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Global Long-Term Demand for Transportation

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Interim Report **IR-06-010**

Global Long-Term Demand for Transportation

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Approved by

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Contents

Abstract

This study deals with developing a framework for estimating transportation demand over the long term to 2100. The demand for passenger and freight transport over the past 30 years has been analyzed in order to identify trends that may be applicable to the future for 11 world regions. Each region has been investigated separately and region-specific attributes and correlation of traffic volume to the development of per capita income have been used to determine relationships between these two variables. The approach is introduced and preliminary results are presented and discussed.

Supervisor's note:

This analysis was conducted as part of IIASA's Young Scientist Summer Program (YSSP). This annual three-month program provides an opportunity for young scientists to join a research team in IIASA to work on a specific research project. Bastian Ruehle worked closely with two other YSSP participants in IIASA's Environmentally Compatible Energy Strategies Program on developing a new modeling tool for constructing future scenarios used to study challenges emerging in the energy system. Mr. Ruehle's work focused on studying and developing a methodology for generating scenarios of future transport demand.

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About the Author

Bastian Ruehle received his Masters degree in 2002 in Chemical Engineering at Chalmers University, Gothenburg (Sweden), where he was a member of the international masters program “Environmentally sustainable process technologies”.

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Global Long-Term Demand for Transportation

Bastian Ruehle

1 Introduction

Transport is essential for society, and in industrialized countries demand for motorized mobility has grown and evolved significantly over the last 30 years. Moreover, the transport sector, with its high dependency on carbon fuels, is expected to account for a significant share of future greenhouse gas emissions in developed countries, contributing to global climate change. However, about 70 % of world population lives in developing regions, where per capita travel demand is currently low. Future trends in mobility—both passenger and freight—in these regions will be of critical importance for the world's fuel supply and carbon dioxide (CO_2) emissions over the 21st century.

Many previous studies dealing with travel demand have tended to focus on a very detailed level and short time horizon, and are therefore of limited use for examining the long-term issues outlined above. This study takes a first step into analyzing the demand for motorized transport until 2100 on a global scale with a subdivision into 11 regions.

Transport is mostly an induced activity either by socio-cultural functions or by production activities, and can be assessed within these categories or as a separate system. Demand for transportation is not just a matter of movement of people and freight over certain distances, but also a matter of speed. For instance, the time people are willing to devote to travel appears to be rather constant, both historically and across different world regions Zahavi, 1974. Thanks to a speed increase by switching to faster modes the covered distances increase while the total time spent remains constant.

The spatial organization of production and exchange of goods is a major influence on the distance over which goods are moved. Moreover, the speed for the delivery of goods depends on the stage of the production process and the required degree of logistics. Therefore, the basic issue in the assessment of the needs for energy services for freight transportation is the following: which transport infrastructure, which modes and which transport organization can keep pace with globalization of the exchange of goods (and services), the increased demand for high-speed delivery, and the long-term increase of the value of goods transported.

For the described work within the **transport sector**, invariants considered in the modeling work are the following:

For passenger transportation, the average time used in transportation per person is assumed to remain constant following the approach of Zahavi and Talvitie, 1980. The theory is based on the assumption that people have a fixed travel time budget. The demand and opportunities for traveling increase with higher incomes. Therefore, it appears obvious, that an increasing travel demand with a fixed time budget requires faster modes of transportation. Parallel to this, people are willing to spend only a certain share of their income on travel. Accordingly, these two concepts are represented with the assumption that the financial share of income and the total time stay constant independently from the wealth of a society.

For each world region there is a single time independent function to link passenger transportation speed with per capita income, for each transportation mode, including cars. This implies a direct relationship between income and traffic volume.

For freight transportation, there is also a single time independent function for each world region linking the freight traffic per inhabitant with the total physical production volume per capita. For this study the production volume has been replaced by the income (GDP per capita). For future development of the projections described here it is advisable to link the physical output of a region's industry and commercial sector to the freight traffic volume.

2 Analysis of historical data

The availability of historical data on passenger transport demand in terms of passenger-kilometers varies significantly between different countries. This is partly because measuring passenger-kilometers is a challenging task, and requires an extensive data investigation, since load factors and efficiencies of cars and other forms of passenger transport are difficult to monitor.

In particular, the traffic volume of the motorized private vehicles can often be only estimated. This applies especially to developing regions, where statistical agencies often do not have sufficient resources to collect reliable data, and in regions, which are inhomogeneous or have undergone major social and political changes.

