POTENTIAL FOR TRANSPORT EFFICIENCY IMPROVEMENTS OF AVIATION TRANSPORTATION SYSTEMS

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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 vehicles, railway systems and aeroplanes. For this purpose the transportation systems in Germany are used as representative examples to describe the methodology.

Moreover the transportation flows and railway networks are analyzed for the different transportation systems on the bases of a 5-phases 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 the assessment of the transportation efficiency of various systems considering the energy investment 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, [5]. In this competition it is important for manufacturers and operators as well as for the political players to know the advantages of a transportation system related to a given mission.

Transportation efficiency is defined by the energy investment spent on a mission, the time needed and the operating cost. The related transportation task is characterized by the payload and the transportation course.

In the past either expenses, the fuel consumption or environmental compatibility, were addressed only, [1], [6], [8]. However for a global assessment of the transportation efficiency all these aspects have to be considered together and should be related to a real transportation scenario.

The specific primary energy investment e_P, which is defined as the energy content of the required amount of prime energy E_P like crude oil related to the performed work W_U composed of the payload moved and the mileage, has been well established as a criterion to quantify the energy effort, [1], [8].

$$e_P = \frac{E_P}{W_U} \qquad (1)$$

Up to now investigations are mainly based on main course analysis, where the phases before reaching the airport or railway station are not taken into account. Also the transportation task is not exactly defined, [1], [8].

Some studies also put a focus at the environmental effects with regard to the noxious emissions and the area needed of automotive, railway or aviation operations, [6], [7]. Technical characteristics of transportation systems are mostly not considered, [7]. Most of the investigations consider only some aspects but do not try to draw the whole picture of influences on transport efficiency. Also the transportation time was not valued in the studies known up to now. In this paper an approach is presented, where one focus is put on the analysis of the transportation processes of aviation, railway and automotive systems. Second the main technical characteristics affecting transport efficiency are compared to calculate the energy effort in a common way for different transportation systems. Based on both analyses a transportation efficiency criterion is developed to compare and assess various transportation systems during design phases but also for infrastructure analysis in the logistics and political fields.

2. NETWORKS AND TIME EFFICIENCY

The analysis of the transportation efficiency begins with the transportation task to be performed. This encloses transportations of cargo and passengers and is determined 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 for continental passenger transportation typically only automotives, high speed trains and airplanes compete with each other.

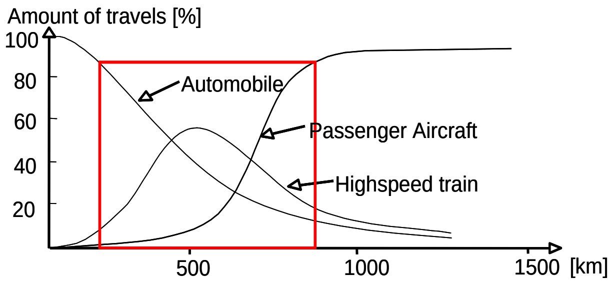

Fig. 1: Competition of Passenger Transport Systems, [5]

The intercontinental transport is mainly performed by ships and airplanes. Other systems do not play a significant role on this distance, which is clearly above *2000 km*. Moreover, the real competition among the systems is on the continental transportation market ranges between *250 km* and approximately *1000 km*. On longer tracks there is no real competition between aircraft, automotive and railway systems. For goods only the transportation ranges are extended up to roughly *2000 km*, where trucks, ships, trains and aeroplanes are competing.

For the purpose of this study the competitive situation of passenger transport in Germany is considered as a representative example for the development of the methodology.

2.1. 5-Phases Model of Transportation Flow

Following the analysis of automotive transportation drains several phases can be identified, which are also visible for railway and aviation systems. The first phase covers a range of about *20km* from the individual starting point to the city limits. A low average speed of about *40 km/h* is typical for this phase, which is called the starting phase. At the local city limit 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* along distances of up to *100 km* until the main course is reached. The main course running on freeways 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 freeways the automobile reaches the city limit of the final destination. The last part of the mission runs through the city to the final individual destination point. This fifth phase called the arrival phase is identical to the first phase. These phases are presented in the 5-phases model of transportation, shown in Fig. 2.

