Small light urban vehicles: a solution for increasing energy efficiency and decreasing CO_2 emissions within city limits

V. Momcilovic, D. Vujanovic & V. Papic
University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia

Abstract

The main idea behind this paper is to impose restrictions on private cars' admittance to restricted areas due to their "weight efficiency". We must take into account that energy efficiency is a direct consequence of the work realized and that the CO_2 emissions are also proportional to this value. In essence, the intention is to minimize the vehicles' weight per consumption unit in order to lower the engine power and therefore the CO_2 emission. In recent years, we have witnessed the percentage of heavier and bigger cars constantly increasing. Those cars, which are weight- and CO_2-inefficient, are present in the city centres where their environmental impact is an important issue. The solution is to impose or influence a change in citizens' purchasing habits towards a small, safe, fuel efficient, "weight efficient" car with lower CO_2 emissions, permitting their owners open access to all "critical" urban areas exempt of "weight charging".

Keywords: vehicle weight reduction, energy efficiency, CO_2 emission, critical urban areas.

1 Introduction

Energy consumption and related energy efficiency are directly linked to the work realized and at the same time the CO_2 emission is proportional to the energy consumption. In essence, in order to decrease the CO_2 emission it is essential to minimize the work that the vehicle must accomplish to realize the trip from one place to another and the most appropriate measure is to lower its weight. In practice in the automobile manufacturing industry one of the applied measures

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consists of lowering the vehicle weight by using new, lighter materials in the manufacturing process, but the real effect of these measures has been annulled by the large number of elements related to passenger safety and comfort importantly influencing the weight of the vehicle. The weight indicator can be observed and analysed not only individually, but also through other derived indicators, for example, per vehicle capacity (kg/passenger seat), per vehicle occupancy (kg/passenger) or even per specific energy consumption unit (kg/energy unit). Another interesting ratio is that of vehicle power and weight. In this respect, Kageson [4] showed that the weight and power rating of new passenger cars increased significantly during the 1980s and 1990s. Not only those buying large cars, but also customers of small and medium-size cars were increasingly offered a variety of engine sizes and power ratings. In a study realized for ECMT [2] it was found that average power ratings rose by more than 9 kW between 1980 and 1990 in France, Germany, Sweden and the United Kingdom.

Although there is a growing need for improvement within public transport, its sustainable energy consumption is still rather high. Therefore, public transport and especially its mass modes are not always a viable solution for the entire city area, particularly not for small density areas, because vehicle weight is high, so such transport would be weight and CO_2 inefficient. That is why by night (early morning hours) the most daily charged lines are often served by buses (more "weight efficient"), which are acceptable for actual transport volumes. Nevertheless, public transport requires a deeper analysis and more complex consideration in the matter of "weight efficiency" than passenger vehicles.

As for private motorized modes, there is still an important volume of everyday passenger car traffic, especially in city centres. For instance, even with highly developed, easily accessible, comfortable, regular and punctual public transport, and although users face everyday traffic and parking congestions, the congestion charging did not show an important decrease in the share of energy and CO_2 inefficient cars accessing critical urban areas. Those users are usually willing to pay the tax. Their "weight inefficiency" is essentially based on two noticed trends: the low vehicle occupancy and on the other hand, an everyday growing stake of heavy private cars (such as SUVs and minivans), being the most inefficient ones among passenger vehicles. SUVs today represent more often sport and luxury vehicles than utility ones – therefore they symbolize their owners' social status. As SUVs are very expensive, paying all of the extra expenses (such as for congestion charging, parking restrictions and fees, etc.) for accessing the city centre or other highly attractive (therefore restricted) areas is not an issue for their owners with their modern though inefficient and "overweight" vehicle. It is likely that only severe restrictions would influence their behaviour. Additionally, the fact is that under any circumstance the SUV users will not completely give up the private car comfort and flexibility, so it is not or is hardly expected that they will switch to public transport or non-motorized modes. The authors consequently do not anticipate that even drastic measures such as banning access to private cars will lead to the expected effects, but would probably increase the number of infractions and yet relocate the problem creating new critical areas.

