IJARIIT INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact Factor: 6.078

(Volume 8, Issue 4 - V8I4-1172)

Available online at: https://www.ijariit.com

Economic and Environmental Impact of Major Transportation Modes

Abdul Kadir M. Poonawala
abdul.poonawala012@gmail.com
Indian Institute of Technology, Mumbai, Maharashtra

Mustafa Patanwala
autoinstitute@gmail.com
Autoinstitute, Mira Bhayandar, Maharashtra

ABSTRACT

The efficiency range of modern transport modes has increased. Fifty-five years ago, 'What Price Speed?' in Ingenia's article illustrated the price to pay in terms of efficiency for faster travel. Economic and environmental demands leading to more efficient transport have been matched by a growth in faster, more fuel-hungry modes brought about by society's need for speed. As society grows wealthier over time, people tend to travel more frequently and over greater distances. Travel demand increases by a factor of approximately 10 for each generation, but the amount of time spent travelling has remained constant at approximately one hour per day per person over the past three decades. The primary reason for this is the development of faster and faster modes of transport. Speed is a key driver for transport developments, although factors such as price, convenience, comfort and safety also play major roles. Transport now consumes a large and increasing proportion of our energy budget. Gabrielli and vonKármán suggested using specific tractive force to make such comparisons. A further examination of this revealed that any form of transport is an economic balance between the cost of the transport and the value of the time that goods or people are capable of during transit. In this article, we have collected data for 4 categories of Transport i.e. Road, Rail, Water & Air. Those points are plotted on the graph plotted for vehicles in 2005, trying to verify the accuracy of those curves. It also helps us to compare different vehicles in terms of Cost/passenger-km and Carbon Dioxide/passenger-km.

Keywords: *Cost/Passenger-Km, Carbon Di-Oxide/Passenger-km, Specific Tractive Force, Efficiency, Environment. Transportation Modes.*

1. INTRODUCTION

With world transport increasing at a rapid pace the evolution of better and faster modes of transport is inevitable. With the advent of newer technology, there also arises the need to conserve the environment in the best possible way without affecting or causing inconvenience.

Different modes of transport have evolved over the last few decades with the main focus on the speed and safety of passengers and goods that it transports. Off late, the need to look for more energy-efficient and eco-friendly transportation modes is realized. Gabrielli and von Kármán assembled a collection of data for installed power, maximum velocity and gross weight for a wide variety of transport modes and predicted what the future generation vehicle of these modes will be in terms of speed and efficiency.

For any vehicle type, motion is achieved through the action of a tractive force, which is the ratio of power (P) divided by velocity(V). If this ratio is further divided by the weight (W) then the non-dimensional specific tractive force (E) is obtained (E=P/WV). The lower the value, the more 'efficient' the transport mode. We have analysed four vehicles in Road, Rail, Air and Water each respectively. These models are taken from a wide variety of parameters like the year of manufacturing, type of use, Indigenous/ foreign, petrol/diesel/electric, and personal/commercial/military use.

The subsequent part of the article tries to analyze various parameters in different modes of transport and then compares them for efficiency and low greenhouse gas emissions.

2. METHODOLOGY

The details like power, weight, velocity, capacity (No of passenger + crew), type of fuel, and carbon dioxide emitted per gram per km were taken from the manufacturer manuals and data available in the public domain. This data was then analysed to compute Specific Tractive Force, fuel consumption per km, cost/passenger km and carbon dioxide/passenger -km.

These data points were then superimposed on the Karman-Gabriel graph which has a specific tractive force in KW/tonne*g*m/s on the Y axis and Velocity in km/h on the X axis.

This plot helps us to determine how accurate were the assumptions made by them and also gives insightful data points regarding various models of transport from fuel/energy and environmental efficiency perspectives.