Transportation processes of high speed trains and aircrafts are similar during the starting phase, where the distances are covered afoot by the passengers, using public traffic or car/taxi, [2], [3]. The starting phase ends at the railway station or airport, because here the city limit is reached and the crossing to the main track takes place. However, for the aviation system longer starting phases of up to *100 km* have to be considered to reach the airport, [2]. By definition these distances are covered by the starting phase and also high- and freeways might be used.
During the transition phase railway and air transportation systems are basically different from automotive systems, since they do not overcome any distance during this phase in the railway station or airport, and they produce no transportation performance during the transition phase. This is a significant difference compared to motor vehicles, which overcome distances of up to *100 km* in the transition phase, which has a significant impact on the transport efficiency.

Phase 1 Start	Phase 2 Transition	Phase 3 Maintrack/Cruise			Phase 4 Transition	Phase 5 Arrival
(0-20km)	(-100km)	(200-800km)			(-100km)	(0-20km)
Car/Truck	Car/Truck	Car/Truck	Break	Car/Truck	Car/Truck	Car/Truck
by feet Bus Car/Taxi	Railway Station	Train	Railway Station	Train	Railway Station	by feet Bus Car/Taxi
by feet Bus Car/Taxi	Airport	Aircraft			Airport	by feet Bus Car/Taxi

Fig. 2: 5-Phases Model of Transportation Flows

2.2. Evaluation of the distances lengths

The shortest and most efficient way to move between two places on earth is to move along the great circle. However, only aeroplanes are principally able to perform this approach in practice. For all land vehicles the route network is affected by topographic elements like mountains, valleys or lakes. To consider this influence on real routes in the analysis, the reciprocal value of the detour factor is introduced as the route efficiency η_R in this study.

$$\eta_R = \frac{x_{Orthodrome}}{x_{real}} \tag{2}$$

It expels the relation of the great circle distance $x_{Orthodrome}$ between the starting point and the final destination on the one hand and the real distance x_{real} between these locations. Fig. 3 presents the individual real route factors for the transport mission routes selected for this

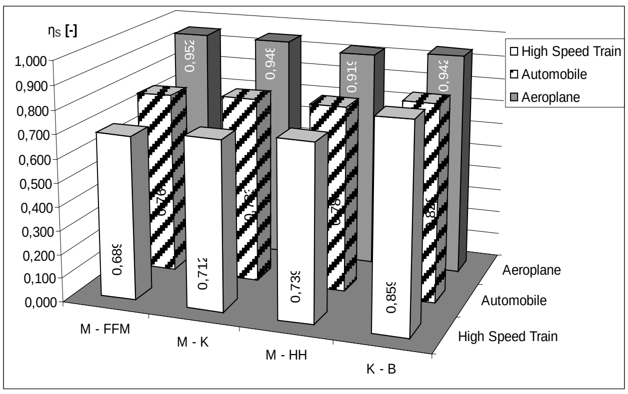

Fig. 3: Route Efficiencies η_R for Various Routes and Transportation Systems

analysis (Munich-Frankfurt M-FFM, Munich-Cologne M-K, Munich-Hamburg M-HH, Cologne-Berlin K-B).

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 go therefore, the largest detours. Only for the East-West route Cologne-Berlin the railway route is shorter than for the automotives. It is also obvious, that in railway networks the distance efficiency varies significantly between *69%* and *86%*, depending on the route, while it is close between *92%* and *95%* for the aviation routes and *77%* and *82%* for the auto route network. This difference between the railway system and the others will affect the specific primary energy effort. Deviations of more than *10%* are observed, compared to general statistical figures of the detour factor, [4]. It is therefore recommended to calculate the real detour factor for each individual route.

2.3. Analysis of the time effort for various transportation missions

The influence of different starting points and destinations, which have a particular influence on the start, transition and arrival phases is to be considered for the analysis of realistic transportation missions. In this study the influence of the starting point was investigated by different starting points around Munich, where Munich-Schwabing (SCHW), Dachau (DAH) about *30 km* North-West from Munich and Rosenheim (RO) about *70 km* South from Munich were chosen as representatives in the typical patch of airports and railway stations, [2], [3].

