Working Paper

# Trends in Global Motorized Mobility
# The Past 30 Years and Implications for the Next Century

*Andreas Schäfer*

WP-95-49
June 1995

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Abstract

The purpose of this paper is threefold. First, it provides a data set of global and regional passenger traffic volume between 1960 and 1990 by the four major motorized transport modes - cars, buses, railways, and aircraft - for 11 world regions. Such a data set has never been compiled before. Second, it forecasts global long term trends in motorized mobility and future modes of transport. The underlying method, pioneered for use in urban traffic planning and never before applied to global forecasts, is based on the assumption that the average user of the transport systems invests fixed budgets of time and money for transportation services. Third, the paper discusses the implications of increasing transport services on energy use because more rapid and flexible modes of transport (e.g. aircraft) are more energy intensive than the slower forms they replace.

The data presented here confirm a path dependency between economic development and motorized mobility in all world regions: rising incomes directly and proportionally have led to rising mobility. To remain on that growth trajectory, more flexible and faster transport systems will be needed (i.e., modal split changes) given a fixed travel time budget. It is concluded that global motorized mobility will increase by a factor of three and related energy use will grow by a factor of 3.2 to 3.5 during the next 30 years based on an annual increase in GDP per capita of two percent.

## Introduction

Globally, a person traveled 1800 km by car, bus, railway or aircraft on average in 1960. This traffic volume more than doubled to some 4200 passenger-km in 1990. In light of a world population growing by 75 percent, absolute motorized mobility increased by a factor of 4, causing a comparable increase in passenger transport energy use and related greenhouse gas emissions, primarily carbon dioxide (also other emissions such as carbon monoxide, nitrogen oxides, and unburned hydrocarbons increased by almost the same order). The globally recognized need for the implementation of effective strategies to reduce greenhouse gas emissions requires a reliable projection of motorized mobility well into the future, and this paper lays one foundation for such projects.

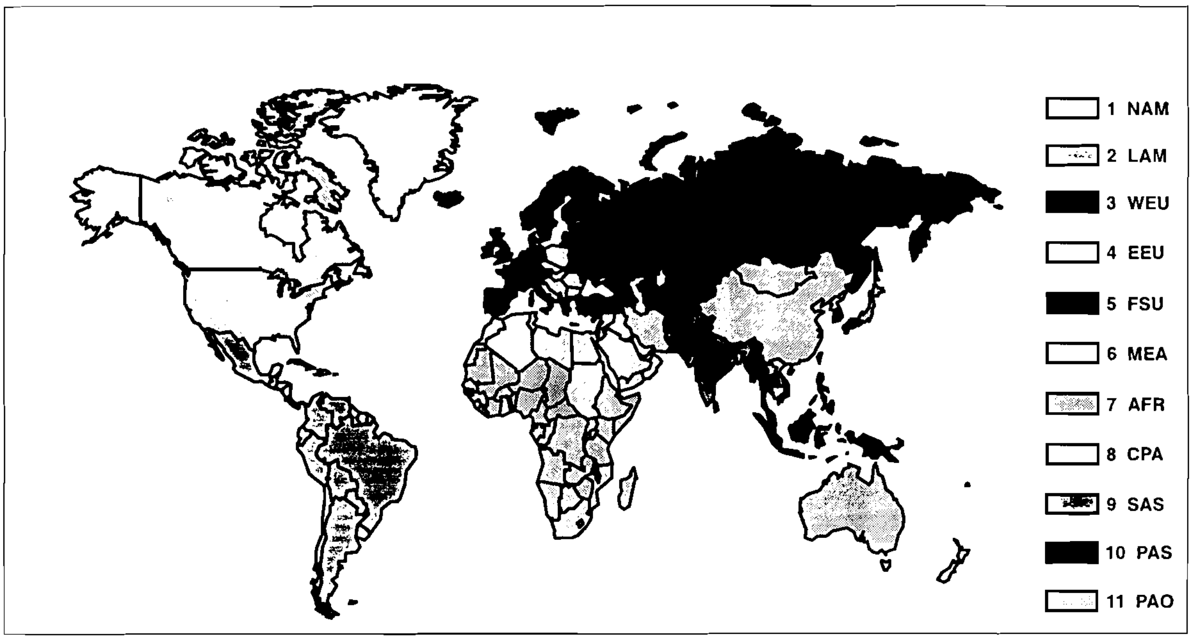
Most of the transport forecasts carried out so far occurred on urban and regional levels. These traffic forecasts generate origin-destination links for optimizing *directed traffic flows* and thus don't coincide with the objective of this paper. National transport scenarios are generally based on (often sophisticated) independent projections of the traffic volume by different transport means over time (Martin and Shock, 1989; Eckerle *et al.*, 1992). These methods typically project total traffic volume by simply aggregating the independent estimates of all modes of transport. Two 'quasi-global' travel projections have built on a similar approach; 'quasi-global' in the sense that they merely consider the traffic volume of passenger cars and aircraft (Grübler *et al.*, 1993) or exclusively focus on road transport means (Walsh, 1993). A completely different approach is based on the projection of final energy consumed in the transport sector (EPA, 1990). Both methods have their advantages but are inherently static since they neglect the interrelation between competing modes of transport.

This paper provides the empirical basis for a methodology that differs from earlier efforts in three ways. First, the projection is based on a global data set of regional motorized mobility (the aggregated traffic volume of cars, buses, railways, and aircraft). Second, in contrast to conventional approaches, per capita motorized mobility is projected in a first step and the related modal split is computed thereafter. Third, there are only two independent variables, population and GDP.

The paper is organized in three sections. Section 1 presents the historical data set of global traffic volume by mode and region from 1960 to 1990. In Section 2 the method mentioned above is used to analyze past trends in transport and project the future traffic volume and related modal split for the world as a whole. Section 3 describes the effect on energy use and carbon dioxide emissions.

## 1. Transport Trends by Mode and Region

This paper compiles a data set of global traffic volume for the first time. The data account for the four major motorized transport modes - cars, buses, railways, and aircraft - and 11 world regions[1]. Data have been derived from many different sources and are described in Appendix 1. The regional disaggregation is illustrated in Figure 1. The 11 world regions can be aggregated into three 'macro-regions', the OECD consisting of NAM, WEU, PAO, the Reforming Economies including EEU and FSU and the Developing Economies including all other regions, i.e., LAM, MEA, AFR, CPA, SAS, and PAS.



1 NAM North America
2 LAM Latin America & the Caribbean
3 WEU Western Europe
4 EEU Eastern Europe
5 FSU Former Soviet Union
6 MEA Middle East & North Africa
7 AFR Sub-Saharan Africa
8 CPA Centrally Planned Asia & China
9 SAS South Asia
10 PAS Other Pacific Asia
11 PAO Pacific OECD

**Figure 1 World regions as defined in the present study.**

*Passenger Cars*

The global passenger car fleet increased from some 98 million vehicles in 1960 to 445 million vehicles in 1990, a factor of 4.5. The increase in worldwide passenger car traffic volume was lower, from some 3 trillion passenger-km in 1960 to some 11.4 trillion passenger-km in 1990, which corresponds to a factor of only 3.8 (Figure 2). The reasons for the declining rate of passenger-km per automobile (from 31,000 in 1960 to 25,700 in 1990) are decreasing occupancy rates, occurring primarily in the OECD, and - to a lesser degree - declining annual distances driven per car (see Figure A-1 in Appendix 1).

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[1] It must be noted that while two and three wheelers are not included in this analysis, they are a significant mode of transport in Asian regions, accounting for about 10 percent of total passenger traffic volume in India (TERI, 1992). Their consideration, however, would not substantially change the projected mobility and modal split of this research and thus have been neglected.

North American (NAM) passenger cars accounted for 70 percent of all passenger-km in 1960; their share dropped to almost 40 percent in 1990, with the shares of Western Europe (WEU) and Other Pacific Asia (PAO) absorbing the difference. The three OECD regions account for 74 percent of global passenger car traffic in 1990.

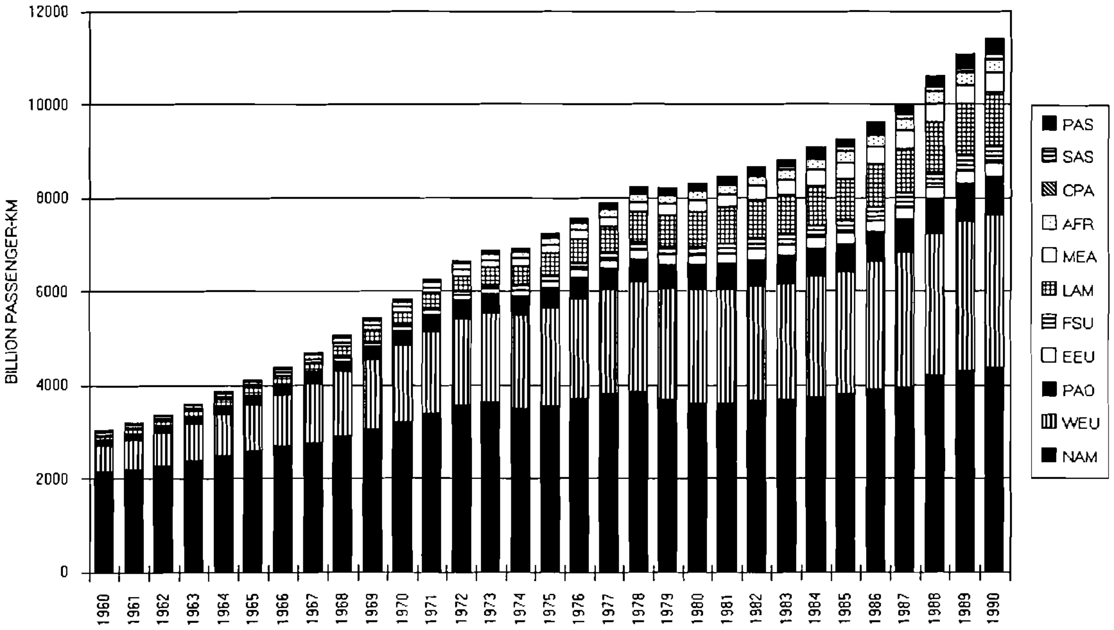

**Figure 2 Passenger car traffic volume in billion passenger-km between 1960 and 1990. Data sources see Appendix 1.**

*Buses*

Buses (consisting of normal sized carriers and mini-buses) experienced the highest relative increase in global motorized mobility of all surface transportation means. Figure 3 shows that passenger-km increased from one trillion in 1960 to almost seven trillion in 1990. Buses contributed most to the mobility growth in developing economies. While three Far East regions Centrally Planned Asia and China (CPA), South Asia (SAS), and Pacific Asia (PAS) account for almost half of the 1990 worldwide bus traffic, the three regions with the highest mobility level NAM, WEU, and PAO, i.e., the OECD, account for merely some 10 percent.

*Railways*

The railway traffic volume accounts for ordinary intercity trains, high speed trains, commuter (suburban) railways as well as for light and heavy rail (tramways and subways). Railways approximately doubled their passenger traffic volume within the last three decades from 1.1 to 2.3 trillion passenger-km as illustrated in Figure 4. This corresponds to the lowest increase of all motorized transport modes. Global railway traffic volume can be allocated on roughly equal shares to the three macro regions, OECD, Reforming Economies, and Developing Economies.