Therefore for developing regions, traffic volume was derived from fuel consumption statistics and vehicle registrations data (AAMA, 1997; AAMA, 1996). For some regions, estimates to 2000 were derived from previous studies, including those carried out at IIASA (Schäfer, 1995). These data were updated based on fuel consumption trends (IEA, 2003).

Within the IIASA-ECS modeling framework the world is subdivided into 11 world regions, as illustrated in Appendix A. These include five industrialized regions (with three-letter abbreviations):

- North America NAM
- Western Europe WEU
- Pacific OECD PAO
- Central and Eastern Europe EEU
- Former Soviet Union FSU

And six developing regions:

- Centrally Planned Asia CPA
- South Asia SAS
- Other Pacific Asia PAS
- Latin America & Caribean LAM
- Middle East & North Africa MEA
- Sub Saharan Africa AFR

Traffic volume data were collected or derived for each region. North American, Western European and Pacific OECD (PAO) traffic volume data are readily available (OECD, 2003; Japan, 2003). Elsewhere where reliable data were not available, traffic volume data was derived from other statistical sources, such as from estimates of fuel consumption in the transportation sector. Recent trends until the year 2000 were derived according to the fuel use within the transportation sector (IEA, 2003). This has been carried out for all remaining world regions for passenger transport. As a base, the figures for aggregated traffic volume from an earlier study (Schafer, 1998) have been used until 1990. The trend for the remaining years until 2001 was derived and aggregated from the fuel consumptions within a region.

One of the key factors affecting demand for transport and traffic volume development is economic growth. The GDP of a country can be seen as an indicator of the material prosperity of a society. For the historic analysis, data on GDP in US$(2000) for each country was aggregated to produce estimates of GDP for the each world region.

The collection and derivation of the data discussed above represents an important first outcome from this work, and Appendix B outlines the availability of this data in accompanying spreadsheet files.

3 Estimating possible future trends in transport demand

To estimate trends and thereby construct reasonable and plausible scenarios for the long term future one has to investigate the crucial factors driving the variables of interest. This decreases the uncertainty and bases the analysis on a plausible causal chain. The key driving force for the development of the traffic volume is income. Two additional factors which strongly influence the character of transportation demand are the modal split and the division of distances into short and long distance traveling. The latter are considered for passenger transport only in this analysis. Based on these factors, the following sections describe a number of alternative approaches for estimating future travel demand. The combination of these approaches applied to each world region is discussed in Section 3.3, whereas Appendix B describes the location of specific data and projections in accompanying spreadsheet files.

3.1 Passenger transportation

3.1.1 Estimating future modal choice

A common approach to determine the modal split in a transportation forecast for an urban or disaggregated region is described by Oppenheim, 1995, who suggests that the modal split is mainly a function of the aggregate attractiveness of different modes to each individual. Since data for the attractiveness is difficult to obtain, the speed of a mode can be seen as a major factor of attractiveness. Given that faster modes of transport are generally more expensive, this implies that a trend of increasing income will result in a shift towards faster modes, which is consistent with the approach described by (Schäfer, 1998).

According to (Schäfer, 2000) distance is also a significant factor affecting modal choice. Figure 1 above illustrates estimated crucial thresholds for changes in modal split. The first of these coincides roughly with distance that can be traveled with 30 minutes of walking, representing 2-3 kilometers. However, in industrialized and motorized societies the automobile plays a significant role already for short distances. The second threshold coincides with the distance that can be covered with 1-day of driving; about 700-800 kilometers. Beyond this point, air transportation clearly dominates and becomes the only possible mode at distances of more than 8,000 kilometers.

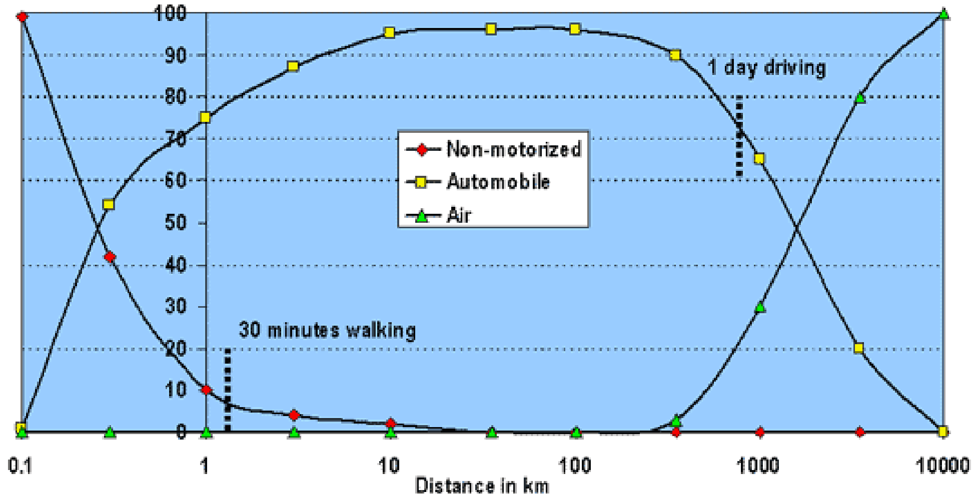


Figure 1: Modal Split in the United States by Passenger Travel Distance, 1995
Source: adapted from /Schäfer 2000/.

