TIME AND ENERGY EFFICIENT TRANSPORT

A PROPOSAL FOR A TRANSPORT SYSTEM ASSESSMENT

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Abstract The growing traffic volume and simultaneous decline of the energy resources raise the question about the most efficient system for a dedicated transportation task. In this study an approach is presented to analyze and assess the transportation efficiency using examples of motor vehicle, railway systems and passenger aircraft

For the development of the methodology presented here the national German traffic scene is taken as a representative use case.

Moreover the transportation chains and railway networks are analyzed for different transportation systems on the bases of a phase model to examine the influence of time.

A comparison of the different technical characteristics of the various systems is given to highlight the potential and limitations for future developments.

A graphical criterion developed in this study allows assessing the transportation efficiency of various systems considering the energy effort and time need in dedicated transportation missions.

1 Introduction

Different transportation systems compete with each other in a multilayered contest around market shares in the constantly growing transportation market of the 21st century. In this competition it is important for manufacturers and operators as well as for the policy maker to know the advantages of a transportation system related to a given mission. To answer this question the required transportation time is as important as the energy effort to be spent for moving a certain payload between to points. But also the corresponding operating costs are important. At last today the emissions generated by a transport system as well as the noise are very important measures in the public view, to characterize the attractivity and efficiency of a transport system.

Based on this analysis transportation efficiency can be characterized by

- the energy needed to perform a dedicated transportation task from door to door
- the time needed for the overall transport mission
- the operating cost associated with the transportation task
- the emissions and noise a transport system creates

While at least the emissions are very closely linked to the energy effort, the generation of noise is mainly independent and caused by technical characteristics.

In the past either expenses, fuel consumption or environmental compatibility were in most cases addressed individually only. Additionally a comparison of different transportation systems was often based on an analysis of the main course only. However for a mission oriented global assessment of the transportation efficiency of a transportation system the whole chain from door to door as well as the energy flow from the prime energy to the transportation energy needed should be taken into account. Such an approach will especially consider the advantages and disadvantages as well as the influence of interfaces in all phases, which provides a more realistic view on the real mission and the overall efficiency.

The specific primary energy effort, which is defined as the prime energy required related to the transportation performance in terms of transport weight and distance, has been well established as a criterion to quantify the energy effort per unit load and unit distance, [1]. But no real tracks from door to door and dedicated mission tasks were considered. Some studies also put a focus at the environmental effects with regard to the carbon dioxide or noxious emissions and the area needed of automotive, railway or aviation operations, e.g. [1]-[5]. Technical characteristics of the transportation systems are not discussed and compared. Also the transportation time was not valued. But a comparison of the technical characteristics allows an estimation of the future potential of an existing system or a new design. The consideration of the overall transportation time is a valuable metric to assess an efficient transportation system.

In the following a phase model is developed to describe the transportation chains of various systems in a common approach. The analysis of the technical characteristics provides afterwards a solution to calculate the energy effort in a transparent harmonized way.

Based on both analyses a transportation efficiency criterion is developed to compare and assess various transportation systems.

2 Transportation Networks

The analysis of the transportation efficiency begins with the transportation task to be performed. This encloses transportations of cargo as well as passengers and is determined crucial by the starting point and final destination point as well as the networks of the different transportation systems. Looking at the overall competitive situation it appears that on continental transports, which cover distances up to approximately 2000 km of passengers only automotives, high-speed trains and airplanes compete with each other.

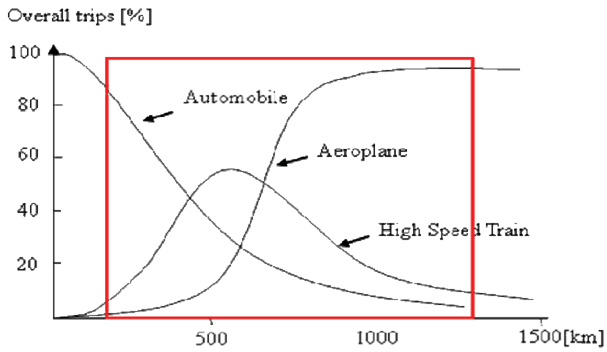

Figure 1: Competitive situation of transportation systems, e.g. [9]

The intercontinental transport is mainly performed by ships and airplanes. Other transport systems do not play a significant role in this market.
Moreover, in the continental transportation market the real competition among the systems is on ranges between about 350 and 1.200 km approximately, where an extension of the competition can be observed especially between the aircraft and the high speed trains. But considering that according to the International Air Transport Association (IATA) nearly 90% of short range flights worldwide are within a range less than 500nm, the range between 350 and 1200km is representative for the scene as well as for the development of the methodology.

2.1 Phase model

Following the analysis of automotive transportation drains several phases can be identified. The first phase covers a range of about 20km from the individual starting point to the local border. A low average speed of about 40 km/h is typical for this phase, which is called the approach phase. At the local border the second phase starts, which is called transition phase. The transition phase is characterized by a changed operating condition at a higher average speed of approximately 70 km/h during distances of up to 100 km until the main course is reached. The main course running on motorways covers the greatest distances up to 1.000 km. The average cruising speed of approximately 120 km/h is also significantly higher. At the end of a mission the automobile leaves the motorway and again through a transition phase using highways the automobile reaches the local border of the final destination. The last part of the mission runs through the city to the final individual destination point. This fifth phase is identical to the first phase.