It was found, that for motor vehicles the time to overcome the start, transition and arrival phases is less than *20%* of the overall transportation time. This time period is called side course time (SCT). For railway transports the side course time is slightly higher at about *25%*. This amount does not vary significantly, if the vehicle chosen for the starting phase will be changed between car and public or urban train. For flights the side course time covers approximately *70%* of the overall course time, Fig.4. Also in this case the vehicle used in the starting phase does not influence the side course time.
Depending on the starting point for transports performed by aeroplanes between *40* and *90* minutes are needed to reach the airport during the starting phase and another *63* minutes are spent during the transition phase in the airport, [4]. 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.
Using high speed trains the average transition time of about *25* Minutes at the starting station and *10* minutes at the arrival station offer only little potential for improvement. A clear increase of the cruising speed offers much more possibilities for the timely efficiency increase of high speed trains.

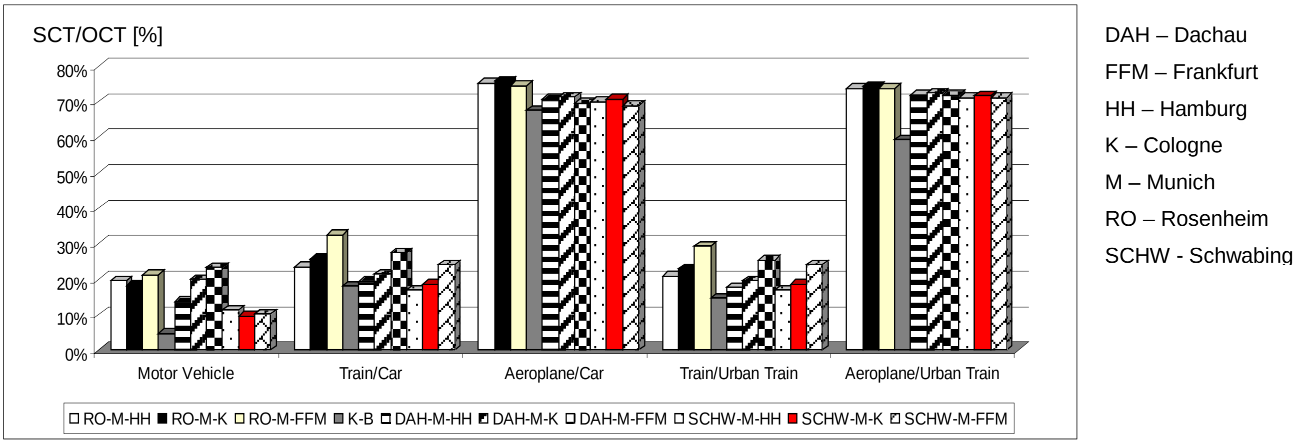

Fig. 4: Side Course Time (SCT) related to Overall Course Time (OCT) for different relations

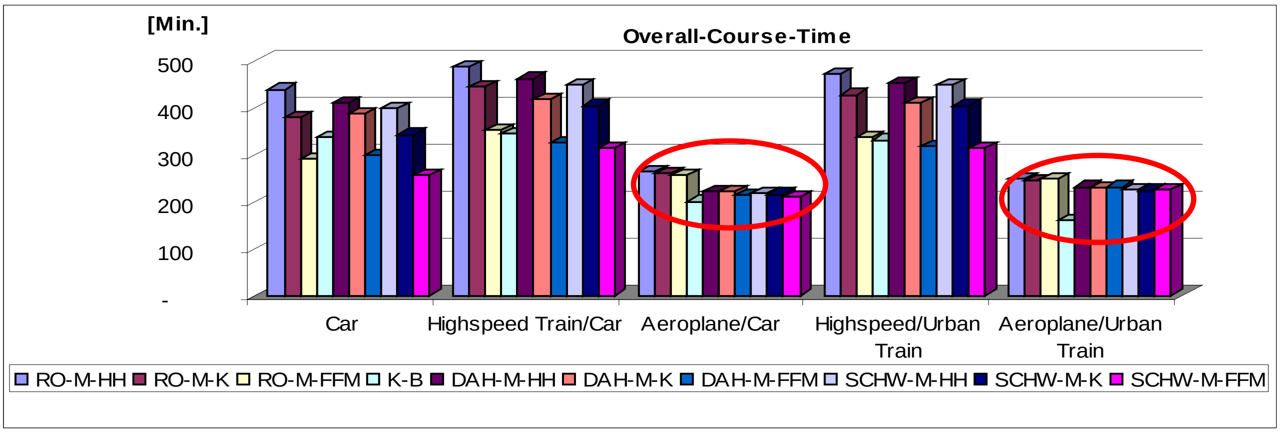

Fig. 5: Overall course time of various transportation systems and relations

Transportation System	Car	High speed Train/Car	Aeroplane/Car	High speed/Urban Train	Aeroplane/Urban Train
Average Speed [km/h]	118,5	109,5	175	112	184