Therefore, the authors' idea is to impose "weight restrictions" for accessing critical urban areas, such as "weight charging". The idea is only to restrict heavy private cars, weighing over the allowed limit, though not delivery, goods, emergency and utility vehicles, which need to access the city centre to carry out communal services (the latter vehicles will be provided with special stickers issued by the proper city authority allowing them to access the central urban area).

2 Methodology

The approach to this problem's solution is to implement access restrictions (even prohibition) to central or critical (attractive) urban areas with the limit for private vehicles weighting over 1.7 tonnes. All of the vehicles over this weight limit should not be allowed to enter the city centre or the critical area without having previously purchased the specific "weight charging" sticker and having paid an adequate period tax (important for "heavier" cars as SUVs). Initially, there should be only two categories: the cars within the limits (yellow label) and those outside it (red label). In a second step, after one year of implementation, an additional limit of 1.3 tonnes should be introduced. Then, there will be three categories of cars: those "weight efficient" under 1.3 t (green sticker), those "moderate" between 1.3 and 1.7 t (yellow sticker) and those "overweight" over 1.7 tonnes (red sticker). The limits can be revised after a couple of years and the lower limit can be even set to 1.0 t, while the upper limit could be 1.5 tonnes.

This solution is quite similar to the CO_2 charging tax in London, which is based on the limit of 120 g/km CO_2 emission and the following periods: 1 day (pre- or post-paid), 5, 20 or 252 consecutive days. The price varies from £8 for one day paid in advance for moderate CO_2 emission cars (121-225 g/km) to £1696 for the same category for 252 days, and £25 a day for higher CO_2 emission cars (>225 g/km) up to £5300 a year. All private cars under the set weight or CO_2 limit are exempt from paying this tax, but either way they have to acquire the green "weight charging" sticker from the proper city environmental or traffic authority.

The enforcement and fine for infractions will be based on monitoring of all vehicles entering the critical zone by communal or traffic police agents. After certain period of implementation (e.g. 6 months or 1 year), a control survey should be realized regarding the share of heavy passenger cars. If their percentage is still close to the referent state, prior to the tax implementation, the amount charged for "weight inefficiency" should be properly increased. When and, of course, if, their stake lowers to around 1%, the next level of limitations should be implemented in the critical urban area. However, if this measure comes out with the expected efficiency, the new limit implementation could mean that the initial limit could be implemented wider, even on the entire continuously built urban area.

The reason for the authors suggesting that the system starts with an initial limit of 1.7 t is because it encloses the majority of present passenger cars (including bigger passenger vehicles). Nevertheless, the passage to the 1.0 t limit should be preceded by an intensive media and marketing campaign aimed at the popularisation of smaller vehicle purchasing (in the sense of raising users' awareness about this measure's influence on the city's environmental protection and sustainable development). This is the way to efficiently decrease the CO_2 emission in critical urban zones and to stimulate the smaller vehicle purchase that would facilitate the restriction of heavier vehicles. Of course, the car manufacturers should also lead the way towards more important vehicle weight decreases. One of the recent examples comes from India with the new Tata Nano light, compact car model, with limited yet sufficient speed for urban use and it is even inexpensive (unfortunately mainly due to savings in passenger safety and comfort equipment).

The SUVs and minivans CO_2 emission calculation method for the observed critical/central urban area comprises:

1. determining the critical/central urban area limits and diameter – D,
2. determining the number (share) of SUVs and minivans entering the critical/central urban area – N, and
3. determining the average CO_2 emission values for all SUVs and minivans – CO_{2avg}.

After having established the central area limits and its diameter (D), the exact number of SUVs and minivans entering the observed central area (that those restrictions are mainly addressed to) during an average working day should be determined (Tuesday–Thursday, mid April or mid October). Those numbers (their share) is determined by traffic counts (surveys) on characteristic corridors entering the central area in three time periods during the day, two peak periods: the morning and afternoon peak hours and one off-peak night period. The share of SUVs and minivans in the survey hours is likewise obtained. The next step is to compare the survey data with those from previous comprehensive traffic studies for the same corridors and the same time periods and after to spread (widen) the available data to the entire zone and the whole day (the number extrapolated with available periods and present shares). Having the total number of those vehicles (N) on average, we can obtain the CO_2 emission from SUVs and minivans for the critical area during an average working day:

$$CO_{2SUV} = \Sigma_i \, D \text{ x } N_i \text{ x } CO_{2iavg} \tag{1}$$

When the restrictions are imposed the number of SUVs and minivans is expected to fall to 1%. Therefore, the difference between the present SUV share and this 1% represents the decreased number of such cars that will lead to expected savings in CO_2 emissions from those vehicles.

