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Limits of Environmentally Friendly Transport

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ABSTRACT: For railway transport to be more environmentally friendly than road transport it is necessary to reach more than the minimum occupancy and load in passenger trafficking and in freight trafficking respectively. It is not of great use to compare average values, e.g., of consumption of energy and emissions of elements of greenhouse gases; a better option is to compare the consumption of fuel per passenger and the same in the case of emissions. When comparing two vehicles of the same or comparable modes of transport (buses, railway units) in local and regional passenger traffic we can describe, with an acceptable simplification, the point of intersection of two lines of both consumption and emissions.

KEY WORDS: transport, environment.

1 MYTHS AND REALITY

There is a deep-rooted hypothesis that there is a general, environmentally greater friendliness of railways in comparison with road transport, irrespective of the volume of goods in goods trains and occupied passenger trains. This is presented in many studies mentioned in [3].

Sufficiently used trains are more likely connected with block trains, passenger trains for commuting in large conurbations, or in the case of long haulage where the probability of gather goods or passengers is higher. But it is not always the case for regional and local railways. They began operating at the end of the 19th or at the beginning of the 20th century, when the only competitors of railways could be navigable inland waterways and horse-drawn carriages. Despite the imposing development of railway technology, the shift from carter's business to lorries has been more impressive. And there has arisen much tougher competition from the side of cars.

The new feature in modal split in transport has led to many comparisons of the consumption of energy in modes of transport and emissions – together with rates of accidents - as the most important indicators of the effects of transport on the environment.

The problem of changed modal split in the case of regional and local railway lines and road transport has been that it is usually primarily illustrated using the consumption of fuel of fully, or supposed high-occupancy, trains with buses or cars. But the local trains are not always occupied enough. Therefore the more predicative indicators could be the specific consumption - consumption per passenger or per tonne of goods carried.

We suppose, with some simplification, the linearity of consumption of fuel and weight of occupied vehicle. It is possible in the first approximation to omit goods´ traffic that is rather poor on the Czech local and regional railways. (In which European countries is it similar?)

With some simplification of the supposed linearity (it is true for predominant parts of curves of occupation and consumed fuel, but not for whole of course) we could describe the relations of weight - consumption of fuel/emissions and, in a similar way, the emissions of greenhouse gases, as two sloping straight lines and to find points of intersection of these two lines. On axis x there is the number of passengers in a train, bus, and car; on axis y consumption of fuel and the same is valid in the case of dependence of the consumption of fuel exhaust – gas- emissions. The vehicle with higher capacity has, as a rule, higher consumption than the vehicle with lower capacity. The point of intersection defines the minimum number of passengers for the vehicle with higher capacity (e.g. train to bus) to be more efficient regarding the consumed energy than the vehicle with lower capacity.

In Figure 1 there is a graph of a comparison of the consumption of fuel (and analogously of emissions) of two modes of transport with different capacities (the most widespread railway unit series 800 or 810 of the Czech Railways and the standard buses Karosa; they both have about 44 seats and we suppose the same running speed.

We compare the most common types of train units for local and regional lines and buses - in the case of vehicles with approximately the same capacity of occupation – and we have found the lower number of passengers more than 17 or 18 passengers in case of the originally used engine some decades ago at the time of production of railway units and more than 12 passengers in case of replaced engines of the latest construction.

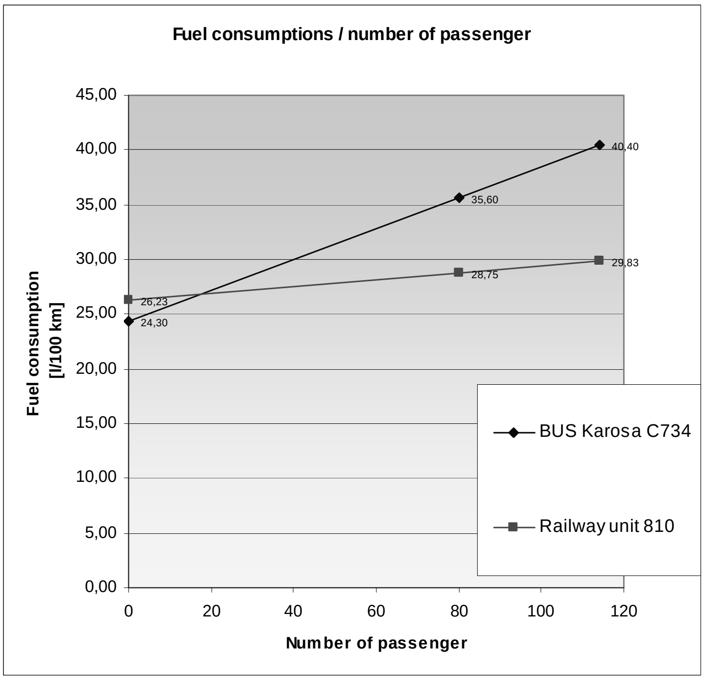


Figure 1: Comparison of fuel consumption per passenger of BUS Karosa C734 and Railway 810

Table 1: Equations of fuel/passenger

Type of vehicle	Equation of straight line in the slope form
Karosa C 734	Q [l]= 24,30 + 0,141 p [pass]
Karosa C 732	Q [l]= 24,89 + 0,14 p [pass]
Karosa C 934	Q [l]= 24,41 + 0,142 p [pass]
Articulated bus	Q [l]= 32,23 + 0,146 p [pass]
810 solo	Q [l]= 26,23 + 0,031 p [pass]
810 + 1 towed c.	Q [l]= 34,31 + 0,032 p [pass]

In the Figures below there is a graph of comparisons of the same vehicles regarding the estimated values of emissions. There were some problems with the compatibility of recalculated emissions - within the automotive industry CO is often used. But from the year 2013, supposing international agreement to the follow-up of the Kyoto protocol, transport should be included into the European scheme of trading emissions, where the main common denominator will be CO2. It was very difficult to find coefficients of conversion of all greenhouse gases, either into CO or into CO2, and to have the same mix of exhaust-emissions.

There was another possibility to use estimates published in the Handbook of estimation of external costs in the transport sector.

At the very end of our work the amended proposal of the new directive, confirmed by the official improvement of this Directive at the end of April in Luxembourg and supporting greater extension of “green” road vehicles and a reduction in consumption, had been approved. Results are in the following Tables (Figures). All situational possibilities are presented. We can find the limit of passengers only when the line also cuts the axis of the quadrant (figure 3 and 4).

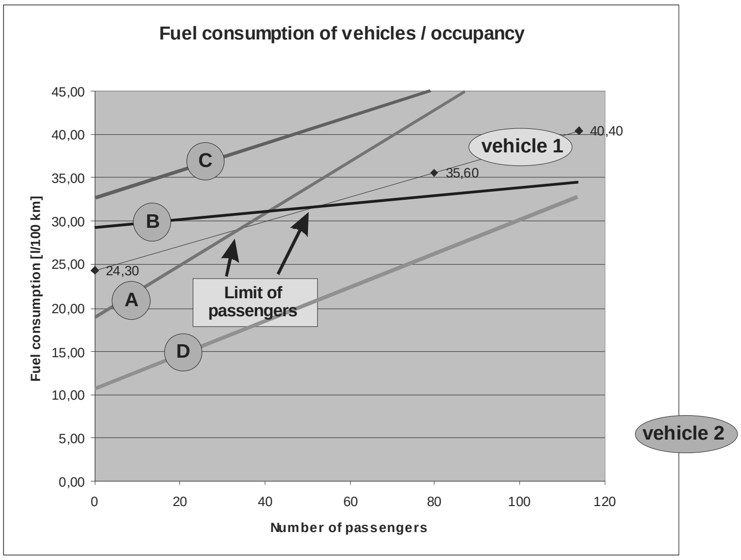
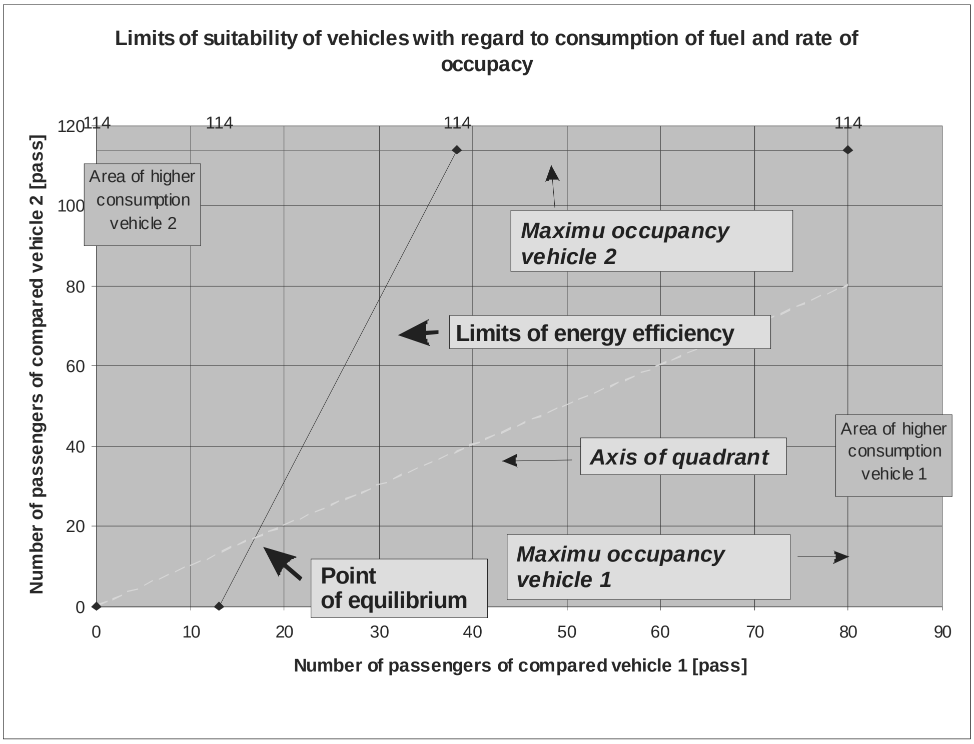


Figure 2: Point of intersection of curves of consumption of fuel dependant on the number of passengers with the same running speed.



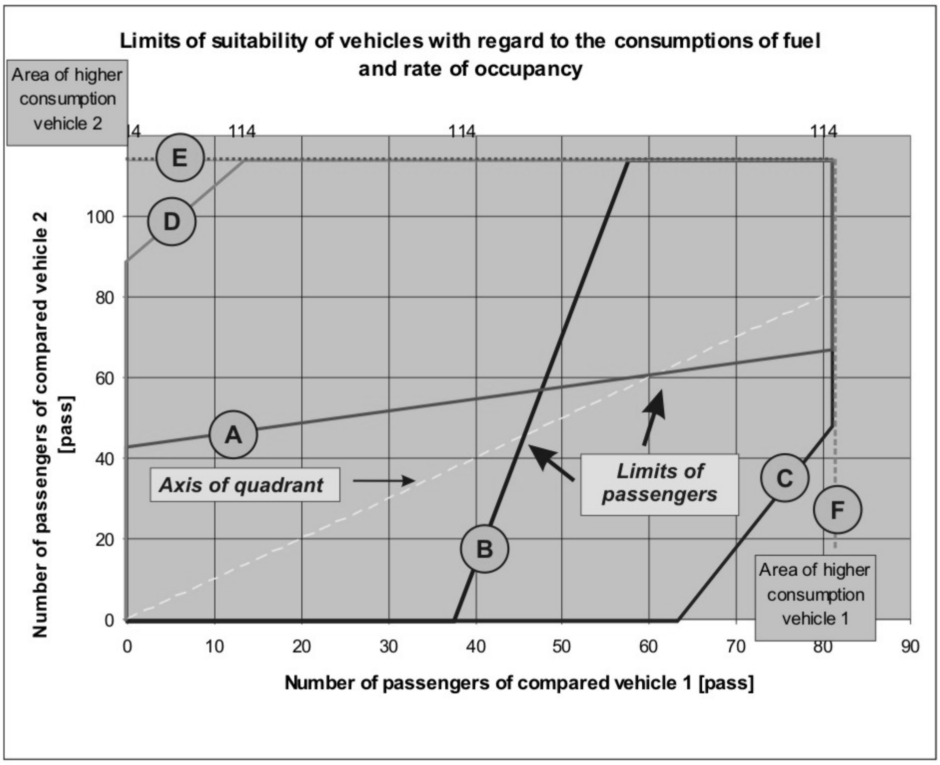


Figure 3, 4: A comparison of the most widespread railway unit series 800 or 810 of the Czech Railways and the standard buses Karosa; they both have about 44 seats and we suppose the same running speed.

Table 2: Limits of suitability of vehicles with regard to the consumption of fuel and rate of occupancy

Vehicle 1 (x1)	Vehicle 2 (x2)
Bus Karosa C 734	Railway unit 810
x1 = 13,679 + 0,223 x2	
Bus Karosa C 732	Railway unit 810
x1 = 9,535 + 0,223 x2	
Bus Karosa C 934	Railway unit 810
x1 = 12,914 + 0,223 x2	
Articulated Bus Karosa	Railway unit 810 + 1 towed c.
x1 = 14,265 + 0,216 x2	
Bus Karosa C 734	Railway unit 810 + 1 towed c.
x1 = 70,158 + 0,223 x2	
2 x Bus Karosa C 734	Railway unit 810 + 1 towed c.
x1 = -46,29 + 0,224 x2	

2 NECESSARY DENSITY OF TRAFFIC

In the Czech Republic there are now 135 railway lines designated as local and regional lines. The annual average on the lines with the highest used capacity of trains (most occupied trains) have been trains with 14.5 passengers (six lines); this indicates that during the peak hours there are some lines with such highly occupied trains that the energy (and emission) efficiency is higher than in bus traffic. The majority of trains are not occupied enough to be more environmentally efficient than buses or even cars.

In all modes of ground transport, there are large costs of infrastructure. In the case of local and regional railway lines, it is necessary to operate the minimum number of trains to cover the costs of their tracks – naturally, in case of local and regional lines with subsidies on account of public services in the general interests, but on a level bearable for public co-funding.

In the Figure below there is a graph describing the yearly average number of passengers in a local or regional train for last year.

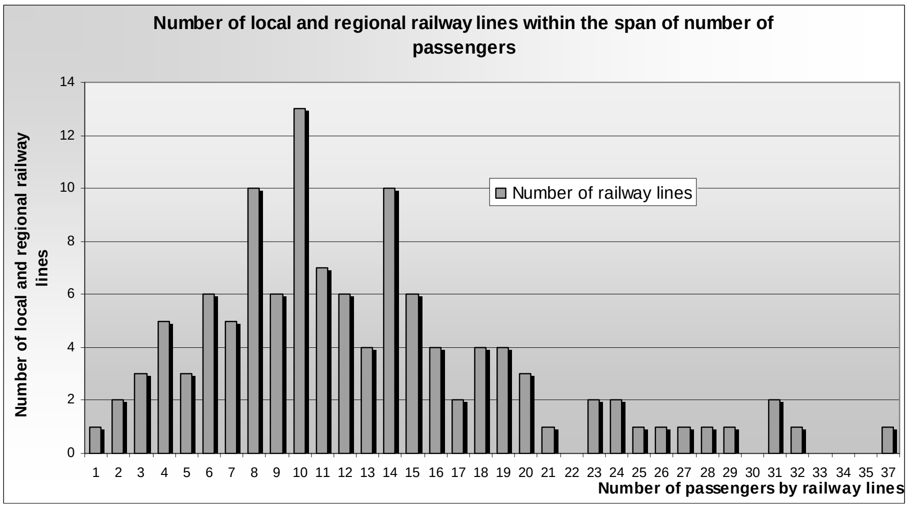


Figure 5: Yearly average number of passengers in a local or regional train.

3 OTHER TOOLS TO SUPPORT RAILWAYS

At the time of the first Pan-European Transport Conference a parole was pronounced: “So much liberalization that is possible, so many regulations that is necessary“. Is it still guilty? Is the consent with state aid approved by the Council of ministers, followed up by the European Commission, the only possible cure to help the railways? Could administrative tools be introduced to add the number of passengers and frequencies of passenger trains to make railways, from the point of view of energy and the emissions of greenhouse gases, more environmentally friendly than buses or, in general, road transport? Would it be acceptable by the European Court of Justice?

4 AND OTHER POSSIBILITIES

The local and regional lines are historical monuments. Is it possible to evaluate them not only from the point of view of economically evaluated means of transport? The stations in the very centres of towns and villages could be very desirable and could be used in favour of centres of tourism or they could be used for other lucrative business unconnected with railway transport. It is preferable to change them into centres of tourist areas – with stations converted partly into boarding houses, restaurants, and other supplementary activities connected with travelling, tourism, recreation, resort or other supplementary activities. Is it possible? Without such a transformation of part of the activities with a supplementary income, a predominant part of these lines could be abolished.