Phase 1	Phase 2	Phase 3			Phase 4	Phase 5
Departure	**Transition**	**Main Track**			**Transition**	**Destination**
Car/Truck	Car/Truck	**Car/Truck**	Break	**Car/Truck**	Car/Truck	Car/Truck
Afoot	Railway Station	**Train**	Railway Station	**Train**	Railway Station	Afoot
Urban Traffic						Urban Traffic
Car/Taxi						Car/Taxi
Afoot	Airport	**Aeroplane**			Airport	Afoot
Urban Traffic						Urban Traffic
Car/Taxi						Car/Taxi

Figure 2: 5-Phases-Model to describe generally the transportation chains, [8]

Transportation courses of railways or aeroplanes run similar during the departure phase, where the distances are covered afoot, using urban traffic/public transport or car/taxi. The departure phase ends at the railway station or airport, because here the local border is reached and the crossing to the main track takes place. However, in the transition phase railway transport and air transport are basically different from transportation using motor vehicles. Railway systems and aeroplanes do not overcome any distance in the transition phase in the railway station or airport. Therefore railway systems and aeroplanes produce no transportation performance during the transition phase. This is a significant difference compared to motor vehicles, which overcome distances of up to 100km in the transition phase, which has an impact on the transport efficiency.

2.2 Evaluation of the distances lengths

The shortest and most efficient way to move between two places on earth is to run along the great circle. In practice this approach can be performed by aeroplanes mainly. The transport network of land vehicles is affected by topographic elements like mountains, valleys or lakes, which cause detours and lead to longer distances. To consider this influence in the analysis, the reciprocal value of the detour factor is introduced in this study as a distance efficiency measure.

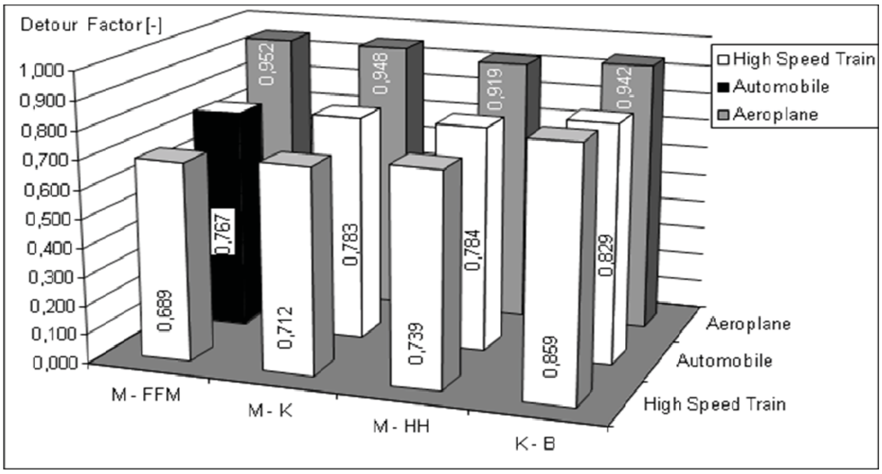

Figure 3: Distance efficiencies

It expels the relation of the great circle distance between the starting point and the final destination on the one hand and the real distance between these locations. For the transport mission routes selected for this analysis (Munich-Frankfurt (M-FFM), Munich-Cologne (M-K), Munich-Hamburg (M-HH), Cologne-Berlin (K-B)) Figure 3 presents the individual detour factors derived from navigation tools and radar plots of the German DFS, [8]. As expected the aeroplane routes show the best and most homogeneous distance efficiencies, while the railway network must strongly adapt itself to the given topography in the distances and goes, therefore, the biggest detours. It is also obvious, that in railway networks the distance efficiency varies significantly between 69% and 86%, depending on the route. In this analysis the distance efficiency affects the specific primary energy effort.

2.3 Analysis of transportation networks

For the analysis of realistic transportation missions also the influence of different starting points and destinations is to be considered, which have a particular effect on the departure, transition and destination phases. It was found, that for motor vehicles the time to overcome the approach, transition and destination phases is less than 20% of the overall transportation time. This time is called feeder course time. For this analysis different starting points within the typical commuter belt of around 100 km were chosen. Schwabing (SCHW), in the center of Munich, Dachau (DAH) about 30km North-West from Munich and Rosenheim (RO) an individual city in the southern area of Munich represent such typical starting points relative to railway stations and airports. The results are given in figure 4.

For railway transports the feeder course time is slightly higher at about 25%. This amount does not vary significantly, if the vehicle chosen for the departure phase will be changed between car and urban train. For flights the feeder course time covers approximately 70% of the overall course time. Also in this case the vehicle used in the departure phase does not influence the feeder course time. All these observations are valid also for various routes, distances, starting and destination points. Only the relation Cologne – Berlin (K-B) provides much shorter feeder times, because in this case the airport, the railway station and the final destination point are very close together in the heart of the city.