3 Present situation worldwide and particularly in Belgrade

According to ECMT [3], transport's share of CO_2 emissions is gradually increasing in all regions of the world; its share of world emissions increased from 22% in 1990 to 24% in 2003. Transport's share is highest in the more developed countries of the OECD (30% in 2003). Within the transport sector, private and commercial road transport has accounted for the great majority of CO_2 emissions in most countries, from which two thirds are split to passenger transport while one third to freight at present. In developed countries some of the CO_2 emissions abatement measures already adopted in the transport sector are expensive per tonne of CO_2 abated, costing upwards of 100 Euros per tonne. Fuel economy measures (ECMT [3]) covering a range of approaches, including engine modification, drive train modification and lowering the weight of cars and fuel efficiency, can be stimulated by three distinct types of measures: technical adaptations in vehicle design, behavioural changes in driving (more fuel efficient driving) and behavioural changes in purchasing automobiles (switching to smaller or lighter or more fuel efficient vehicles).

The share of CO_2 emission from inefficient passenger vehicles in the recent years, the SUVs and minivans, is in constant growth, especially in developed countries, but also in developing and countries in transition. In Table 1, an example of the annual growth rate of shares of SUVs and minivans in the total number of registered vehicles in Germany from 2003 until 2007 is given.

Table 1: Share of SUVs and minivans from all registered cars in Germany on January 1, 2008.

Year	SUV's	SUV share (%)	Minivans	Minivan share (%)	Total SUV's and minivans	Total share (%)
2003	742 371	1.7%	1 452 848	3.3%	2 195 219	5.0%
2004	830 752	1.8%	1 931 043	4.3%	2 761 795	6.1%
2005	939 292	2.1%	2 288 446	5.0%	3 227 738	7.1%
2006	1 098 605	2.4%	2 652 776	5.8%	3 751 381	8.2%
2007	1 236 822	2.7%	3 043 973	6.5%	4 280 795	9.2%

Source: Kraftfahrt-Bundesamt (KBA) - German Federal Motor Transport Authority [5]

In Table 2, the evolution in the SUVs and sport cars share in EU-15 is shown, which is the most important growth in view of the starting positions beside lower medium and small cars' categories.

Table 2: New passenger car registrations in EU-15 – breakdown by segments (%).

Years	Small	Lower Medium	Upper Medium	Executive	SUV, sport cars	Unknown
1990	30.4	27.7	22.9	13.0	2.4	2.7
1995	32.9	31.4	18.7	14.0	2.9	0.1
2000	32.7	34.2	15.7	12.7	4.6	0.1
2001	32.8	33.8	15.9	12.6	4.9	0.1
2002	32.7	33.9	14.8	12.7	5.7	0.1
2003	34.2	32.4	13.7	12.9	6.6	0.1

Source: Kageson [4]

According to the latest data obtained from the UK Vehicle Certification Agency (from February 2008) regarding the CO_2 emissions by fuel type (petrol and diesel), it is obvious that, regarding the CO_2 efficiency, diesel fuelled cars are more efficient than the petrol ones, first of all by the indicators' lowest value (99 to 108), but also according to the number of vehicles satisfying the limit of 120 g/km (15 – 37, by more than double).

As for the situation in Belgrade, it will be illustrated best by the results of the recent traffic survey on the most important corridors heading to the city centre, which is shown in the following paragraphs.

3.1 Traffic flow characteristics survey in Belgrade's city centre

For the actual example of Belgrade and the present set of actions towards lowering the vehicle weight in the critical areas, the old city centre was chosen (area encircled by the circular tram line 2, marked in yellow (light grey) in Figure 1).