REFERENCES

[1] Bickel, P. & Friedrich, R. *Methodology 2005,* update Commission; P. Biskel et all., Stuttgart 2006.

[2] Coll. BIVŠ and external associates: *The evaluation of the economic impact of delays of construction of selected road communications*. Study for Ministry of Transport 2008.

[3] INFRAS, CE Delft, Fraunhofer Gesellschaft – ISI, University of Gdansk. *Handbook of estimation of external costs in the transport sector. Within the study Internalisation Measures and Polices for All external cost of Transport (IMPACT*). Version 1.0. Delft December 19th 2007 and 1.1 February 2008.

[4] Peltrám A. & Drahotský I. *Enforcing vehicles with the lower influence on the environment*. Doprava, vol. 50, iss. 6, pp. 3-4.

[5] *Accepted revised proposal for a Directive of the European Parlament and of the Council on the promotion of clean and energy efficient road transport vehicles* (IP/08/1570, COM/2007817 final.

Involvement of Aviation Activities in the Scheme for Greenhouse Gas Emission Allowance Trading

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ABSTRACT: The European Union includes the Environment as one of the four main target areas requiring greater effort. One pillar of EU environmental policy is the Greenhouse Gas Emission Trading System. In the EU directive 2008/101 it was held that aviation will be added to the system of greenhouse gases trading. Despite the relatively low volume of aviation emissions, the danger of aviation emissions emitted in the higher atmosphere tips the scales. Aviation will be part of the ETS from year 2012, but the most important decisions and customizations of the ETS system for aviation are to be done now. The involvement of aviation in the ETS presents many difficulties and problems, which need to be solved to allow the ETS to bring benefits to both aviation and the whole of society as well.

KEY WORDS: greenhouse gas, ETS, aviation.

1 EUROPEAN UNION GREENHOUSE GAS EMISSION TRADING SYSTEM

The European Union Greenhouse Gas Emission Trading System (EU ETS) is an executive part of EU climate policy. The ETS is anchored in Directive 2003/87/EC. The main goal of the ETS is to force producers of greenhouse gases to decrease volume of greenhouse gases produced by charging a part of emissions. The EU ETS mechanism is targeted on large emitters of carbon dioxide within the EU, about 11 000 operators which covers about 45% of EU carbon dioxide production. The EU ETS works on a “cap and trade” basis – each member country of the EU has its own limit of emissions which is covered by allowances which are redistributed between involved subjects. Allowances (EUA - one allowance represents the right to produce one ton of carbon dioxide) are distributed by national governments according to a national allocation plan on the basis of their Kyoto protocol commitments. The whole cap of allowances is smaller year by year and thus the operator receives fewer allowances on emissions each year. That forces them either to reduce their emissions or to buy allowances from the other operators who produced less emission and saved their allowances for trade. The EU ETS is planned in 3 phases till the year 2020 and the main goal is a reduction in emissions of 21% compared to year 2005. Since January 2008, the 2nd Trading Period is under way which will last until December 2012. The present resemblance of the ETS is not definitive. The European Commission proposed a number of very important changes to the scheme.

The main changes are the following:

- There will be one EU-wide cap on the number of emission allowances instead of 27 national caps. The annual cap will decrease along a linear trend line, which will continue beyond the end of the third trading period (2013-2020).
- A much larger share of allowances will be auctioned instead of allocated free of charge.
- Harmonised rules governing free allocation will be introduced.
- Part of the rights to auction allowances will be redistributed from the Member States with high per capita income to those with low per capita income in order to strengthen the financial capacity of the latter to invest in climate friendly technologies
- A number of new industries (e.g. aluminium and ammonia producers) will be included in the ETS; so will two further gases (nitrous oxide and perfluorocarbons).
- Member States will be allowed to exclude small installations from the scope of the system, provided they are subject to equivalent emission reduction measures
- These changes were mentioned in Brussels, 23 January 2008 Questions and Answers on the Commission's proposal to revise the EU Emissions Trading System. They are fundamental and if adopted they will change the situation on the allowance market and thus change the prices of EUA. Changes are widely discussed and active lobbying is under process. The main effort of EU is to stabilize the price of allowances, because only a stabile price is a guarantee for the investor to realise an acquisition for the reduction of emissions. The first phase of ETS resulted in a total depreciation of EUA 2007 (allowances for first phase), which was due to the wrong estimation in the volume of emissions in first phase (2005-2007) and overmuch EUA were allocated freely. The EU does not mean to allow that situation to happen again. Figure one shows an overview of the average settlement prices of EUA contracts (curve) traded on the ECX (European climate exchange). Columns indicate the volume of traded EUA. The curve shows underflow connected with the global economic recession that reduces industrial production and thus CO2 emissions. On the other side the columns show that traded volume is higher, because of low price. Speculative buys show that at least part of the involved organisations expected a significant rise in the EUA price in the future and the depreciation of EUA 2007 had passed out of mind. The actual price of EUA on ECX from 1st June 2009 was about €13.30 and was slowly decreasing.

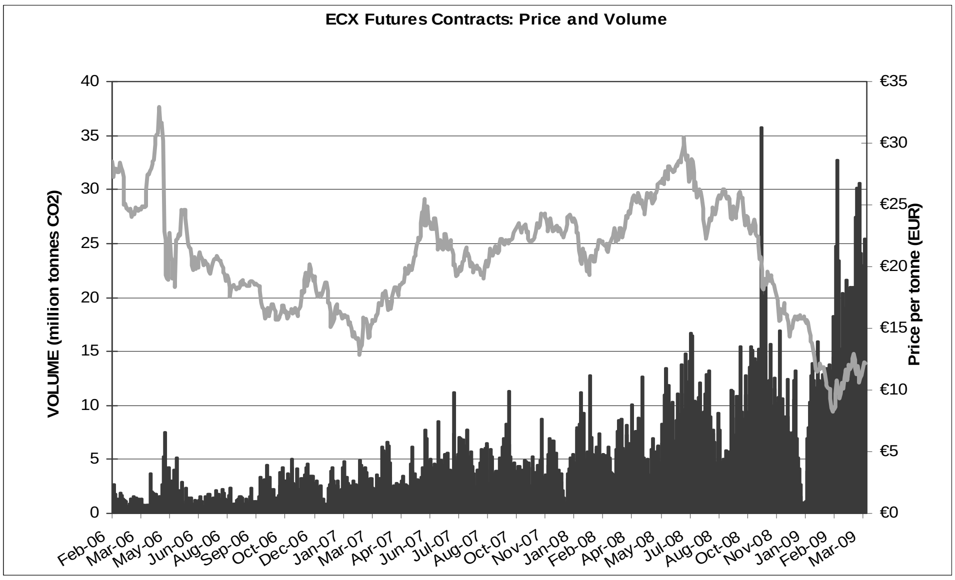

Figure 1: EUA prices at the European Climate Exchange

2 INVOVLVEMENT OF AVIATION ACTIVITIES IN THE SCHEME FOR GREENHOUSE GAS EMISSION ALLOWANCE TRADING

Aviation emissions represent only about 5% of all greenhouse gases emissions. That is quite a small percentage, but the main reason to include aviation in the ETS was the rapid growth of air transport in the late 90´s and at the beginning of the 21st century. But as shown in Figure 2, the global economic depression hit aviation seriously. Air transport is in its deepest depression ever and is the worst depression of all means of transport.

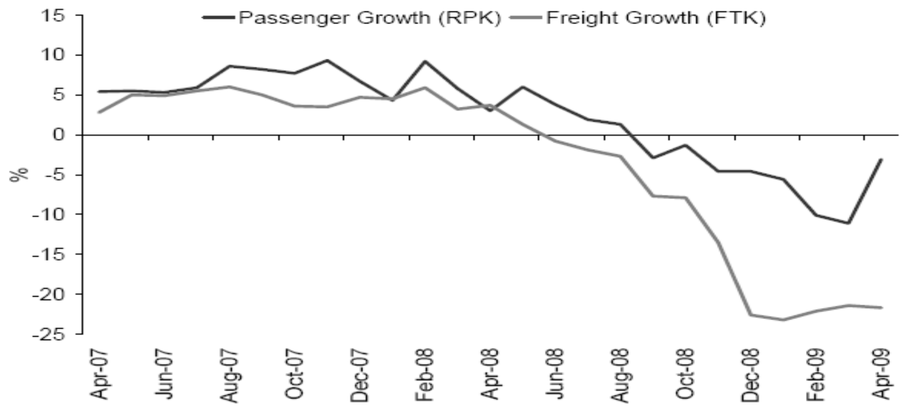

Figure2: International air transport passenger and cargo growth

With the decrease in air transport the main reason to involve air transport in the ETS disappeared, or, at least for next few years, is less important, but a new reason appeared. The new reason why to involve air transport in ETS are contrails. Contrails have been considered possible modifiers of regional climate. Contrails may increase total cloud and cirrus cloud amounts, and consequently change the Earth's radiation balance. As a result, surface and upper tropospheric temperatures may change. According to IPCC (Intergovernmental Panel on Climate Change) Aviation Special Report in the future, contrail cloudiness and radiative forcing are expected to increase more strongly than global aviation fuel consumption because air traffic is expected to increase mainly in the upper troposphere, where contrails form preferentially, and because aircraft will be equipped with more fuel-efficient engines. More efficient engines will cause contrails to occur more frequently and over a larger altitude range for the same amount of air traffic. The contrail cover would increase even more strongly if the number of cruising aircraft increases more than their fuel consumption. Higher cruise altitudes will increase contrail cover in the subtropics; lower cruise altitudes will increase contrail cover in Polar Regions. Future climate changes may cause further changes in expected aircraft-induced cirrus cover. But the LOSU (level of scientific understanding), in the area of aviation produced aerosols and cloudiness, is still low. Further research in this area is essential for a correct assessment of the exposure. Uncertainties about the impact of aircraft emissions in higher atmosphere, and fear from possibly more serious consequences, are now the main reasons why aviation shall prevail in ETS. For example, maritime transport inclusion in the ETS has been prepared for a longer period than the inclusion of aviation, but with a consideration for the economic depression, the inclusion of maritime transport in ETS has been recessed without date.

The Directive 2008/101/EC of the European Parliament includes some aviation activities in ETS. ETS will apply on flights to and from EU airports from 1.1.2012. Year 2012 should be a test phase for this project. The progress in the reduction of greenhouse gas production should be stronger than in the older ETS phases now because aviation will be involved directly from the test phase into the stricter phase 3 of ETS. There will be differences for aviation ETS to secure a smooth changeover into phase 3. For year 2012 the amount of EUA to be located is equal to 97% of historical aviation emissions and the total quantity of allowances to be allocated to aircraft operators shall be equivalent to 95 % of the historical aviation emissions multiplied by the number of years in the period. This percentage may (and is expected to) be reviewed as part of the general review of this Directive. Historical aviation emissions means the average of the annual emissions in the calendar years 2004, 2005 and 2006, but by 2 August 2009, the Commission shall decide on a change of the historical aviation emissions, based on the best available data, including estimates based on actual traffic information. 85 percent of EUA shall be given for free, 15% shall be auctioned. This percentage may be increased as part of the general review of this Directive. There shall be a 3% reserve from all EUA to be allocated for operators:

(a) who start performing in aviation after the monitoring year for which tonne-kilometre data was submitted, or

(b) whose tonne-kilometre data increases by an average of more than 18 % annually between the monitoring year for which tonne-kilometre data was submitted

This 3% reserve is important especially for EU newcomers because their air transport market is not fully established yet, and is expected to grow rapidly. If there were not any reserve ETS a strong market disadvantage for the operators from these countries would be created. As ETS is primary targeted on large operators, there are some borders for aviation operators to be involved in ETS.

The ETS shall not include flights performed by aircraft with a certified maximum take-off mass of less than 5700 kg, flights performed by a commercial air transport operator operating either: fewer than 243 flights per period for three consecutive four-month periods; or flights with total annual emissions lower than 10000 tonnes per year. There are other flights excluded from ETS, such as flights performed exclusively for the transport on official missions of a reigning Monarch, Heads of State, Heads of Government , all military activities, SAR (search and rescue), all VFR flights, training flights, flights which take off and landed on the same airport and flights for scientific purposes, etc..

Air transport emissions shall be monitored by calculation. Emissions shall be calculated using the formula: Fuel consumption × emission factor. Fuel consumption shall include fuel consumed by the APU (auxiliary power unit). Emission factor should be taken from 2006 IPCC Inventory Guideline, unless emission factors identified by accredited laboratories are more accurate. Each kind of fuel has its own emission factor. The emission factor used for most aircraft fuel is 3.15. This means for the purposes of ETS for each 1 tonne of fuel burned 3.15 tonnes of greenhouse gases are produced. The emission factor shall take into consideration the danger of contrails and if the danger of contrails will be proven, it is expected that the emission factor will rise. The allocation of allowances is solved on the principle of aviation activity. The amount of aviation activity shall be calculated in tonne-kilometres using the following formula: tonne-kilometres = distance × payload. Where: "distance" means the great circle distance between the aerodrome of departure and the aerodrome of arrival plus an additional fixed factor of 95 km; and "payload" means the total mass of freight, mail and passengers carried. For a rough conception, emission cost sample scenarios for Lufthansa are given in figure 3. All benchmarks are made to work with the high level of uncertainties on some key factors and calculations for many different scenarios are to be taken in consideration. Scenarios for Lufthansa are positively influenced by the fact that Lufthansa operates mostly modern aircrafts with good fuel consumption rate, scenarios for airlines with an older fleet would be worse.

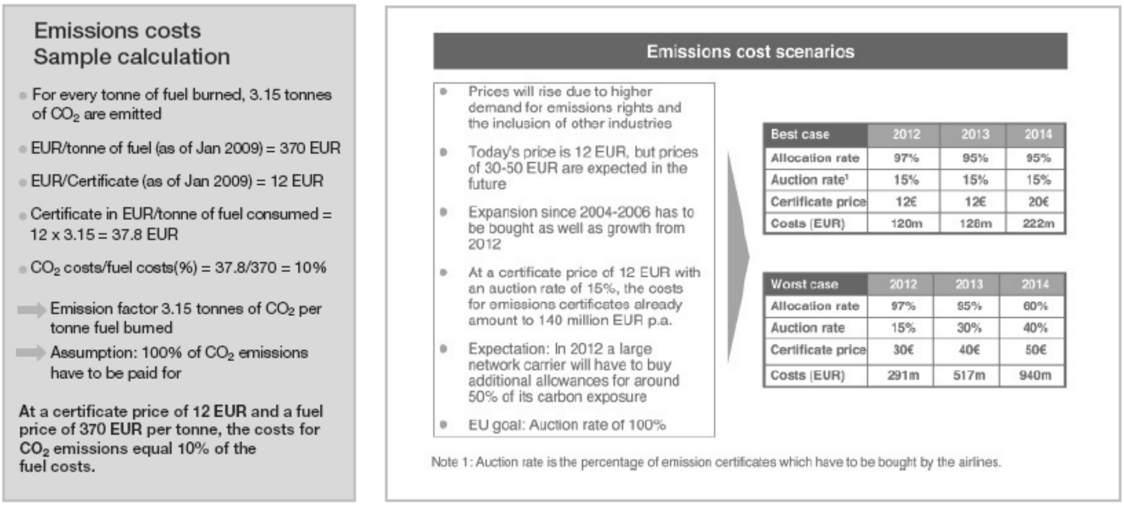

Figure3: Emission cost scenarios for Lufthansa

As the sample calculation shows nowadays EUA costs are about 10% of fuel costs, and with only 15 % of EUA needing to be bought, but a rise in the price of EUA is expected in the future. The worst of all scenarios counts with a price of 90 EUR (100EUR is fine for emissions without allowance) per EUA and 100% EUA auctioned – the outcome approximately adds an additional 60% to fuel cost. That would be devastating especially for low cost airlines. It should be mentioned that the EU is supporting ecologically less dangerous fuel, these fuels have significantly smaller emission factors, some have a factor = 0, that means no EUA needed and all allocated can be purchased. But there is still no real alternative fuel for a minimum of the next 5 years. ETS should be the reason why airliners should support research into the area of "green" jet fuel.

3 PROBLEMS CONNECTED WITH INVOVLMENT OF AVIATION IN ETS

The main problem with the inclusion of aviation in ETS, already mentioned above, is the uncertainty about future development. The percentage of EUA allocated freely or auctioned, as well as the rate of decrease of the whole cap, is absolutely necessary for the reasonable planning of emission reduction. The EU has to give definitive and mandatory information about the future of the ETS. The difference between 15% and 100% of EUA auctioned is enormous and makes long term investments in emission reduction highly risky. This high level of risk is understandably weakening efforts on emission reduction and devaluing the whole idea of ETS. Combining the contending concerns of the environmental lobby on one side and airliners on the other side is challenging, but compromises have to be accepted as quickly as possible.