Table 1: Average Speeds of Different Transportation Systems on the Route Rosenheim-Munich-Hamburg

As shown in Fig. 5 transports performed by aeroplanes are mainly independent of the starting point and the overall range, while the overall course time of trains and automotives varies with the starting point, the routes and distances during the starting and transition phases. All these observations are valid also for various routes, distances, starting and arrival points. Only the relation Cologne – Berlin (K-B) provides much shorter side course 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.
The significant side course time of aeroplanes is recovered by a high main course speed of about *480* to *600 km/h* between departure and landing, which is achieved during a period of approximately *45* to *55* minutes. During the main course phase the aeroplane provides a very high transport performance. Keeping in mind, that no transportation performance is achieved during the transition phases and only a low performance is reached in the starting and arrival phases, the main effect of the main course performance on the overall efficiency becomes obvious.
The average speed of the aeroplane is decreased by more than *50%*, when all five phases of a transport mission are considered, Table 1. However the speed is still *50%* above the one of cars or trains.

As a conclusion improvements of the efficiency of air transportation missions are to be considered for the starting, transition and arrival phases more than an increase of the cruising speed of the aircraft. Improved road and railway networks around the airport might reduce the side course time 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. Especially the reduction of the de-/boarding times at the airport could be realized by a new design like roll-on/roll-off technologies. But also the internal process of the airport and the aircraft services at the gate provide potential for further improvements.

3. ANALYSIS OF THE DRIVING RESISTANCE

In order to identify technical capabilities and potential for improvements the influences on the driving resistance should be considered. The driving resistance of the different transportation systems is affected by the following contributions:

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

Looking at the different contributions, speed and mass are identified as key parameters, which have a big impact on the transportation performance, as well as the quality of the drivetrain system. 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

Because the vehicle mass affects nearly all driving resistances it is essential for the transportation efficiency. To describe the influence of the interesting payload and the total mass to be moved, the construction efficiency η_K is introduced which just describes this relation. The definition of the total mass has a clear influence on the result. For high speed trains like TGV and ICE the zero fuel mass m_{ZFM} is representative, because no fuel is carried on bord, while the maximum “Take Off” mass m_{TOM} is typical for all other transportation systems. In that manner the total mass is composed of the operating empty weight m_{OEM}, the maximum payload m_{Pmax}, and in case of m_{TOM} as a reference the fuel mass m_F additionally.

$$\eta_{K_{TOM}} = \frac{m_{P\max}}{m_{OEW} + m_{P\max} + m_F} \tag{3}$$

$$\eta_{K_{ZFM}} = \frac{m_{P\max}}{m_{OEW} + m_{P\max}} \tag{4}$$

In the following a detailed analysis of various passenger transportation systems is presented using both definitions of the construction efficiency.

Railway systems indicate the lowest construction efficiency of about *10%* for passenger trains. Cars achieve values between *22%* and *28%* depending on their size, while *17%* to *21%* efficiency is realized by aeroplanes, taking the maximum take off mass as a basis.

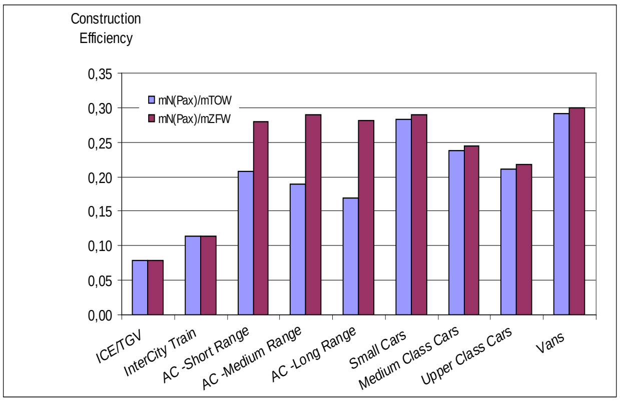

Fig. 6: Construction Efficiencies η_K of Different Passenger Transportation Systems

If the zero fuel weight is taken as a basis, no changes are observed for cars and trains, while aeroplanes improve their results by more than *10%*, and now they are competitive to cars. This indicates the big impact of the fuel mass of nearly *30%* on the take off weight.