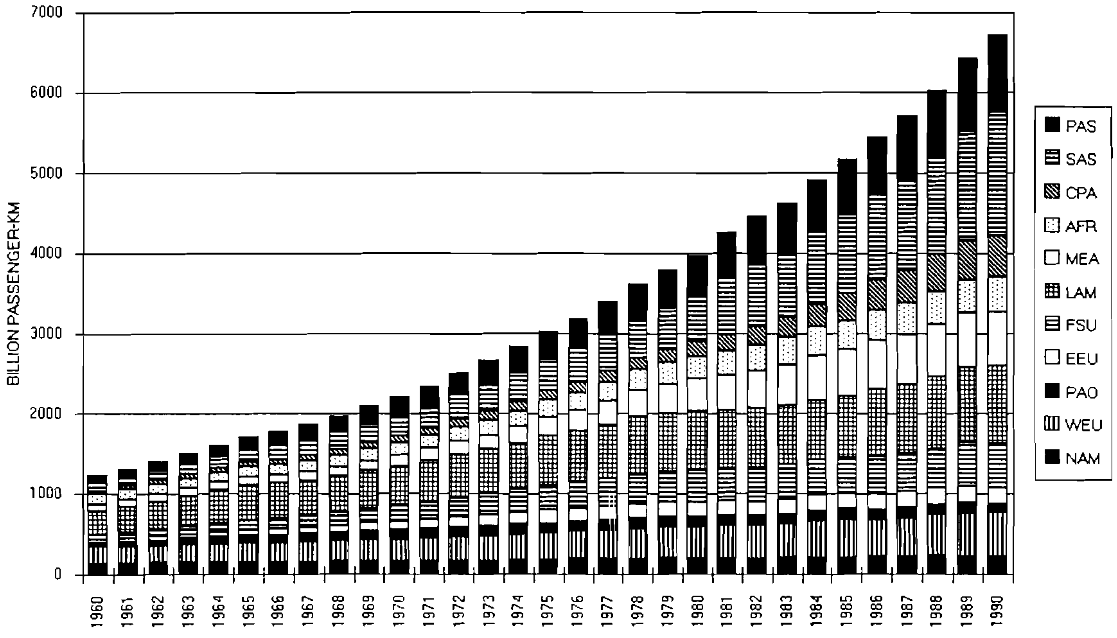

**Figure 3 Bus traffic volume in billion passenger-km between 1960 and 1990. Data sources see Appendix 1.**

Within the macro-regions railway traffic volume is distributed inhomogenously. For instance, CPA and SAS account for roughly 70 percent of total railway traffic volume in the developing regions throughout the entire historical time horizon; this still translates into an increasing share from 15 percent in 1960 to 26 percent in 1990 in global railway travel. Not surprisingly, CPA and SAS regions, as well as FSU contributed most to the increase in global railway traffic.

Though projects on the operation of high speed rail systems are underway in most the world regions, high speed trains still operate in countries of only two regions, i.e., in Japan (PAO region) and in some Western European countries (WEU region). While they accounted for almost 19 percent of railway passenger-km in Japan and some 5 percent in WEU, their global share was merely some 4 percent in 1990. Similarly, the contribution of commuter and urban railways to total railway traffic volume is strongly region dependent. While suburban rail in the SAS region (primarily India) accounted for about 20 percent of total railway travel during the last 20 years, the corresponding share was about 50 percent of total railway traffic volume in the PAO region (essentially Japan) in 1990. Tramways and subways accounted for roughly 20 percent of total railway traffic volume in the WEU, EEU, and FSU region during the past 30 years. In the LAM and NAM region, where the traffic volume of intercity traffic is considerably lower, the share of urban railways to total railway traffic volume increased to almost 40 percent in 1990. In contrast, the traffic volume light and heavy rail is negligible in MEA, AFR, CPA, and SAS.

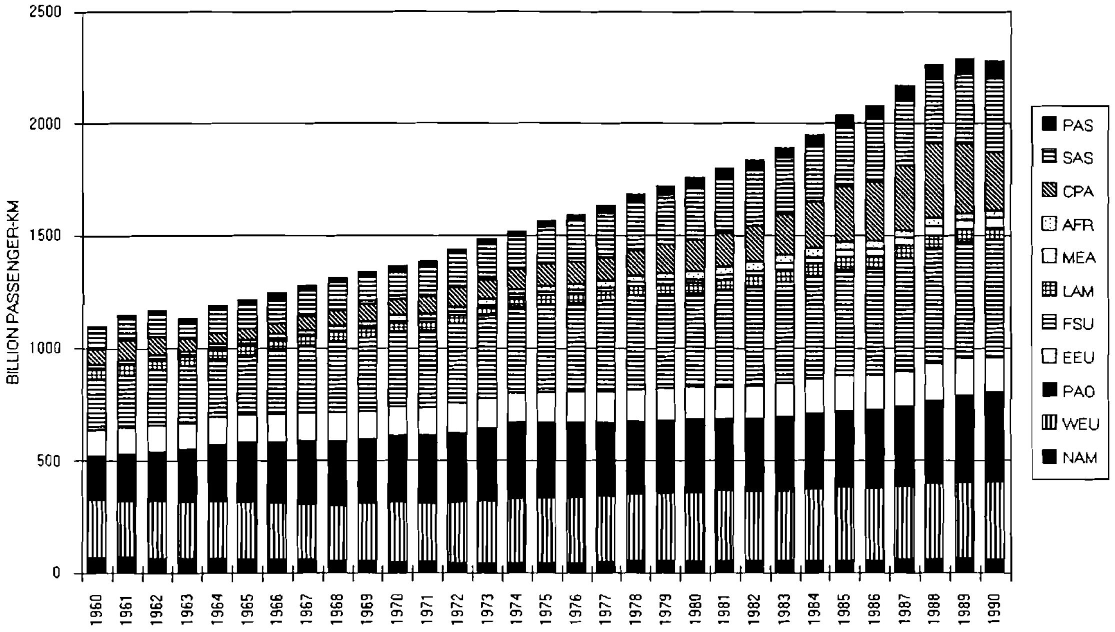

**Figure 4 Railway traffic volume in billion passenger-km between 1960 and 1990. Data sources see Appendix 1.**

*Aircraft*

Between 1960 and 1990 air traffic increased by a factor of 13, by far the highest increase in passenger traffic volume. Figure 5 shows that air traffic was merely 150 billion passenger-km in 1960 or 3 percent of global motorized traffic. In 1990, air traffic accounted for some 2 trillion passenger-km, or 9 percent of global passenger traffic volume, which almost equals the amount of global railway travel. As with passenger cars, air traffic is dominated by the OECD regions (NAM, WEU and PAO), still accounting for two-thirds of global aircraft passenger-km today.

A comparison of Figures 2 to 5 shows that by far most of the high quality transport services (in terms of flexibility and speed) occur in the OECD region, i.e., some 70 percent of total car and almost 70 percent of total air traffic volume. Figure 6 shows the motorized mobility per capita in 1960 and 1990 from a regional perspective. The global per capita traffic volume grew by a factor of 2.3. While the highest *absolute* growth occurred in the OECD regions, less mobile regions experienced the highest *relative* growth. The highest increase occurred in PAS with a factor of 6, 2.6 times the world average. Though the higher relative increases in less mobile areas led to decreasing ratios among all world regions, mobility levels are still distributed quite unevenly in different parts of the world.

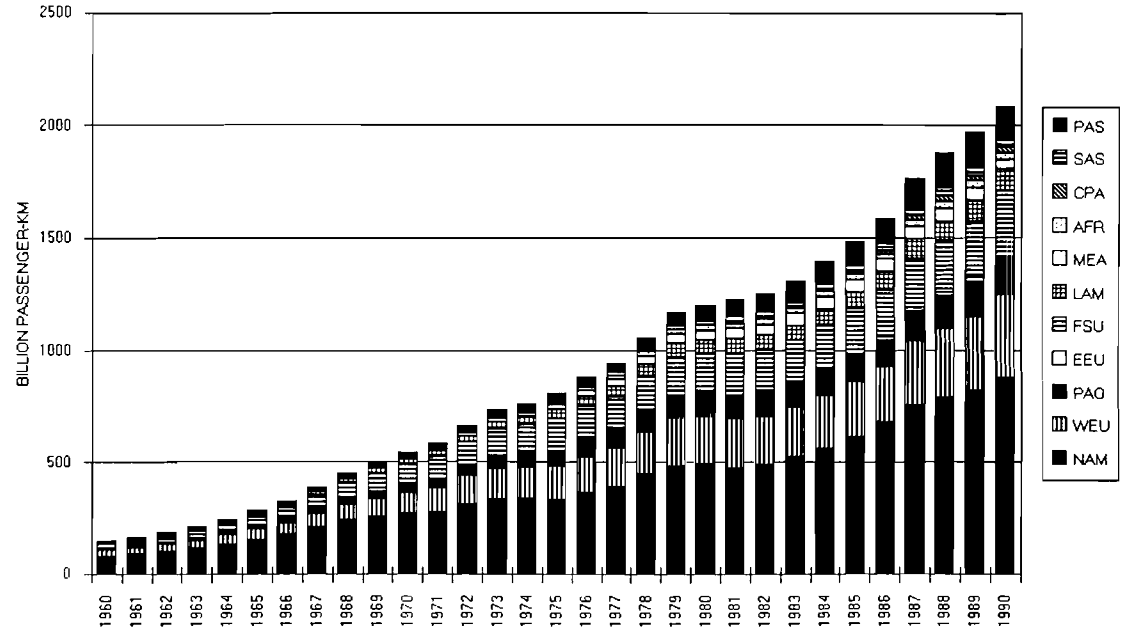

**Figure 5 Aircraft traffic volume in billion passenger-km between 1960 and 1990. Data sources see Appendix 1.**

Regions with the highest per capita income travel most (NAM, WEU, PAO). In contrast, regions with the lowest per capita income travel least (CPA, AFR, SAS). Typically, the largest difference in mobility exists between the highest income region and one of the lowest income regions, i.e., NAM and CPA with a factor in excess of 30. NAM accounts for merely five percent of global population, but its motorized traffic volume corresponds to 25 percent of global motorized passenger-km. In NAM one travels about 19,800 km per year, while in CPA one travels only 630 km a year with a motorized transport mode[2]. The three OECD regions, 16 percent of the world population in 1990, account for 50 percent of global motorized passenger-km.

In 1990, a person traveled 4250 km on average. 91 percent of total passenger travel occurred on the earth's surface and 9 percent on airways. Roads are the most significant infrastructure, carrying 81 percent of global passenger traffic volume. More precisely, 51 percent of the global traffic volume was provided by passenger cars, 30 percent by buses, 10 percent by railways and 9 percent by aircraft.

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[2] This ratio would somewhat decline if one includes two and three wheelers in the analysis.