3.1.1.1 Estimating future modal split via market shares

One approach for considering modal split development is presented in Figure 2. This figure presents historical shares of different transport modes for Japan. This historical series has been used to estimate possible future modal split functions, based on the factors described above. The same approach can be applied to any region where sufficient transport mode-specific data from the past are available.

The projection formulas for modal split development presented in Figure 2 were derived with statistical methods and are designed to incorporate the main drivers of transport demand discussed in Section 1. In the example presented in Figure 2 the only transport modal share which does not develop with a monotonous slope is the automobile. On the basis of this projection, the share of cars is expected to peak at about 60 % (when per capita incomes reach around US$50,000) and then to slowly stabilize at about 40 %, since it is expected that cars will remain the main supplier for short distance travel. Buses, railways and ships follow a declining trend. Airborne traffic is expected to constantly increase its share to a level of about 30 % for a respective income of 100,000 US$ per capita.

For each region, a similar analysis was conducted. Additionally to the chosen assumptions the sum of all shares shall not exceed 1. Eventually the vector has to be normalized to 1 before being multiplied with the total volume of passenger kilometers, which is estimated based on the method discussed briefly in Section 3.1.3.

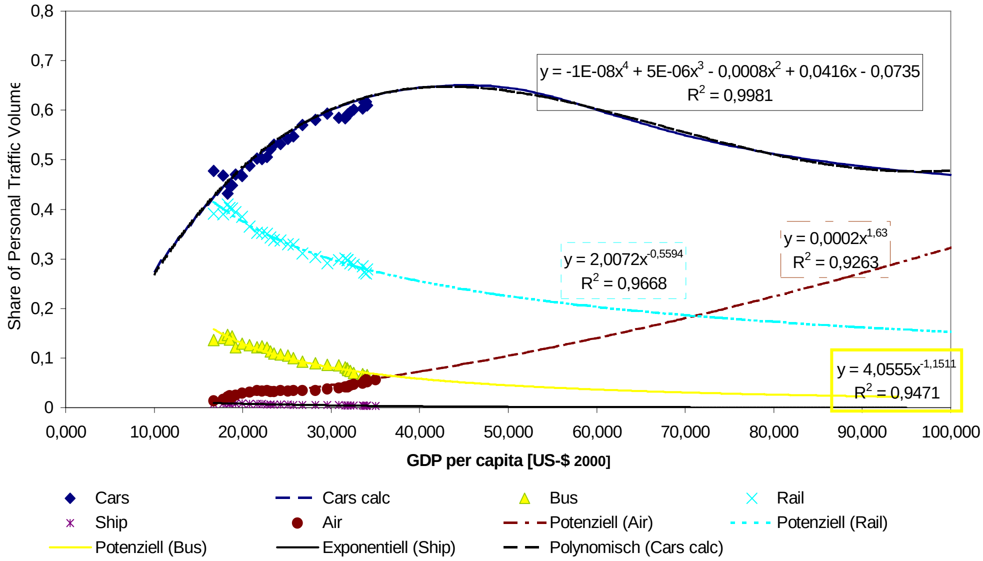


Figure 2: Passenger Transport Modal split in Japan; including Projection Formulas
Source: based on historical data described in Section 2.

3.1.1.2 *Estimating modal split via traffic volume*

In contrast to the described modal share approach in the previous section, one alternative method explored in this analysis estimates modal shares by considering the traffic volume supplied by each mode independently. In this approach, separate assumptions are made for the per capita traffic volume of each distinct transport mode. Figure 3 shows the application of this approach to the NAM region. Buses and rail follow a stable, slightly declining trend. Meanwhile cars follow an increasing trend but reach a saturation level expressed with a logarithmic function, which best captures the impact of a shift to faster travel modes (in this case air). For high-speed modes, in particular air travel, a linear function has been found to be most suitable, based on historical trends in industrialized countries.