The examination of the construction efficiencies for cargo transport systems expels for railway systems and trucks much better efficiencies of more than *60%*, while transport aircrafts only achieve values of about *20-26%*.

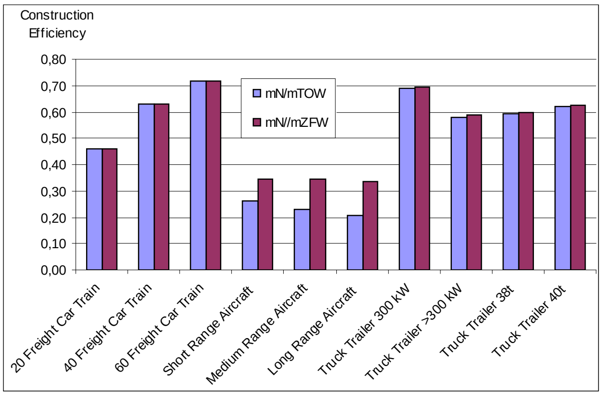

Fig. 7: Construction Efficiencies η_K of Different Cargo Transportation Systems

As a conclusion light weight design remains a main issue for passenger and cargo aircraft development. Also for high speed passenger trains the empty weight should be reduced further to improve their competitiveness. New design approaches for freighter/transport aircraft could be considered also, e.g. taking the freighter configuration as the design basis.

3.2. Aerodynamic Efficiency

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 tendency with the aeroplane drag appears unclear first, because the absolute drag increased by nearly *50%* over the time, while the lift was improved by more than *60%* for cruising conditions. The following table provides the drag and lift coefficients in cruise of the A300B4 and the A330 as an example.

Aerodyn. Coefficient	**A300B4 (1972)**	**A330 (1992)**
CA	0,38	0,632
CW	0,024	0,0357

Table 2: Aerodynamic Coefficient of Different Aircraft Generations

Due to the very close coupling of drag and lift, the aerodynamic efficiency *E* or lift/drag ratio is more significant. The following table gives an overview of the development of the aerodynamic drag of the different transportation systems.

	Cars	Lorry	Truck	Train	Aeroplane
CW 1980	0,5	0,9	0,75	1,76	0,024
E [-]	-	-	-	-	15,8
CW-Change [%]	-40%	-32%	-28%	-38%	46%
CW (today)	0,3	0,6	0,5	1,1	0,035
E [-]	-	-	-	-	17,7
E –Improvement	-	-	-	-	12%
ΔCW Potential	0,02	0,12	0,20	0,20	-

Table 3: Development of the Aerodynamic Quality of Different Transportation Systems

Moreover the data of the A300B4 compared to those of the A330 used in this context show an increase of the lift/drag ratio of *12%*. Both aircraft are comparable in respect of their size and mission and represent the technological development. However the improvement of the lift/drag ratio of the aircraft is less compared to motor vehicles and trains.

A comparison of the absolute drag of the different transportation 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 in the future. 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. For the whole route the influence of the drag increase due to tunnels is clearly less than *1.5%*, which is negligible for the following calculations, [4].

3.3. Other resistances of interest

The climbing resistance leads to an additional resistance along the route for inclination phases and provides an additional potential energy contribution with the slope. If one considers the climbing gradient along the respective routes, an increase of *0.004%* for the route Cologne – Berlin up to *0.112%* between Munich and Frankfurt is observed as mean values, [4]. 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 trajectory. However the additional thrust required during the climbing phase has to be considered for the overall energy effort.

The rolling resistance contributes about *0.25%* to railway systems and *1%* for passenger cars, [4]. For aeroplanes an amount of approximately *1.3%* is to be considered during the start and landing phase. All these values are very low and will be therefore neglected for the calculations, as long as their influence is nearly the same on all transportation systems.

3.4. Influence of drive trains

The engines and transmission systems are to be considered for the transportation efficiency also. They are summarized to the drive train efficiency η_{DT}, which is composed of the engine efficiency η_E and the efficiency of the transmission system/gear box η_G.

$$\eta_{DT} = \eta_E \cdot \eta_G \qquad (5)$$

As a result the analysis of different drive trains given in Table 4 has shown that electric drives of railway systems are the most efficient ones, indicating about *80%* efficiency.