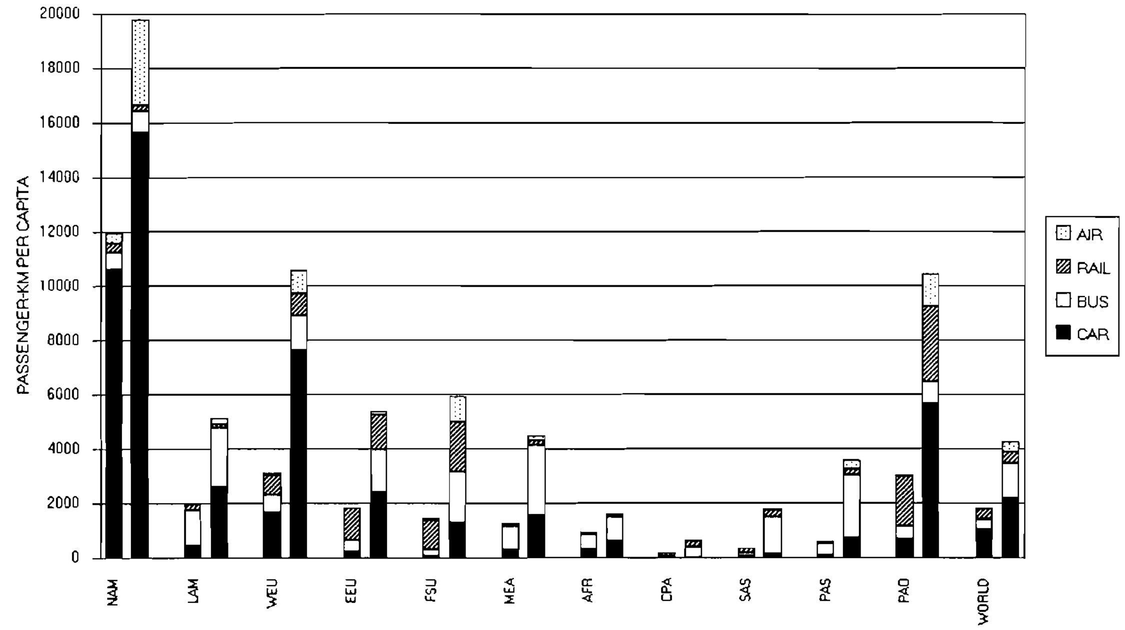

**Figure 6 Motorized mobility per capita, region, and mode in 1960 and 1990. Data sources see Appendix 1.**

## 2. Transport as a Function of Economic Development

### 2.1. Traveler's Behavior: Money and Time Budgets

The behavior of individual travelers is highly variable. Travel surveys suggest that individual behavior depends on a variety of parameters, e.g., household income, sex, profession, age class, population density, etc. Thus, dependent variables such as the amount of money and time that individuals spend on transportation follow a distribution function. However, the fact that the mean values of these distribution functions may remain constant over time has created intense discussion among transport economists in the 1970's and early 1980's (see for instance Kirby, 1981).

Tanner (1961) is most likely the pioneer in exploring traveler's behavior with regard to the so-called money and time budgets. He suggested a *constant budget of generalized costs* (the aggregate of money and monetarized time expenditure on transportation services) per person on average, independent of residential density. In contrast, Zahavi (1981) discovered *constant budgets of both money and time* per traveler (a person making at least one trip a day), when analyzing travel data of US and European citizens. He suggested that travelers invest somewhat more than one hour per day for their travel on average (travel time budget) and finance their travel by spending a constant share of household income (travel money budget). The latter accounts for between 3 and 5 percent for households relying on public transport services and for some 10 percent for those owning an automobile. Thus, on a higher level of aggregation the travel money budget is a function of the car ownership rate.

Figure 7 illustrates the travel money budget versus the motorization rate for a number of OECD countries. The travel money budget increases from about 5 percent at a motorization rate of almost zero passenger cars per 1000 capita (e.g. carless households in the USA in 1909 shown in Figure 7) up to a value between 10 and 15 percent at about 200 cars per 1000 capita and remains approximately constant at higher ownership rates. Seemingly an ownership level of about 200 cars per 1000 capita corresponds to the threshold at which most mobile households operate a car and thus represent the group accounting for the major travel expenses. The different saturation levels can be explained by relative price differences in the economy.

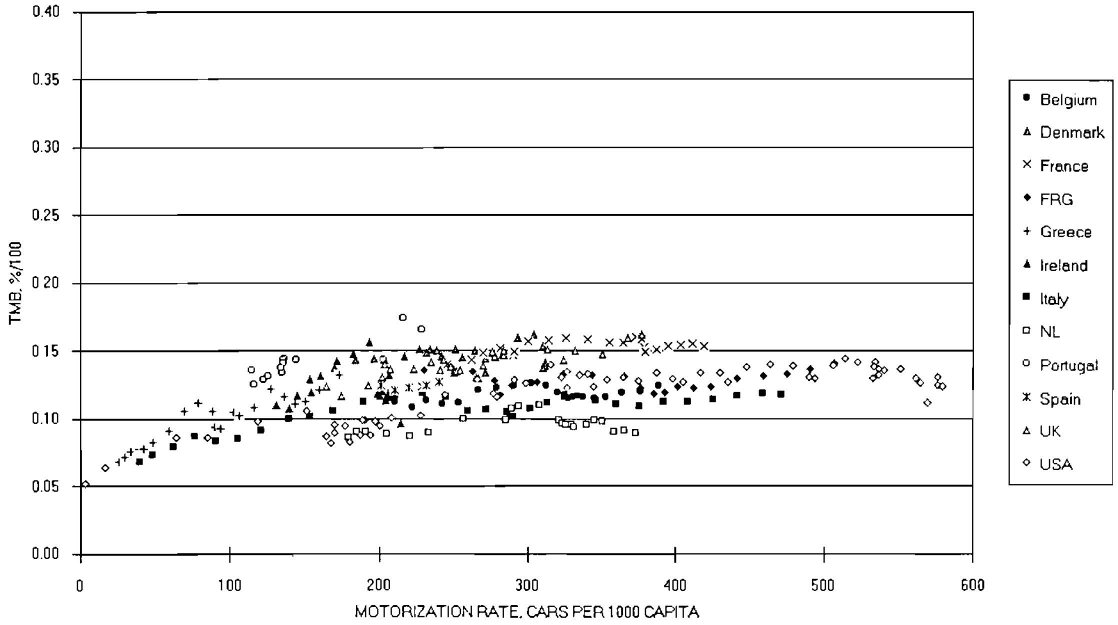

**Figure 7 Travel money budget versus car ownership rate for a number of OECD countries. Source: Eurostat (1994), Davis and Strang (1993), DOC (1975), UN (1960 - 1994), CSO (1994), DOT (1988). Time period of country data: Belgium, France: 1970 - 1992, Denmark: 1966 - 1992, FRG, Greece: 1970 - 1991, Ireland: 1970 - 1989, Italy: 1960 - 1992, Netherlands: 1969 - 1991, Portugal: 1977 - 1989, Spain: 1980 - 1985, UK: 1965 - 1992, USA: 1909, 1914, 1919, 1921, 1923, 1925, 1927, 1929 - 1940, 1948 - 1992.**

Table 1 shows the daily travel time budget per person and traveler for several Western European countries. The average is close to 1.1 hours per person and 1.3 hours per traveler per day. Besides slightly oscillating travel behavior, the variation of time budgets is because of travel surveys themselves, which are not directly comparable in space and time (due to different age groups included, varying days considered, different survey methods, etc.).

| Country | Year | hr per Person | hr per Traveler |
|---|---|---|---|
| Austria | 1983 | 1.12 | 1.39 |
| Finland | 1986 | 1.18 | n.a. |
| France | 1984 | 0.88 | n.a. |
| Germany | 1976 | 1.14 | 1.27 |
|  | 1982 | 1.19 | 1.45 |
|  | 1989 | 1.03 | 1.21 |
| Great Britain | 1985/86 | 0.92 | n.a. |
|  | 1989/91 | 1.01 | n.a. |
| Netherlands | 1979 | 1.00 | n.a. |
|  | 1987 | 1.18 | n.a. |
|  | 1989 | 1.17 | n.a. |
| Switzerland | 1984 | 1.16 | 1.39 |

**Table 1 Daily travel time budget per person and traveler for a number of Western European countries. Source: DIW (1993), GFV (1986), Orfeuil and Salomon (1993), DOT (1994), Vliet (1994). n.a. not available.**

There is only very limited data on travel money and time budgets available for inhabitants of developing countries and some of which have been found contradictory. Thus, we assume that the average traveler in less developing countries behaves like one in OECD countries from a certain per capita GDP on.

It has to be stressed again that both budgets represent the average of individual behavior with completely different preferences and are the mean of distribution functions. Thus there is still disagreement among transport researchers concerning the validity of fixed budgets of travel time and money: while one group of researchers is searching for stability at very aggregate levels, the other group is seeking to (understand) variability at highly disaggregated levels (Kirby, 1981). Since this paper relates to very aggregate levels of data, we follow the first group and rely on a stability of both money and time budgets.

## 2.2. Traffic Volume

We have seen that travel expenses are a fixed share of household expenditures. Thus growing household income results in increasing expenditures on travel and consequently rises per capita mobility. This relationship seems to be universal, since all world regions are following one trajectory as illustrated in Figure 8. For practical reasons, purchasing power parity adjusted per capita GDP (UN, 1993a) has been used as an indicator of the average household income.

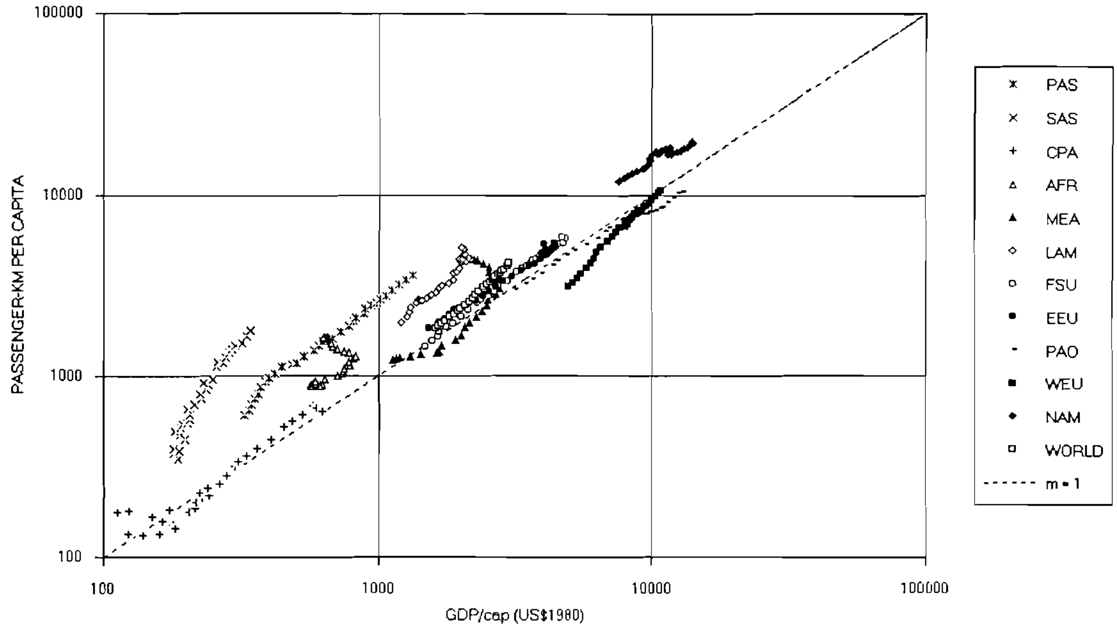

**Figure 8 Motorized mobility (car, bus, rail, and aircraft) per capita by world region versus GDP per capita between 1960 and 1990.**

As the MEA and AFR regions illustrate, this dependency applies also to economic stagnation and decline since the aggregated traffic volume decreased over the long term. The delaying response to decreasing per capita GDP can be explained by the fact that the existing transport systems, in which investments already occurred, are used throughout their useful lifetime; part of it won't be replaced thereafter. The relatively high mobility of the SAS region compared to the world development at a certain per capita GDP is caused by the purchasing power parity adjustments of the raw GDP data (in market exchange rates, current national currency). Tests with other macroeconomic data sets (Heston et al., 1993; UN, 1993b) suggest that SAS is in line with the world trajectory.

