc 15 kVac	15 kVac	1.5/3 kVdc 15/25 kVac	1.5 kVdc 25 kVac	1.5 kVdc 25 kVac	1.5 kVdc 25 kVac

** New Pendolino and train according to the bid December 2008*

	TGV Eurostar	SPAIN AVE	SWEDEN X2000	JAPAN NOZOMI
Length (m)	393	200	193	335
Number of places	846	320	433	923
Total weight (t)	752	420	399	710
Weight on the drive axle (t)	17.0	17.0	17.5	11.1
Installed power (MW)	12.7	8.8	4.8	12
Maximum speed (km/h)	300	300	220	270
Power supply	0.67/3 kV dc 25 kV ac	3 kVdc 25 kVac	1.5 kV dc 16 kV ac	25 kV dc 60 Hz ac





Nuovo Pendolino for Cisalpino AG

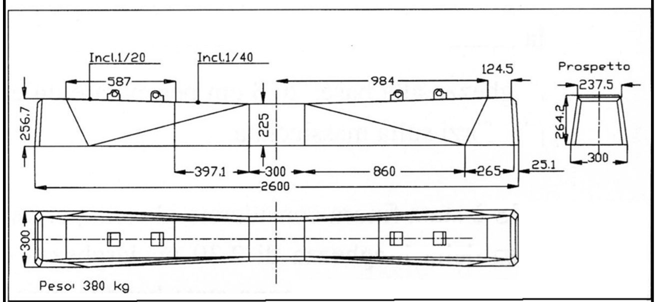
Technical characteristics of New Pendolino	
Maximum speed	250*Km/h*
Tilting actuators system	Electro-hydraulic
Composition	EMU with tilting body composed by 7 elements
Power supply	3*kV*/25*kV* a 50*Hz*/15*kV* a 16 2/3 *Hz*
Car body constriction	Aluminium
Traction power at wheels	5500*kW*
Maxim force of traction e	226*kN*
Traction performances (acceleration 0-40*km/h*)	0,48
Maximum non compensated acceleration	2
Train length	187,4*m*
Train max width	2,83*m*
Height of pavement from the rail plain	1250*mm*
Weight of the train at normal load	421*t*
Max weight per axle	16,5*t*
Places - seats	432+2
Signalling instrumentation	SCMT, ERTMS (2°livello)

Rail network		Direct current			Alternate current, monophasic	
		<1000V	1500V	3000V	15kV-16,7 Hz	25kV-50 Hz
Austria	OBB				100%	
Belgium	SNCB			100%		
BIH	BHŽJR					100%
Bulgaria	BDZ					100%
ex Czech Republic	CD		2,22%	57,78%		40%
Finland	VR					100%
France	SNCF		47,48%			52,52%
Germany	DB+DR				100%	
Great Britain	BR	39,75%				60,25%
Italy *	FS			100%		AV
Norway	NSB				100%	
Netherland	NSB		100%			
Poland	PKP			100%		
Romania	CFR					100%
Spain	RENFE			93,15%		6,85%
Sweden	SJ				100%	
Switzerland	SBB/FFS				100%	
Hungry	MAV					100%

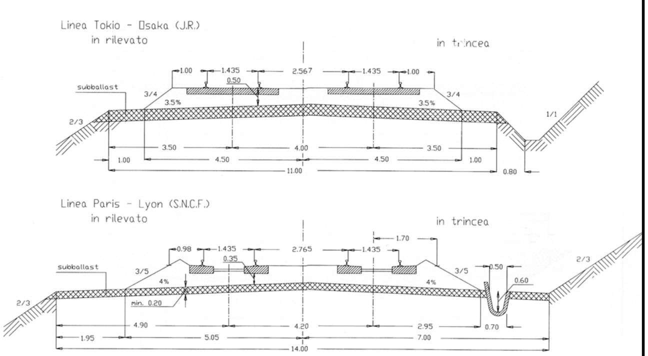
* Excluding AV/AC network

Extension of some EU rail networks with electric traction ('90s)