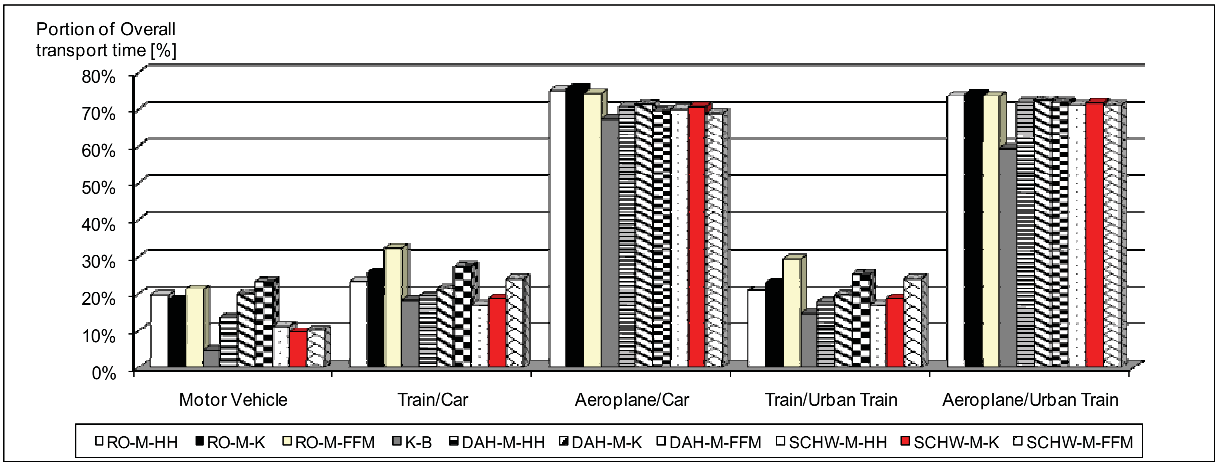

Figure 4: Feeder course time related to overall course time for different relations, [8]

Depending on the starting point for transports performed by aeroplanes between 40 and 90 minutes are needed to reach the airport and other 63 minutes are spent at the different stations in the airport, [8]. At the destination airport again around 34 minutes are needed to leave the airport and also up to 90 minutes are used to reach the final destination. This figures have been recorded by own measurements in 2000-2002, where especially the "Quick Check-in" capability and internet bording were not developed that far.
Using high speed trains the average time of about 25 at the departure station and 10 minutes at the destination station offer only little improvement potential. A clear increase of the cruising speed offers much more possibilities for the efficiency increase of high speed trains.
As a conclusion improvements of the efficiency of air transport missions are to be considered for the departure, transition and destination phases less than an increase of the cruising speed of aircrafts. Improved road and railway networks around an airport might speed up the departure and destination phase significantly. More direct access to the gates in the airport, shorter boarding times and shorter holding times for the passengers at the gates can improve the efficiency in the transition phases also.
A view at the overall transportation times provides another vision. Transports using aeroplanes last between 200 and 250 minutes mainly independent of the overall range.

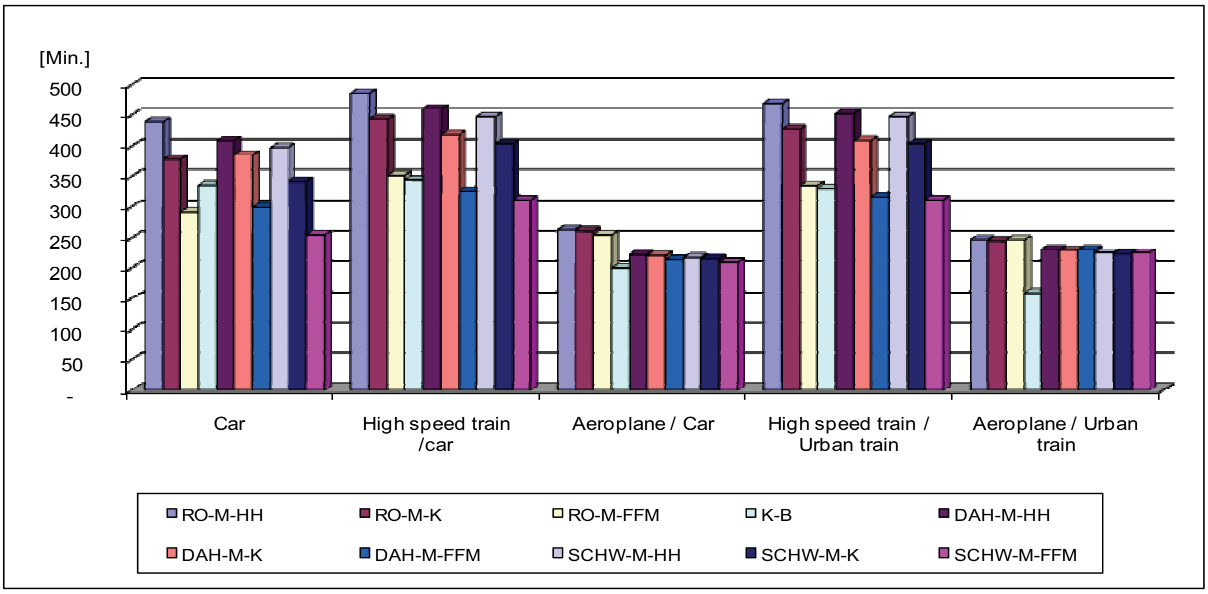

Figure 5: Overall course time of various transportation systems and relations

The significant feeder course time effort of aeroplanes is recovered by a very high main course speed of about 700 to 800 km/h, which is achieved during a period of approximately 45 to 55 minutes. In the main course phase the aeroplane provides a very high transport performance. Keeping in mind, that no transport performance is achieved during the transition phases and only a low performance is reached in the departure and destination phase, the influence of the main course performance on the overall assessment becomes obvious.