The quantitative relationship between per capita mobility and economic growth can be expressed by a simple linear approach

$$\frac{pkm}{cap} = m \cdot \frac{GDP}{cap} + b \qquad (1)$$

with $m$ being the slope and $b$ a constant. If $m$ equals unity, *pkm/cap* grows equally with *GDP/cap*, i.e., $m$ corresponds to an income elasticity one. For illustrative purposes, this case is shown in Figure 8 through the straight line $m = 1$ and $b = 0$. Seemingly this curve corresponds to the regional very long term trends. On the other hand, per capita mobility can be expressed by

$$\frac{pkm}{cap} = \frac{TCE}{cap} \cdot TMB \cdot \sigma \qquad (2)$$

*TCE* being total consumer expenditure, *TMB* the travel money budget, and $\sigma$ a factor representing the average inverse consumer costs of transport with unit km/\$. Thus

$$m = \frac{TCE}{GDP} \cdot TMB \cdot \sigma \qquad (3)$$

with $b << GDP$. In the following, we assume the slope $m$, i.e., the product of the right hand side of equation (3) to be constant over a short to medium term time horizon[3].

What are the implications of that dependency? Given a global per capita GDP of \$(1980) 3000 in 1990 and an average annual growth rate of two percent (such as between 1960 and 1990), per capita GDP will be about \$(1980) 5400 in 2020. Equation (1) suggests that the 1990 global motorized mobility per capita will almost double by 2020[4]. In light of a world population increasing by 50 percent by 2020, absolute motorized mobility will increase by a factor of three[5]. Most of the projected growth will occur in developing countries, especially in the SAS, PAS, and CPA regions, where high economic growth rates suggest significant mobility increases: based on an average annual growth rate in per capita GDP of 4 percent, CPA mobility will increase from 635 km per capita in 1990 to 2430 km per capita in 2020[6], an almost four-fold increase. Longer term estimates have to be based on individual regions rather than on the world trajectory alone, because of the slightly different slopes of the regional trajectories. Consequently, the world trajectory will be rather non-linear on the very long term.

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[3] As long term data series of most world regions suggest, *TCE/GDP* slightly decreases with increasing level of economic development (UN, 1993a). For instance, in the OECD macro region *TCE/GDP* dropped from 67 percent in 1950 to 63 percent in 1960 and declined by merely 1 percentage point during the next 30 years, i.e., to 62 percent in 1990; globally it merely decreased from 63 percent in 1960 to 61 percent in 1990. As illustrated in Figure 7, the travel money budget increases up to motorization levels of about 200 cars per 1000 capita and levels off thereafter. On the other hand, $\sigma$ decreases with increasing motorization rate since the km-specific consumer costs are higher for cars than for buses and the inverse consumer costs thus result in lower values of km/\$. At higher motorization rates most of the traffic volume is covered by passenger cars and thus lower fares of bus traffic weigh less; therefore we can expect the inverse unit costs to level off as well. Consequently there is good evidence that the product of TMB and $\sigma$ remains approximately constant at all motorization rates, i.e., over time. Assuming that the changes in *TCE/GDP* will be also minor in future, $m$ can be considered to be approximately constant over short to medium periods.

[4] The regression equation is pkm/cap = 1.715*GDP/cap - 1026, $R^2 = 0.99$

[5] Both U.N. medium population projection and World Bank forecast a 50 percent increase of 1990 world population by 2020 (U.N., 1992; Bos et al., 1992)

[6] The regression equation is pkm/cap = 1.242*GDP/cap - 65.4, $R^2 = 0.97$

## 2.3 Modal Split Changes

As has been shown in Figure 8, increasing per capita GDP generates a (predictable) growth in per capita motorized mobility. In addition, each traveler has a fixed travel time budget, i.e., merely spends somewhat more than one hour a day for travel on average as illustrated in Table 1. Consequently increasing mobility must cause a change in the modal split towards more flexible and faster transport systems, able to cope with increasing transport demand at the same travel time available. Thus, the higher per capita GDP, the faster and more flexible the transport infrastructure. This is the dynamic element of the scenario.

This relationship is shown in Figure 9 for the SAS, PAS, and MEA regions. At low levels of economic development, collective vehicles account for virtually all transport services as seen in the SAS region. Before 1960 railways dominated the transport sector. As economic progress occurred, buses became the primary mode of transport due to their greater flexibility, i.e., lower travel time. Today, individual and high speed transport means account for less than 10 percent of total passenger-km and serve only a small share of the population. The PAS region illustrates that as per capita GDP grows, the share of bus passenger-km saturates due to the faster increasing traffic volume of passenger cars and aircraft. The MEA region shows that further economic growth results in the replacement of bus services by passenger car traffic since cars provide significantly higher mobility levels.

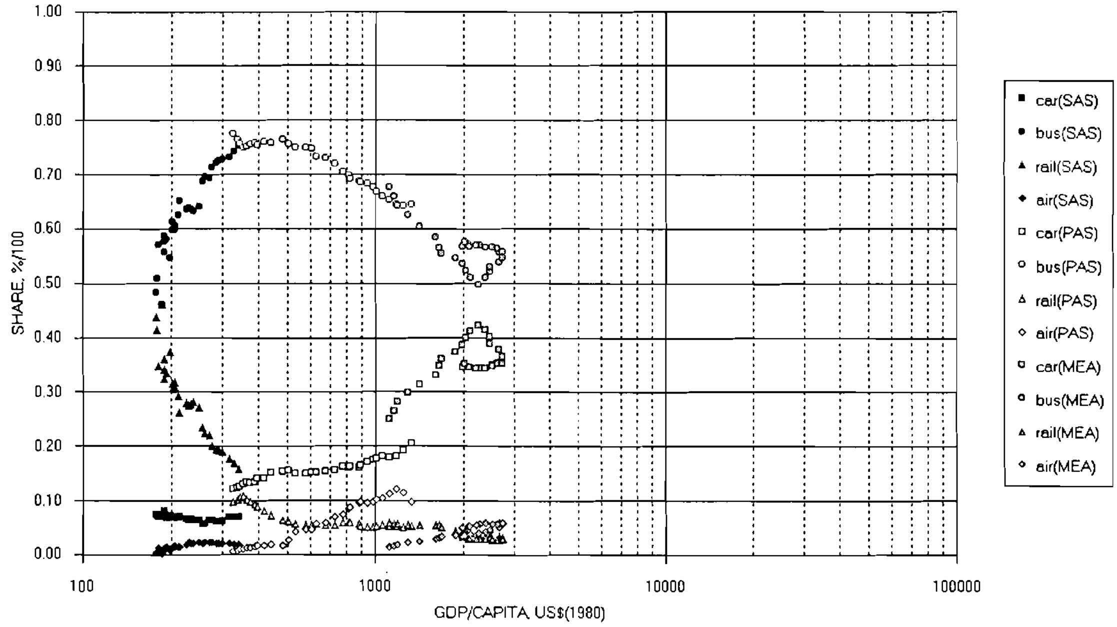

**Figure 9 Modal split versus GDP per capita between 1960 and 1990 for three world regions, i.e., SAS, PAS, and MEA.**

As illustrated in Figure 10 the same development occurred in EEU. While passenger cars become the dominant transport mode, the share of buses and railways further declines; high speed transport systems still have a negligible market share. It is likely that the EEU path will follow the WEU path as seen in the same figure. The share of traffic volume from passenger cars peaks at some 70 percent, while air traffic further increases, meanwhile rail and bus services maintain a low share in special market niches (mainly high density population areas). In Figure 10, high-speed rail has been aggregated to aircraft due to the similar quality of service.

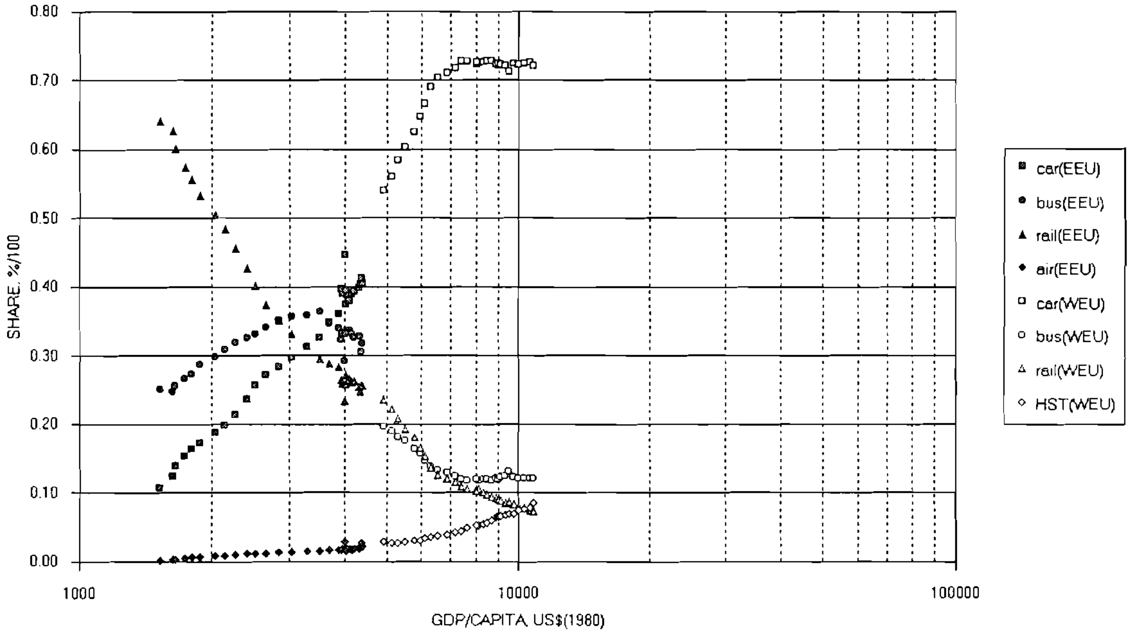

**Figure 10 Modal split versus GDP per capita between 1960 and 1990 for two world regions, i.e., EEU and WEU: cars, buses, railways, and high speed transport means (aircraft and high speed trains).**

A similar development is shown in Figure 11 for the PAO region, which is dominated by Japanese travel. The share of railway traffic dropped from 60 percent in 1960 to some 20 percent of total passenger-km in 1990 (high speed trains have been aggregated with aircraft to a high speed transport category). The traffic volume of high speed transport means has just exceeded that of buses; a further increase of their share will cause a saturation of the share of passenger car traffic volume. A more extreme picture exists for NAM where virtually all passenger traffic is split between passenger cars and aircraft (Figure 12). Air traffic, offering still greater mobility through significantly higher speeds, is strongly increasing its market share at the expense of passenger cars. The same figure shows that LAM may develop like NAM.