3.1.2 *Estimating demand on the basis of short-distance travel demand*

A number of previous studies investigated the short distance demand on a very detailed level. (DOT, 2004) estimate that the average commuter in the Washington DC area travels a distance of 25 km each day for work. For the determination of short distance travel these numbers have been taken as a base for estimating metropolitan travel behavior and distances. It has been assumed that for a business commuter there are 200 working days, leading to an average of approximately 5000 pkm/year. Within the society this group is assumed to account for 30 % of the population, on the basis of age structure and the distribution within society. Additional short distance travel is assumed to be for private non-work purposes. Actual figures for private travel demand vary substantially across a number of surveys (e.g. Mobilitätpanel, 1998; NTS, 2004). For the aggregated analysis within this study an average demand for private short distance travel has been derived for each region. The logarithmic relation in Figure 4 represents the short distance behavior for the NAM region.

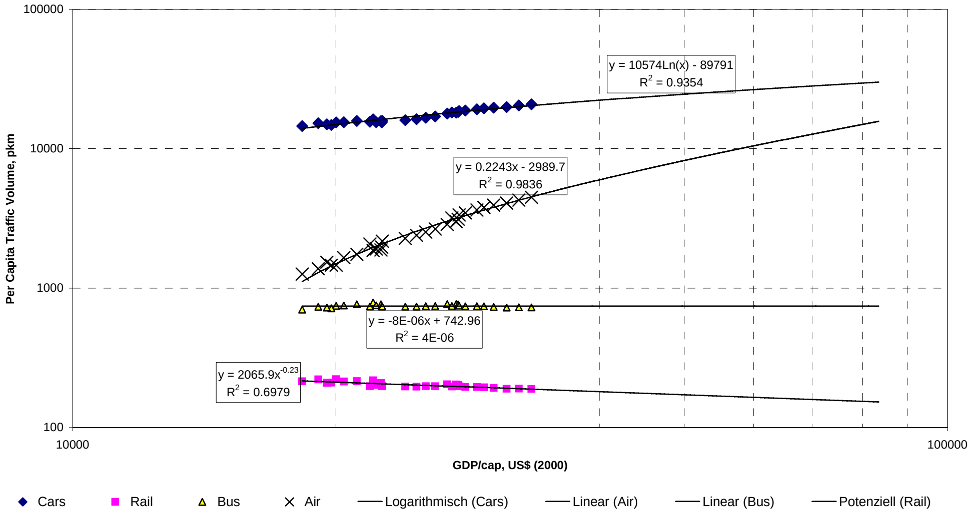


Figure 3: Passenger Transport Modal split and Traffic Volume – NAM; incl. Projection Formulas

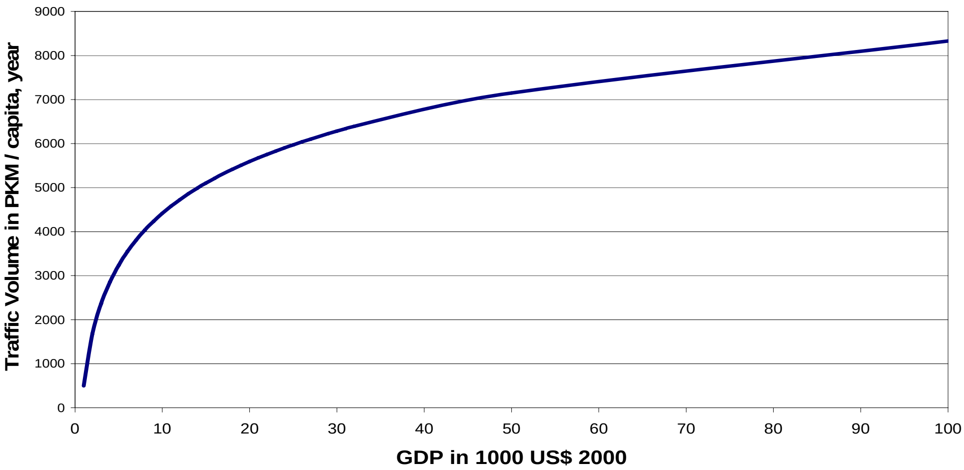


Figure 4: Estimated relationship between income and short distance passenger transport demand, NAM

Source: estimates based on DOT, 2004; Mobilitätpanel, 1998, NTS, 2004

While conducting this study, it at first appeared that this approach focusing on short-distance travel was applicable to all world regions. Hence, the method was applied to the OECD regions NAM, PAO and WEU. For EEU and FSU it was assumed that a similar trend is followed after crossing a per capita income threshold of US$15,000. However, for other, developing, world regions it was found that this approach was unsuitable, owing mainly to the major differences in urban structure in developing countries compared to developed countries, in addition to difficulties in calibration resulting from poor data availability.