Combination	Car	High speed train/ Car	Aeroplane/Car	High speed train / Urban Train	Aeroplane / Urban train
Average speed [km/h]	**118,5**	**109,5**	**175**	**112**	**184**

Table 1: Average speeds of different means of transport on the route Rosenheim-Munich-Hamburg

The resulting average speeds covering all five phases of a transport mission confirm these statements, because the aeroplane is about 50% faster than high speed trains and motor vehicles. The influence of the performance levels in the different phases on the overall transport efficiency will be considered by the transport efficiency criteria.

3 Analysis of the driving resistance

The driving resistance of the different modes of transport is affected by the following influences:

- the aerodynamic drag
- the rolling resistance
- the acceleration resistance
- the curves resistance
- the climbing resistance

Drag	Automobile	Train	Aeroplane
Aerodynamic Drag	$\frac{\rho}{2}\cdot V^2 \cdot C_W \cdot A_S$	$\frac{\rho}{2}\cdot V^2 \cdot C_W \cdot A_S$	$\frac{\rho}{2}\cdot V^2 \cdot C_W \cdot A_F$
Rolling resistance*	$f_R \cdot m \cdot g$	$c_0 \cdot m \cdot g$	$\mu_R \cdot g \cdot \left(m_{Bug} + m_{Haupt}\right)$
Curve resistance	$f_K \cdot m \cdot g$	$\frac{650}{r-55}\cdot\frac{1}{1000}\cdot m \cdot g$	—
Acceleration drag	$m \cdot \left(1+e_{Fi}\right)\cdot \dot{V}$	$\left(1+e_{FB}\right)\cdot a \cdot m$	$m \cdot \dot{V}$
Climbing resistance*	$m \cdot g \cdot \sin\gamma$	$I \cdot m \cdot g$	$m \cdot g \cdot \frac{\dot{H}}{V}$

m	Mass
ρ	Air density
V	Speed
C	Aerodynamic drag
r	Radius of the track curve
f	Friction coefficient of automotive tires
μ	Friction coefficient of airplane tires
γ	Climbing angle
g	Gravity
H	Change of altitude
e	Correction of acceleration due to engine characteristics

Table 2: Driving resistance contributions of various transportation systems

Looking at the different definitions, speed and mass are identified as the driving factors, which also have a big impact on the transportation performance. Since the driving resistance determines mainly the energy effort to be spent for a certain mission, the various contributions will be assessed in the following.

3.1 Analysis of the vehicle masses

The vehicle masses to be moved affect nearly all driving resistances and, therefore, are from essential importance for the power required and the transportation efficiency. Here the biggest differences also appear between the different transportation systems. To describe the influence of the interesting payload and the total mass to be moved, the construction efficiency is introduced which describes this relation. The definition of the base factor has a clear influence on the result. For high speed trains like TGV and ICE the zero fuel weight is representative, because no fuel is carried on bord. The construction efficiency is consequently defined as the relation between the maximum payload (m_N) and the overall mass to be moved, which contains the payload and the operating empty weight (m_{OEW}) as defined in the aerospace community.

$$\eta_{Km_{ZFW}} = \frac{m_{N\max}}{m_{OEW} + m_{N\max}} \tag{1}$$

On the other hand automobiles and airplanes have to carry the fuel on bord during the mission. Therefore the fuel mass (m_{Kr}) must be taken in to account additionally.

$$\eta_{Km_{TOW}} = \frac{m_{N\max}}{m_{OEW} + m_{N\max} + m_{Kr}} \tag{2}$$

In the following figure averaged values of the construction efficiency are presented for different transportation systems. For example a Mercedes A140, as part of the small cars group offers 475kg payload at 1460kg total mass, 942kg empty mass and 43kg fuel mass.

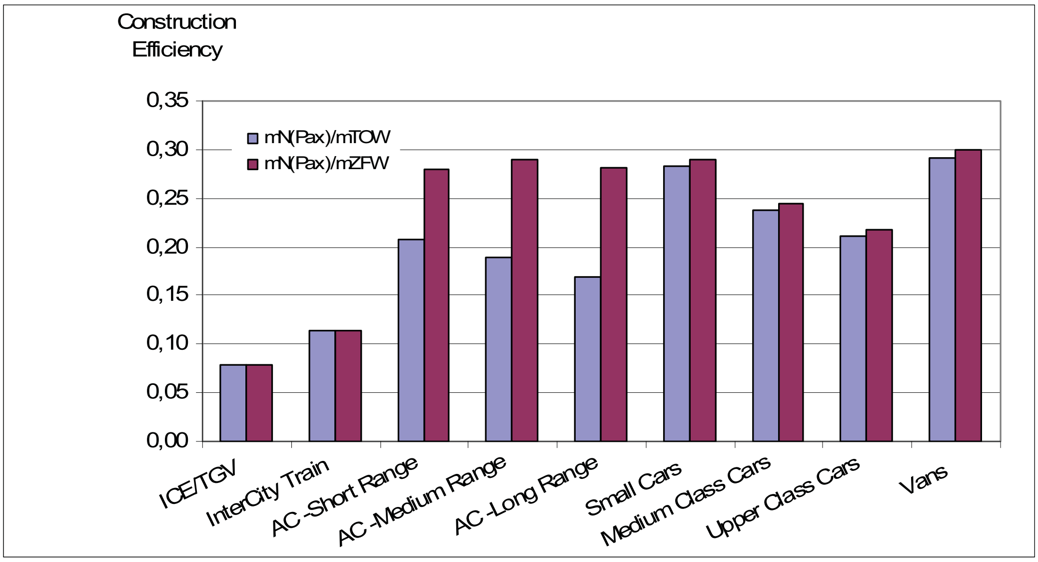

Figure 6: Construction efficiencies of different transportation of passengers means