Other problems are connected with the expected additional costs of ETS. The cost of allowances will be same for all operators, but there will be additional costs depending on the business model or geographical location of operator, which will create uneven conditions on the part of the airlines. In "Analysis of the EC Proposal to include Aviation Activities in the Emission Trading Scheme", which was prepared by Ernst & Young and York Aviation in 2007, is a warning that the ETS will hit especially low cost airliners seriously because their product is much more price sensitive than the product of airliners oriented on business clients. Because of the price sensitivity, low costs can not afford to raise their prices and will have to compensate the ETS costs by decreasing their profit. Another problem can arise from the administrative requirements connected with the ETS. As each subject involved in the ETS has to have an authorized monitoring plan for emissions, another monitoring plan for tonne-kilometre output and yet another agenda connected with trading on EUA exchange, it is obvious that there will be administrative costs. According to the E&Y analysis these costs are estimated to be about 150 000 EUR per year. That is another burden, especially for small airlines. Another threat is so called "carbon leakage". Because of the competitive disadvantage of EU operators, who are involved in the ETS, against non EU operators, there is a high risk that passengers who use some EU airports only as a transition hub will rather use a non EU hub (and non EU airliners too) to avoid additional costs from ETS. Airports and airlines operating from airports near EU borders will also be challenged by operators from near non EU airports, and airlines involved in ETS will oppose the market disadvantages against operators which are not involved in ETS, due to not meeting the requirements. All these market disadvantages are serious problems and the EU is aware of this situation and is working on some solutions. As mentioned above, air transport is now facing its worst depression ever and this depression will negatively influence the implementation of ETS in aviation. In a time of financial instability for airlines it is complicated to implement an ETS supporting strategy in their own business plans. The best way to profit from ETS is to buy modern aircraft with a better fuel consumption rate. For most airlines the ETS will only be another burden in a time of crisis. For some of them it could be the last strike for their tight budgets. On other hand there should be some positive effects too. Apart from the reduction in greenhouse gas emissions, there should be some competitive advantage for the airlines involved if ETS or a similar scheme will be adopted in other parts of the world. The same situation is with competition from other means of transport. What is today a disadvantage, could become advantageous, if another means of transport will adopt a similar scheme of emission trading and face the same problems as aviation today. ETS could also be an advantage for some business models of airlines that will benefit from a reduction in emissions and trading with EUA. No less important will be the investments in alternative jet fuel research, which may bring new power sources and make aviation less dependant upon crude oil.

REFERENCES

Ernst&Young and York Aviation, Analyses of the EC Proposal to Include Aviation Activities in the Emission Trading Scheme. Available from: <http://www.europarl.europa.eu/hearings/20070627/tran/ambrose_summary_en.pdf

Ernst&Young and York Aviation, Inclusion of Aviation in the EU ETS: Cases for Carbon Leakage . Available from: <http://www.iaca.be/index.cfm?AFF5184E-BDBE-2776-0CC0-9E3D55BCA9FB

Directive 2003/87/EC of the European Parliament and of the Council. Available from: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:EN:PDF>.

Directive 2008/101/EC of the European Parliament and of the Council. Available from: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:008:0003:0021:EN:PDF>

UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change 1998 Available from: <http://unfccc.int/resource/docs/convkp/kpeng.pdf>

IPCC, Aviation and the Global Atmosphere. 2001.

Lufthansa Consulting, Sustainable aviation: emission trading, March 2009.

Solar Cars and Energy Effiecient Management System

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ABSTRACT: This paper summarizes the basic assumptions that led to a thesis which investigates the use of high efficiency solar cells used by solar cars, with the main aim of minimizing energy consumption in such a vehicle. A solar car is special in the way that there is not only energy consumed, but also generated. This energy should be used in the most efficient way, for example with the use of a combination of different energy storages, such as high efficiency batteries and super capacitors.

KEY WORDS: Solar energy, Solar Cell, WSC (World Solar Challenge), Super cap.

1 INTRODUCTION

In the 20th century there was a rapid development in industry and new computer technology. New computers that can operate faster then their forerunners along with tiny microchips allow the use of controlling processes in most technological branches. In this way technological development can reduce costs in production companies and can help them work more efficiently. On the other hand, more and more electricity is being used to fulfill the high energy demand. It is enough for us to compare the electrical house appliances used these days with those used 20 or 50 years ago to realize how much the electricity demand has increased. Without thoughtfully considering when buying new household devices that will consume more energy, we are turning into a consuming society that does not think about the surrounding environment.

It is no wonder that to be able to cover high electricity demands more energy needs to be produced- the majority of it coming from coal, gas or nuclear power stations. All these electricity producers clearly introduce a hazard for the environment. Although the efficiency of coal fired power stations has increased to about 40%, for the final product delivered to the customer, which might be our homes, this number will drop to just a fraction of the energy that was originally stored in the fuel. These days there are activities by some political parties and associations that try to reduce the negative impact on our environment caused by burning fossil fuels. Unfortunately the cheapest way to produce energy still has a green card and with all honesty this can not be changed in the near future.

Technological development helps to further develop different areas of science so new technologies can be used and try to compete with the old and environmentally harmful energy producers. As an example wind, water or solar energy can be mentioned. When comparing an average-sized coal power station that can generate about 1000 MW we would have to build approximately 200 wind power stations. On one hand this introduces high costs and also a large area of coverage when building such power plants, but on the other hand the fuel, wind, is there and it is free. Similarly, solar power is for free, but it is not used to the extent that it could be. The main reason is that the high price of high efficiency solar cells introduces a breakpoint in their wide utilization.

There are campaigns that try to present new technologies, such as solar power, to the public. An example of such an action would be the introduction of solar cars in a competition known as “World solar car challenge” that takes place on regular basis in Australia. This is a friendly competition where solar powered cars drive a distance of over 3000 km through a desert driven by the power coming from the sun. The main concern of this paper is based on a dissertation thesis, which is still being processed, considering such a vehicle and designing an onboard system that would take care of energy burned by driving and also taken from the solar energy. Different driving modes will be considered and as a result a system will be designed that will manage the energy consumption. If, for example, the profile of the track would already be known this system could optimize the energy outflow so the finish destination will be reached. Furthermore, an electrical design that possibly improves the efficiency of this vehicle will also be considered. Controlling processes that will optimize the energy consumption will be included.

2 SOLAR CAR TECHNOLOGY

2.1 WSC “WORLD SOLAR CHALANGE”

World solar challenge is, without a doubt, one of the most famous and prestige campaigns that promote alternative energy sources - in this case solar energy. The race takes place on a track which covers 3021 km through the Australian outback, from Darwin to Adelaide. Along the track there are 9 check points where the racing teams have to stop. The distance between those outback towns varies between 300 and 500 km. The start of the race is in Darwin with a short presentation where the solar vehicles are introduced, and there is also some time for a chat with the members of the racing teams. The next stops are Katherine (318km), Dunmara (633km), Tennant Creek (987km), Alice Springs (1498km), Cadney Homestead (2025km), Glendabo (2430km), Port Augusta (2719km) and the final stop is in Adelaide after 3021km. Teams entering this contest have to comply with strict regulations which are limitations for the solar car construction. The main limits will be introduced:

- As already stated the solar panel area should be no more than $6m^2$.
- As the race is over public roads, the cars have to adhere to the normal traffic regulations; however, there is a special note in the official regulations remarking on the tendency of drivers to take advantage of a favourable road camber in order to capture the maximum amount of solar energy.
- A minimum of 2 and maximum 4 drivers have to be registered. If the weight of a driver (including clothes) is less than 80 kg, ballast will be added to make up the difference.
- Driving time is between 0800 and 1700 hours. In order to select a suitable place for the overnight stop (alongside the highway) it is possible to extend the driving period for a maximum of 10 minutes, and this extra driving time will be compensated by a starting time delay the next day.

- At various points along the route there are checkpoints where every car has to pause for 30 minutes. Only limited maintenance tasks (no repairs) are allowed during these compulsory stops.

- The capacity of the batteries is limited to a mass for each chemistry (such as Lithium Ion) equivalent to approximately 5 kWh maximum. At the start of the race, the batteries may be fully charged. Batteries may not be replaced during the competition, except in the case of a breakdown. However, in that case a penalty time will apply.

- Except for the maximum outer dimensions, there are no further restrictions on the design and construction of the car.

- The deceleration of the dual braking system must be at least 3.8 m (149.6 in)/s².

2.2 BASIC SOLAR CAR ARRAGEMENT

The basic system arrangement of a solar car would consist of three main components – the motor, where electric energy is transformed into mechanical kinetic energy, the battery (or other power source), and finally solar cells that transform energy in the light into electrical energy. In the case of the solar car the physical energy stored in the light is transformed into electrical energy and then back to mechanical energy in the form of motion. Unfortunately the present efficiency of solar cells as such is not good enough to provide a sufficient amount of energy for car momentum. There has to be a separate power source that can provide the car with additional energy.

2.3 SOLAR CELL

There is a large spectrum of solar cells on the market these days, however the efficiency of the solar cells differ dramatically. The common solar cells in households would have an efficiency of just about 10%, whereas the most efficient cells used on space ships achieve close to 30%. For solar cars very efficient solar cells also need to be used to produce more energy from a smaller area. Unfortunately those cells are produced with expensive technology and expensive materials, so the cells also introduce a very high cost. One of the market's leading developers and producers of solar cells is the company EMCORE. One of their solar cells is going to be selected for further explanation and also for energy management design and calculations. As is commonly known, a solar cell or photovoltaic cell is a device that converts light energy into electrical energy by the photovoltaic effect. A typical current-voltage characteristic of this cell type is shown in figure 1.

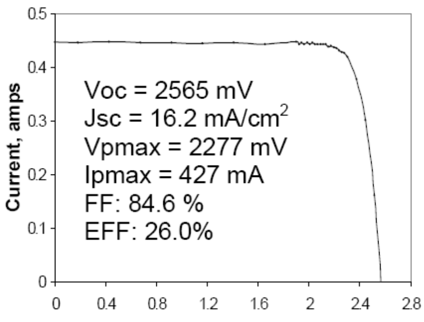

Figure 1: Solar cell current voltage characteristic

As shown in this characteristic graph the nominal voltage of one cell is approximately 2.5V, which can deliver a current of about 420mA. This would be with an efficiency of 26%. This percentage actually means how much of the provided solar energy will be converted to electrical energy.

A solar cell's energy conversion efficiency (η, "eta"), is the percentage of power converted (from absorbed light to electrical energy) and collected, when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, Pm, divided by the input light irradiance (E, in W/m²) under standard test conditions and the surface area of the solar cell (Ac in m²).

$$\eta = \frac{P_{\lim}}{E * A_c}$$ **Equation 1**

So the next step would be to determine how much solar energy can be expected or how much irradiance is delivered from sun. The trend measured by research institutes indicates following data for irradiance *E*:

- In a summer day 1000 to 1050 Wm^{-2}
- In a winter day 300 Wm^{-2}
- By a clouded sky 100 Wm^{-2}
- In the night 0.01 Wm^{-2}

Considering the high solar irradiation of $1000\ Wm^{-2}$, a solar cell efficiency of 30% and an area of $1m^2$, the possible solar energy that can be used these days transformed into electrical energy can be calculated with Equation :

$$P_{\lim} = \eta * E * A_c$$ **Equation 2**

According to new regulations for the WSC (World Solar Challenge) in Australia the solar cell area is limited to $6m^2$ which will represent solar power of:

$$P_{\lim} = 1800W$$

This is the solar power output that needs to be taken into consideration when designing the energy management. This is approximately the maximum solar power that can be generated by the onboard solar cells.

Recent studies in research institutes have developed high efficiency solar cells. The world record in efficiency was reached in Germany at the Fraunhofer-Institut für Solare Energiesysteme ISE in January 2009 – a world record of 41.1% of efficiency for multi-junction solar cells.

Scientists from the Frauenhofer Institute for Energy systems ISE have reached an efficiency of 41.4% in the transformation of light into electrical energy. The sun light was concentrated 454 times on a 5 mm^2 plate, which is known as a multi-junction semiconductor and is made of GaInP/GaInAs/Ge”. [1]

[1] [5] Pro-physik : „*Weltrekord: 41,1% Wirkungsgrad für Mehrfachsolarzellen*“, Internet scientific journal

3 VEHICLE MOVEMENT

3.1 MOVEMENT FORCES

While the vehicle is moving, there are resistance forces that try to stop its movement. The resistance usually includes tyre rolling resistance, aerodynamic drag and grading resistance. According to Newton’s second law, vehicle acceleration can be written as

$$\frac{dV}{dt} = \frac{\sum F_t - \sum F_{tr}}{\delta M_v}$$ **Equation 3**

Where V is vehicle speed, $\sum F_t$ is the total tractive effort of the vehicle, $\sum F_{tr}$ is the total resistance, M_v is the total mass of the vehicle and δ is the mass factor, which is an effect of rotating components in the power train.

Equation 3 indicates that speed and acceleration depend on tractive effort, resistance and vehicle mass. For investigation into further movement the movement forces displayed in figure 2 are calculated as shown in the following equations.

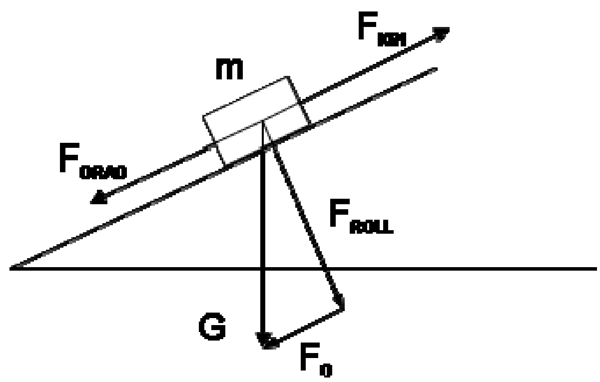

Figure 2: Ascending motion and forces

Acceleration force

When the velocity of the vehicle is changing, there needs to be a force applied which is known as acceleration force. This force will provide linear acceleration of the vehicle and is given by the equation derived from Newton’s second law

$$F_{Kin} = \mathrm{m} * \mathrm{a}$$ **Equation 4**

Drag Force

Drag force is due to the friction of the vehicle body through the air. It is a function of the frontal area, shape and actually all protrusions that introduce a resistance to the air flow around the car.

The formula for this component is:

$$F_{\mathrm{Drag}} = \frac{1}{2} * \rho * \mathrm{v}^2 * \mathrm{A} * \mathrm{C_D}$$ **Equation 5**

Rolling resistance force

The rolling resistance is primarily due to the friction of the vehicle tyre on the road. The rolling resistance is approximately constant, and hardly depends on the vehicle speed. It is proportional to the vehicle weight. Another part of this force would be friction in the bearing and the gearing system. The equation is defined as:

$$F_{\mathrm{Roll}} = m * \mathrm{g} * \mu_{\mathrm{rr}} * \cos\alpha$$ **Equation 6**

Grading resistance

When a vehicle drives up or down a slope, its weight produces a resistance force, which is always directed to the downward direction. This component either opposes the forward motion (ascending) or helps the forward motion (descending). The grading resistance force can be expressed as:

$$F_G = m * g * \sin\alpha$$ **Equation 7**

With these equations the total tractive effort can be calculated for different driving modes as in the equation:

$$M_v \frac{dV}{dt} = F_{te} - \left(F_{Roll} + F_{Drag} + F_G\right)$$ **Equation 8**

Where *dV/dt* is the linear acceleration of the vehicle along the longitudinal direction and M_v is the vehicle mass. The first term on the right hand side is the total tractive effort and the second term is the resistance.

When considering these calculations it is obvious that when there is going to be given a certain speed that a car should reach, then, according to design and car parameters, these forces can be determined and therefore the final resulting force. Using the forces calculation the entire mechanical power needed for certain vehicle movement can be determined as in the equation:

$$P_{mech} = \tau * \omega = F * r * \frac{v}{r} = F * v$$ **Equation 9**

When ignoring other friction forces and losses the mechanical power can be considered equivalent to the electrical power. The electrical power will be used to determine and design the power demand for the power supply and therefore the power that has to be onboard to provide enough energy for motion.

For the detailed solar vehicle design a GPS device is going to be used to record a profile of the track, time and speed. This data can be monitored, transferred to computer and finally evaluated, for example in an excel spreadsheet. figure 3 shows a short selection of data taken with a GPS device and transferred to excel.

Position	Time	h [m]	Depth	Leg Length	s [m]	Leg Time	t [s]	Time	v [km/h]
S33 47.414 E151 16.726	02/03/2008 12:49	11.7		16.3	16.3	0:00:02	2.31	2	29
S33 47.424 E151 16.725	02/03/2008 12:49	13.1		18.5	34.8	0:00:02	2.31	5	33
S33 47.433 E151 16.725	02/03/2008 12:49	16		15.4	50.2	0:00:02	2.31	7	28

Figure 3: GPS data

Figure 4 represents an ascending track that rises from about 10 m to approximately 50m in 50s. For this motion example the corresponding forces and power are determined.