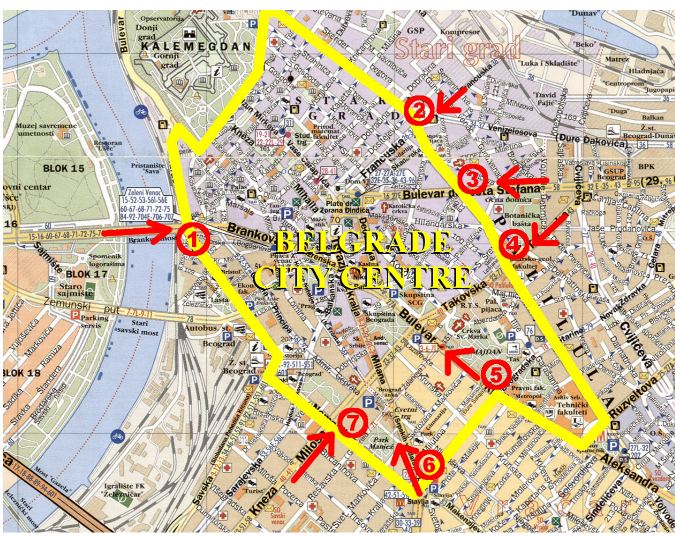

Figure 1: Belgrade city centre and the traffic survey corridors.

Regarding the traffic situation in Belgrade, the situation is being surveyed regularly by field traffic flows counts, realized every two years on the entire street and road network (including counts on external corridors). Those surveys are realized by the Faculty of Transport and Traffic Engineering for the authority in charge of traffic in Belgrade (the Secretariat for Transport). Considering that the last survey was realized back in 2006, at that time no special attention was given to the category of SUVs and minivans. Nevertheless, they have been integrated into the category of bigger private cars with an engine size ≥1100 cc.

As the central Belgrade area has been precisely determined, the referential state had to be established before the implementation of any measures for vehicle weight and CO_2 emission abatement, and additionally for energy efficiency enhancement of those vehicles allowed to circulate in the critical area.

Upon determining the perimeter of the central area and its diameter D (which in this case is 3.0 km) the following step is to determine the share of SUVs and minivans. In order to estimate the actual number of SUVs and minivans (their share in the traffic flow) in Belgrade, an average Tuesday has been chosen (April 15, 2008) for the control traffic survey on all incoming directions toward the central area of Belgrade (shown on Figure 1). This survey comprised the morning peak hours – MPH (7:00-9:00), to estimate vehicle shares for the employees working in the centre, then in the afternoon peak hours – APH (from 16:00 to 18:00), to appraise the shares among population living in the centre (though working outside, and getting back home from work), and finally in the characteristic night (off-peak) hours – NOPH (21:00 to 23:00) in order to include all vehicles travelling to the city centre for amusement (leisure), since this narrow central urban area is very attractive because of a large concentration of cafes, clubs and restaurants, mostly frequented in the night time (starting from 22:00). In traffic counts, the following categories have been observed: Small Passenger Vehicles, Bigger Passenger Vehicles, SUVs and Minivans, Combined and Delivery Vehicles, Buses and Lorries (trucks). The results of traffic survey, from April 2008, are shown in the Table 3 and following figures (Figure 2, Figure 3 and Figure 4).

Table 3: Control traffic survey of flows towards Belgrade centre, selected periods only, 2008.

Access corridors	Small cars	Bigger cars	SUVs & minivans	Combi & Delivery	Buses	Lorries (trucks)	TOTAL	Access share %
Access 1	4686	7970	687	847	711	159	15060	33.33%
Access 2	1357	1898	202	187	183	55	3882	8.59%
Access 3	1351	2357	211	225	378	17	4539	10.05%
Access 4	768	1735	213	211	150	63	3140	6.95%
Access 5	2265	3891	321	284	190	3	6954	15.39%
Access 6	1109	2309	134	144	255	11	3962	8.77%
Access 7	2496	4131	404	265	293	53	7642	16.91%
TOTAL	14032	24291	2172	2163	2160	361	45179	100.00%

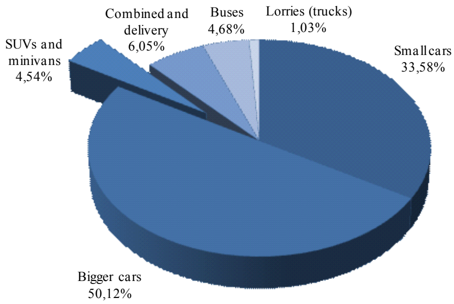

Figure 2: Vehicle category shares in the MPH, 2008.