An ICE1 train has an overall weigt of 795,8t with 689 passengers of 90kg mass. Independently from the basis railway systems indicate the lowest construction efficiency of about 10% for passenger trains. Cars reach an efficiency between 22% and 28% depending on their size, while 17% to 21% are shown for aeroplanes, taking the maximum take off weight as a basis. If the zero fuel weight is taken as a basis, no significant changes are observed for cars and trains, while aeroplanes improve their results by more than 10% and are now comparable to cars.
The examination of the construction efficiencies for cargo transport systems expels for railway systems and trucks values of more than 60%, while transport aircrafts only reach values of about 20%. As a conclusion light weight design remains a main issue for passenger and cargo aircraft development. Also high speed passenger trains need a significant reduction in their empty weight to improve their competitiveness.

3.2 Aerodynamic Efficiency

The analysis of the development of the aerodynamic drags for trains, motor vehicle and aeroplanes has shown clear reductions of 30% to 40% for motor vehicles and trains since 1980. The following table gives an overview of the development of the aerodynamic drag.
The tendency with the aeroplane drag appears unclear first, because the absolute drag increased by 12% over the time. Due to the very close coupling of drag and lift the aerodynamic efficiency is more significant. Moreover the data of the A300 compared to those of the A330 used in this context show an increase of the efficiency of 12%. Both aircraft are comparable in respect of their size and mission tasks and represent the technological development. The improvement of the aerodynamic efficiency of the aircraft is less compared to motor vehicles and trains.

	Cars	Lorry	Trucks	Trains	Aeroplane
C_W 1980	0,50	0,90	0,75	1,76	0,024
E [-]					15,8
C_W-change [%]	-40%	-32%	-28%	-38%	+12,0%
C_W (today 2003)	0,30	0,61	0,54	1,09	0,035
E [-]	-	-	-	-	17,7
E –improvement	-	-	-	-	+12%
ΔC_W potential for impr.	0,0155	0,1225	0,195	0,2	

Table 3: Develpment of the aerodynamic qualities of different means of transport, [8]

A comparison of the absolute drag of the different traffic systems is not possible, because the related cruising speeds as well as the reference surfaces and the respective vehicle lengths are basically different.

Significant future reduction potentials for the different transportation systems are not to be expected any more. With regard to the influence of tunnels on drag only railroads are affected by tunnel passages. The resulting drag increases between 2 – 4% during a tunnel passage, so that for the whole distances the influence is to be expected clearly less than 2%, which is negligible for the following calculations.

3.3 Other resistance interests

The climbing resistance leads about the highway inclination to an addition resistance with the increase or to an additional potential energy contribution with the slope. If one considers the climbing gradient about the respective whole distances, an increase of 0.004% on the route Cologne – Berlin up to 0.112% between Munich and Frankfurt is observed. This influence of the climbing gradient on the overall driving resistance is negligible for real routes. The climbing drag of aeroplanes during start and landing phase amounts between 1.3% and 6.5% of the whole distance. In addition thrust of the aeroplane during the climb phase has to be considered to the whole power demand.

The rolling resistance contributes in the area of 0.25% to railway systems and 1% with the passenger cars. For aeroplanes an amount of approximately 1.3% is to be considered during the start and landing phase. However also this is very low and negligible.

3.4 Influence of drivetrains

For the comparison of the vehicle impulses the engines (η_M) and transmission (η_G) efficiencies are summarized to the drive train efficiency.

$$\eta_A = \eta_M \cdot \eta_G \tag{3}$$

If the drivetrain efficiency only is considered electric drives of railway systems are the most efficient ones, indicating about 80% efficiency. Combustion drive trains of motor vehicles and aeroplanes are less efficient with 33% to 42%. However, for an integrated consideration of the drive train the efficiency chain of the energy supply is to be considered too.

Efficiency	Car gasoline engine	Car diesel engine	Train ICE	Metrorapid	Aeroplane
Drivetrain η_A	0,336	0,422	0,816	0,796	0,326
Provision of energy η_{Ege}S	0,927	0,927	0,342	0,342	0,927
η_{PN}	0,311	0,411	0,279	0,272	0,302

Table 4: Drive train efficiencies of various transportation systems, [8]

Due to the high transformation losses associated with the electricity generation the relations change. The diesel drive turns out the best drive train. The aero engines reach a comparable efficiency like the gasoline engines and the electrical engines, which looses a lot of their efficiency. This analysis clearly indicates that a transport efficiency assessment of different transportation systems has to consider also energy sources and transformation processes. It is obvious, that electrical engines are really efficient, but electricity itself is not a high value energy carrier.

4 A transortation efficiency criteria

The transportation efficiency indicates a weighed balance between the expected economic benefit and the expenditure required for it. The expected effective output consists of the payload to be carried which should be moved as fast as possible between two places. The required primary energy related to the expenses spent on the construction and operation of the transportation system can be characterized by the specific primary energy effort (e_P).