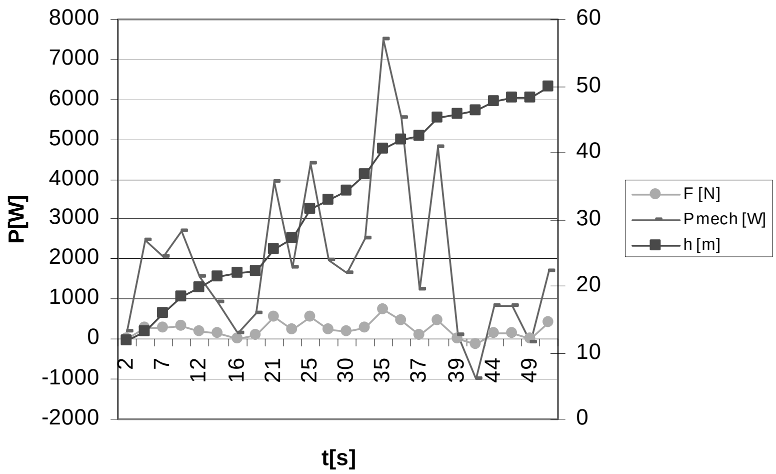

Figure 4: Power estimation

The estimation of electrical power can be used in many different ways to manage the energy onboard of the vehicle. According to the track profile and other track conditions the amount of energy or power that will be needed can be determined. Thus the power output can be controlled and can be managed, for example, to keep the power release in a desired manner it can be limited.

3.2 DRIVING MODES

The fundamental point for this thesis was the assumption that there are different driving modes and different driving situations that have different power requirements. The focus is going to be on special driving modes, such as acceleration, deceleration, and ascending and descending motion.

When optimizing these driving modes it is necessary to consider what energies are entering the system and what energy is going to be transformed into motion. It is understood that in the case of a solar car there is external energy from the sun, which is going to load the energy source on board of the solar car.

In these special situations, there is much higher energy demand than even for motion. In other words it would be preferable if there would be a power source that would be active for even motion and a power source that would cover the high energy demand. This would mean a combination of a source with high energy density, such as a battery, and a source with high specific power, such as an Ultra capacitor, also known as a Super cap. To be able to fully understand the advantages and drawbacks of these, a short introduction of Super capacitors, with a comparison to the battery, follows.

4 SUPER CAPACITOR VERSUS BATTERY

4.1 INTRODUCTION

Whereas a regular capacitor consists of conductive foils and a dry separator, the Super capacitor crosses into battery technology by using special electrodes and some electrolyte. There are three types of electrode materials suitable for the super capacitor. These are: high surface area activated carbons, metal oxide, and conducting polymers.

The high surface electrode material, also called a Double Layer Capacitor (DLC), is the least costly to manufacture and is the most common. It stores the energy in a double layer formed near the carbon electrode surface. To operate at higher voltages, super capacitors are connected in series. On a string of more than three capacitors, voltage balancing is required to prevent any cell from reaching over voltage.

The energy density of the Super capacitor is 1 to 10Wh/kg. This energy density is high in comparison to a regular capacitor but reflects only one-tenth of that of the nickel metal-hydride battery. This relationship is indicated in figure 3. Whereas the electro-chemical battery delivers a fairly steady voltage in the usable energy spectrum, the voltage of the super capacitor is linear and drops evenly from full voltage to zero volts. Because of this quality, the super capacitor is unable to deliver the full charge. If, for example, a 6V battery is allowed to discharge to 4.5V before the equipment cuts off, the super capacitor reaches that threshold within the first quarter of the discharge cycle. The remaining energy slips into an unusable voltage range. A DC-to-DC converter could correct this problem but such a regulator would add costs and introduce a 10 to 15 percent efficiency loss.

Technology	Lead Battery	NiMH	Li-Ion	Supercap
Nominal Voltage [V]	2.0	1.3	3.8	-
Max. Charge Voltage [V]	to 2.7	to 1.7	4.0	to 3.0
Min. Discharge Voltage [V]	1.5	0.8	2.7	0
Specific Power [W/kg]	to 400(1200)	to 900	to 1500	**9000**
Specific Energy [Wh/kg]	**30**	70	70 to 120	4
Temperature usability [°C]	-30 to 60	-25 to 55	(-25) to 45	-30 to 80
Charge and discharge cycles	~300	~1500	~1500 (600)	**~500 000**

Figure 5: Super cap and battery comparison

On the other hand the super capacitor has a very high specific power that can be approximately ten times higher then batteries in this comparison chart. So rather than operate them as a main battery, super capacitors are more commonly used as memory backup to bridge short power interruptions. Another application is improving the current handling of a battery. The super capacitor is placed in parallel to the battery terminal and provides a current boost on high load demands.

The charge time of a super capacitor is about 10 seconds. The ability to absorb energy is, to a large extent, limited by the size of the charger. The charge characteristics are similar to those of an electrochemical battery. The initial charge is very rapid; the topping charge takes extra time. In this design the Super cap would be charged from the solar cells. Immediately after the super cap would be discharged through a high power demand driving the logic would then be to change to battery supply and the super cap would be charged from the solar cells. Provision must be made to limit the current when charging an empty super capacitor. A resistance must be provided that will limit the charging current to the super cap. In terms of charging method, the super capacitor resembles the lead-acid battery. A full charge occurs when a set voltage limit is reached.

Unlike the electrochemical battery, the super capacitor does not require a full-charge detection circuit. Super capacitors take as much energy as needed. When full, they stop accepting a charge. There is no danger of overcharge or any 'memory' effect. The super capacitor can be recharged and discharged virtually an unlimited number of times.

Unlike the electrochemical battery, there is very little wear and tear induced by cycling and age does not affect the super capacitor much. In normal use, a super capacitor deteriorates to about 80 percent after 10 years. The self-discharge of the super capacitor is substantially higher than that of the electrochemical battery. Super capacitors with an organic electrolyte are affected the most. In 30 to 40 days, the capacity decreases from a full charge to 50 percent. In comparison, a nickel based battery discharges about 10 percent during that time.

Advantages

- Virtually unlimited cycle life - can be cycled millions of time.
- Low impedance - enhances load handling when used in parallel with a battery.
- Rapid charging -super capacitors charge in seconds.
- Simple charge methods - no full-charge detection is needed; no danger of overcharge.

Limitations

- Linear discharge voltage prevents use of the full energy spectrum.
- Low energy density - typically holds one-fifth to one-tenth the energy of an electrochemical battery.
- Cells have low voltages - serial connections are needed to obtain higher voltages. Voltage balancing is required if more than three capacitors are connected in series.
- High self-discharge - the rate is considerably higher than that of an electrochemical battery

A test was carried out at a Demo Car at Siemens VDO in Germany with an integrated starter generator that was alternatively connected to a battery (36V) and a Super capacitor (42V). Measured data for boost and regenerative deceleration are displayed in figure 4.

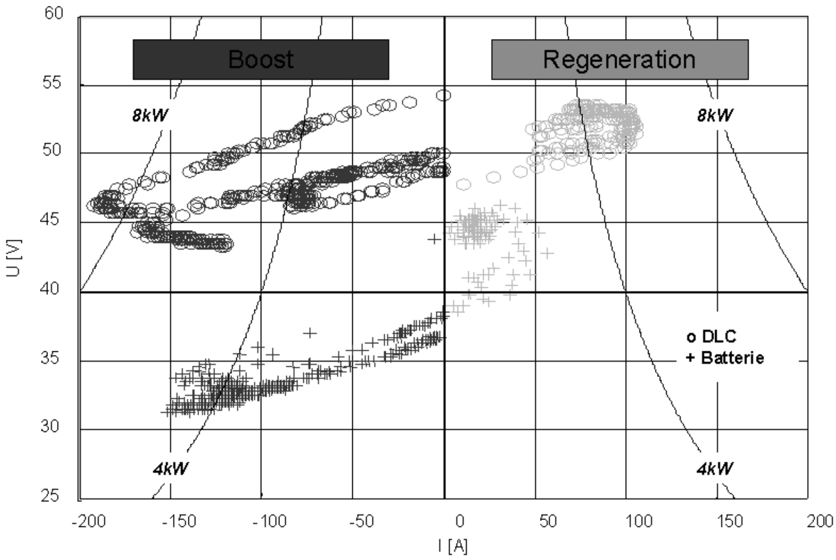

Figure 3: Comparison for boost and regenerative deceleration with Battery and Super capacitor

The measured data show that the Super capacitor can provide much higher power output during the peak discharge process. In this case the power output from the Super capacitor is almost double in comparison to the battery, comparing 8 to 4 kW during the boost process and 6 to 3 kW during the deceleration mode.

4.2 POWER SOURCE SELECTION

It was already mentioned that when the power consumption would exceed internally set limits then the control logic would use a different power source. This would be either a battery or capacitor. Following the same example that was used for power calculation the data can be recorded, as shown in figure 5.

Once the power demand exceeds the power limit (for example *P_lim* 2000 W) the power source selected is going to be the Super capacitor.

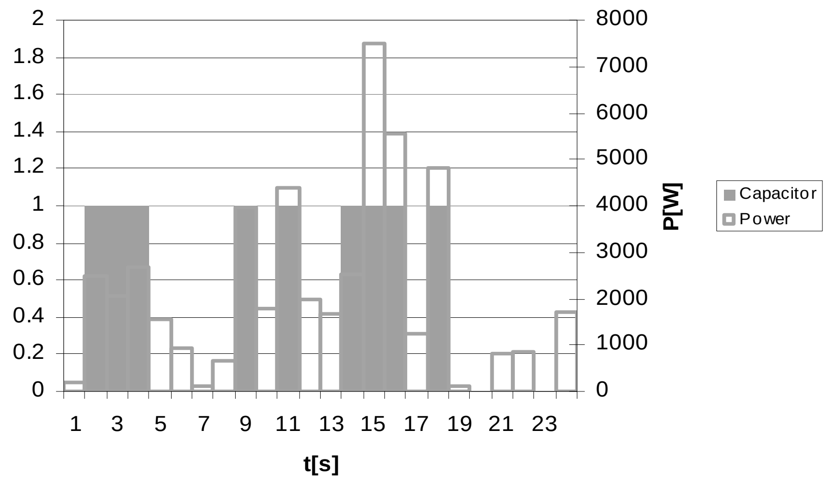

Figure 4: Power source selection (Capacitor or Battery)

When considering the charge and discharge power from the battery and capacitor, the amount of remaining charge can be calculated during their operation. So in the next example the battery will be discharged only when the needed power will not exceed

P_lim and the capacitor will be discharged only when it exceeds this limit. This can be compared with a battery discharge only.

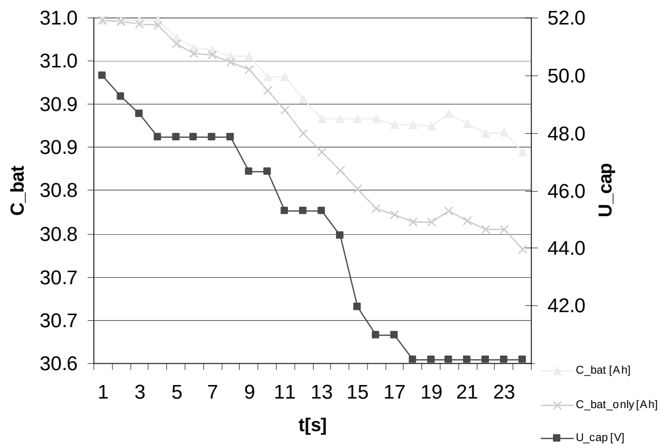

Figure 5: Comparison of different power source in operation

The capacity of energy stored in capacitor is the square proportional to the remaining voltage. In the case of the battery the capacity caused by discharging with a certain electrical current was subtracted.

Figure 6 clearly demonstrates the combination of ultra capacitor in purple, discharging from 50 to 40V, and the battery in yellow, where the capacity sinks from 31 to about 30.9 Ah. In the other example, where only a battery, in light blue color, was used, the battery capacity dropped from 31 to almost 30.8 Ah. This shows that by using the Super capacitor for quick discharge and also charge cycles, the capacity of the battery will remain higher. Since the charging times for the ultra capacitor are clearly shorter with minor losses, the battery capacity will experience smaller energy outflow.

7 CONCLUSION

The use of alternative energy resources has gained popularity with the effect of global warming and other negative effects from the common energy production using fossil fuels. Even though there is a limitation for any physical process, including the transformation of solar energy to electric, there is a necessity to use environmentally friendly resources. This concept is selecting the best qualities of different energy storages to maximize the efficiency of a solar vehicle.

Charging the Super capacitor from solar cells is more efficient then charging a battery. The reason is the low internal resistance of the Super capacitor. So the energy can be stored more efficiently in the capacitor and can be used during high power demands. This will provide additional power stored in the battery.

Further investigation will focus on the combination of such storages and the design of a basic model that can be simulated under real road conditions. The power consumption will be determined according to an active driving mode and track profile. The road information will be recorded with a GPS and imported into the simulation to allow the use of real data. The result should confirm better energy usage compared with the standard setting with only one energy storage.

REFERENCES

[1] Douglas, H., Pillay, P.**:** "*Sizing Ultracapacitors For Hybrid Electric Vehicles*", Internet source, University of Cape Town, Clarkson University 2008.

[2] Ehsani, M., Gao Y., Gay Sebastien, E., Emadi Ali: "*Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory, and Design*", CRC Press LLC, USA 2005.

[3] Fasemi Navid, S., Sharp, R. P., Stan Mark A., Aiken J. D., Clevenger, B., Hou Hong, Q.: "*Radiation-Hard High-Efficiency Multi-Junction Solar Cells for Commercial Space Applications*", Internet source, Emcore Photovoltaics, Albuquerque 2008.

[4] Maxwell Technologies: "*How To Determine The Appropriate Size Ultracapacitor For Your Application*", Internet source, Maxwell Technologies, October 2004

[5] Pro-physik: „*Weltrekord: 41,1% Wirkungsgrad für Mehrfachsolarzellen*“, Internet source, Fraunhofer-Institut für Solare Energiesysteme ISE, January 2009.

[6] Šimánek, M.: "*Entwicklung und Aufbau eines Mikrocontroller gesteuerten Transfergates für hohe Ströme*", Diplom Thesis, Siemens Automotive, Regensburg 2002.

[7] Šimánek, M., Piáček, P.: "*Solar Cars*“, 7th international conference and exhibition in transport and technologies for sustainable development, Karlovy Vary: The society for Sustainable Living, 2004.

Tracing Traffic Information Identity in Distribution Systems

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ABSTRACT: Tracing messages and information passing through a distribution system is necessary for resolving problems and improving performance. This paper summarizes the requirements, analyzes the aspects, proposes a conceptual approach, gives an example of possible implementation, and summarizes the findings. A number of challenges are uncovered, for example prescribed identification schemes in the system; versioning; repetition of incoming and outgoing messages; multiple output channels; recycling of IDs; invalid messages, etc. The key requirement is to trace messages with information on the input and output of the distribution system by assigning the proper identifier information. Unfortunately, identification schemes are different as to the information provider, in the central data store and in each output channel; the solution must keep track of these differences, and therefore events affecting the assigned information identity must be documented. The same applies to transactions, affecting information existence, as is the case with information deletion due to expiration. A sample of possible implementation shows that linking information between different types of log records might be greatly simplified if processed information keeps track of the transaction which has imported the information into the system.

KEY WORDS: identity, messaging, traffic and travel information.

1 INTRODUCTION

In the distribution of traffic information many parties and systems are involved. When designing, developing, testing and running such a system, tracing the identity of the information through the whole distribution process is essential to help things run, to improve performance and to resolve complaints and problems.

1.1 AIM, METHODOLOGY AND RESULTS

The aim of this paper is to analyze the identity of information in traffic information distribution systems, and propose a design for logging transactions which would allow the tracing of the identity of information in messages from the original information provider up to the consumer and from the consumer back to the provider. The solution must cope with the fact that with given identification schemes of the data provider and of the distribution channel, the same message can be broadcasted repeatedly and *the ID* in distribution channel might be recycled. The presented analysis and design is a byproduct of designing a system for testing the distribution of traffic information in TPEG format using distribution over the Internet and DAB - Digital Audio Broadcast (Vlcinsky, 2009). TPEG stands for a specific format of traffic messages which allow a precise description of traffic related events and their location. The design was created using a software development methodology, called the Unified process (Arlow, 2007), which introduces 5 main activities (Requirements, Analysis, Design, Implementation and Testing). The first two activities were used (Requirements and Analysis) and their corresponding models were covered by a team review. The core results are analytical documents consisting of an analytical class model and use a case model. In this paper, requirements and assumptions' are summarized and recommendations for tracing the identity are stated. These results shall generally be usable in many information distribution systems, not only being limited to TPEG, or even only to traffic information.