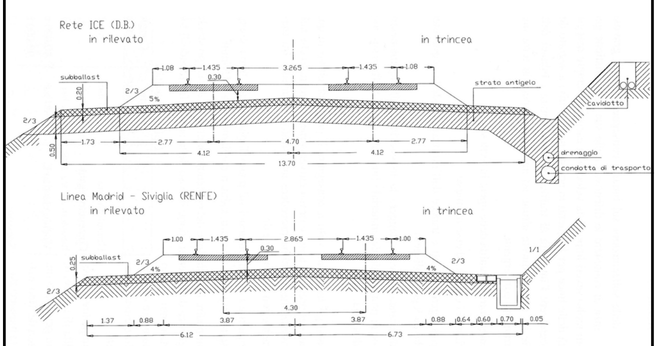
Mono-block sleepers for HSL (e.g. Italy)

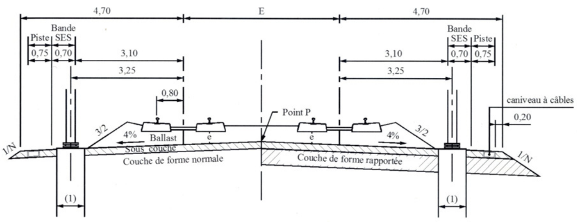


Sections of HSL – double track, straight



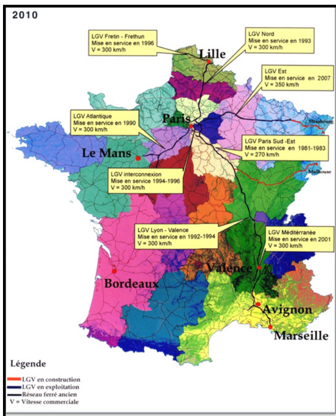
Sections of HSL – double track, straight



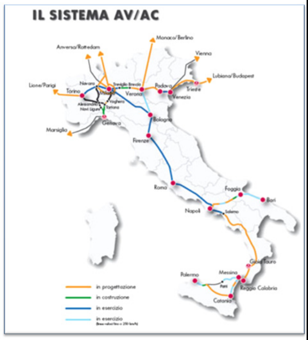


Cross section of a French High Speed Railway (LGV).

Fonte/Source: Revue générale des chemins de fer, n°220, ott.2012, pag. 9



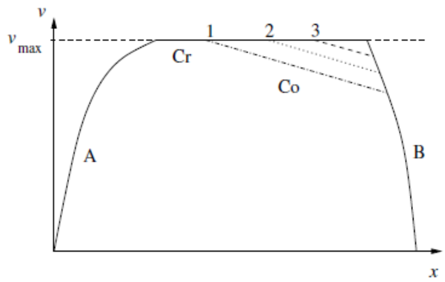
Maps of the high speed railway network in France (LGV) operational and under construction. Year 2010; and in Italy (2015)



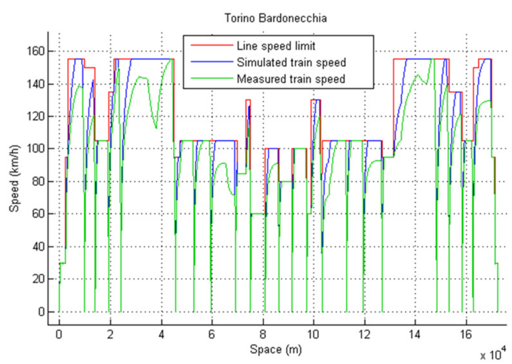
Source: Revue générale des chemins de fer, n°220, ott.2012, pag. 8

Rail transport systems :

energy



Motion stages of a train in a section: acceleration (A), cruising (Cr), coasting (Co), braking (B); x axis represents space.