In addition, future changes in demographics and social trends in developing regions, (such as increasing average population age, leading initially to a larger working-age population but later to an increasing dependency ratio) add an extra layer of complexity and uncertainty. Developing estimates of short-distance travel requires a large number of assumptions about traveling behavior of different age and social groups. Without a strong empirical basis, this is considered to be too complex to be considered within this study. Therefore, in the final calculations of travel demand presented in this report the separate classification of short and long distance travel was not considered.

3.1.3 Estimating demand based on aggregated traffic volume

The demand projection methodologies outlined in Sections 3.1.1 and 3.1.2 were applied for five industrialized world regions (NAM, WEU, PAO, EEU and FSU), as discussed. For the remaining regions (all but OECD and EEU), historical data sets were analyzed to estimate simple relationships between aggregate traffic volume and income. This approach, rather than the alternatives discussed above based on modal volumes and short/long-distance travel, was employed because of the limited data availability and credibility for many of these regions. Accordingly, the results presented for these regions are relatively uncertain, and further research is warranted beyond the scope of the analysis discussed here.

3.2 Freight transportation: aggregated traffic volume approach

In the case of freight transportation, a similar simple aggregate traffic volume approach as discussed above in Section 3.1.3 was applied for 6 (NAM, PAO, WEU, EEU, FSU, CPA) out of 11 regions. That is, historical relationships between income and traffic volume were analyzed to derive suitable mathematical equations reflecting these relationships, presented for freight transport in Figure 5. For the remaining 5 world regions (SAS, PAS, LAM, MEA, AFR) there are insufficient data on freight transport, highlighting the need for further studies.

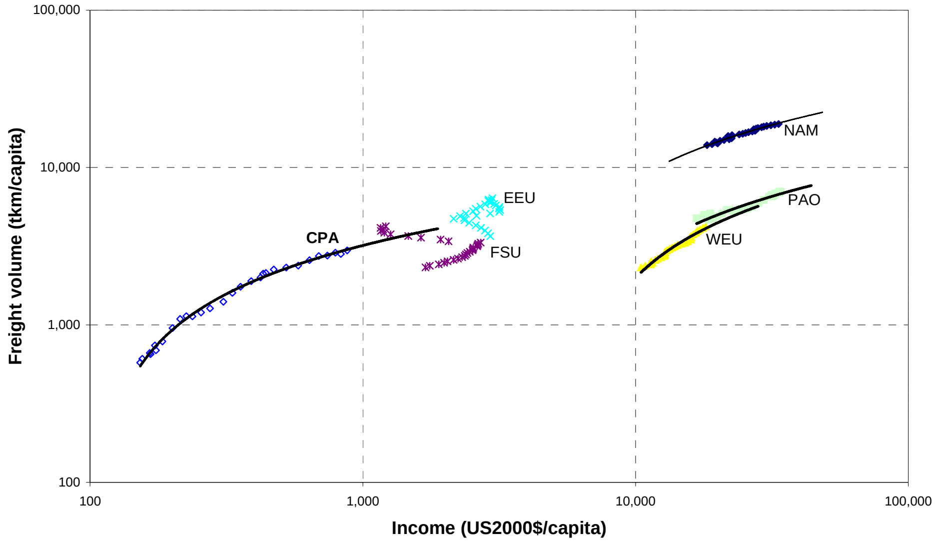


Figure 5: Historical and estimated future relationship between income and freight transport volumes, selected regions

3.3 Regional application of modeling alternatives

The application of the range of projection approaches described in Sections 3.1 and 3.2 to each of the 11 world regions is described in the following section. Crucial assumptions, data limitations and some preliminary findings are also discussed.

3.3.1 Western Europe (WEU), North America (NAM) and Pacific OECD (PAO)

3.3.1.1 Freight transportation

The data analysis for each of the three industrialized and highly developed regions—WEU, PAO and NAM—were carried out in a similar way. In the case of freight transportation, the historical income–freight volume relationships presented in Section 3.1.3 were applied to future income scenarios. This straightforward approach generated plausible results, and more complicated alternative formulations were deemed to be unsuitable since this approach to freight demand projections is only provisional, with the eventual aim being to apply a formulation based on physical volumes, as discussed in Section 1.

3.3.1.2 Passenger transportation

For passenger transport, travel demand was derived from the projected traffic volume of each individual transport mode (Section 3.1.1.2). As an alternative, the approach of splitting the demand into short and long distance travel is also suitable for these regions (Section 3.1.2), with the long distance travel demand expected to behave as a linear function of income in all three regions, although with varying slopes depending on other factors, such as infrastructure, relative costs, travel behavior and geographic differences.