1.2 WHAT ARE TPEG AND DAB?

TPEG is a new standardized technology for the encoding and distribution of Traffic and Travel Information providing modular a toolkit solving various applications, transmission methods, location referencing methods and devices. *DAB* is a digital radio technology for broadcasting radio stations providing a primary service (radio stations) and also a data service, usable for the distribution of traffic information.

1.3 EVENT, INFORMATION, MESSAGE AND OTHER MESSAGING TERMS

When an *event* happens, (primary data information) a *provider* should create *information* about this event. The information is then transmitted in the form of different *messages* to other systems. In this paper we assume that the message comes into our *distribution system*, is stored internally there and might be distributed via distribution *channels* to *consumers*. If existing information is updated, a new *version* of the information for a given *ID* is created. As a result, the information about the same event is stored in multiple places. To update the information everywhere, information identifiers are used for updating messages.

1.4 IDENTITY, IDENTIFICATION SCHEMES AND *ID* RECYCLING

Information, describing one event, has an assigned *ID*, which uniquely identifies the information and together with a version identifies the unique status of the information in time. The *ID* is used as method for referring to one unique object and is considered as unique only within the so called *identification scheme*. If a passport number is an ID, and the passport was issued by the Czech Republic, then the identification scheme might be called the "Czech Passport". If the range of possible *ID* values is relatively small compared to the number of identified items, then the uniqueness cannot be guaranteed forever and the time for so-called *ID recycling* comes. Even with recycling, uniqueness must be respected at least at a given moment, so that at any one moment only one logical object can be referred to by one ID. When recycling, the *ID* must be supplemented by a timestamp or at least a time period to refer to a proper object.

1.5 SCOPE

The scope of the solution starts at the moment that the distribution system receives a message from the information provider and ends with sending the message to the consumer. Only the creation and collection of log data is discussed here. The evaluation of gathered data is outside of the scope of this paper.

2 TYPICAL TRAFFIC INFORMATION DISTRIBUTION SYSTEM

2.1 PRIMARY INFORMATION PROVIDER, DISTRIBUTOR AND CONSUMER

The primary information provider’s main responsibility is to provide "good quality information". From an information identity point of view quality can be defined as the fact that the same event is described by a piece of information only once, so that no merging of duplicated information is necessary. The distributor receives messages with information from the provider and manages the distribution via one or more channels. From an information identity point of view, the distributor must internally keep track of each unique piece of information without creating unnecessary duplicates. The distribution channel is fed by data from the distribution system and allows broadcasting, or another method of distribution, to consumers. The consumer receives the transmitted information in the form of a message and uses it. For auditing purposes, the consumer shall be able to provide the received message in an unchanged form together with a timestamp denoting when the message with the information was received.

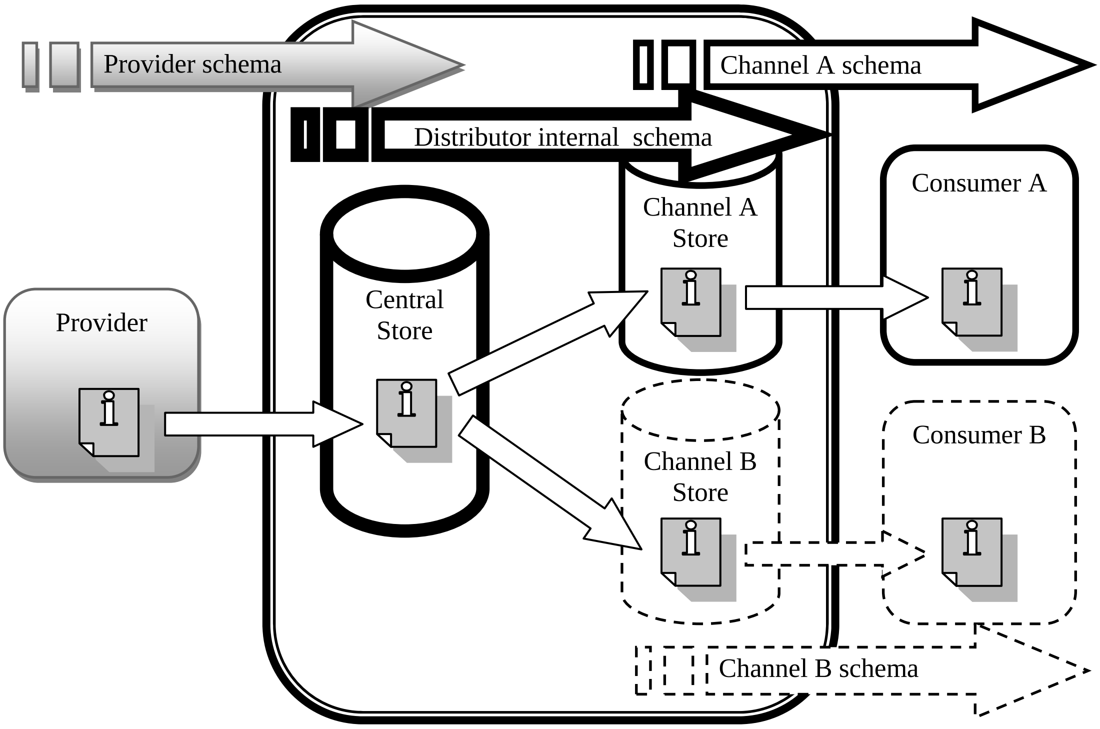

Figure 1: Information, messages and identification schemas through the distribution chain

2.2 CHALLENGES

Real life traffic information distribution (sending TPEG over DAB channel, TMC over RDS channel, etc.) brings the following challenges:

- *Fixed identification scheme of information provider* – the provider uses its own identification scheme and the distributor has no real chance of forcing the distributor to modify it.
- *Versioning information* - as time goes on, the same event might change and the information describing it needs to be updated. To allow information updating, versioning must be used.

- *Repeatedly received information* – the provider might send a message with the same information more than once. Assuming the *ID* of the information is the same in both cases the distributor must not create duplicates of the information.
- *Channel specific identification schemes* - each channel might use different identification scheme. *IDs* from the provider or internal *IDs* are often not usable due to the different types of *ID*.
- *Recycling IDs in channel* - some channels (e.g. TPEG over DAB) might use *ID* with a limited range of possible values, thus requiring the recycling of *IDs* over time. It is assumed that recycling is possible only for the *IDs* whose information has already expired.
- *Sending messages to the channel repeatedly* - some distribution channels (typically DAB for TPEG or RDS for TMC) use message repetition. The message is broadcast repeatedly to ensure at least one reception by the consumer and to allow error checking.
- *Information expiration* - information has a limited validity in time and might expire before it is distributed.
- *Message rejection* - some messages might be at some point in the distribution rejected as invalid and therefore not distributed further on.
- *Some messages in the channel might get lost* - not all messages sent to the channel are necessarily received by a consumer.

3 REQUIREMENTS

The following requirements for a logging system were identified:

- Traceability of messages and information.
- Logging must not overload the distribution system.
- Allow asynchronous processing.

3.1 TRACEABILITY OF MESSAGES AND INFORMATION

The system shall create log data, which allows the tracing of information traveling through the system by means of messages. Tracing starts at the moment a message is received by the distribution system and continues to the moment a message with the same information is sent to the channel.

Tracing of messages with information from the provider to the consumer must be possible. For each message with information from the provider, all messages sent to the consumer must be identifiable. Tracing of messages from the consumer back to the provider must be possible. For any message received by the consumer, the originating message with the information from the provider must be identifiable.

3.2 LOGGING MUST NOT OVERLOAD THE DISTRIBUTION SYSTEM

Because it is more important to distribute the information then to trace it, the system must not endanger the distribution itself. For this purpose the following requirements are set.

- Logging must not block the distribution and shall not consume many resources.
- Offline evaluation of logged data is acceptable.
- Allow the archiving and purging of older information and log records. An evaluation of log records must be possible even with an incomplete set of records.

3.3 ALLOW ASYNCHRONOUS PROCESSING

When a message is received, a number of different steps shall be done, like receiving a complete message, validating the message structure, reading the external information *ID* and comparing it to *IDs* already in the system, and assigning an internal *ID*. Despite the fact, that all the steps can be completed in one (synchronous) step, the logging system shall not put this constraint on the distribution system and must also allow asynchronous processing (when for example the reception and validation might happen in different processes).

4 TYPICAL SCENARIOS IN INFORMATION DISTRIBUTION

Typical scenarios in information distribution are as follows:

- Scenario: Receive message from provider.
- Scenario: Assign information to output channels.
- Scenario: Send message with information to output channel.
- Scenario: Archive and purge expired information.

The scenarios mentioned here do not prescribe the internal logic of the distribution system (as logging shall fit into different distribution designs with different internal logic). Their purpose is to depict the general logic and serve as a basis for the description of a proposed logging solution.

4.1 SCENARIO: RECEIVE MESSAGE FROM PROVIDER

This scenario is triggered by the reception of a message containing information from the provider.

1. Receive data from the provider, store it as an incoming message, respond to the provider that the data have been received and create a log record of the type *DataReceived*.
2. Validate the structure of the incoming message if invalid; create a log record of the type *ProblemReport*.
3. Read the incoming message and try to find an external information *ID*, compare this with the internal records of the external *IDs*, assign an internal *ID* if necessary, and create log records of the type *ProviderIdFound* and *IntIdAssigned*.

5 STORE THE INFORMATION AND MARK IT READY FOR DISTRIBUTION

5.1 SCENARIO: ASSIGN OUTPUT CHANNELS TO INFORMATION

This scenario is triggered by the creation of new or updated information in the internal data store of the distribution system.

1. Evaluate the information and find which output channels shall be distributing it.
2. For each assigned channel:
   a. Store or update the information in the internal channel data store and create a log record of the type *AssignedToChannel*.
   b. If necessary, assign an internal channel information *ID* and create a log record of the type *ChannelIdAssigned*.

5.2 SCENARIO: SEND A MESSAGE WITH THE INFORMATION TO THE OUTPUT CHANNEL

Depending on the type of channel and client, this scenario can be initiated by a client request, or by the channel itself, which might run in a continuous loop. The following steps are for a channel which sends messages in a continuous loop:

1. Find the information to send in the internal channel data store
2. Send a message with the information to the channel and create a log record of the type *DataSentToChannel*
3. If applicable, wait for a response and record the result in a log record of the type *ChannelResponse*.
4. Continue with the next information to send.

5.3 SCENARIO: ARCHIVE AND PURGE THE EXPIRED INFORMATION

This scenario is typically triggered by an internal scheduler:

1. For each data store (central distribution store and internal channel stores) search for information which has expired.
2. Archive expired information.
3. Purge archived information from data stores
4. Create a log record of the proper type for each piece of purged information

6 SOLUTION

6.1 LOG ATOMIC TRANSACTION FOR ASYNCHRONOUS PROCESSING

Receiving a message is an important transaction and we might think of a log record telling us the time of reception, data validity, external *ID* and internal *ID*. However, this design would be forced to receive the message in one single synchronous step, or it would make asynchronous processing with logging quite difficult. Because of this, transactions like reception shall be split into small atomic transactions, which are then easy to record regardless of synchronous or asynchronous processing.

6.2 RELEVANT TRANSACTIONS

Any transaction which affects information existence or handles any type of *ID* for the information must be recorded by means of a log record. The following transactions are considered:

- *Transactions related to message reception*: Receiving a message from the provider, recognizing external information *ID*, assigning internal information *ID* and rejecting a message as invalid.
- *Internal transactions*: Purging expired information from the central or channel data store.
- *Transactions related to sending a message to a channel*: assigning information to the output channel, assigning channel specific *ID* to information, sending the message to the output channel, receiving a response from the output channel.

6.3 STRUCTURE OF LOG RECORDS

Structure of log reports must follow a few simple requirements:

- *Loose coupling*: to allow easy purging and archiving of log records without breaking data integrity, loose coupling must be used. Thus to limit the number of references, the structure must be as flat as possible, even if some data would have to be repeated. Another rule is that any referencing to other records or objects must be by value, which can be found in a (preferably archived) object.

- *Common attributes of a log record*: each log record shall contain information about when the transaction happened (timestamp), which systems participated in the transaction (can be given by context, but for multiple providers and multiple output channels it might require using the system or channel name), identity and version of the information in the participating systems, a simple description of the result and, if necessary, the data of the exchanged message. To allow a standard and simplified description of possible problems, the general object *ProblemReport* might be used and referred to from any log record. The following Figure shows the type of log records proposed.

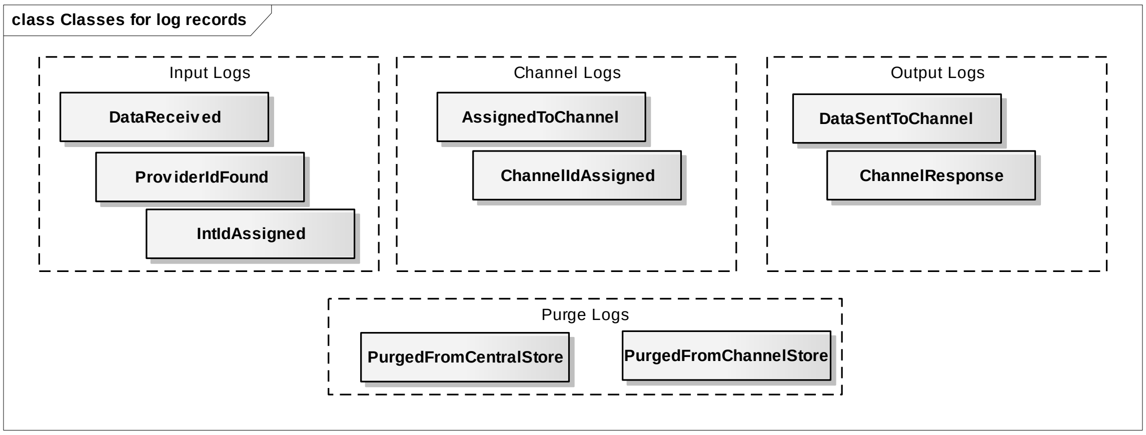

Figure 2: Classes for log records.

7 AN EXAMPLE OF POSSIBLE IMPLEMENTATION

To make the understanding of the proposed solution easier, an example of possible implementation is given. The distribution system shall have a single input channel, process TPEG RTM data and distribute it via two DAB channels, one for the eastern and another for the western part of a country. The information for the middle part of the country is distributed by both channels.

All log records will be written asynchronously to a database. The system will allow the export of log records in the XML Atom web syndication format with one entry per log record and using a specific namespace for the storing structure of the log record (each type of record is possible to store in such a structure). Offline processing of log records is expected in separate system, which will be able to load these XML files and do the processing and evaluation. To prevent data overrun in the log database, the scheduled task is used to archive and delete older records. Input log *DataReceived* also contains the data which were received to make the monitoring of the data exchange possible. Each import transaction gets a unique *uuid* string, which is stored with the received data, as well as with the log record. Input log *ProviderIdFound* contains the transaction *uuid* (to make linking to the *DataReceived* log record possible) and adds the *ID* and version found in the message. Input log *IntIdAssigned* contains the transaction *uuid*, together with the assigned internal information *ID* and the internal version. A field of type update, new, unchanged, ignored or updated is used to identify if the information was already in the system and what happened to it. Channel log *AssignedToChannel* uses the import transaction *uuid*, internal information *ID* and an internal version. Channel identification string “east” or “west” is used to denote the channel the information was assigned to. For the same import transaction more log records might appear as information, for the middle part of the country might fit into “east”, as well as “west”, channel region selection criteria. Channel log *ChannelIdAssigned* still uses the import transaction *uuid* (all the time related to the import to the distribution system, not to the channel). Channel identification, internal channel *ID* of the information and version is recorded. Output log *DataSentToChannel* uses the import transaction *uuid*. As information is sent to DAB repeatedly in cycles, the log also records the sequence number of the cycle. Channel identification, internal channel *ID* of the information and version is also recorded.

Output log *ChannelResponse* is not used as DAB does not return any return code. Purge log *PurgedFromCentralStore* is used when the scheduler runs a script archiving and purging the expired information and is written after the information is deleted from the central store. It contains the import transaction *uuid*, internal *ID* of the information and version. Purge log *PurgedFromChannelStore* has the same structure as the output log *DataSentToChannel*. Output log *DataSentToChannel* might optionally contain the data which are really sent. However, as sending data to channel is frequent activity, this option is used only when testing the system and not in production use, as it might slow down the system.

8 CONCLUSIONS

Tracing the identity of traffic information in real distribution systems might get complex and is a complicated topic. This paper tries to help by uncovering the many hidden aspects and by proposing general solutions. The distribution system must take into account that identification schemas at the provider, central distribution store and each distribution channel might be different.