Efficiency	**Car gasoline engine**	**Car diesel engine**	**Train ICE**	**Metro-rapid**	**Aero-plane**
Drivetrain η_{DT}	0,336	0,422	0,816	0,796	0,326
Energy Supply η_{ES}	0,927	0,927	0,342	0,342	0,927
η_{EN}	**0,311**	**0,411**	**0,279**	**0,272**	**0,302**

Table 4: Drive train Efficiencies of Various Transportation Systems

Combustion drive trains of motor vehicles and aeroplanes are less efficient at η_{DT} of *33%* to *42%*.

However, for an integrated consideration of the drive train the efficiency of the energy supply η_{ES} is to be considered too. It is composed of the energy transformation efficiency η_T and the energy distribution efficiency η_D received from statistical investigations, [8].

$$\eta_{ES} = \eta_D \cdot \eta_T \qquad (6)$$

Due to the high transformation losses associated with the electricity generation the situation changes. These losses are summarized by η_{ES} are caused by the power stations, the electricity network and the transformation stations. Because for fossil energy carrier like gasoline these losses are less, the diesel drive train turns out to be the best, if the energy efficiency η_{EN} is used.

$$\eta_{EN} = \eta_{DT} \cdot \eta_{ES} \quad (7)$$

The aero engines reach a comparable efficiency like the gasoline engines. The electrical drive trains loose 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 form of energy.

4. A TRANSPORTATION 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 needed and the value of the design 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 specific primary energy and the required transportation time as well as the operating cost. Four areas indicate immediately the transportation efficiency of a system related to a given mission.
The lower left quadrant expels optimal transportation systems which realize short transportation times with a low specific primary energy effort.
Unfavorable transportation systems are visible in the top right area. The top left area indicates systems which realize a short transportation time with a higher specific primary energy effort. In the lower right area at last transportation systems are present which reach a low primary energy effort, but require a longer transportation time. The future extension of the criterion by the cost factor pursues the same interpretation also regarding that influence.

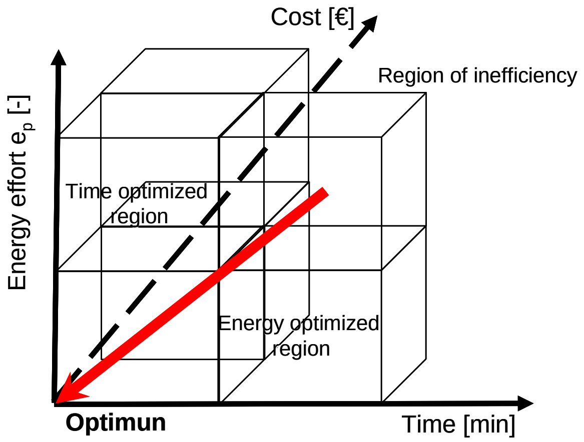

Fig. 8: Transportation Efficiency Criterion

By this three dimensional representation the benefits of a transportation system can be easily compared to others. The less the specific primary energy effort and the required transportation time as well as the expenses, the more efficiently the transportation mission is performed. Therefore, the theoretical optimal point is located in the 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_U to the resulting transportation performance along a given route, which is given by the carried mass m_{TOM} and the mileage x_{real}. It was shown, that this specific primary energy effort corresponds to the lift/drag ratio, well known in the aerospace community,[1]. These influences are represented in the first part of the formula below.

$$e_p = \frac{E_U}{m_{TOW} \cdot g \cdot x_{real}} \cdot \frac{1}{\eta_T \cdot \eta_D} \cdot \frac{1}{\eta_{DT}} \cdot \frac{1}{\eta_R} \cdot \frac{1}{\eta_K \cdot \eta_O} \quad (8)$$

Design assessments as well as the operational conditions are covered and represented by several efficiency factors. The efficiency of the whole driving chain is considered by the transformation efficiency η_T and distribution efficiency η_D as well as the drivetrain efficiency η_{DT}.