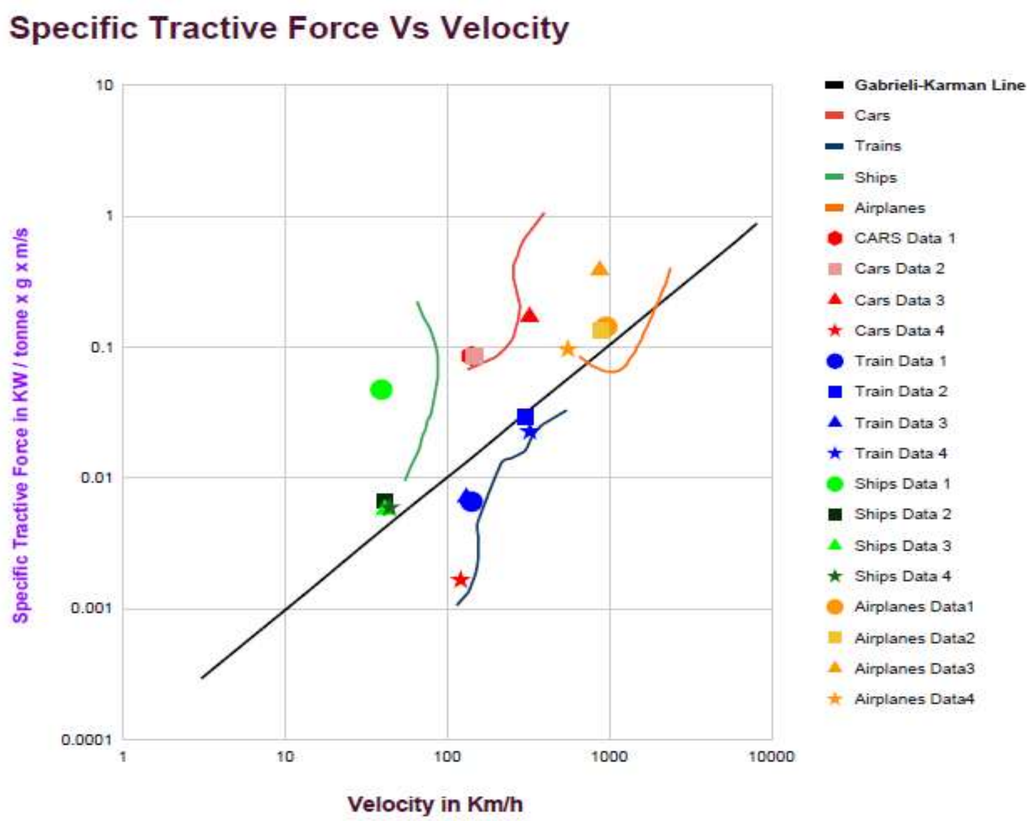

Figure-1: Plot of various transportation modes with Velocity on X-axis and Specific Tractive Force on Y-axis.

3. RESULTS AND DISCUSSIONS

3.1 Analysis for Road Transport : Cars

- Most of the data points plotted for cars i.e. from Car data 1 to Car data 3 which represents road vehicles launched before 2005 are close to the curves plotted in Ingenia's article indicating that the curve was predicted accurately.
- Car data 4 which is data for the latest electric vehicle (Tata Nexon) shows significant improvement in terms of specific tractive force and thus is plotted below the Gabrieli -Karman Line indicating significant improvement in terms of performance.
- Two data points (Car Data 1 & Card Data 2) almost overlap each other indicating that most of the vehicles in the pre-2005 era had comparable performance characteristics.
- With the advent of Plug-in EV, there has been a significant change in the performance of road transport vehicles. However higher range and cost of the vehicle is still a major challenge for the overall adoption of EVs as an alternative for IC engine-powered vehicles.

CARS	Power (KW)	Weight (Tonne x g)	Velocity (kmph)	STF	Cost /Passenger-km	CO2/ Passenger-km
TATA SAFARI	64	19.44	140	0.084675	0.990	29.286
MARUTI 800	33.5565	9.81	145	0.084943	1.389	32.614
2003 bentley continental gt	412	27.468	319	0.169273	4.189	102.500
Tata Nexon EV	96.234	1750	120	0.00165	0.155	17.714

<u>Assumptions:</u>

- Cost of Petrol In India is considered Rs. 98/liter
- Cost of Diesel in India is considered Rs. 90/liter

- Carbon Dioxide emission for Hydrocarbon Vehicles is taken as per the data provided by the manufacturer.
- Electricity unit cost is assumed at Rs. 8/ kW-h
- Assuming the electricity is produced by coal-based power plants and around 915g of Carbon-dioxide is produced per kW/h of unit produced.
- As per the specifications by Tata Motors Nexon has a range of 312 km and consumes 30 kW-h units of electricity for full charge. It means 0.096 units per km

Comparison:

- It is evident from the above table that cost/passenger-km is lowest for the electric vehicle followed by Tata Safari, Maruti 800 and Bentley.
- This shows that among the vehicles running on hydrocarbon fuels the one with maximum capacity and moderate power is the cheapest in terms of running cost.
- It should be also noted that EV's although having zero tailpipe emissions, the electricity that it uses produces Carbon-dioxide in the atmosphere specially with major electricity production still being coal-based.