The most important transaction in the system is the import of data from the provider. Using *uuid* for this transaction and keeping track of it through the whole distribution system simplifies the tracking path of information through all the processing steps. Each transaction affecting any type of *id* or version must be recorded. Recording the deletion of information due to expiration should not be omitted, as we would lose the information where the information disappeared.

9 AKNOWLEDGEMENT

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10 REFERENCES

Arlow, J.; Neustadt, I.: 2007. *UML2 a unifikovaný proces vývoje aplikací Průvodce analýzou a návrhem objektově orientovaného softwaru*. Vydání první Brno: Computer Press, 2007. ISBN 978-80-251-1503-9.

Vlcinsky, J.: 2009. *Architecturing future-proof distribution of traffic and travel information using TPEG.* Transactions on Transport Sciences, Praha.

Driver Behavior Influenced by an Aggressive Factor

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ABSTRACT: This paper presents systematic research dealing with aggressive driving in the Czech Republic. There is limited information concerning reckless driving, aggressive driving or road rage either in the Czech Republic or in European Union. A lot of opinion polls were carried out, unfortunately based on subjective feelings, which refer to some differences (e.g. gender or age). The systematic survey of driver´s behavior, which proceeds further in cooperation with Faculty of Transportation Science, Ministry of Transport and Police Headquarters, is helping to describe the aggressive behavior of drivers in the Czech Republic and suggest possible ways to avoid this risk factor.

KEY WORDS: reckless driving, aggressive driving, road rage, road accident, prevent.

1 INTRODUCTION

The majority of road accidents are still caused by human factor, either by vehicle drivers or the other road users. According to the world statistics it seems to be between 50 – 70% of all road accidents. According to the impact assessment study completed in 2007, the most serious offences of accidents caused by human factor in the EU are:

1. Speeding (30 % road fatalities)
2. Influence of alcohol (25 % road fatalities)
3. Non-use of seat belts (17% road fatalities)
4. Failing to stop at a red light (4 % road fatalities)

In other words, some 75% of all road deaths are caused by one (or more) of these four traffic offences. Aggressive driving might be involved in all of these offences (with the exception of not using seat belts); therefore it can be considered seriously dangerous and worthy of investigation. For this reason systematic research on the field of aggressive behavior started about two years ago. The goal of the research was to analyze the current situation on the Czech roads, concerning events which could be classified as aggressive behavior, including their classification into several categories.

For the systematic surveying of drivers' aggressive behavior in the Czech territory, a special research team was created: the Faculty of Transportation Sciences in cooperation with the Ministry of Transport and the Police Headquarters.

2 CONCEPT DEFFINITIONS

Aggressive driving is not properly defined in Czech terminology. It would therefore be useful to have a look into American terminology, where aggressive driving is described in each form. There are three main conceptions concerning aggressive driving (source: NHTSA – National Highway Traffic Safety Administration; Washington, USA):

1. Reckless driving – driving with no/less respect for the other road users.

2. Aggressive driving – “when individuals commit a combination of moving traffic offences so as to endanger other persons or property”. Some other institutions prefer another definition: “the operation of a motor vehicle involving three or more moving violations as part of a single continuous sequence of driving acts, which is likely to endanger any person or property.” Some behaviors typically associated with aggressive driving include: exceeding the posted speed limit, following too closely, erratic or unsafe lane changes, failure to obey traffic control devices (stop signs, yield signs, traffic signals, railroad grade cross signals, etc.).

3. Road rage – is a criminal offence, “an assault with a motor vehicle or other dangerous weapon by the operator or passenger(s) of one motor vehicle on the operator or passenger(s) of another motor vehicle or is caused by an intent that occurred on a roadway.”The mentioned above investigation considers Reckless and Aggressive driving.

3 AVAILABLE INFORMATION ABOUT AGGRESSIVE DRIVING

Czech Republic is one of the few states in European Union that has a “Reckless/Aggressive driving” category included in road accident statistics. The percentage in this category of the total number of road accidents in the Czech Republic is about 0.5%. Although this data is based only on witness’s statements, table 1 adverts to gender differences. It is worth noting that the general number of accidents is decreasing in contrast to the rate for women which is increasing. Further data investigation also shows age differences.

Table 1: Reckless/Aggressive driving, item 12-506 (source: Police Headquarters)

year	number of accidents	offender men/women	killed persons
2005	570	511/59	7
2006	590	518/72	5
2007	554	472/82	2
2008	550	468/82	2

Several opinion polls which were undertaken all around the world can also help as another source of information focusing on aggressive driving. These opinion polls are also based on the subjective feelings of polled persons, but take into account gender and age differences (e.g. men hate to feel limited by other drivers, women hate to be endangered, aggressive ways of driving seems to be rising, etc.). There are several causes, which can launch aggressive behavior on the roads. It might be competitive instinct, inferiority complex, an occasion to punish the other road users, or social standards (common or normal behavior). These causes can also be intensified by high testosterone level or premenstrual syndrome which is also caused by higher testosterone and lower estrogen level. The following hypothesis about victims is based on the above-mentioned facts: they are probably young drivers (20-35 years), due to a low level of responsibility and foresight, higher temperament and risky behavior, and probably of male gender, because of the higher testosterone levels and competitive instinct, etc.

4 INVESTIGATION PROCEDURE – THE FIRST STEP

The first step of aggressive behavior investigation undertakes to analyze a real situation on the Czech roads. There are three floating cars equipped with digital cameras installed on the top of cockpit front panel currently used for this experiment. This camera records the main part of the front field of view as seen by the car driver.

Systematic filling of the database with records of the driver’s behavior in real-life situations on roads started in spring 2007. Fully digital cameras are used for recording (Panasonic SDR-S 150E and Sony HDR-CX6). For short distances (up to about 5m), the recorded quality allows one to recognize the number plate of the car in front. A recorded example is shown in figure 1Figure 1.

Figure 1: Recorded quality – car overtaking a tram in Prague city center, neglecting also the solid white line and red light (Panasonic SDR-S 150E camera)

Figure 2: Recorded quality – overtaking from the right side across the solid line on motorway (Sony HDR-CX6 camera)

Floating cars are driven mainly through Central Bohemia Region, Prague, motorway D1, etc. Each record is properly described in the database, including the important data about the offence, location, type and color of the vehicle, driving time period and in some cases also victim description, see table 3 (license numbers are willfully intercepted). There are about 177 records of various lengths currently described in the database, which is continuously filled in. The average recording length is about 20 minutes, total length is 61 hours. There are about 577 items with aggressive behavior described in the table. When we compare it to the number of total driving license holders in the Czech Republic, which are 6 398 585[1] (including passive drivers), we will find 577 cases to be an interesting sample size (0,01 %). Distribution of the driving directions according to road type was almost equally divided – 53 % rural area, 47 % urban area (shown in table 2).

Table 2: Road type

road type	urban area	rural area	motorway
driving time [%]	47	33	20

Table 3: Database structure - example

			Offence description					Time of event		Vehicle		
vid. No.	date	start time	speeding	over-taking	others	route	loca-lity	actual mm:ss	total mm:ss	color	type	lic. No.
N4	19.9. 2007	10:09	cca 20 km/h over			D5 Prague Plilsen		9:42	50:37		bus	
				in-consider over-taking			Motor way	14:37			Avia	2K1 xxxx
			over-speeding	breaking safe distance			Motor way	15:30		black	Škoda Octavia II combi	6A2 xxxx
			over-speeding	breaking safe distance			Motor way	18:49 and 44:49 again		Silver	BMW 5	1H4 xxxx
			over-speeding	breaking safe distance			Motor way	22:45		white	Škoda Fabia combi	4A1 xxxx
			over-speeding	breaking safe distance			Motor way	22:52		metal l. gray	Audi A6 (slightly damaged from rear)	5A6 xxxx
			over-speeding	breaking safe distance			Motor way	32:00		white	Škoda Fabia combi	5A5 xxxx
			cca 20 km/h over				Motor way	32:37		metal l. gray	VW Passat	3A0 xxxx

Observed aggressive events are possible to divide into several parts, shown in Tabletable 4. When the driver commits more than one offence at the same time, only the most serious

[1] Up to 31. 12. 2008. 60 % men, 40 % women.

offence is included in the table. (e.g. if speeding is combined with aggressive overtaking, only overtaking is included)[2].

Table 4: The example of results

offence	freq. urban area	urban area 4 traffic lanes	freq. rural area	motor-way	freq. total (urban + rural)	freq. total (% share from total)	type of the vehicle
over speeding up to 15 km/h			insignificant				
over speeding, c. 15 km/h	40	34	60	50	100	17,3	79xOA, 9xOR, 8xD, 4xM
over speeding, c. 20 km/h	13	12	67	61	80	13,9	61xOA, 11xM, 4xOR, 2xD, 2xA
over speeding more than 20 km/h	3	2	43	32	46	8	34xOA, 6xM, 4xOR, 2xD
aggressive overtaking/ tram overtaking/ improper lane changing/ braking continuous line)	90	42	29	14	119	20,6	75xOA, 22xM, 10xD, 6xN, 5xOR, 1xA
overtaking from the right side (traffic in lines excl.)			37	37	37	6,4	22xOA, 13xM, 1xOR, 1xD
breaking safe distance	36	31	93	91	129	22,4	119xOA, 7xOR, 3xD
pedestrians (crossing on red signal/besides ped. crossing), reckless cyclists	24	4	1		25	4,3	22xP, 3xC
too slow driving	7	0	8	8	15	2,6	12xOA, 2xN, 1xA
other	3	1	5	3	8	1,4	5xOA, 1xN, 1xM, 1xD
failing to give way	5	2	2	2	7	1,2	4xOA, 1xD, 1xM, 1xN
incorrect road signs or signals	1	0	5	2	6	1	
turning across the continuous line	5	1	0	0	5	0,9	3xOA, 2xN

Explanatory notes:

O – Off Road/SUV
M – Motorcycle
N – Truck
C – Cyclist(s)
D – Van/Pick-up
A – Bus
OA – Passenger car
P – Pedestrian(s)

The percentage distribution of offences from table 4 is shown in figure 3. There are about 577 offences, from 177 records in Table4, described during the almost one year terrain investigation procedure (from autumn 2007 till summer 2008). The total length

[2] Number of combinated items: 129 (22,4 %), mainly overspeeding with breaking safe distance.

of described records is 61 hours (exactly 3667 minutes). The most frequent aggressive behavior is speeding (226 events total, 39.2% of total aggressive offences), aggressive overtaking (156 events total – overtaking from the right side included, 27% of total aggressive offences), and the third is breaking safe distance (129 events total, 22.4% of total aggressive offences). The number of reckless pedestrians is also noteworthy. The frequency of reckless or aggressive driving behavior on the Czech roads is about 6.4 minutes.

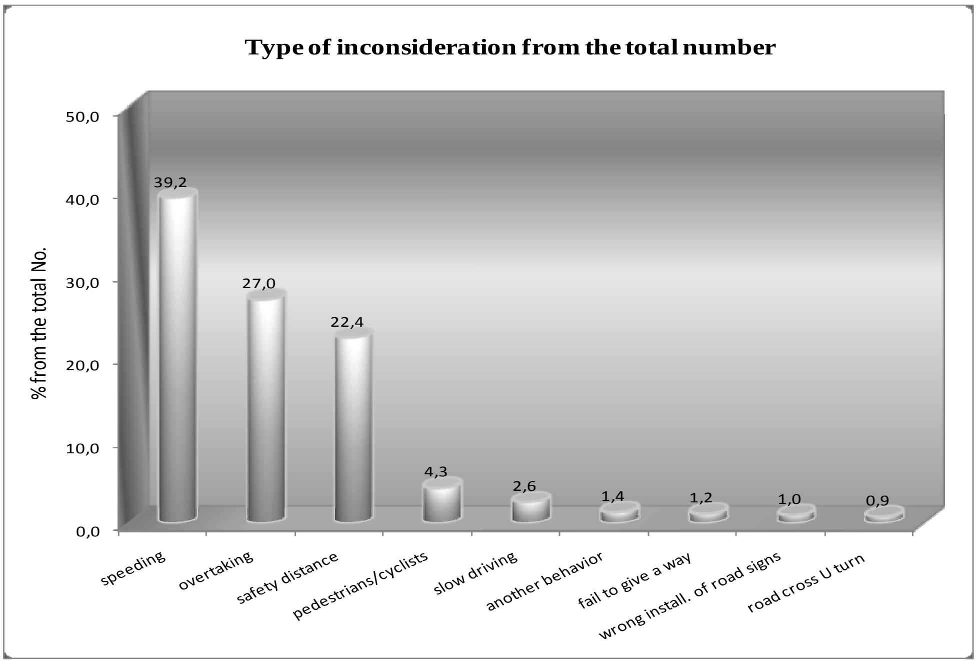

Figure 3: Type of inconsideration from the total number

REFERENCES

European Commission – Directorate-General for Energy and Transport. 2008. *EU energy and transport in figures, Statistical pocketbook 2007*, ISBN 978-92-79-07082-2

Ředitelství služby dopravní policie Policejního presidia České republiky, Praha, 2008, *Survey on accidents on roads in the Czech Republic, 2007 (Přehled o nehodovosti na pozemních komunikacích v České republice za r. 2007)*

Ředitelství služby dopravní policie Policejního presidia České republiky, Praha, 2007, *Survey on accidents on roads in the Czech Republic, 2006 (Přehled o nehodovosti na pozemních komunikacích v České republice za r. 2006).*

Ředitelství služby dopravní policie Policejního presidia České republiky, Praha, 2006, *Survey on accidents on roads in the Czech Republic, 2005 (Přehled o nehodovosti na pozemních komunikacích v České republice za r. 2005).*

Novák M., Faber J., Tichý T. Svoboda P. Tatarinov V. *Driver psychic state analysis based on EEG signals*. Neural Network World, vol. 16, 2006, No.1, 25-39.

Proposal for a Directive of the European parliament and of the Council facilitating cross-border enforcement in the field of road safety, Brussels, 19. 3. 2008, COM(2008) 151 final, 2008/0062 (COD), pg. 4, http://ec.europa.eu.

Bonding of Structural Parts of Vehicle Bodies and Aspects of Passive Safety

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ABSTRACT: Many new materials, technologies and new structural solutions are applied in vehicle bodies. With the application of new, non-conventional materials we obtain better capabilities, a higher level of safety, and, last but not least, weight reduction. At a time when energy savings are sought after, weight reduction is a great motivational factor for the application of composites, aluminium and magnesium alloys, etc. The use of non-conventional materials is connected with requirements for a different technology for the manufacture of vehicle bodies, as well as the issue of mutual connection of individual parts. Completely different actions, which we are not accustomed to in current structures, take place at the boundaries of mechanically, as well as chemically, different substructures. The current pieces of knowledge relate mainly to contemporary materials, or possibly to the classical ways of connecting – welding, screwed joints, and the like. However, we do not completely understand the largely expanding bonded joints, and, in combination with non-conventional materials, we know even less about them. Computer simulations are of no help because the characteristics of these bonds are not described very well. The below-mentioned experiment was focused on this area of structural bonding of composite materials; its objective was to clarify these relations. The actual experiment included a crash test of a vehicle with a body made from composite materials, whose deformation zone had individual elements bonded with various types of structural adhesives. The deformation zone of the experimental body was designed on the basis of the knowledge obtained from tensile tests. The tests were to verify mechanical characteristics of structural joints. Based on the obtained knowledge it was possible to specify the suitability of the use of individual joints and materials in the deformation zone. The outcome of the performed experiment is a judgement of the destruction of individual joints, destruction of the entire body, and fulfilment of passive safety criteria.

KEY WORDS: vehicle body, non-conventional material, composites, structural adhesive, boundary relation, passive safety.

1 TENSILE TESTS OF BONDED JOINTS

1.1 TEST SAMPLES

19 sets of samples joined using four different adhesives, in combination with six bearing materials (see Figure 1) were defined for tensile tests. The goal was to verify the characteristics of mutual relationships between the materials and general mechanical characteristics. Individual samples were loaded by shear in tension, which is one of the basic loads in real practice.

The following adhesives were selected to bond the samples: Dinitrol F500, Dinitrol PU F500LP, IPS Weld-On SS1505 and joint by overlamination. The selection of these types of adhesives was carried out on the basis of the empirical knowledge of the producers of composite body parts.

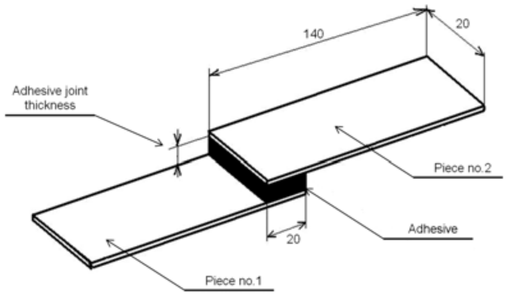


Figure 1: Shape of tensile sample

Dinitrol F500 is a polyurethane adhesive material designed for exposition to high mechanical load. It is a structural, high-strength adhesive. Application of the adhesive is recommended by the manufacturer through a primer Dinitrol 550 Multiprimer.