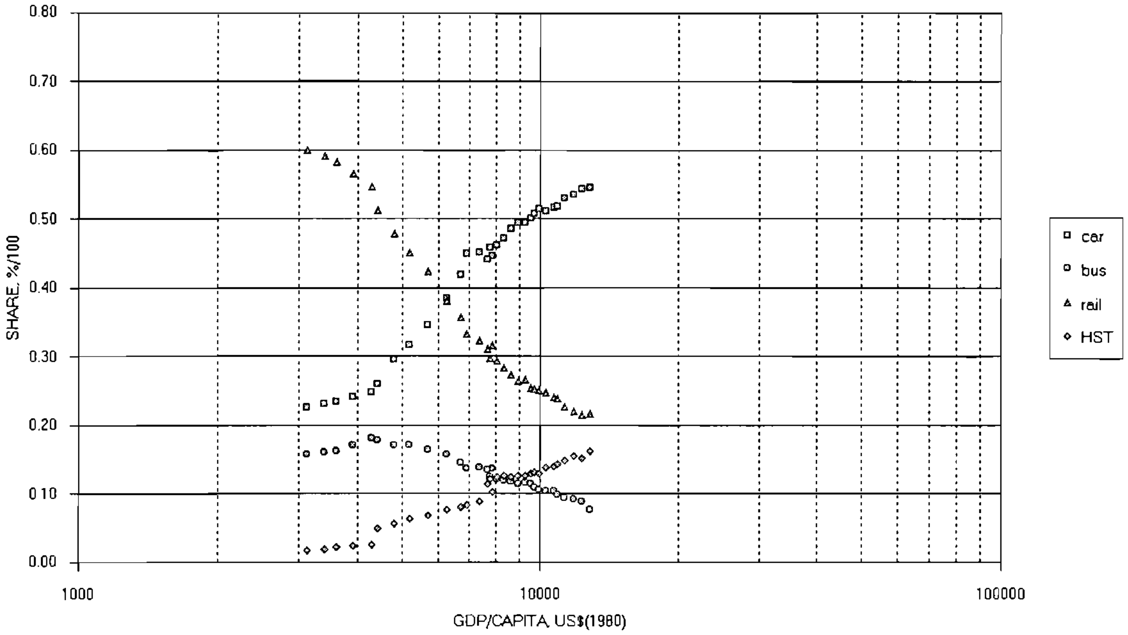

Figure 11 Modal split versus GDP per capita between 1960 and 1990 for the PAO region: cars, buses, railways, and high speed transport means (aircraft and high speed trains).

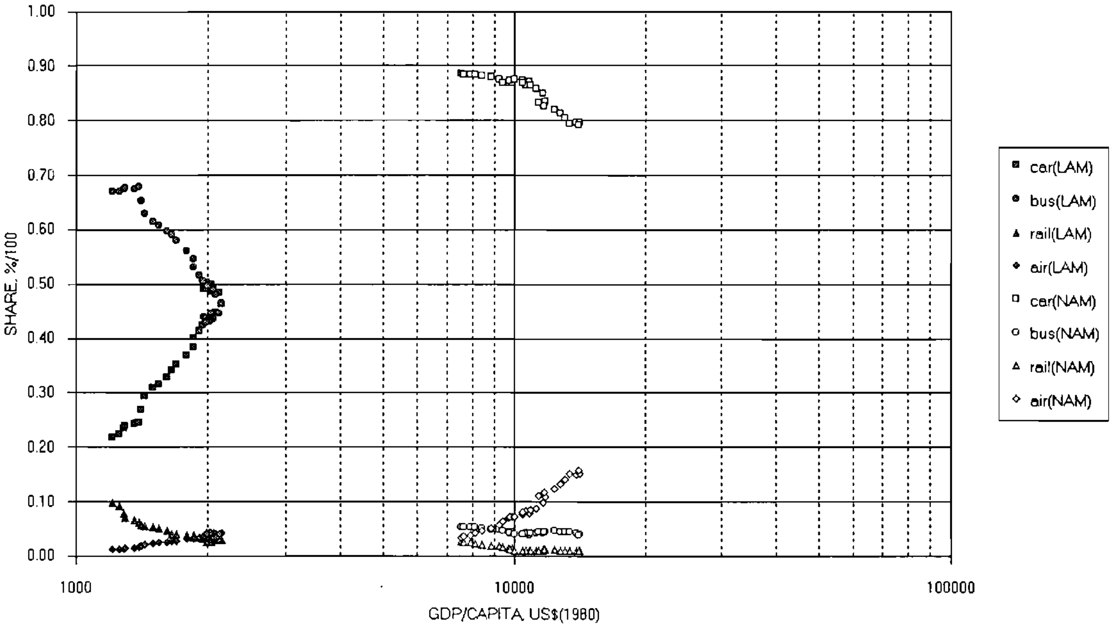

Figure 12 Modal split versus GDP per capita between 1960 and 1990 for two world regions, i.e., LAM and NAM.

How do regional modal splits compare to the world as a whole? At first glance, Figure 13 seems counterintuitive. Though the share of railway traffic volume decreases and that of air services increases, the share of bus traffic volume partially replaced that of passenger cars - despite the lower mobility potential. This contradiction is resolved if one recalls the 'phase-displacement' among the region's modal splits with respect to per capita GDP and time: Figure 2 and 3 show a stronger increase of global bus traffic compared to the traffic volume of passenger cars. This development was favored by the beginning saturation (PAO) and already decreasing share of passenger car traffic volume (WEU, NAM) in the OECD regions (Figure 10-12).

Figure 13 further extends the global modal split until 2020, based on an average annual growth rate in per capita GDP of two percent. The figure only presents a rough estimate since a thorough forecast requires *regional* modal split projections. The latter have to be based on regional projections of economic development and have to satisfy several constraints such as constant travel time budgets and similar modal split developments as preceding world regions[7].

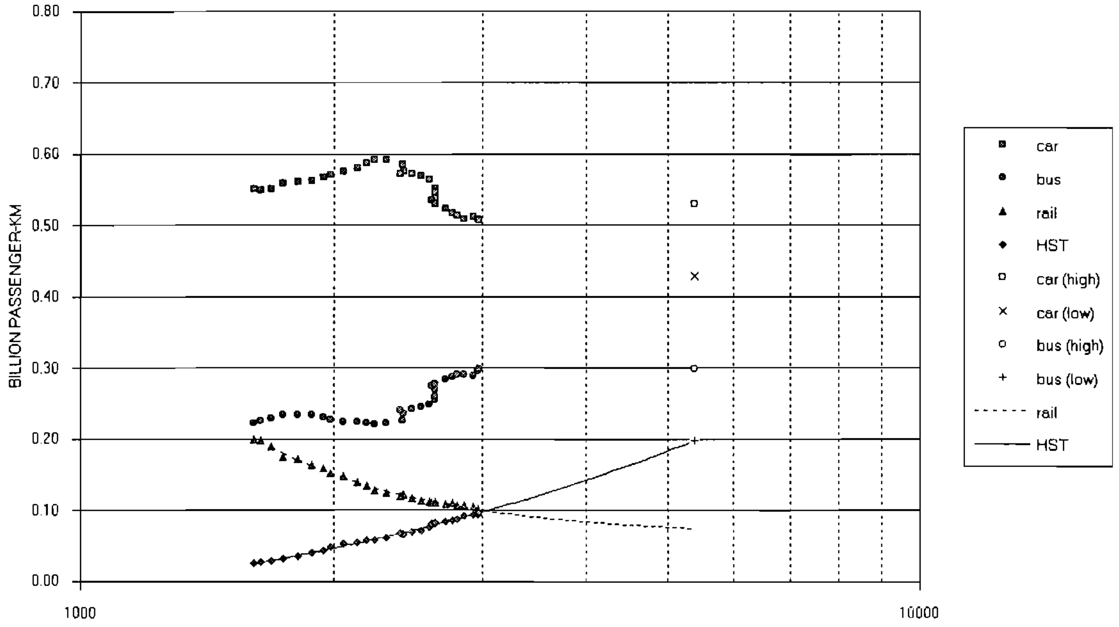

**Figure 13 World modal split versus GDP per capita between 1960 and 1990 and the likely further development until 2020.**

The estimate presented here has been done as follows. Since the share of high speed transport systems (aircraft and high speed trains) and railways show the same

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[7] While the former constraint applies to the three leading regions NAM, WEU, and PAO, for which we assume the travel time budget to remain approximately constant, the latter constraint relates to all other regions. It is because higher levels of per capita mobility require a minimum share of flexible and high speed transport means which can be derived from the leading regions.

development throughout all world regions, they are extrapolated using a simple logistic and hyperbolic fit, respectively. As a result aircraft traffic volume may account for 20 percent and railway traffic volume for merely 7 percent of global passenger-km by 2020. Due to the phase-displacement, the share of car and bus traffic volume has been estimated as a range. An interregional comparison shows that the share of bus traffic may increase in CPA (see Appendix 2) and SAS from some 60 and 75 percent to about 80 percent of total passenger-km in 2020. In all other world regions, the share of bus passenger-km either saturates (including FSU which is like AFR and CPA shown in Appendix 2) or declines. This suggests that the share of bus traffic volume will gradually decrease. As a first estimate we assume the share of bus traffic to be between two limits, i.e., to remain at the 1990 level of 30 percent (bus/high) or to decrease by 10 percentage points (bus/low). Consequently the share of car traffic will range from 43 percent (car/low) to 53 percent (car/high) of total passenger-km. Putting this into perspective of a three fold increase of the absolute motorized mobility, absolute passenger car traffic will grow by a factor of 2.4 to 3.0, bus traffic by 2.9 to 1.9, railway traffic by 2.1, and high speed traffic (aircraft and high speed trains) by 6.3. The latter estimate has to be seen in the perspective of US aircraft manufacturers forecast of a four fold increase in air traffic by 2020 (Covert *et al.*, 1992).

## 2.4 Consistency Check: The Global Motorization Rate in 2020

In contrast to conventional transport forecasts, where motorization rates are an *input* variable into the forecasting model, this method provides motorization rates as an *output* variable. For that purpose we assume an average rate of 31,000 passenger-km per automobile, comparable to the global 1960 number (see Section 1). This number is higher than the 1990 figure, since it is based on both higher load factors and higher vehicle-km per automobile; it is therefore consistent with the strong increase in automobile travel in developing regions (see Figure 9). Based on this assumption, the global automobile fleet will consist of 0.9 to 1.1 billion cars in 2020, i.e., 2 to 2.5 times the 1990 level, depending on the range in automobile traffic volume of 42 to 52 percent. This figure translates to an increasing global motorization rate from 84 cars per 1000 capita in 1990 to a number between 114 and 141 in 2020. Figure 14 shows that this range is well in line with the historical development.

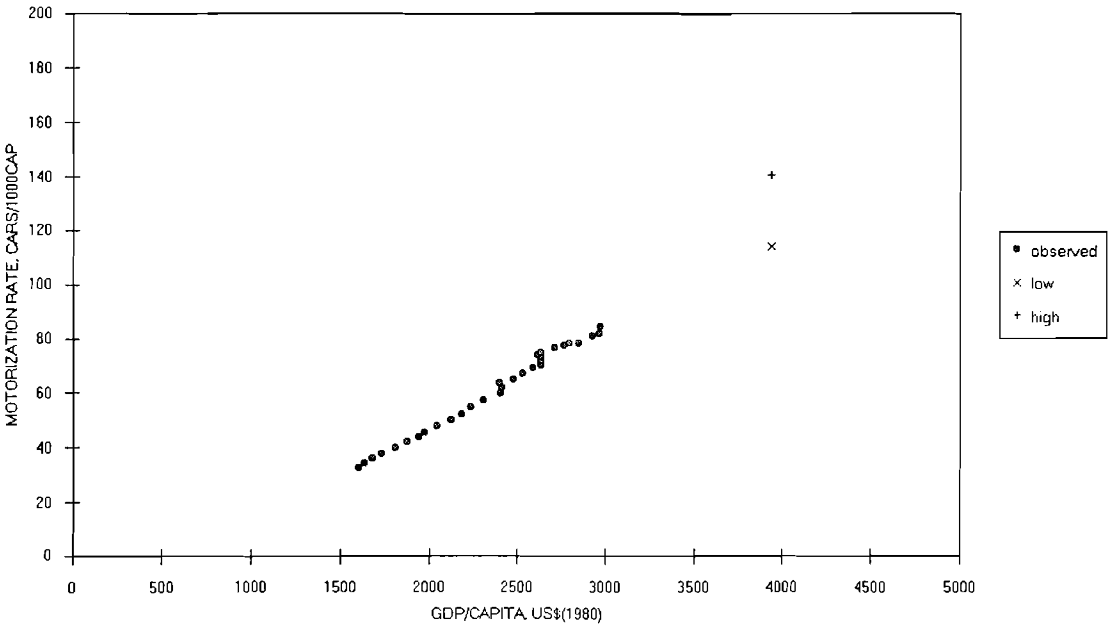

**Figure 14 Global motorization rate between 1960 and 1990 and the estimated range in 2020 as an output of the scenario.**

## 3. Impact on Energy Consumption

We have already seen that a two percent annual growth rate in world per capita GDP may result in a doubling of global motorized mobility per capita. However, this doubling of motorized mobility does not mean a doubling of per capita energy consumption. Rather energy consumption is also determined by the weighted change in transport mode energy intensities due to modal split changes. The EEU region serves as an example for such an estimate. Thereafter, a rough estimate will be given for the world.