3.2 Analysis for Rail Transport : Trains (Mostly electric)

- All 4 data points considered for this study are close to the curves plotted in Ingenia's article indicating that these curves are very accurate for rail transport.
- Since all the 4 data points are either on or below the Gabrieli -Karman Line shows that rail transport is one of the most efficient transport systems that evolved over the years although it was predicted 50 years back then that rail transport might become obsolete.
- Train Data 1 (Rajdhani Express) and Train Data 3 (Double Decker Express) are very close to each other since they both are using the same WAP7 engine. With the minor difference in their speed and weight, their performance is almost the same.
- Train Data 3 (N700 Series Shinsaken SANYO (Japan)) is on the Gabrieli -Karman line indicating the best performance amongst all the rail transport considered before 2005. This also shows that high-speed rail transport is one of the most efficient public transport options.
- Train Data 4 (ICE 3) is plotted towards the right and below the Gabrieli -Karman line indicating even further improvement in the last 15 years specifically in high speed rail transport performance with higher speed and lesser specific tractive force.

TRAINS	Power (KW)	Weight (Tonne x g)	Velocity (kmph)	STF	Cost /Passenger-km	CO2/ Passenger-km
Rajdhani (WAP-7)	4567	17981.73	140.0004	0.0065309	0.215735294	29.24411765
N700 Series Shinsaken SANYO (Japan)	17080	7014.15	300	0.0292221	0.839104308	49.21669501
MUM-AHD Double Decker	4565	17981.73	130	0.0070304	0.143261719	19.41992188
ICE 3	8000	4012	320	0.0224349	1.222363946	64.83843537

Assumptions:

-Cost of Electricity in India for Indian Railways is assumed based on online data to be Rs. 6.75 / unit.
- Cost of Electricity in Japan for Railways is assumed based on online data to be 0.208 $ that Rs. 15.6 / unit assuming 1$=75Rs.
- Cost of Electricity in Germany for Railways is assumed based on online data to be 0.230 $ that Rs. 17.25 / unit assuming 1$=75Rs.

Comparison:

- It is evident from the above table that cost/passenger-km is lowest for the Indian Trains Rajdhani & Double Decker Express.
- Double Decker express is slightly cheaper because of the more seating capacity of the coaches.
- N700 trains and ICE trains are almost 5-6 times more expensive than Indian Trains with their speeds double that of Indian Trains. This may be also because of the electricity charges almost being thrice than that in India.
- From the above table, it is clear that CO2/passenger-km is lowest for the Indian Conventional trains as compared to the High-speed trains of Japan & Germany.

3.3 Analysis for Water Transport : Ships (Defense, Cruise , Ferry)

- 3 Data Points i.e. Ship Data 2, Ship Data 3, and Ship Data 4 are very close to each other and moderately close to the curves plotted in Ingenia's article for ferries and cruises indicating that these curves are accurate for these categories.
- Data Point 1 for a defence Patrol Vehicle (Sukanya Class Patrol Vehicle) is drifted away from the other points and also from the Ingenias curve. It is closer to the curve for Hovercraft plotted in the original Ingenias articles. This shows that defence vehicles although a very important resource is not very efficient in terms of performance. That is expected as its role is to carry heavy payload and defence equipments and reasonable speeds.
- Ship Data 2, Ship Data 3, and Ship Data 4 are towards the left and above the Gabrieli -Karman line indicating that their performance is good in terms of specific tractive force but not in terms of velocity. Huge tankers and Container carriers not included in this study are more efficient and run below the Gabrieli -Karman line as it has less drag and therefore are very economical.

- Ship Data 4 (MS Queen Victoria) has shown very slight improvement and therefore is the closest to Gabrieli -Karman line and also has shifted slightly towards the right. This shows that there is not much improvement in terms of performance of Cruise ships in the last 15 years.

SHIPS	Power (KW)	Weight (Tonne x g)	Velocity (kmph)	STF	Cost /Passenger-km	CO2/ Passenger-km
Sukanya Class Patrol Vehicle	9410	18540.9	39	0.046863	5.322699728	739.0124542
Costa Atlantica (July 2000)	63370	839922.39	41	0.00663	8.548516028	185.2830482
MS Pride of Rotterdam (RO-Ro Ferry 2001)	37800	587864.25	41	0.00565	6.974310163	253.4183865
MS Queen Victoria	63400	883380.69	43.9	0.005886	8.955657352	207.7387616

Assumptions:

- Cost of Diesel in India is considered Rs. 90/liter.
- Cost of Diesel in Italy is considered 1.49 Euro which is Rs. 127.64/liter.
- Cost of Diesel in Rotterdam is considered 1.30 Euro which is Rs. 111.37/liter.
- Cost of Diesel in the UK is considered 1.28GBP which is Rs. 127.89/liter.
- Overall efficiency of a Diesel power plant is considered 50%.
- Calorific value of Diesel is taken as 45000 KJ.
- It is assumed that around 2680g of Carbon Dioxide is released on the combustion of 1lit of Diesel.