Dinitrol PU F500 LP is an adhesive on the basis of polyurethane prepolymers. It is again a flexible type of adhesive with high ductility. The difference between it and F500 is in the decreased content of filling – solid particles. Both types of Dinitrol adhesives are one-component adhesives.

IPS Weld-On SS1500 is a compact series of two-component adhesives on the basis of methacrylate. The adhesive is designed for joints under very high mechanical load. This type of adhesive was selected as a representative example of rigid joints, enabling almost no mutual movement of the connected parts.

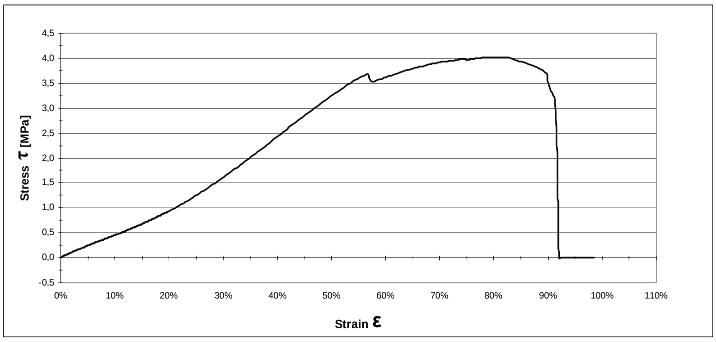
Overlamination is the last tested joint type. In this joint type, at least one of the bearing parts has to be made from composite material and the other part is applied on it – lapped over. The connection is made by two or more layers of composite that overlap the applied part. To achieve a good connection between the basic – bearing layers of the composite and the overlapping layers, the applied part is perforated. The bearing parts included materials commonly used in vehicles, such as steel plate, aluminium plate, steel plate with galvanic zinc surfacing, steel plate with zinc dipping surfacing, rust-free plate, and glass fibre composite as a representative of composite structures.

1.2 DEVICES USED FOR LABORATORY TESTS

An Instron, model 3382, loading machine was used to carry out the tensile tests. It is a device for tensile and compression tests of materials with a working range of up to the force of 100 kN. The accuracy of the loading force is 0.5% and the maximum frequency of data recording 100 Hz. The outcome of the tensile tests was a stress-strain diagram for each tested sample.

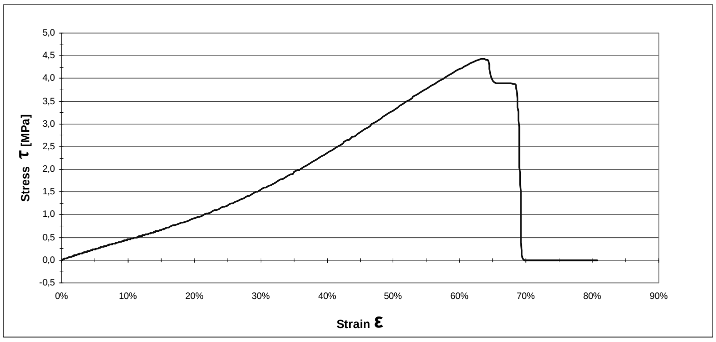
1.3 RESULTS AND THEIR EVALUATION

The typical course of the stress-strain diagram of the adhesive **Dinitrol F500** is depicted in Graph 1. The course shows linear dependence from the beginning of the tensile test almost up to the strength limit. In the case of some samples non-linearity occurred at approximately 80 to 85% of maximum strength. The reason for this behaviour is a higher portion of plastic deformation of the adhesive. The adhesive F500 achieves average strength limit values of 4.3 MPa. The values of relative elongation were around 75%. Based on the performed tests it can be stated that the adhesive is suitable for sets of road, as well as rail, vehicle bodies and special superstructures exposed to the largest loads. During the tests, the adhesive showed good adhesion to a wide range of materials (metals even with various surfacing, composites etc.).



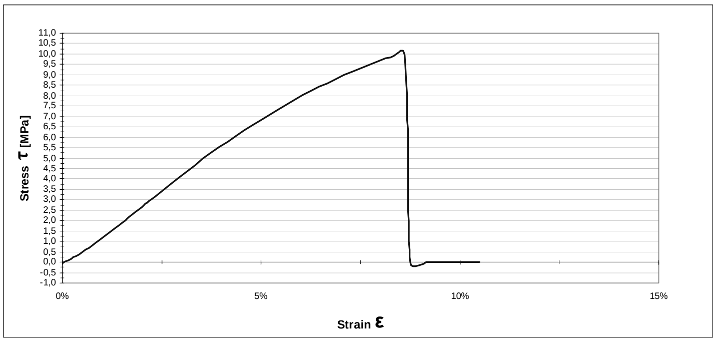
Graph 1: Stress-strain diagram of Dinitrol F500 adhesive

The course of the stress-strain diagram of the adhesive **Dinitrol PU F500 LP** is linear up to the maximum tensile force (see graph 2). There then occurs destruction and quite immediate loss of strength. The maximum tension reached values of approximately 5.2 MPa. As opposed to the adhesive Dinitrol F500, these joints do not feature elastic deformation in the area of maximum tension. Much better adhesion between the primer, the adhesive and the bearing material was apparent during the analysis of the test samples. The samples with the adhesive PU F500 LP reached values of relative elongation of about 75%, i.e., comparable with the type F500. There were no apparent differences between the stress-strain diagrams from the point of view of different types of bearing materials. Thus, the adhesive has approximately the same behaviour in composite, as well as metal, joints.



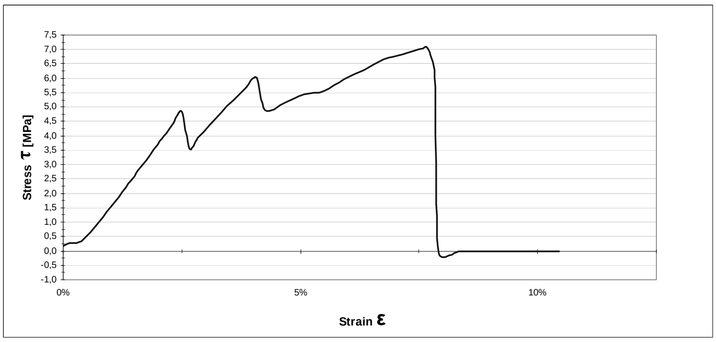
Graph 2: Stress-strain diagram of Dinitrol PU F500 LP adhesive

Samples of joints bonded by the adhesive **IPS Weld-On SS1505** behaved much more explicitly during the tensile tests in comparison with all other samples. The strength limit is very easily visible in the course of the stress-strain diagram (see Graph 3). When the strength limit was exceeded, immediate destruction, and hence also loss of strength, occurred. The adhesive reached strength values of 9.5 MPa, which is about twice as much as in the case of Dinitrol adhesives. The adhesive IPS Weld-On SS1505 reached values of relative elongation of between 8 and 11.5%. It is a very rigid bond, which enables almost no mutual movement in the joint. The inclination of the stress-strain diagram is quite steep. The adhesive shows quite good adhesion to the bearing material. Damage of the joint occurred in the material of the adhesive, but also by delamination of the composite. Hence, application of these types of adhesives is suitable for a wide range of structural bonds in vehicles. Advantages of the adhesive IPS Weld-On in comparison with Dinitrol adhesives are in the technological area, as well as the mechanical properties. A primer is not necessary for bonding; strength of the joints under shear load is two to three times higher and also possesses a higher thermal endurance (-55 °C to +121 °C). Resistance to chemical exposition is good as well. The adhesives IPS Weld-On are characterized by a combination of high strength and rigidity.



Graph 3: Stress-strain diagram of IPS Weld-On adhesive

The last joint type was **overlamination**. In this case we are not talking about bonding in the strict sense of a word. Nevertheless, this type of joint is quite often used in technical practice, both in rail vehicles and in bus bodies. The typical course of the stress-strain diagram is hard to determine (see Graph 4) in case of this joint. Destruction of individual composite layers or the ripping off of one of the bearing parts occurs during the tensile tests. The destruction is spread gradually, and thus the course of the stress-strain diagram features several leaps in the strength limits. The strength of this joint is around 3.25 MPa. As regards flexibility it is a very rigid joint with relative elongation of 7.7%, which enables very small mutual movement of parts.



Graph 4: Stress-strain diagram of over-laminated point

2 DYNAMIC EXPERIMENT – CRASH TEST

2.1 CRASH TEST CONCEPTION

Experimental verification of properties of joints under dynamic load was carried out using a crash test. Joints of structural parts from various materials were put into a vehicle body that was designed specifically for this crash test. The evaluation also included an evaluation of the non-aggressiveness of such a vehicle on other crash participants.

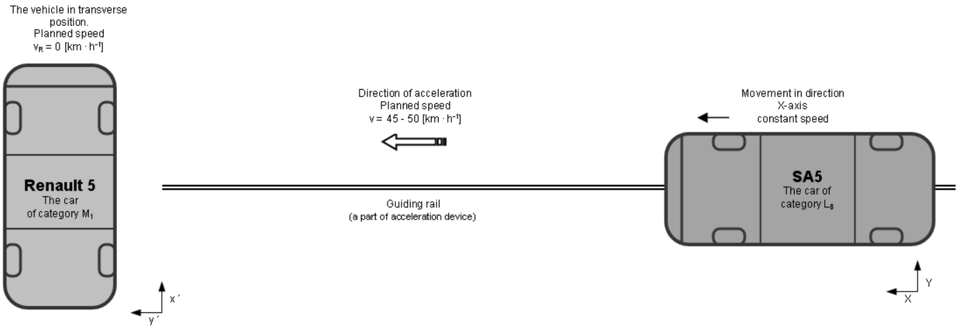


Figure 2: Layout before crash test

The crash test conception was selected to simulate a compatible crash of two vehicles when one of them has not respected the right of way at a crossing in town traffic. The layout before the crash is shown in Figure 2. In the crash test, the main vehicle had all-composite body (hereinafter SA5). Based on the analysis of results of tensile tests and proceeding recommendations, a concept of a deformation zone of this body was proposed. Bonded joints, as well as overlamination, were used in the construction of SA5. The planned speed of the crash was 45 to 50 $^{km}/_{h}$. The vehicle was accelerated and directed by a device for the acceleration of vehicles. A manikin dummy was put into the vehicle to evaluate the key indicators of passive safety of the SA5 vehicle and the impact on passengers.

The second crash test participant was the vehicle Renault 5. Before the crash test the vehicle was positioned perpendicularly to the axis of movement of the SA5 vehicle. The speed of Renault 5 at the moment of the crash was zero. The frontal impact of the SA5 vehicle was directed at the “B” pillar of the right side of the Renault 5 vehicle. A child dummy (size P3) in a child seat was placed on the right rear seat. An evaluation of the crash test and factors of passive safety was carried out with the use of records from accelerometers, which were placed on the body of SA5 and measured acceleration in the direction of movement of the axis of the vehicle (X-axis). Furthermore, we placed a three-channel accelerometer to the head of the Manikin dummy; it measured acceleration in the direction of axes X, Y, and Z. The last accelerometer was placed into the head of the child dummy in the vehicle Renault 5. This sensor recorded acceleration in the direction of the axis y’ of the coordinate system of the vehicle Renault 5, which corresponds with the axis X of the vehicle SA5.

2.2 THE MAKING OF THE EXPERIMENTAL BODY SA5

An all-composite body of a small town vehicle of category L_B, which was manufactured in small series for Auverland A5 vehicles (designed for town operation with a maximum speed of 50 $^{km}/_{h}$ and a 600 ccm engine), was used as a basis for the special body designed for the dynamic test. Only the shell of the body from the original vehicle, made from glass fibre composite, which was designed as self-bearing, was used for the experiment. The floor pontoon, as well as some parts exposed to larger forces (places for the attachment of the engine, attachment of axles, etc.), were reinforced by inserts of aluminium and galvanized plate bonded with the composite by overlamination. All bearing elements and deformation supports, which were able to produce deformation work, were removed from the frontal deformation zone.

These elements were replaced by reinforcements that were made on the basis of knowledge obtained from the tensile tests. In the new version of the deformation elements we used flexible types of structural adhesives (Dinitrol), rigid joints (adhesive IPS Weld-On), as well as joints with overlamination.

The conception of the new proposal of the deformation was based on a gradual increase in rigidity of individual elements and joints. Hence, the front part of the body had the character of a progressive deformation zone, which became tougher with the progressing deformation and created higher and higher deformation work. At the beginning of the impact action the rigidity of deformation elements is relatively small; the body should behave favourably when hitting pedestrians, i.e., the body should not be aggressive against the pedestrians.

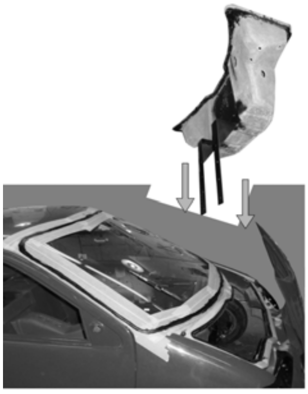


Figure 3: Front boot

The first part of the deformation zone consisted of a front bumper manufactured only from composite material. Composition of the laminate with a total thickness of 4.5 mm contained 50% of glass reinforcement thanks to the application of 1 layer of standard fabric and 1 layer of multiaxial fabric.

The second part of the deformation zone was created by integration of a part of the front boot, which is entered into the front part of the body (see Figure 3). It did not have any strength function in the original body. In this case, the part of the boot was bonded around the entire circumference to the body by the flexible adhesive Dinitrol, so the strength of this part participated in the absorption of deformation energy. Three reinforcing elements were placed between the front bumper and a part of the boot. The centre of the body was a laminate “U”-profile of sandwich structure with a thickness of 4 mm, where “coremat” formed the core of the laminate. The bonded area of the bumper was 20,000 mm^2 and on the side of the boot it was 25,000 mm^2. Reinforcements from steel plate with a thickness of 1.5 mm were placed on both sides of the body. The reinforcements were bonded to the front bumper profile by a joint area of 19,500 mm^2 and to the front part of the boot area by a joint area of 8,000 mm^2. The flexible structural adhesive Dinitrol was also used for bonding.

The third deformation zone degree was designed with the application of rigid joints. A steel plate profile was placed between the boot part and the partition separating the area for passengers; on the side of the partition it was screwed on and with the bottom part of the boot it was bonded by overlamination. The overall area of overlamination of both reinforcements was 16,800 mm^2. To increase the adhesion of overlamination with the bearing part the steel plate was perforated.

The last structural reinforcement was from composite material reinforcements placed into the boot. These very rigid reinforcements were fit together with the boot to fit as accurately as possible with the surface of the boot walls, and subsequently they were bonded to the walls by the adhesive IPS Weld-On SS1505. The thickness of the laminate in the middle of the reinforcement ribs was 5 mm, and on both ends the ribs were reinforced by the so-called head of the rib to a total thickness of 11 mm. The composite was reinforced with glass fabric with a rectangular arrangement.

2.3 CRASH TEST CONDITIONS

During the crash test, the vehicle SA5 was accelerated using a pulley device for the acceleration of vehicles, which also performs the leading and self-centring function. The basis of the accelerating device was a sufficiently long rail enabling the acceleration of the vehicle to the specified speed and its stabilization. Another vehicle with sufficient power is used as a source of the traction energy. Inside the rail there is a slider placed on ball bearings.

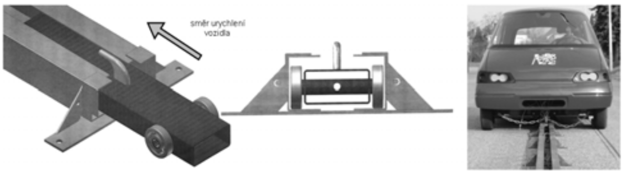


Figure 4: Accelerating rail

The slider was accelerated using a steel cable. The vehicle SA5 was attached to the slider by a chain. At the end of the rail there was a self-locking brake to stop the slider. The accelerated vehicle became unhooked and continued due to inertia for another 1m approximately to the point of crash. Figure 4 shows the accelerating device.

2.4 CRASH TEST EVALUATION

The impact of the vehicle SA5, whose actual speed was 47 $^{km}/_{h}$, moved the vehicle Renault 5 by approximately 3 m (*Note: measured against the centre of the car*). Figure 5 shows the final position of the vehicles after the crash test.