EEU motorized mobility may reach 10,500 passenger-km per capita by 2020 (i.e., the 1990 level of WEU), given an average annual per capita GDP growth rate of 2.6 percent. Figure 10 suggests that such a mobility increase can be achieved by following the WEU modal split between 1960 and 1990. The share of traffic volume of passenger cars would increase by almost 60 percent, that of buses and railways would be reduced by two-thirds, and air traffic would increase by a factor of three. Energy use and carbon emissions would rise by 25 percent per passenger-km from modal split changes alone, utilizing a constant ratio in primary energy per passenger-km of 4 : 2 : 1.3 :1[8] for EEU aircraft, passenger cars, railways and buses[9].

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[8] This estimate is based on a variety of sources. The major sources are IEA (1992), DIW (1991), Davis and Strang (1993), EPA (1991) as well as the database described in the Appendix.

[9] For this estimate specific energy consumption as measured in MJ/passenger-km was kept constant for each mode. That is a justifiable simplification, given that the reduction in load factors may offset efficiency

Multiplying this constant ratio by the increase in per capita mobility, one finds that the total passenger transport energy use and carbon emissions would increase by a factor of 2.5 per capita.

Essentially the same estimate can be done for the world as a whole. Calculating a primary energy ratio of 5 : 3.5 : 1.5 : 1[10] for aircraft, passenger cars, railways and buses, the increase in primary energy consumption per passenger-km will be 8 to 17 percent (depending on the scenario for the share of car traffic volume being between 42 and 52 percent). Based on a doubling of per capita mobility, per capita energy use will increase by a factor of 2.2 to 2.3. If also taking into account an increasing world population by 50 percent, global energy use and carbon emissions from passenger transport may increase by a factor of 3.2 to 3.5 based on 1990 levels[11].

## 4. Conclusion

During the past 30 years, global motorized mobility per capita has more than doubled. Though the highest relative increase has occurred in developing regions, huge gaps in mobility still exist among different world regions (higher than a factor of 30): OECD countries merely represent 16 percent of the world population but account for 50 percent of global traffic volume. That discrepancy, however, will decrease further during the next century.

This is because economic development is a driving force for increasing motorized mobility. Since all world regions are roughly following one trajectory between per capita mobility and economic development, economic growth rates will determine future mobility levels. High growth rates of GDP per capita in primarily Far Eastern countries will result in more balanced per capita mobility levels among the world regions. Based on a linear relation between per capita GDP and per capita mobility (i.e., a constant product of total consumer expenditure to GDP times travel money budget times inverse consumer transport costs), global per capita mobility will double by 2020 given an annual increase in GDP per capita of two percent. In light of an increasing world population of 50 percent, global mobility will grow by a factor of three.

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improvements. In 1990, average occupancy rates in Eastern Europe were as follows: 234 passengers per train, 27 passengers per bus and 2 passengers per car. On the other hand there were 132 passengers per train, 21 passengers per bus and 1.7 passengers per car in Western Europe (UN, 1992 and 1993 as well as own estimates). This suggests that primary energy consumption of Eastern European trains are expected to be reduced by some 40 percent, that of buses by some 20 percent and that of cars by 15 percent by 2020.

[10] This estimate is based on a variety of sources and has been derived on a regional basis. The major sources are IEA (1992), DIW (1991), Davis and Strang (1993), SSB (1992), TERI (1992), EPA (1991) as well as the database described in the Appendix.

[11] As with EEU, it is assumed as a first approximation that specific energy use per passenger-km remains constant for each mode.

The necessity to keep on the mobility path requires the switch from a less flexible or slower transport mean to more flexible or faster transport systems, given a fixed travel time budget. Thus, economic development can be considered as being the cause for changes in the model split too. The evolution of modal splits appears to be a substitution process over per capita GDP, i.e., from railways to buses to cars and aircraft in all world regions.

Based on a preliminary estimate, a likely modal split (42 to 52 percent car, 30 to 20 percent bus, 7 percent railways and 21 percent high speed transport means, i.e. aircraft and high speed trains), will increase energy use per passenger-km by 8 to 17 percent. The total effect of higher mobility, a more energy intensive modal split and an increasing world population by 50 percent suggests an increase of 3.2 to 3.5 in energy use and emissions from global passenger transport.

*Acknowledgments*

This paper benefits a lot from discussions with David Victor. The comments of Leo Schrattenholzer, Clas-Otto Wene, and Harry Geerlings on an earlier draft are highly appreciated. Special thanks go to Lucy Nolan for her assistance in editing earlier drafts.

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# Appendix 1
## Data Description

This Appendix summarizes the data sources and estimation procedures. The data was double checked with national statistical abstracts wherever possible. Though excellent agreement existed in most of the cases, a few discrepancies existed which were solved in all cases. Minor data inconsistencies of less than 0.5 percent of regional passenger-km are not discussed. All population and GDP data were derived from UN (1993a).

### *Air Traffic*

While *scheduled* passenger-km were taken from ICAO statistics (UN, 1972, 1974, 1977, 1983/84, 1990/91), those from *charter* flights are based on IATA statistics (IATA, 1960 - 1991) and allocated to the regions in proportion to scheduled traffic. The regional disaggregation of 1960 data (scheduled and charter) is based on IATA. Data between 1960 and 1968 were linearly interpolated, with the exception of the FSU and NAM country USA, where country statistics were used (SCS, 1973, 1977, 1980, 1985, 1988, 1989; USDOC, 1975).

### *Road Traffic*

Road Traffic includes passenger cars and buses. As already stated, two- and three-wheelers are excluded from the analysis.

### NAM

Since no data on Canadian road traffic volume was available, all numbers were derived from the US and extrapolated to Canada on a per capita basis, as the US population accounts for about 90 percent of NAM population. US vehicle-km of passenger cars were taken from Highway Statistics (U.S.DOT, 1970-1991) and USDOC (1975). Car occupancy rates were taken from the Nationwide Personal Transportation Surveys 1977, 1983, and 1990 (Hu and Young, 1992). Since there exist no numbers before 1977, an occupancy rate of 2 people per car was estimated for 1960 as it was in Germany (DIW, 1991). Data from intermediate years were interpolated. Bus passenger-km account for intercity buses (ENO, 1992), urban buses (APTA, 1992a,b), and school buses. Passenger-km of urban buses before 1978 were estimated using the following equation ($pkm$ = passenger-km, $NoT$ = given number of trips, $d$ = trip distance, $\delta$ = average distance):

$$pkm = \sum_i NoT_i \cdot d_i = \delta \sum_i NoT_i = \delta \cdot NoT \qquad \text{(A-1)}$$

$\delta$ was assumed to be the mean value of the numbers between 1978 and 1990. Vehicle-km of school buses were derived from Highway Statistics (U.S.DOT, 1970-1991) and Transportation Energy Data Book (Davis and Strang, 1993). Since the occupancy rate was only available from 1990 on (Davis, 1994), it was assumed to be equal to the 1990 number, i.e., 19.4 passengers per bus, during the whole time horizon.

WEU

Car and bus passenger-km were based on the Annual Bulletin of Transport Statistics for Europe (UN, 1960-1993), IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992), and ECMT (1989). In addition, German, Switzerland, and Great Britain transport data were taken from national statistics (DIW, 1991; BFS, 1992; DOT 1977, 1983, 1985, 1993).

EEU

Automobile passenger-km estimates were based on country specific vehicle-km per car, the passenger car population and an occupancy rate decreasing from 2.5 in 1960 to 2.0 in 1990. Hungarian and Polish vehicle-km data were available from UN (1960-1993) and IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992); those of other EEU countries was estimated to be 10,000 km per car and year. In the case of Former Yugoslavia, UN and IRF statistics could be used directly. Bus passenger-km were derived from on the Annual Bulletin of Transport Statistics for Europe (UN, 1960-1993), IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992), and ECMT (1989). Data exclude Albania.

FSU

Traffic of privately owned passenger cars was based on the number of private vehicles, an average annual distance traveled of 10,000 km, and a car occupancy rate of 2.5 people during the whole time horizon. The passenger car population from 1970 on was taken from the statistical yearbook (SCS, 1973, 1977, 1980, 1985, 1988, 1989). For the decade before a linear increase from zero to the 1970 value was assumed. The same source provided the numbers for passenger-km from taxis and company vehicles. The average annual distance traveled of 10,000 km per car is based on an estimate of the International Energy Agency (IEA, 1990). As with the EEU region, the car occupancy rate was assumed to decrease from 2.5 to 2 people per car. Bus passenger-km were derived from the Annual Bulletin of Transport Statistics for Europe (UN, 1960-1993).

CPA

China accounts for more than 90 percent of the CPA population for the whole time horizon. Since sufficient data for the other CPA countries (except Hong Kong) was not available, Chinese road traffic data were extrapolated on a per capita basis. All data have been taken from the Chinese Statistical Yearbook (SSB, 1993). Data of urban bus transport was based on the Chinese urban bus fleet between 1960 and 1990 and the number of passengers per bus in 1990. Since the number of privately owned passenger cars was only 37,000 in 1992 (SSB, 1993), corresponding passenger-km were much less than one percent of CPA bus traffic. Therefore, they were excluded in the CPA region except Hong Kong. Hong Kong data were treated separately (IRF, (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992).

### SAS

Like CPA, Indian road transport data were extrapolated to the SAS region. India accounts for more than 75 percent of the SAS region during the 31 year time horizon. The primary data source was the TERI Energy Data Directory & Yearbook (TERI, 1992). Data were available for the years 1961, 1970, 1975 and 1980 to 1985. Intermediate years were exponentially interpolated. 1960 and 1985 to 1990 data were extrapolated based on the number of transport means for each category, assuming a constant vehicle-km and occupancy rate.

### PAO

Australian and New Zealand road traffic data were based on IRF statistics (IRF, 1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992). While missing passenger-km of intermediate years were interpolated, those before or after a series of given data were estimated based on the number of registered vehicles. The vehicle population was taken from IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992) and MVMA (1980, 1983, 1987, 1990, 1992, 1994). Japanese traffic data are taken from Japanese Statistical Yearbooks (SB, 1972-1992).