The design efficiency η_K describes the portion of payload of the total take off mass m_{TOM}.
The used payload capacity is given by the operating efficiency or load factor η_O. At last the route efficiency η_R represents the length of the orthodrome compared to the real mission length. Efficiency factors cover all relevant influences on transportation efficiency are.
Using such a dimensionless form allows the application to different transportation systems in a comparative way.
The useful energy E_U is determined by the fuel consumption or the summation of contributions to the driving resistance.
Moreover a link is given between fuel consumption contained in the end energy and the useful energy by the drivetrain efficiency:

$$E_E = \frac{E_U}{\eta_{DT}} \qquad (9)$$

The end energy can be calculated from the fuel consumption by

$$E_E = \dot{m}_F \cdot H_u \cdot \frac{x_{real}}{V} \cdot T_{\max} \cdot \delta_T \quad \text{Aircraft} \qquad (10)$$

$$E_E = m_F \cdot H_u \cdot x_{real} \quad \text{Automotive}$$

$$E_E = E_{E_{Train}} \cdot V \cdot x_{real} \quad \text{Electric Train}$$

For aircraft systems the end energy E_E is determined by the fuel flow m_F, the lower heating value H_u, the airspeed V, the real distance x_{real} and the leveled thrust $T_{max}*\delta_T$.
The end energy of automotives is composed of fuel consumption m_F, the lower heating value H_u, and the mileage x_{real}. At last for electric trains the end energy is derived from the consumed electrical power E_{ETrain} the driving speed V and the mileage x_{real}.
With these calculations it is possible for operators of transportation systems like airlines, railway societies or logistics agencies to identify the most appropriate transportation means for a given task. The manufacturers of traffic systems as well are able to verify their design compared to competitive systems under realistic mission conditions. At last one can compare easily competing transportations systems in dedicated regions.

5. RESULTS

The criterion was applied to different passenger transportation missions. The results indicate 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 requires the shortest cruising time by fare.
However, also the highest specific primary energy investment is associated with the aircraft.

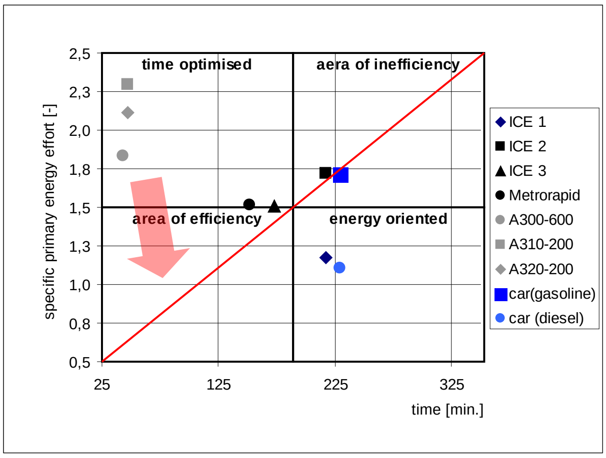

Fig. 9: Transportation efficiency on the main course Munich - Frankfurt

It should be noted, that all systems close to the 45°-line like gasoline cars, ICE 2 and 3 and also Metrorapid provide a good balance between energy effort and transportation time. They are declared as efficient.
However ICE 2 and gasoline cars are located more in the upper right region. They are not considered as efficient, because they need remarkable energy for a higher transportation time. Metrorapid and ICE3 show a well balanced relation of specific primary energy effort and transportation time. The diesel passenger car and the ICE1 reach the lowest specific primary energy effort associated with the longest transportation time.
In this analysis load factor of *55%* is chosen for all examined vehicles, which is advantageous to the trains, typically operating at that level. One has to keep in mind, that aeroplanes normally are operated today at *70%* load factor approximately, so they are not utilized at their

best level in this case. However the A320 is used in a nearly efficient way in this particular case, compared to the other aircraft.
If the evaluation is extended to the overall route including start, transition and arrival phases the general view continues.