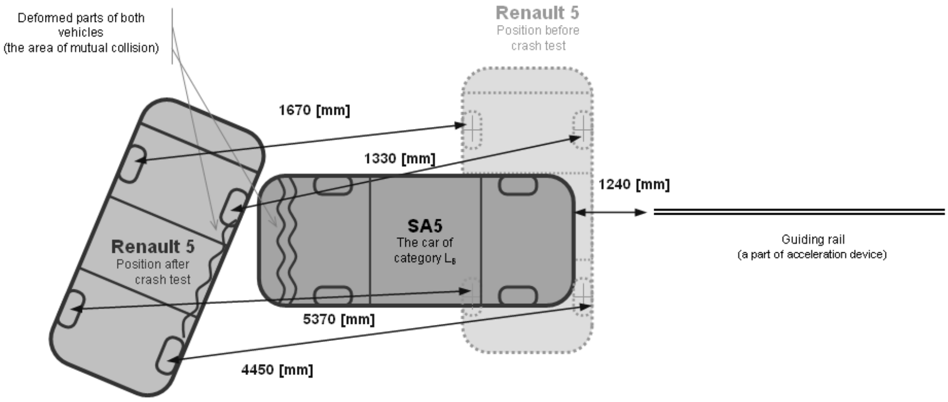
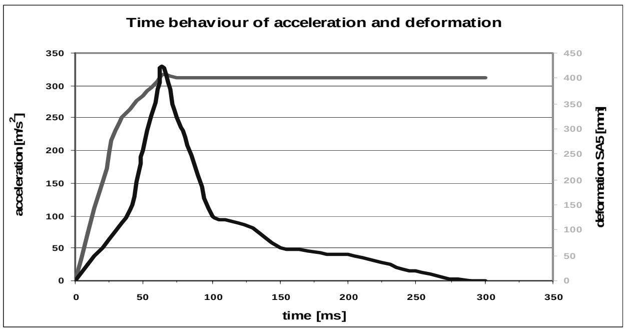
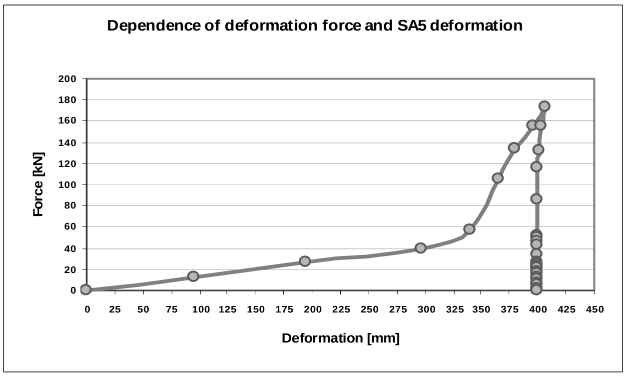


Figure 5: Layout after crash test

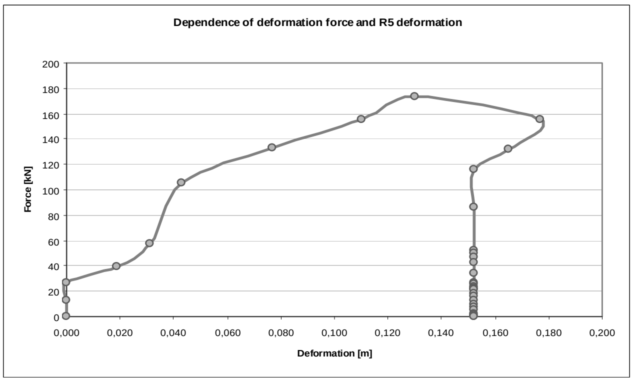
Outputs from the accelerometers were connected to the B&K analyzer, which processed the data. The actual evaluation of courses of acceleration was carried out using the software HyperWorks-HyperGraph. Filters were applied to the actual courses – they removed higher harmonic values from the entire course of acceleration. An evaluation of passive safety on both used dummies using the HIC method (head injury criterion) was carried out using the above-mentioned software. From the accelerometer placed on the body of the vehicle SA5 we obtained the actual course of acceleration of the body in time (see Graph 5). Acceleration values in periods of 10 ms were read from the graph. Deformations were read from high speed camera records with the same sampling frequency. The deformation force was calculated from these data. The dependence of the deformation force on the deformation is depicted in Graph 6. We performed the same calculation of the deformation force and read the deformation values from the high speed camera records for the vehicle Renault 5. The course of the dependence of the force on the deformation is apparent in Graph 7.



Graph 5: SA5 Acceleration & deformation



Graph 6: Deformation force of SA5

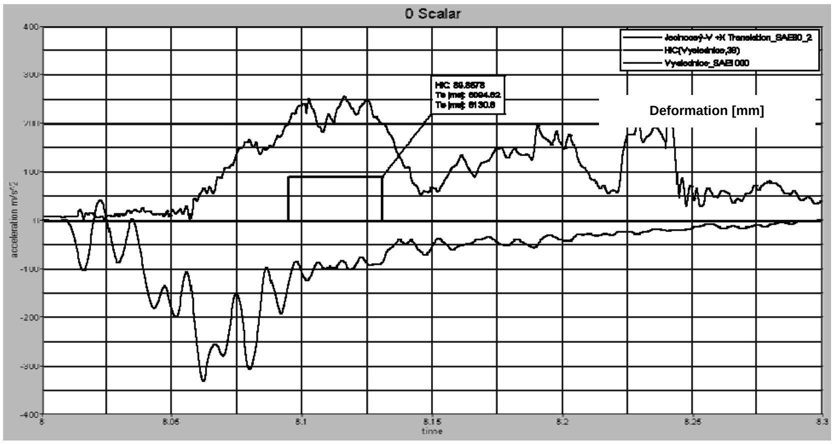


Graph 7: Deformation force of R5

The input energy of the entire set is the kinetic energy of the vehicle SA5. When we simplify it slightly, this energy divides into three main parts – the deformation work of SA5, the deformation work of R5, and the work to move the vehicle R5. The deformation work of both vehicles equals the area below the curve in the graph of the dependence of force on the deformation. By integrating the function f(x) in a closed interval we obtain the deformation work of each vehicle:

W_{SA5} = 14 727.5 J; W_{R5} = 20 555.4 J; W_p = 9 553.3 J *) ***work to move the vehicle R5*****.**

The body of the vehicle SA5 deformed smoothly from the front bumper up to the partition of the passenger area. Graph 8, which depicts the course of acceleration measured directly on the solid part of the body, shows gradual degradation of individual reinforcing elements. If simplified slightly, this part of the course could be replaced by a linear course.



Graph 8:

During the deformation, the axle was bent and the wheels came into contact with the body. Deformation work was thus transmitted to the frame of the body; it spread mostly through the door sills, partition of the passenger area, “A” pillars and “B” pillars. Cracks and other damage were visible at these parts. Nevertheless, the important thing was that no external part penetrated into the passenger area and the passenger area remained completely preserved.

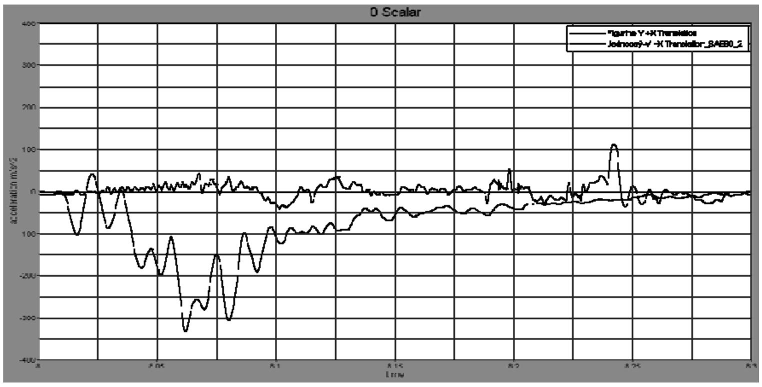
Figure 6: Deformation of SA5

Figure 7: Deformation of R5

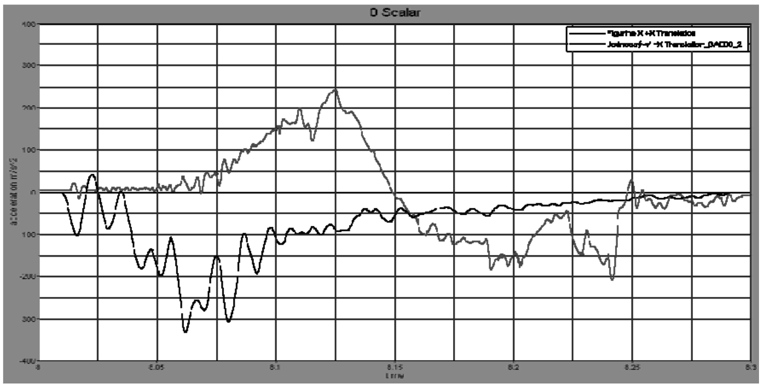
Figure 8 & 9: Deformation of SA5 interior

One of the main outcomes of this experiment was an evaluation of the composite body of the vehicle SA5 from the point of view of passive safety. We analyzed data from accelerometers placed in the head of the Manikin dummy. Courses of acceleration in the direction of axes X, Y, and Z are depicted in Graphs 9 to 11. The graphs always show two curves. The curve below the X-axis shows acceleration on the solid part of body of the vehicle SA5 and it is provided in the graphs for reference, so that the shift of the course of acceleration of the dummy in comparison with the body is apparent. Graph 8 shows the result of acceleration in the head of the dummy. The red field then depicts the evaluation of the HIC criterion within a period of 36 ms. The calculated value of HIC was 89.85 (the critical value is 1000). The value of maximum acceleration measured on the body was 32.8 m.s^{-2}. Maximum acceleration measured in the head of the dummy was 26 m.s^{-2} in direction of the X-axis.

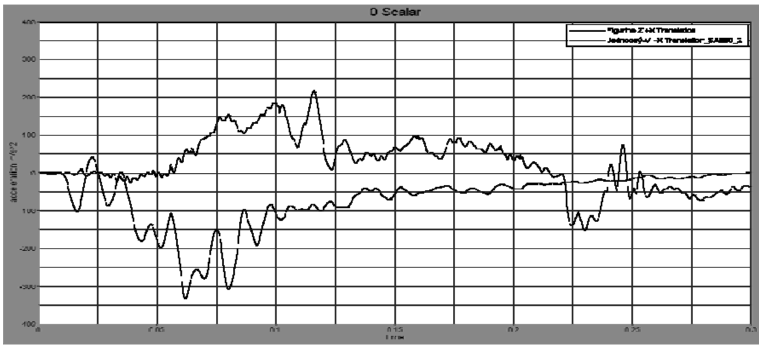
Since a child dummy was placed in a child seat on the right rear seat in the vehicle Renault 5, which was standing crosswise, HIC evaluation was also carried out to deduce how aggressively or friendly the vehicle SA5 behaves to other crash participants.



Graph 9: X-axis acceleration of Manikin



Graph 10: Y-axis acceleration of Manikin



Graph 11: Z-axis acceleration of Manikin

The value of HIC on the P3 dummy was 115.05 (see Graph 12). It is a higher value than in case of the Manikin dummy, but since the limit value is 1000, we can state a hypothesis that the all-composite body SA5 is friendly towards passengers, as well as towards other crash participants.

2.5 EVALUATION OF INDIVIDUAL JOINT TYPES AFTER THE CRASH TEST

From the point of view of destruction of individual joint types on the body, the worst results were achieved by connections made by overlamination. Severe destruction occurred at these joints during the crash test. The inserted plate part acted as a separator of individual laminate layers in the composite structure. Delamination, and ripping of the layers above and below the insert (see Figure 10), occurred during the load.

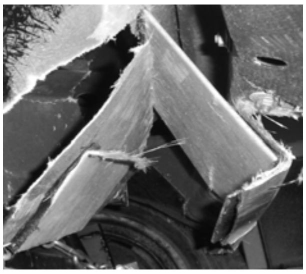
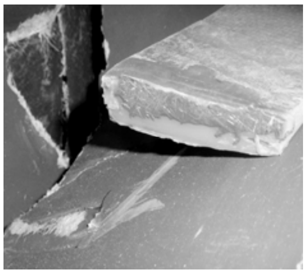
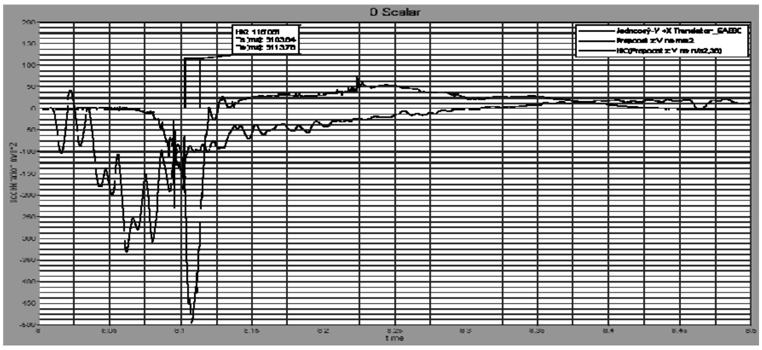




Figure 10 **Figure 11** **Figure 12**

Reinforcements bonded by flexible structural adhesives Dinitrol were not damaged by the crash. The reason was their high elasticity, but also the overdesigning of these joints by approximately 27%. Thus, due to the impact energy there occurred destruction of the actual reinforcements (rupture of the laminate, bending of the steel plate), and the bonded joints remained without damage (Figure 11). As regards the laminate ribs bonded by the adhesive IPS Weld-On SS1505 into the boot area, the portion of the produced deformation work was lower than the original expectation. The reason was the application of the joint to a place where the surface layer of the boot wall had been finished with a gel coat.



Graph 12:

Its cohesion with other composite layers (matrix, glass reinforcement) is lower, and during the vehicle deformation the rib reinforcements were broken open with a part of the gel coat (Figure 12). Despite this bonded joint not being fully utilized, the portion of the produced deformation work was high, which is indicated by the extent of damage of the surrounding bearing parts of the body.

3 CONCLUSION

By generalizing the knowledge obtained from the performed tensile tests and crash experiment it is possible to state several recommendations for the application of bonded joints in vehicle body structures, mainly in combination with composite materials. Polyurethane structural adhesives of Dinitrol F500 type designed for high mechanical load and showing a high degree of relative elongation under tensile load are suitable for application on the structural parts of vehicle bodies, as well as parts of deformation zones, where large deformations can be expected. In the case that the deformation occurs in the areas of elasticity, the adhesive is capable of following the deformed bearing element of the body, while the bonded joint is not degraded in any way and maintains its strength. If plastic deformation of body parts occurs, it is good when the adhesive is still elastic and the degradation of joints occurs later on. This effect is supported by a high degree of elongation of the adhesive. The use of polyurethane adhesives is also suitable for the bonding of soffit panels to bearing space frames, for example, and where oscillations occur. These adhesives, thanks to their flexibility and the common thickness of the bonding joint of 2-6 mm, are able to dampen or even completely absorb part of the oscillations.

The analysis of the results of the adhesive Dinitrol PU F500 LP during the experiment confirmed a very good adhesion to the basic materials and a strength of around 15-20% higher than in the case of F500. It is therefore suitable to use these adhesives for the bonding of windows, for instance. In these applications it can be generally expected that the adhesive will act as a bridge between the body and a very rigid window. Thanks to the combination of strength and flexibility the adhesive does not transmit forces from the body to individual points in the window, but rather spreads the load to a larger area.

The methacrylate adhesives of the type IPS Weld-On SS1505 are suitable due to the large strength of joints for the application on structural bearing elements of vehicle bodies, where a large strength load is expected. On the other hand, the small relative elongation of adhesives needs to be taken into account. The adhesives are not capable of dampening the oscillations. Connections made by these very rigid adhesives are suitable for the last degree of the progressive deformation zone. Besides the bearing parts of vehicle bodies, the application is possible on parts with a small contact area, which serve mainly for the transmission of forces produced by the part itself. For example, attachments of parts in the interior, hinges, etc. Joints made by overlamination are technologically greatly feasible and financially more favourable in comparison with the above-mentioned adhesives. On the other hand, the performed tests showed that the strength, as well as the flexibility, of these joints is very low. This disadvantage can be compensated in practice by enlarging the contact areas of the joints, which brings with it a negative effect – an increase in weight. A connection by overlamination can be used in body parts that are not exposed to such a large load, or in places where pressure loads will be the predominating load on the joint. Overlamination in places with the occurrence of vibrations is not very good either. Thanks to a suitably selected structure, composition of materials, and the applied adhesive it is possible to produce a sufficiently safe deformation zone with a progressive or constant absorption of energy, which will also be considerate of pedestrians.

REFERENCES

Kovanda, J., Satochin, V.: *Passive safety of vehicles*, Czech Technical University in Prague.

Bares, R.A.: *Composite materials*, SNTL, Prague. 1988.

Kovanda, J., First, J., Lenk, J., Micunek, T.: *Equipment for vehicle acceleration during dynamic testing of passive safety (VYZ616.005/04)*, Prague. 2004

Magazines JEC magazine Composites and Automotive News Europe.

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