The transportation efficiency criterion shows in graphical form the balance between the required primary energy and the required transportation time as well as the operating cost. Because the three parameters energy, time and cost can easily cover also intermodal transport chains, the criterion is able to assess also such heterogeneous transportation tasks. Four areas indicate immediately the transportation efficiency of a system related to a given mission. The lower left quadrant expels optimal traffic systems which also realize short transportation times with a low primary energy effort. Unfavorable traffic systems are found in the top right area. The top left area indicates traffic systems which realize a short transportation time with a higher primary energy effort. In the lower right area at last traffic systems are present which reach a low primary energy effort, but require a longer transportation time. The future extension of the criterion around the cost factor pursues the same interpretation also in that of the third dimension. As long as a transport system or transport chain is placed along the diagonal a balanced solution is found.

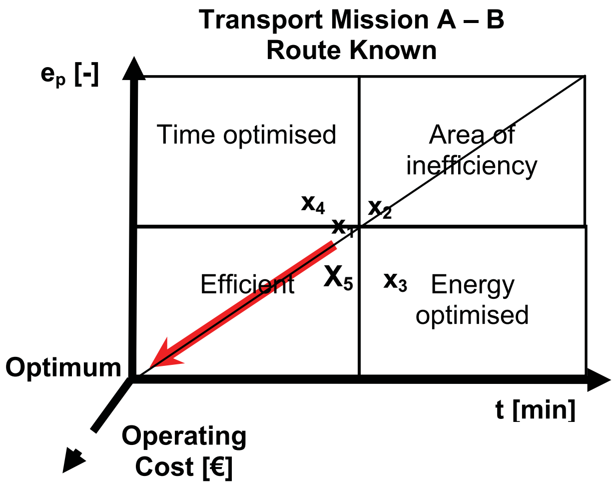

Figure 7: Transportation efficiency criterion

By this three dimensional representation the benefits of a transportation system can be easily compared to others. For example the point x_5 indicates the relatively best intermodal transportation because it provides a fast transportation using a relatively small amount of energy. The less the primary energy effort and the required transportation time as well as the expenses, the more efficiently the transportation is executed. Therefore, the theoretical optimal point is located in the coordinate origin. However, the criterion also shows the balance between low energy applications and the corresponding transportation time.

4.1 The specific primary energy effort

The specific primary energy (e_P) indicates the relation of the invested energy effort (E_N) to the resulting transportation performance along a given route (m*g*x). It is called specific because the required energy is related to the transport performance. These influences are given by the first part of the formula below.

$$e_P = \frac{E_N}{m_{ges} \cdot g \cdot x_{ist}} \cdot \frac{1}{\eta_U \cdot \eta_V} \cdot \frac{1}{\eta_A} \cdot \frac{1}{\eta_K \cdot \eta_O} \cdot \frac{1}{\eta_S} \tag{4}$$

Design assessments as well as operational assessments are also covered and represented by several efficiency factors. The efficiency of the whole driving chain is considered by the transformation η_U and distribution efficiency η_V which describe how prime energy is transferred into secondary energy as well as the drivetrain efficiency η_A. The design efficiency η_K as given in figure 5 describes the portion of payload of the total take off mass. The used payload capacity is given by the operating efficiency $\eta_{O.}$ also known as the load factor., which can be received from statistics or it will be individually defined for all transport systems to be compared to get a common mission task. At last the distance efficiency as given in figure 3 represents the real mission length compared to the great circle distance. By these efficiency factors all relevant influences on transportation efficiency are covered. Using such a dimensionless form the application to different transportation systems is possible in a comparative way.
The useable energy E_N can be determined from the fuel consumption or from the summation of the driving resistance contributions. Moreover a link is given between fuel consumption contained in the final energy, which describes the energy state just before energy is transferred into transport performance and the useable energy by the drive train efficiency:

$$E_E = \frac{E_N}{\eta_A} \tag{5}$$

The final energy can be calculated from the fuel consumption m_B and the energy content of the fuel H_u by

$$E_{E_{Flz}} = \dot{m}_B \cdot H_u \cdot \frac{x_{ist}}{v} \cdot F_{\max} \cdot \delta \quad \text{(aircraft)}$$

$$E_{E_{Pkw}} = \dot{m}_B \cdot H_u \cdot x_{ist} \quad \text{(motor vehicles)} \tag{6a-c}$$

$$E_{E_{Bahn}} = \dot{E}_{E_{Bahn}} \cdot x_{ist} \quad \text{(Electrical Train)}$$

The useable energy, which is required, might be also determined by summing up the different driving resistances of interest along the distance.

$$E_N = \sum F_{W_i} \cdot x = \left(F_{W_{Aero}} + F_{W_{Roll}} + F_{W_{Steig}} + F_{W_{Besch}}\right) x + E_{NA} \tag{7}$$

In this formula the F_i elements represent the various driving resistances like aerodynamic drag, rolling resistence, climbing resistence, etc. In addition all transport vehicles need additional energy for various on board systems, which is covered by E_{NA}.
With this calculation method it is possible for operators of transportation systems like air transport companies, railway societies or logistics agencies to identify the most appropriate means of transport for given real intermodal transportation tasks. The manufacturers of traffic systems like aircraft manufacturers as well are able verify their design compared to competitive systems in realistic mission condition.