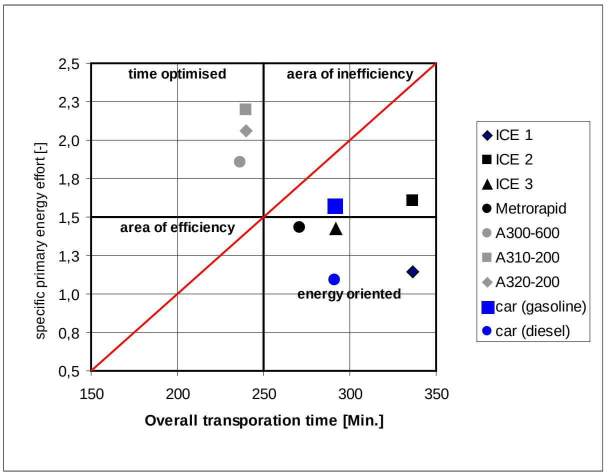

Fig. 10: Transportation Efficiency on the Route Rosenheim-Frankfurt/Main

The lead over of the aeroplane in time is significantly reduced due to the extensive time consumption during the side course phases. But also the overall energy effort A300 and A310 are slightly reduced because the energy effort is positively affected by the modal split of the various transportation systems during the starting and arrival phases. Because in this phases urban trains and cars play the main role associated with lower energy effort, also the total energy effort of the A300 is slightly reduced. This effect is not so obvious with the A320, because the absolute amount of passengers at *55%* utilization is lower and therefore their contribution of specific low primary energy effort in the side course phases is lower. Also for the railway systems a slight decrease of the overall specific energy effort is observed.
Because the principle relations between the various transportation systems do not change, high speed is directly correlated with high energy investment and less efficiency.
The main course energy effort is clearly dominating the overall effort. The side course phases (start, transition, and arrival) are driving the overall transportation time. These observations highlight the potential improvements in transportation processes and efficiency.
In another analysis the influence of the starting point is to be examined. Moreover the following Fig.11 shows, that a starting point close to the heart of the city favours the time advantage of the aeroplane on the main route. A short transition phase for motor vehicles and a shorter starting distance to the railway station and airport have a positive effect. Also the overall transportation time for motor vehicles and high-speed trains is reduced.
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 higher energy effort. It is far to observe that the new high speed trains like the ICE3 and the Metrorapid become a serious competitor, because they combine together more positive whole transportation times with moderate specific primary energy effort.

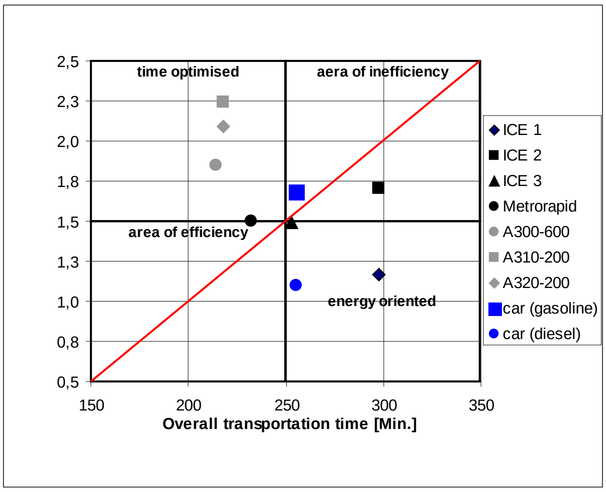

Fig. 11: Transportation efficiency on the route Schwabing – Munich – Frankfurt / Main

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.
For future developments improvements and better competitiveness of the aviation system require a reduction in the primary energy effort to improve the transportation efficiency. Also

significant improvement of the transportation times in the starting, transition and arrival phase must be realised, which affects more the infrastructure of the airport and the motorways around them.

This requires to consider the aviation system as the whole to reduce the starting phase by better networked airports, reduced boarding/ deboarding slots e.g. through rollon/rolloff designs of the aircraft and airport gates. Also high-lift systems can provide further capability to speed up the starting and landing of the aircraft.

6. SUMMARY

A method of a task oriented and integrated evaluation of the transportation efficiency of different transportation systems is presented. The analysis of the chains for cargo and passenger transportation with different systems concluded uniformly in a 5-phase model. Railway systems and aeroplanes produce no transportation performance in the transition phases. The aeroplane transportation system spends about *70%* of the overall transportation time during the start, transition and arrival phases, compared to approximately *25-30%* for trains and cars. This imbalance in traveling time is one main reason for the high energy effort for air traffic, because aeroplanes recover a part of the time investment of the side courses during the main courses.

The analysis of the driving resistance indicates the high empty weight or imbalance between this and the take off mass as the essential technical disadvantage of high speed trains. This is also partially true for aeroplanes. The analysis of the different drivetrains shows, that the electric drives loose their advantage with the engine efficiencies by the high transformation losses associated with the generation 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. It can be determined on the bases of the specific primary energy application and overall transportation time depending on the individual mission. An extension of the criterion to operating cost is also described for future investigations. 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. It is efficient in time only. The new high-speed trains ICE3 and Metrorapid are efficient in time and energy effort and prepared to become a serious competitor for aeroplanes on distances up to 1000 km. Parametric studies for design aspects of future cargo and passenger aircrafts and trains should be performed to extend the database of realistic evaluations.

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