Comparison:

- It is evident from the above table that cost/passenger-km is lowest for the RO-RO Ferry as compared to the cruise ships Costa Atlantica & MS Queen Victoria.
- Although the cost/passenger is lowest in Sukanya Patrol vehicle but since it is not a commercial transport vehicle it will not be a fair comparison. Also cost of diesel in India is very low when compared to other countries.
- From the above table it is clear that CO2/passenger-km is lowest for Costa Atlantica and highest for Sukanya Patrol Vehicle.
- When compared to other modes of transport the cost per passenger as well as CO2 per passenger is the highest for Water transport Vehicles.

3.4 Analysis for Air Transport : (Commercial Passenger & Private Jets)

- 3 data points (Air plane Data 1,2,4) considered for Air Planes are close to the curves plotted in Ingenia's article indicating that the curves are accurate.
- Airplane Data 3 (Learjet 60) a private jet is plotted away from the other 3 commercial aircraft and also from the Gabrieli -Karman line indicating that private jets are not very efficient in terms of performance although they are very luxurious and convenient mode for a few high-income groups.
- Air plane Data 1, 2 are very almost overlapping indicating that commercial planes with slightly different capacities and speed are still having comparable performance characteristics. They are also to the right and closest to the Gabreili -Karman line indicating that the most efficient amongst all the models considered for the study.
- Airplane data 4 (Lancair IV) is very close to Gabreili -Karman line when compared to Airplane Data 1 (Learjet 60) indicating huge performance improvement in the private jet category in the last 15 years.

AIRPLANES	Power (KW)	Weight (Tonne x g)	Velocity (kmph)	STF	Cost /Passenger-km	CO2/ Passenger-km
Boeing 777-300	90037.5	2425.032	945	0.141441	1.727915827	75.71359122
Airbus A330	76421.44	2374.02	871	0.133108	1.108533975	48.57359768
Learjet 60	9588.88	105	863	0.382555	4.218723504	184.8554784
Lancair IV	230	15.79	550	0.095347	1.864570149	81.70149254

Assumptions:

- Cost of Aviation Fuel in India is considered Rs. 52.49/liter.
- Full tank gives a full range is assumed.
- Density of Aviation Fuel is considered 840g/lit.
- It is assumed that around 2300g of Carbon Dioxide is released on the combustion of 1lit of Aviation Fuel.

Comparison:

- It is evident from the above table that cost/passenger-km is lowest for the A330 as compared to its counterpart commercial aircraft Boeing 777.

- Learjet 60 is a premium private jet has the highest cost/passenger-km.
- Lancair IV although in the private aircraft category has a very low cost/passenger-km when compared to Learjet indicating significant improvement in technology and performance.

4. CONCLUSION

- Since all the points superimposed on the curves plotted in Ingenias "What Price revisited Curve" are close to their respective mode curves indicating that the curves are accurate.
- Detailed analysis and comparison in each mode of transport gives useful insights about the performance and efficiency improvements in the last 50 years and also indicates development in the last 15 years.
- Analysis across various modes reveals that trains are still the most efficient mode of transport having plots below the Gabreili -Karman line and drifting towards the right, while ships are the least efficient mode of transport.
- Detailed analysis across all modes also allows us to compare various modes of transport in terms of Cost/passenger-km and Carbon Dioxide/passenger-km. The data shows that trains and Electric vehicles have the least cost/passenger-km and also carbon dioxide emission /passenger-km followed by airplanes . It helps passengers and policymakers to take an informed decision while choosing the most fuel efficient as well as an environmental friendly mode of transport.

5. ACKNOWLEDGEMENT

The authors would like to thank Mr Yusuf Darwajawala, co-founder of Autoinstitute Mumbai, and all the team members of the Autoinstitiute extending their invaluable support and expertise. The authors also acknowledge the financial and infrastructure support provided by the Autoinstitute in its goal to become an institute of excellence in research and development and its undeterred focus to preserve the environment under its " We care for the environment " initiative.

6. REFERENCES

[1] Ingenia, Issue 22, March 2005, "What price speed - Revisited"
[2] https://en.wikipedia.org/wiki/Tata_Safari
[3] https://en.wikipedia.org/wiki/Maruti_800
[4] https://www.carfolio.com/bentley-continental-gt-107602
[5] https://en.wikipedia.org/wiki/Indian_locomotive_class_WAP-7
[6] https://en.wikipedia.org/wiki/N700_Series_Shinkansen
[7] https://en.wikipedia.org/wiki/Mumbai_Central%E2%80%93Ahmedabad_Double_Decker_Express
[8] https://en.wikipedia.org/wiki/Sukanya-class_patrol_vessel
[9] https://en.wikipedia.org/wiki/Costa_Atlantica
[10] https://en.wikipedia.org/wiki/MS_Pride_of_Rotterdam
[11] https://en.wikipedia.org/wiki/Boeing_777#Specifications
[12] https://en.wikipedia.org/wiki/Airbus_A330
[13] https://en.wikipedia.org/wiki/Learjet_60#Specifications