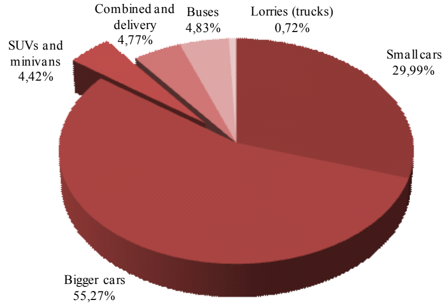

Figure 3: Vehicle category shares in the APH, 2008.

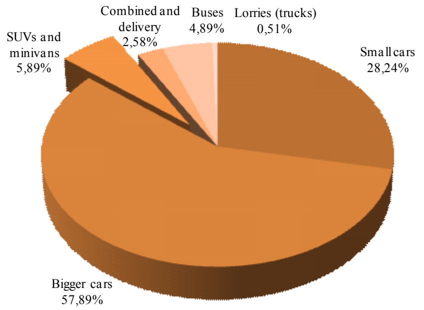

Figure 4: Vehicle category shares in the NOPH, 2008.

The authors' expectations from previous observations of the Belgrade central area were: variations in the traffic flow shares of selected vehicle categories (SUVs and minivans) along the day, the shares in MPH and APH do not vary significantly while in the night (NOPH) their share increase importantly, almost by double. In the survey, this was not precisely the case, since the SUV share did change significantly but not by double (from 4.5% to almost 6%). However, in absolute values during the day the SUVs and minivans heading to the city centre was quite consistent, only from 8:00 to 9:00, their number was more important on all access corridors. Still, upon our assessment their share is slightly higher than experts' estimation of their stake (3%). Although, unfavourable weather conditions may have caused certain increase in the total number of vehicles on the streets, the SUVs share did not vary significantly during different day intervals.

The hourly intervals were analysed from the comprehensive traffic flow survey in Belgrade (2006) and their shares in the daily traffic (distribution of flows) have been then applied and adapted to data from 2008 control survey (Figure 5).

As a result from previous tables and graphs, it has been observed the distribution of hourly intervals on the entire day (0:00 – 24:00), as shown in the Table 4 and illustrated by the Figure 6.

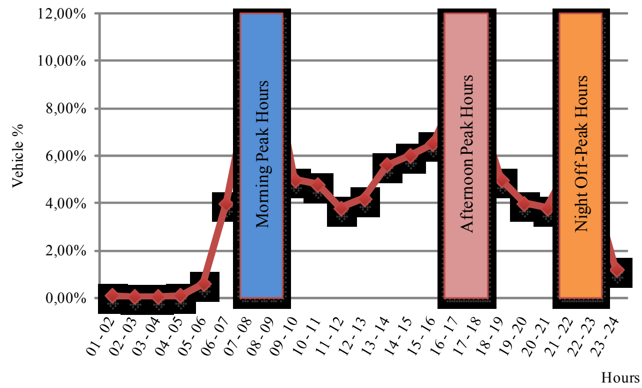

Figure 5: Time intervals' shares (MPH + APH + NOPH), 2008 (extrapolated daily distribution).

Table 4: Traffic flows on chosen accesses towards Belgrade centre, reported for the entire day, 2008.

Access corridors	Small cars	Bigger cars	SUVs & minivans	Combi & Delivery	Buses	Lorries (trucks)	TOTAL	Access share %
Access 1	10142	17907	1598	1699	1576	321	33243	33,31%
Access 2	2951	4146	429	380	402	112	8420	8,44%
Access 3	2974	5266	472	455	846	37	10050	10,07%
Access 4	1725	4083	512	478	346	144	7288	7,30%
Access 5	4914	8649	722	577	410	7	15279	15,31%
Access 6	2494	5086	316	294	569	20	8779	8,80%
Access 7	5377	9151	884	562	654	116	16744	16,78%
TOTAL	30577	54288	4933	4445	4803	757	99803	100,00%

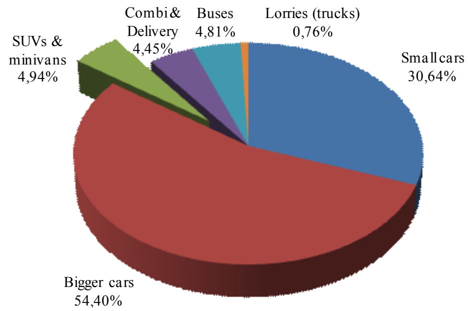

Figure 6: Estimation of category shares in the entire daily flow in the direction to the centre of Belgrade, 2008.