5 Results

The criterion was applied to different passenger transportation missions. The results highlight the special characteristics of the different systems. In a first step the main course only was investigated, i.e. the main travel route between e.g. Munich and Frankfurt. It appears that the aeroplane shows the shortest cruising time by fare. However, also the highest specific primary energy application is associated with. In this analysis an operating efficiency or load factor of 55% is chosen for all vehicles compared, which is advantageous to the trains, because the aeroplanes are utilized today more than 70%, s. [9].

It is further recognizable that ICE3 and the Metro Rapid show a well balanced relation of specific primary energy effort and transportation time. The diesel passenger car and the ICE1 show the lowest specific primary energy need associated with the longest transportation time.

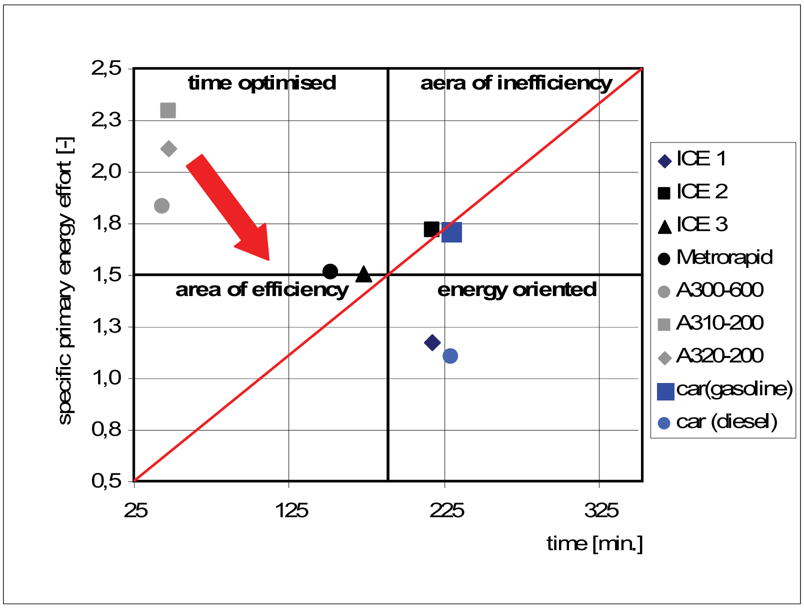

Figure 8: Transportation efficiency only on the main course Munich – Frankfurt

To improve one of the transport systems in such a scenario, e.g. the aircrafts should be designed in a way, that the need lees energy and, as a compromise for a well balanced design the cruise time may increase.

If the task is slightly modified and 100 passengers instead of 55% operating efficiency are considered to be carried between Munich and Frankfurt, the individual rates of utilization change and it will be clear that for this task the A320 represents the optimal means of transport. All high speed trains and also the medium range Airbus 300 are less efficient due to their reduced operation efficiency. Cars are not able to perform such a dedicated task.

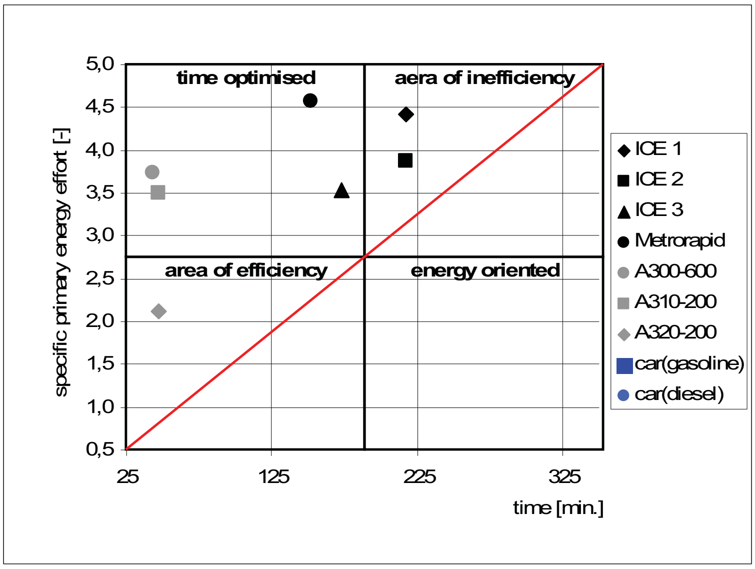

Figure 9: Transportation efficiency by the transportation of 100 passengers

If one extends the evaluation to the overall route including departure, transition and destination phases the general view continues. However, the aeroplane is still of advantage for time efficiency but it is significantly reduced due to the intensive time consumption during the feeder course to reach and leave the airport.