### LAM, MEA, and AFR

The traffic volume in these three regions was estimated based on the number of registered vehicles (IRF, 1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992 and MVMA, 1980, 1983, 1987, 1990, 1992, 1994), times an average occupancy rate and the annual distance driven per vehicle. The annual distance driven per car is a function of the motorization rate. With increasing levels of passenger car ownership, annual vehicle-km per car decrease and subsequently saturate between 10,000 and 16,000 km (the saturation level itself depends on a variety of parameters, such as travel time budget, travel money budget, relative costs of transport carriers, population density, availability of public means of transport, quality of service of mass transport systems, etc.). The decrease is because the first cars entering the market are bought due to a strong need; further vehicles are used as additional household cars and thus are driven less. The overall effect is a reduction in car specific annual km. Figure A-1 shows such a curve for Japan and Germany between for ownership rates ranging from 1 to 150 cars per 1000 capita (SB, 1972-1992 and DIW, 1991)[12]; saturation occurs at about 10,000 km per car in Japan and 13,000 km in Germany. The German curve was taken as the basis of estimate for annual vehicle-km per car in the LAM, MEA, and AFR region, due to lower population density and lack of competing rail infrastructure compared to Japan. This assumption is being confirmed by the data points of passenger cars operating in Israel which fit well with German numbers at motorization rates between 100 and 200 cars per 1000 capita. The average occupancy rate, which was selected to be 2.5 people per passenger car throughout the entire time horizon, is consistent with load factors measured in Indian urban traffic (TERI, 1993). Due to the higher motorization rate, the average automobile occupancy rate in LAM was assumed to decrease to 2 people per car during the 31 year time horizon.

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[12] These were the only reliable data available. Corresponding US statistics begin to report from 1936 (DOC, 1975); at that time, however, the motorization rate was already 189 cars per 1000 capita.

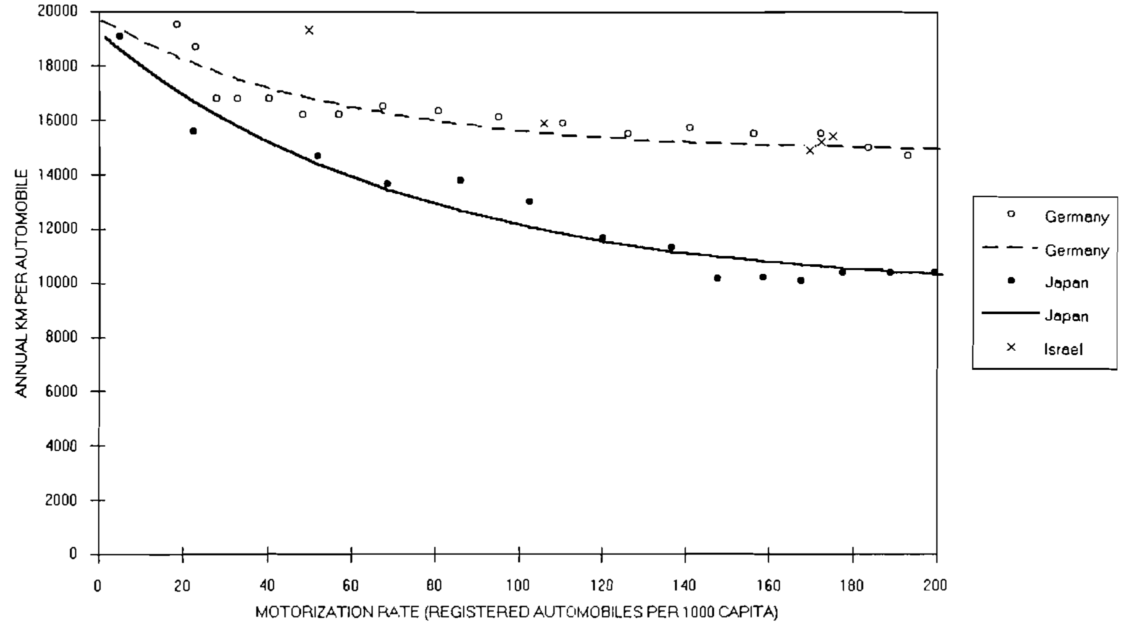

Figure A-1 Vehicle-km per car depending on automobile motorization rate in Japan, Germany, and Israel (SB, 1972-1992; DIW, 1991; CBSI, 1993). The plotted curves ($R^2 = 0.947$ for Japan and 0.819 for Germany) are of the type $y = \exp(-x)+C$.

Note the difference of Figure A-1 to the increase and subsequent saturation of the travel money budgt as a function of the motorization rate as shown in Figure 7. In Figure A-1, saturation occurs with an increasing share of *additional* household vehicles (irrespective of the diffusion level of first household vehicles). In contrast, the saturation of the travel money budget depends on the saturation of *first* household vehicles in Figure 7.

Table A-1 indicates the motorization rate and the annual distance driven per car as a result from the curve in Figure A-1 in 1960 and 1990 for the three regions LAM, MEA, and AFR.

| | Cars/1000cap | Occ. Rate | Ann. Dist. (km) |
|---|---|---|---|
| LAM | 11 - 86 | 2.5 - 2 | 18850 - 15850 |
| MEA | 6 - 36 | 2.5 | 19300 - 17400 |
| AFR | 6 - 13 | 2.5 | 19300 - 18800 |

Table A-1 Motorization rate, occupancy rate, and annual distance traveled per car in the LAM, MEA, and AFR region in 1960 and 1990. Source: IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992), MVMA (1980, 1983, 1987, 1990, 1992, 1994), and DIW (1991).

Similarly, the traffic volume of buses was estimated by the product of registered buses, the annual distance traveled per bus, and an average occupancy rate. As with passenger car traffic volume, the number of registered buses was taken from IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992) and MVMA (1980, 1983, 1987, 1990, 1992, 1994). The annual distance traveled per bus was derived from survey data published by the International Union of Public Transport (UITP, 1964, 1968, 1975, 1979, 1985/86). The same statistics were the basis of estimate for bus occupancy rates. In both cases it was assumed that intercity buses show identical characteristics like urban buses. Table A-2 illustrates the main numbers used.

| | Occ. Rate | Ann. Dist. (km) |
|---|---|---|
| LAM | 35 - 30 | 60000 |
| MEA | 40 | 60000 |
| AFR | 40 | 60000 |

**Table A-2 Estimates of occupancy rate and annual distance driven per bus between 1960 and 1990 in the LAM, MEA, and AFR region. Source: UITP (1964, 1968, 1975, 1979, 1985/86).**

PAS

The traffic volume of both passenger cars and buses is based on individual traffic data series of six countries representing 90 percent of the PAS population, i.e., Indonesia, South Korea, Malaysia, Philippines, Taiwan, and Thailand. The main sources concerning the number of registered vehicles have been Statistical Abstracts, i.e., for Indonesia (BPS, 1986, 1993), for South Korea (NSOK, 1978, 1984, 1994), for Malaysia (DOS, 1986, 1994), for the Philippines (NSOP, 1980, 1986, 1988, 1989, 1990, 1992), for Taiwan (CEPD, 1987 and SBW, 1986), and for Thailand (NSOT, 1970-1071, 1981-1984, 1993). In addition, IRF (1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992) and MVMA (1980, 1983, 1987, 1990, 1992, 1994) statistics have been used. Contrary to the LAM, MEA, and AFR region, the annual distance driven per passenger car was derived from the Japanese development illustrated in Figure A-1. This is because Korean data essentially confirm lower mileage per passenger car. Due to the low motorization rate between 1960 and 1990 (ranging from 2 to 27 cars per 1000 capita), the occupancy rate was assumed to be 2.5 people per car, such as measured in Indian urban transport (TERI, 1993).

Bus traffic volume of Korea and Taiwan were obtained from Korean National Yearbooks and the Taiwanese Yearbooks (both cited above). Special attention has been dedicated to the distinction between normal sized buses and mini-buses. The latter, continuously increasing its market share in the past, currently accounts for about 85 percent of total registered buses. The separation is significant. Due to the lower carrying capacity and annual distance driven of mini-buses, load factor and average mileage per registered bus continuously decreased since 1960. The registered number of different bus sizes was merely reported in the Thailandese and - to some extend - in the Philippine statistical abstracts; thus the annual shares of normal and mini-buses in Indonesia and Malaysia were estimated based on the development in Thailand. The estimate of annual distance traveled per bus type and corresponding load factors were based on UITP statistics (1975, 1979, 1985/86). Again, it was assumed that intercity bus characteristics (in terms of annual distance driven per bus and bus occupancy rate) are identical to urban buses. Table A-3 summarizes the major parameters.

| | Occ. Rate | Ann. Dist. (km) |
|---|---|---|
| Normal sized Bus | 40 | 70000 |
| Minibus | 10 | 25000 |
| Jeepney (Philippines) | 10 | 15000 |

**Table A-3 Estimates of occupancy rate and annual distance driven for different public road vehicles between 1960 and 1990 in the PAS region. Source: UITP (1964, 1968, 1975, 1979, 1985/86).**

Estimates were double checked with other sources. Traffic measurements in rural roads on Jawa island (Indonesia) in 1989 as well as two travel surveys from 1972 and 1985 for Jakarta (VWS Karlsruhe, 1991, 1992) served as an independent mean for data check; Korean data were checked with KEEI (1995).

*Railways*

Railways include passenger-km from suburban and intercity transport. The major source were UN Statistical Yearbooks (UN, 1972, 1974, 1977, 1983/84, 1990/91) and the Annual Bulletin of Transport Statistics for Europe (UN, 1960 - 1994).

NAM

US intercity railway passenger-km were based on ENO (1992) and commuter railway traffic on APTA (1992a,b). Canadian railway passenger-km were taken from UN Statistical Yearbooks (UN, 1972, 1974, 1977, 1983/84, 1990/91).

WEU, EEU, FSU

Railway passenger-km were based on UN (1960-1993). These numbers include high speed rail transport in the WEU regions. Since the traffic volume of high speed rail is not explicitly indicated, its share was calculated from CER (1994).

MEA

Primary railway passenger-km sources were Mitchell (1982) and UN Statistical Yearbook (UN, 1972, 1974, 1977, 1983/84, 1990/91). In addition, compiled country statistics were used (SBW, 1989a,b, 1990, 1993). The data contain one inconsistency. Passenger-km in Sudan were zero between 1960 and 1980. The 1981 figure was 5.5 percent of regional passenger-km.

AFR

Primary railway passenger-km sources were Mitchell (1982), UN Statistical Yearbooks (UN, 1972, 1974, 1977, 1983/84, 1990/91) and FOS (1987). In addition, compiled country statistics were used (SBW, 1990a,b, 1991a,b, 1992a,b, 1993). More than half of all passenger-km relate to South Africa. South African passenger-km were estimated between 1960 and 1984 based on equation (A-1). The number of trips were taken from SBW (1968, 1974, 1981, 1985); the average distance was calculated to be 35 km in 1985. This fits well since by far most of the passenger-km were related to commuting from suburbs to city centers. Data inconsistencies were primarily due to changes in the aggregation level. Swaziland: first reported passenger-km in 1981 (2.7 percent of total); Tanzania: first reported passenger-km in 1981 (1.7 percent of total); Uganda: first reported passenger-km in 1981 (0.6 percent of total). Moreover, there were no numbers available related to passenger-km in Mauritania.

### CPA

CPA primary railway passenger-km source was the Chinese Statistical Yearbook (SSB, 1993) and UN Statistical Yearbook (UN, 1972, 1974, 1977, 1983/84, 1990/91). In addition, compiled country statistics were used (SBW, 1991, 1992, 1993).

### LAM, SAS, PAS

The primary railway passenger-km sources were Mitchell (1982) and UN Statistical Yearbook (UN, 1972, 1974, 1977, 1983/84, 1990/91). In addition, compiled country statistics have been used (SBW, 1989, 1990, 1991, 1992a,b,c, ).