3.2 Measures' effects evaluation

Primarily, it is indispensable to assess what will be a realistic decrease in the daily number of vehicles from the target category. For this purpose, the share of

SUVs and minivans has been estimated in the entire daily traffic toward the city centre. Afterwards, an experts' estimation has been realised related to the defined (target) percentage of heavy passenger cars' share in the traffic flow, based on the estimation of vehicles expected to decrease in the "critical" area. When this number of vehicles is estimated, their new average daily fuel consumption is calculated (based on their average mileage through and inside the zone) and by this CO_2 emission.

If we adopt that the target share of weight inefficient SUVs is around 1%, then we can assess the saving in the number of SUVs for 3.94%, i.e. the total number of less such vehicles' entering the city centre area a day is 3,935. Their average daily mileage in the city centre being 3.0 km, we obtain the potential CO_2 emission savings directly and only from the decrease of SUVs and minivans' share in total of 3.542 t CO_2.

Nevertheless, if we go back to the statement that most of the "inefficient" vehicles' drivers do not want to give up on using cars we expect that the number of bigger vehicles will rise for ~3% and smaller ones also for ~1%. Since their CO_2 emission will grow for 1.173 t, the total potential CO_2 emission savings will be 1.195 tonnes. Additionally, if we succeed to report the big passenger vehicles' users mainly to small cars for about 4% and just a small percentage (0.15%) to other more efficient modes, we can realize CO_2 emission savings of 2.509 t CO_2. Those shown improvements are estimated as realistic for our specific environment (up to 5% change in behaviour). If this or even more aggressive policy succeed to increase the percentage of people going greener – toward public transport and non-motorized modes, we can expect better results, but still not a miracle.

In such situation, with average CO_2 emission indicators for: small cars at 120 g/km, bigger cars at 225 g/km and for SUVs at 300 g/km from an initial average value for the given traffic estimated at 193.4 g/km, just the SUVs decrease for 4% will lower it to 188.9 g/km and bigger cars' decrease (for also 4%) will lessen it to 184.4 g/km, which is not an important saving if the auto industry do not achieve more important weight and power savings for urban vehicles. This measure has been already proved as efficient, so Kageson [4] considers that reducing the specific CO_2 emissions of cars to 120 g/km could be achieved without a marginal loss of welfare by engine and car downsizing the abatement cost is low to moderate, even negative.

4 Conclusion and further research

The authors wish to emphasize the need for "weight efficiency" within the private cars' categories, which should motivate the automobile manufacturers to produce "lighter" cars (with the existing technology) for one to two passengers only for urban purposes. It should be a safe, efficient vehicle with the minimum possible weight (especially engine weight and power) in order to decrease fuel consumption and, of course CO_2 emissions as well as other greenhouse gases (GHG). Such a car would allow their owners to access all "critical" and attractive urban areas.

The objective of such measures is to influence the users' awareness, impose moral principles, that the purchase of an inefficient, excessively "overweight" vehicle has a wide negative impact on an entire society and on environmental protection. Secondary, but not less important objective is to influence the automobile manufacturers to initiate the mass production of "lighter" vehicles (without excessive power or weight). Incentives, institutional measures and tax exemptions would be very useful for those manufacturers acting toward a more sustainable urban environment and would motivate those who still haven't acted in this manner by either importantly increased taxes and duties on irresponsibly "overweight" vehicles (over the determined weight limit) or even favourable financial loans and incentives toward R&D in this field.

Additionally, the car labelling programme is expected to give wider results in the coming years with the growing awareness of driving urban population in view of city's sustainability illustrated by an increase in share of newly registered small passenger cars that mainly pertain to fuel economy classes A and B with less than 120 g/km.

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