Both methods have been described in the previous sections. After investigating the results for different SRES scenarios the approach via modal passenger traffic volume was found to be more suitable.

In Figure 6 and Figure 7 the results that were calculated with the two different approaches are presented for the SRES scenarios. The modal traffic volume method gives significantly lower per capita traffic volumes. This could be explained by the fact that with the modal approach seems to consider more thoroughly the regional characteristics. However, the results for WEU seem surprisingly low compared to the NAM traffic volume. This can be explained partly by regional income differences, which are an important driving force of traffic volume. For instance, under the B2 scenario in the year 2100 NAM reaches an income level of over US2000$120,000/cap while WEU stays clearly under US$70,000/cap. If WEU achieved the same income levels as NAM the traffic volume would reach 36,823 km/cap (Modal) and 71,782 km/cap (SD/LD), which is closer to the figure for NAM.

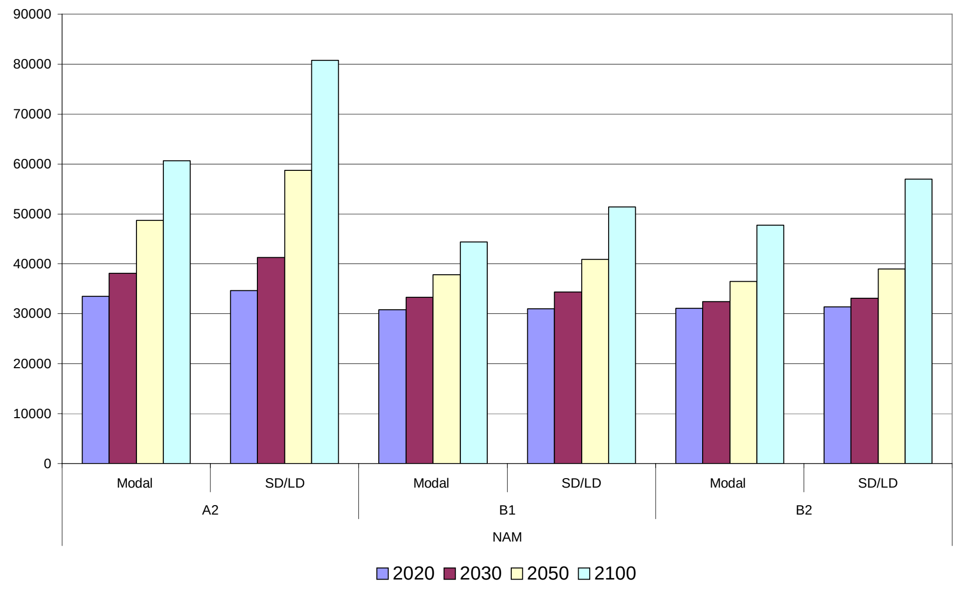


Figure 6: Traffic Volume per Capita, NAM – comparison of SRES scenarios using different calculation methods (passenger-km)

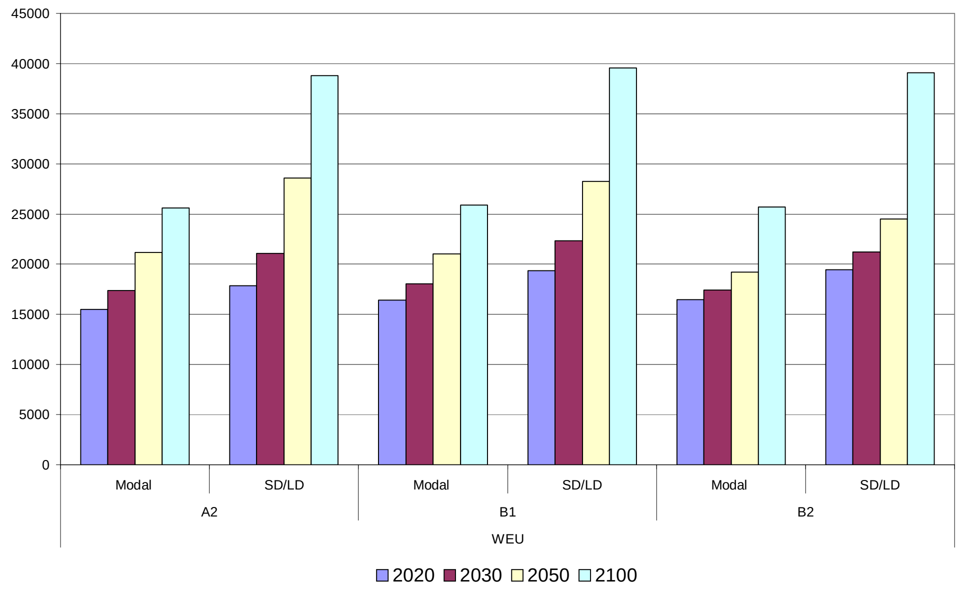


Figure 7: Traffic Volume per Capita, WEU – comparison of SRES scenarios using different calculation methods (passenger-km)