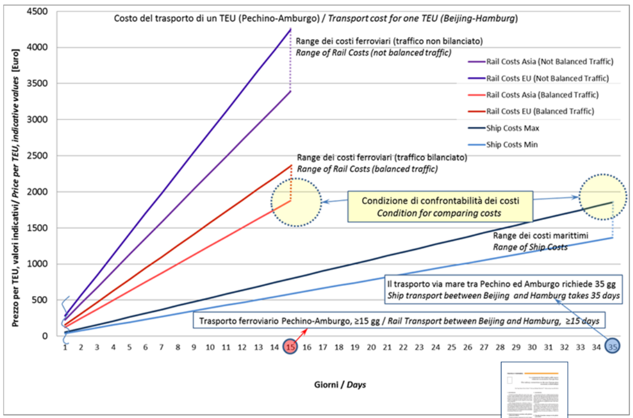
Energy consumption: little revolutions

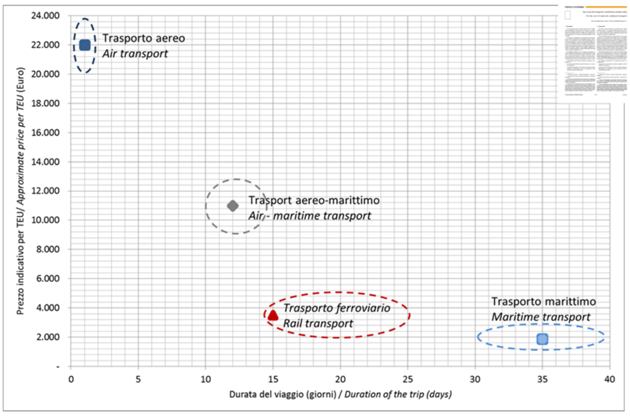
1. Synchronization with signalling or traffic lights (e.g. tramways)
2. Signalling (ETCS 2, 3) for control of advancement
3. Regenerative braking during deceleration

Thanks also to the introduction of new signalling and control systems, able to actively modify the target running diagram (for example, applications with ETCS-2 could be imagined), the braking stages could be limited in terms of both number and intensity, allowing the monitoring of the working conditions the rolling stock is submitted to.

Present and future of rail transport

Main railway connections between Europe and West Russia - Source: UNECE (2008)



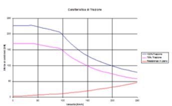


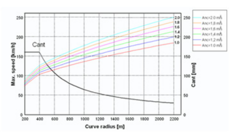
Present and future of rail transport

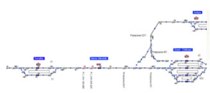
- Railways are alive, with their limits, yet undeniable unconquered points of strength
- Rail transport has inside the concept of collection : if this falls, its reasons may fall too
- Energy; *road pricing* (EU)
- Transport planning: no concurrence, when growth is limited, with analysis of WTW and LCC
- Granted service : punctuality or regular service, without breakdowns and very low risks; speed
- Automation in PT with new technological solution (tilting trains on secondary and main lines, ETCS II/III, mobile block, tele-diagnostics, management and traceability of rolling stock on the rail network), which are anyway required also for the road transport («ITS»).

MAIN SOURCES

- Dalla Chiara B., Engineering and design of railway systems - trains, lines, operation, innovation and telematics, Ed. CLUT, pages 1-366 (UK), Oct. 2012, ISBN 9788879923231
- Dalla Chiara B., Hauser G., Elia A. (2008). I treni ad assetto variabile: evoluzione, prestazioni e prospettive / *Tilting trains: evolution, performances and perspectives*. Ingegneria Ferroviaria. vol. LXIII, ISSN: 0020-0956. N. 7-8, pp. 609-648, CIFI - Collegio Ingegneri Ferroviari Italiani, luglio-agosto 2008
- Dalla Chiara B., Iannino A. (2013), “*Active or passive tilting trains: simulation and comparison on the Sardinian rail network* / Treni con assetto cassa passivo o attivo: simulazione e confronto sulla rete sarda di RFI”, Ingegneria Ferroviaria, vol. LXVIII, ISSN: 0020-0956. Numero 3, pagg.221-238, Marzo 2013







MAIN SOURCES

- Dalla Chiara B., Pellicelli M., De Bonis L., “The railway connections in the new Europe-Asia economic relationships / Le connessioni ferroviarie nelle nuove relazioni economiche Europa-Asia”, Ingegneria Ferroviaria, vol. LXVII, ISSN: 0020-0956. Numero 3, pagg. 249-271, Marzo 2012
- Dalla Chiara B., Pellicelli M., “On the cost of road-rail combined transport / Sul costo del trasporto combinato strada rotaia”, Ingegneria Ferroviaria, vol. LXVI, ISSN: 0020-0956. Numero 11, pp. 951-965, Novembre 2011
- Bruno F., Coviello N., Dalla Chiara B., Di Paola A., Pagliero P., Viktorov V., The energy consumption of trains in operation: simulation, a methodology for the analysis and influence of the driving style / Il consumo energetico di treni in esercizio: simulazione, metodologia di analisi ed influenza dello stile di condotta , Ingegneria Ferroviaria, vol. LXX, ISSN: 0020-0956. Numero 4, April 2015, pp. 327-357

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