### PAO

Australian railway passenger-km data were taken from IRF statistics (IRF, 1965, 1970, 1973, 1976, 1980, 1985, 1990, 1992) for the years 1963 to 1968 and 1988 after having cross-checked them with Australian Yearbooks (ABS, 1965, 1970, 1975, 1980, 1985, 1990, 1992). While railway passenger-km from intermediate years were linearly interpolated, the 1989 and 1990 figures were assumed to be identical to the 1988 passenger-km. New Zealand's railway traffic volume was taken from the UN Statistical Yearbook (UN, 1972, 1974, 1977, 1983/84, 1990/91). Japan's railway passenger-km data were taken from Japanese Statistical Yearbooks (SB, 1972-1992).

### *Urban Railways (Light and Heavy Rail)*

Data on tramways and subways have been generally derived from statistical abstracts, UITP Handbooks of Public Transport (UITP, 1964, 1968, 1975, 1979, 1985/86), and data collected by Newman and Kenworthy (1991). Since the latter two references merely publish data of individual years, intermediate years had to be interpolated. In a number of cases there were no data available between 1983 and 1990. Then the 1983 level was assumed to be constant through 1990 which may sometimes result in a slightly underestimated traffic volume. Most travel data are published in terms of passengers carried. To obtain passenger-km they have to be multiplied with an average travel distance (see equation A-1). While the mean travel distances are most often available for subways, they were assumed to be 3.5 km for tramways unless individual numbers were given.

NAM

Data have been taken from US APTA (1992a,b) and extrapolated to the NAM region on a population basis. Passenger-km were estimated from 1960 to 1978 according to equation (A-1).

LAM

Urban rail primarily includes subways operating in Argentine, Brazil, Chile, Mexico, and Venezuela. In addition, tramways operating in a few Mexican cities are included. Besides statistical yearbooks of Mexico (INEGI, 1993) and Venezuela (OCEI, 1992), the major source of information were the UITP Handbooks of Public Transport (UITP, 1975, 1979, 1985/86).

WEU

Statistical abstracts for the WEU region include those of Portugal (INEP, 1981, 1991, 1993), Spain (INEE, 1961, 1971, 1981, 1991, 1993), Belgium (INS, 1961, 1966, 1975, 1977, 1979, 1981, 1986, 1991), France (INSEE, 1981, 1991, 1993), Netherlands (CBS, 1964), Austria (ÖSZ, 1961 - 1991), and German Democratic Republic (SA, 1977, 1990). In addition, national transport statistics have been used from Switzerland (BFS, 1992), Germany (DIW, 1991), and Great Britain (1977, 1983, 1985, 1993). Additional data sources were UITP (1964, 1968, 1975, 1979, 1985/86) and Newman and Kenworthy (1991).

EEU

Statistical abstracts for the EEU region include that of the former Czechoslovakia (FSO, 1965, 1970, 1975, 1980, 1985, 1977, 1982, 1991), Poland (CSOP, 1967, 1975, 1980, 1983, 1992), Hungary (HCSO, 1961, 1966, 1971, 1975, 1980, 1981, 1986, 1987, 1990), Bulgaria (NSI, 1974, 1991, 1993), Romania (NCS, 1976, 1994), and former Yugoslavia (FSOY, 1993). Additional data has been derived from the Historical Statistics of former Czechoslovakia (FSO, 1985) and from UITP Handbooks of Public Transport (UITP, 1964, 1968, 1975, 1979, 1985/86).

FSU

Urban tram and subway traffic were taken from SCS (1973, 1977, 1980, 1985, 1988, 1989). The traffic volume between 1960 and 1980 was estimated according to equation (A-1).

MEA, AFR, CPA, SAS

As suggested by UITP (1975, 1979, 1985/86), the traffic volume of urban rail measured at different years turned out to be negligible compared to intercity and suburban railway traffic .

PAS

The traffic volume of Korean subways was taken from NSOK (1978, 1984, 1994) and that of Manila elevated rail from NSOP (1988, 1989, 1990, 1992).

PAO

Besides Japanese Statistical Yearbooks (SB, 1972-1992), the traffic volume of urban railways has been derived from UITP Handbooks of Public Transport (UITP, 1964, 1968, 1975, 1979, 1985/86).

# Appendix 2

This Appendix includes the modal split curves for the regions FSU, AFR, and CPA. The three figures show a similar trend towards faster and more flexible transport systems with increasing per capita GDP.

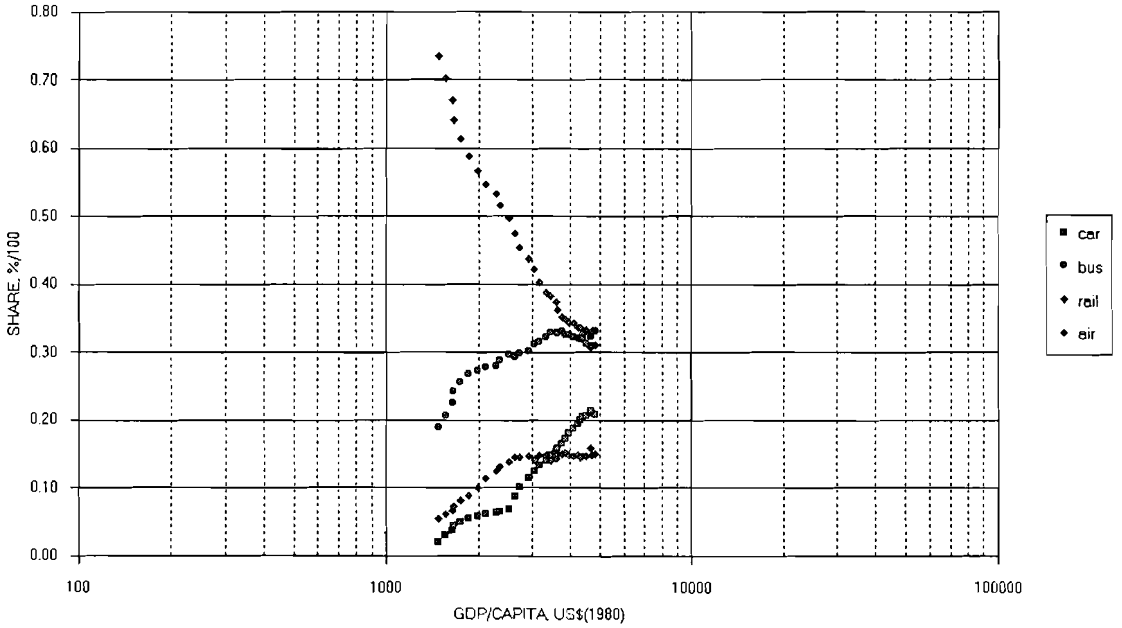

**Figure A-2 Modal split versus GDP per capita between 1960 and 1990 for the FSU region: cars, buses, railways, aircraft.**

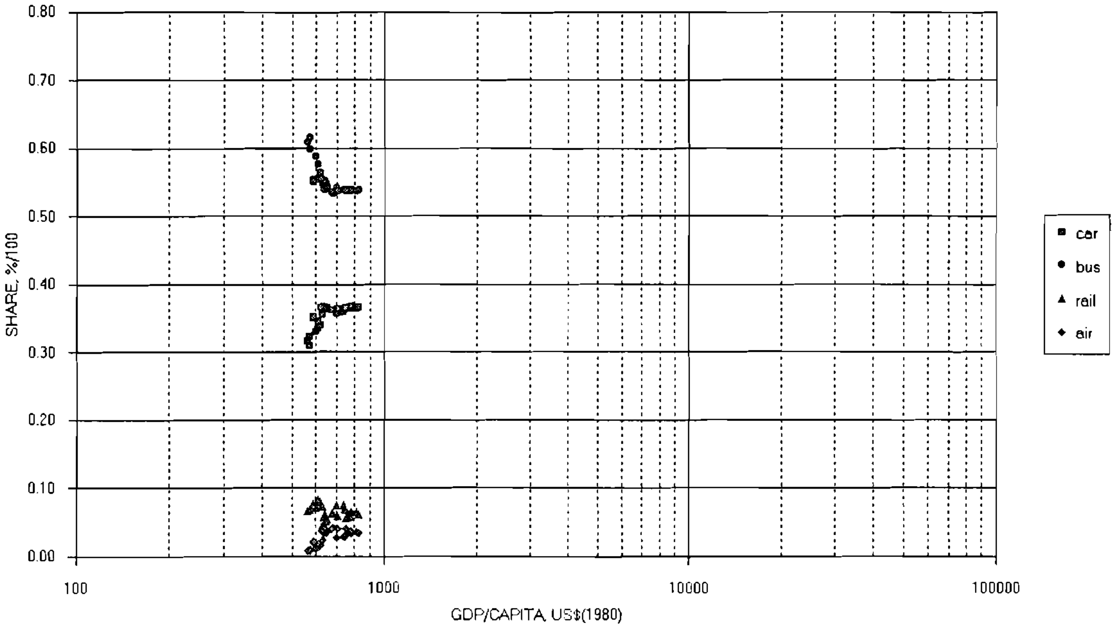

Figure A-3 Modal split versus GDP per capita between 1960 and 1990 for the AFR region: cars, buses, railways, aircraft.

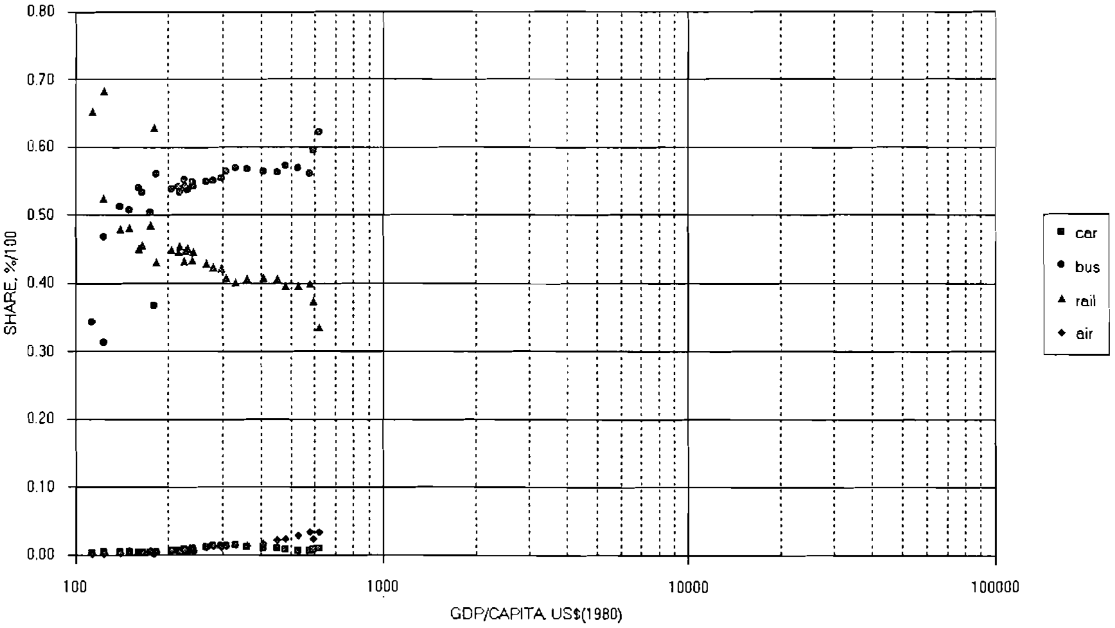

Figure A-4 Modal split versus GDP per capita between 1960 and 1990 for the CPA region: cars, buses, railways, aircraft.