Generally it has to be stated that the results for PAO region may be inhomogeneous due to major differences between the two major countries in this region (Japan and Australia). Meanwhile this problem does not appear to the same extent in other regions. Specifically, Japanese travel volume may saturate at higher incomes because of geographical and urban-form constraints, whereas in Australia population centers are very geographically dispersed and hence this country cannot necessarily be expected to follow the same trend as Japan. Therefore the weighting within this region is very important and country-specific assumptions must be checked carefully before being applied to the rest of the data set.

3.3.2 Former Soviet Union (FSU) and Eastern Europe (EEU)

Both the FSU and EEU experienced a sharp drop in income after the political change in the early 1990s. Therefore it is necessary to exercise caution when deriving equations from the historical relationship between income and traffic volume for these regions.

3.3.2.1 Freight transportation

The freight transport volume of Eastern Europe closely correlates with growth in income since 1992 and can be reasonably described with a logarithmic function. It is assumed that this trend will apply to future economic growth and will be followed until 2010. However, continuing to apply this trend over the longer term would result in per capita freight volumes significantly overtaking those in WEU (see Figure 5), which seems somewhat implausible despite historical volumes being above those in WEU at least from the early 1970s to the mid-1990s. This period is seen as unusual, and the accompanying freight transport was based on a set of driver forces and institutions that have largely been abandoned. Therefore, from 2010 the WEU level has generally been used to estimate Eastern European freight demand levels, although for exploring additional scenarios this assumption can be varied.

The freight transport of the FSU has been constantly increasing over the last 30 years independently from the development of the income. However, over the last half of the 1990s an increase in income occurred, and it is possible to use the relationship between income and freight traffic volume of this time period for future trends. This approach is inconsistent with long-term trends in this region, although these arose during very unusual circumstances that are unlikely to be repeated. However, it may be worth considering an alternative method with an independency from future income development.

3.3.2.2 Passenger transportation

According to statistical sources the passenger travel in both the FSU and EEU region drastically decreased in the early 1990s, but recovered in the second half of the decade. Deriving future development from this inconsistent data set requires a number of assumptions, some of which are uncertain and speculative.

For EEU the approach applied for the OECD regions has been chosen (that is, modal split has been determined according to traffic volume as discussed in Section 3.1.1.2). It is assumed that car travel demand in this region will follow a linear increasing trend until per capita incomes reach US$10,000. After passing that threshold the logarithmic function of WEU will be followed. In comparison, the other transport modes are assumed to develop independently to WEU and growth rates are derived directly from historic transport data.

The FSU region also follows the aggregated WEU trend after crossing the US$15,000 income threshold. These parameters are chosen after a carrying out a sensitivity analysis for the long-term results for different scenarios.

3.3.3 Centrally Planned Asia & China (CPA)

3.3.3.1 Passenger transportation

In the past annual incomes in the CPA region have averaged significantly below US$1000 per capita. Furthermore CPA has recently experienced rapid development, and its future economic and demographic development is considered to have major implications for the entire world. Data from the CPA region has been collected mainly from China, which accounts for about 90% of the CPA population. The data analysis is based on the Chinese Statistical yearbook (China, 2002).

For passenger transport a linear function has been estimated based on historical data until a defined income threshold of US$6,000 per capita is achieved. After that, the CPA region is assumed to follow the logarithmic trend of LAM (see Section 3.3.5 below) and above US$10,000 to follow the NAM trend respectively. Importantly, CPA does not follow the trend of PAO due to the geographical differences between these two regions (with PAO dominated by Japan). For instance, large cities in China are geographically significantly separated, meaning that large distances may need to be covered within the national boundaries.

3.3.4 Sub-Saharan Africa (AFR) and Middle East & North Africa (MEA)

3.3.4.1 Passenger transportation

From 1970 to 2000 there has been, on average, no growth in income in Africa. The statistical explanation for that is that the population increased by a factor of more than two over the last 30 years, while the GDP of Africa increased by a factor of less then two. In this region there is no observation of a historic correlation between income and traffic volume, which has increased constantly.