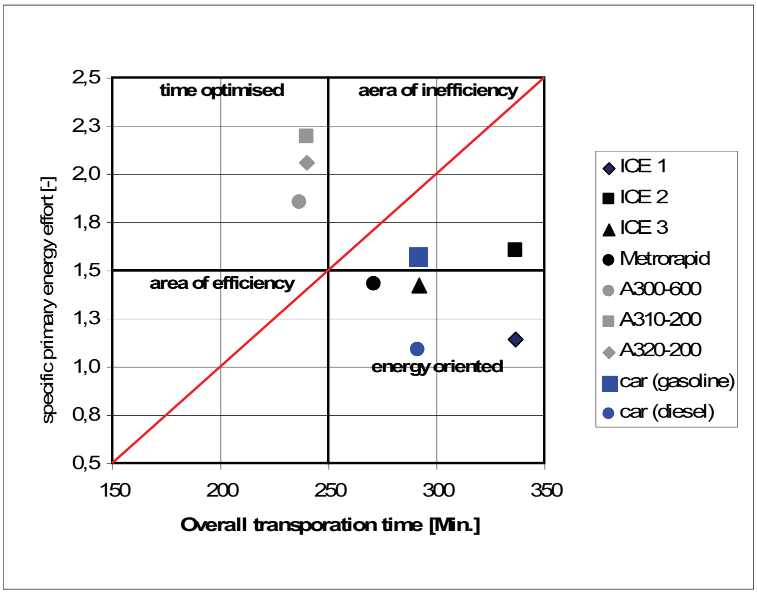

Figure 10: Transportation efficiency on the route RO m FFM

This result also underlines, that high speed is directly correlated with high energy effort and less transport efficiency. Transportation efficiency is characterized by the harmonized balance between energy effort and overall transportation time. The main course energy effort is clearly dominating the overall effort. The feeder phases (departure, transition, and destination) are driving the overall transportation time. These studies highlight the potentials for improvements in transportation processes and efficiency.

In another analysis the influence of the starting point is to be examined. Moreover the following picture shows, that a starting point close to the center of the city, which means a short transition phase for motor vehicles and a shorter departure distance to the railway station and airport, favours the time advantage of the aeroplane on the main route. Also the overall transportation time for motor vehicles and high-speed trains is reduced.

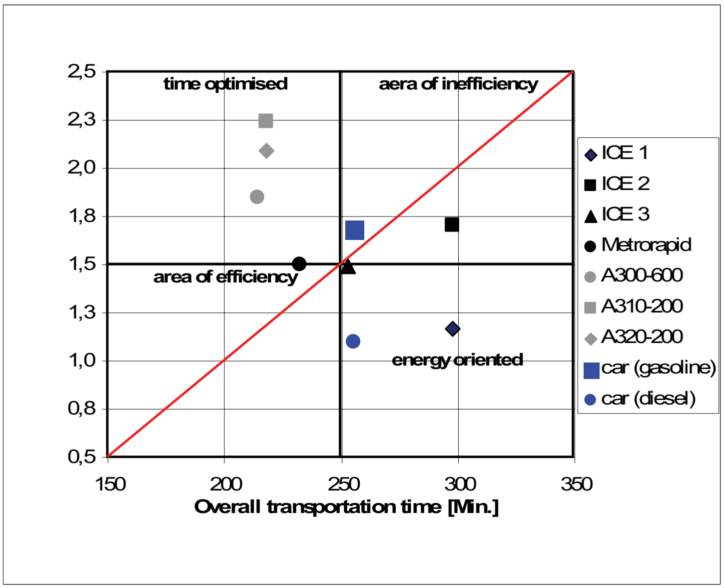

Figure 11: Transportation efficiency on the route Schwabing – Munich – Frankfurt / Main

The starting point just as the whole travel route has no crucial influence on the tendency, that the aeroplane remains the fastest transportation system. However this benefit is paid by a proportionally high energy effort. It is obvious that new high-speed trains like the ICE3 and the Metrorapid become a serious competitor, because they tie together more positive overall transportation times with moderate specific primary energy effort. For cars short transportation times are only possible to a limited extent. The first generation high-speed trains like ICE1 combine low specific primary energy effort, going along with longer overall transportation times in consequence of the lower main cruising speed. The comparison of the aeroplanes and the modern high-speed trains highlights the design direction for future developments. Aeroplanes require a very high primary energy effort in a very short time period for a significantly high cruising speed. Modern high-speed trains realize a 60% lower averaged cruising speed compared to aircraft resulting in an approximately 30 minutes longer travelling time only. Here the significant amount of time spent in the bottleneck of the airport and during the feeder phases are becoming obvious. For future developments of air traffic systems a reduction in primary energy effort should be achieved, and also in significant improvement of the transportation times in the departure, transition and destination phase must be realized.

6 Summary

A method of a task oriented and integrated analysis of the transportation efficiency of different transportation modes is presented. The analysis of the chains for cargo and passenger transportation with different systems concluded uniformly in a 5 phase model. This model highlights, that railway systems and aviation produce no transportation performance in the transition phases. The air transport system spends about 70% of the overall transportation time during the departure, transition and destination phases. This imbalance in traveling time is one main reason for the high energy effort of air traffic.

The analysis of the driving resistance indicates the high empty weight or imbalance between this and the take off weight as the essential technical disadvantage of high speed trains. This is also partially true for aeroplanes. The analysis of the different drive trains shows, that the electric drives loose their advantage with the engine efficiencies by the high transformation losses during the production of electricity. Rolling resistance and climbing gradient resistance have no crucial influence on the driving resistance of the separate means of transport.

A graphical transportation efficiency criteria is developed to assess the efficiency of transportation systems in terms of energy demand, transport time and transport cost depending on the individual mission. First examinations with real transportation tasks have shown that the aeroplane represents the fastest means of transport correlated with the highest specific primary energy application. The new high-speed trains ICE3 and Metro Rapid are prepared to become a serious competitor for aeroplanes on distances up to 1200 km. Parametric studies for design aspects of future cargo and passenger aircrafts and trains should be performed to extend the database of realistic evaluations.

The investigation has shown, that the five phases model is useful to identify time related bottlenecks without modeling to much details. In addition the assessment criterion is applicable to compare different transport systems in intermodal transport chains. In the next step more dynamic models will be developed to investigate the sensitivity of the criterion and it will be extend to cost and environmental assessment capability.

7 Literature

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