For developing future estimates, it is assumed that if incomes increase at a rate below the average growth in traffic volume over the past 30 years of 2.4%, then traffic volume will continue to follow the linear development path of the past 30 years. However, if the income increase exceeds the threshold of 2.4% per annum, we assume that traffic volume grows at the same rate as the income. This is highly speculative but appears to be reasonable in comparison with increases in traffic volumes per capita in developed regions over the past 3 decades, which have averaged below 2.4% (i.e. NAM: 1.7%, PAO: 1.6%, WEU: 2.4%). For the MEA region there appears to be little correlation between GDP and traffic volume. Therefore the same approach has been chose as for the AFR region. If the annual increase of income surpasses the average traffic volume increase, the GDP ratio is taken as factor for the respective traffic volume development. The particular historic value of 4.3 % is rather high and therefore expected not to be exceeded frequently.

3.3.5 *Latin America & the Caribbean (LAM), Other Pacific Asia (PAS), South Asia (SAS)*

3.3.5.1 *Passenger transportation*

The remaining three regions currently exhibit a relatively high travel demand considering their respective low per capita incomes. Considering the region-specific geographical parameters and the past trends, a declining correlation between income and traffic volume is estimated to be a likely future development. Accordingly, future passenger traffic volumes are assumed to follow a logarithmic function, yet follow the NAM trend for incomes above US$10,000 per capita.

4 Main results

This chapter presents the results obtained by applying the approaches discussed in Sections 2 and 3 to different long-term scenarios from the IPCC’s Special Report on Emission Scenarios (SRES, 2000). This represents an important extension to the SRES scenarios, which treated transport activity in a fairly aggregate and stylized way. However, it should also be mentioned that although the goal here is to develop transport projections consistent with the main drivers of population and economic development used in SRES scenarios, this does not necessarily mean these results are consistent with all elements of the SRES scenarios. This represents an area for further analysis.

The development trends for the three SRES scenarios B1, A2 and B2, including important drivers of energy and transport demand such as population, economic activity and technological development, are presented schematically in Table 1. The importance of demographic and economic trends was highlighted in Sections 2 and 3, but technology improvements are also relevant to future travel demand, although less directly. Technology improvements, however, have a direct bearing on how travel demand translates into final energy demand.

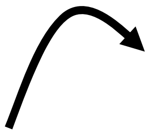
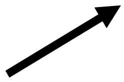
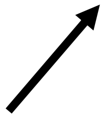
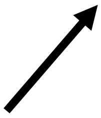
Based on the methodologies described in Section 3, the total per capita traffic volume results for the B2 SRES scenario are presented in Table 2. It can be seen that the application of the methodology described in this report produces results indicating that NAM will maintain the highest level in mobility. For the B2 scenario per capita traffic volume in the NAM world region increases by 80% over the next century.

In comparison, in the A2 scenario average per capita travel demands in NAM reach about 60,000 km per year in 2100 (as seen in Table 4), which represents a more than doubling of demand.

Returning to the B2 scenario, the regions CPA, EEU, FSU and MEA are projected to follow the WEU trend and reach a per capita travel demand of about 25.000 pkm in 2100. That range will only be exceeded by LAM at about 35,000 pkm for the B2 and about 30,000 pkm under the A2 and B1 scenarios.

In comparison, the projections for PAO and PAS are lower, with each reaching about 15,000 pkm/capita. The world’s poorest regions, SAS and AFR are expected to account for a significant 12,000 pkm/cap and 8,000 pkm/cap, respectively.

Table 1: Global development of key parameters for chosen SRES scenarios

Scenario	Population	Economy	Technology Improvements
B1			
A2			
B2			

Source: SRES 2000

Table 2: Per capita passenger traffic volume in 11 World regions 2030, 2050 and 2100 for B2 scenario (pkm/capita per year)

	Statistics	B2					
	1999	**2030**	**1999 = 100**	**2050**	**1999 = 100**	**2100**	**1999 = 100**
NAM	**26218**	31094	119	36525	139	47708	182
PAO	**11555**	12984	112	14608	126	17152	148
WEU	**10287**	16443	160	19187	187	25721	250
EEU	**4257**	7173	168	16665	391	25862	607
FSU	**1849**	5047	273	11259	609	26350	1425
CPA	**896**	4954	553	16806	1876	26919	3005
SAS	**2454**	4378	178	9018	368	12054	491
PAS	**6522**	10628	163	14000	215	16026	246
LAM	**7054**	11938	169	24994	354	35013	496
MEA	**6134**	9117	149	16409	268	23724	387
AFR	**1905**	2781	146	5748	302	8271	434

Table 3: Per capita passenger traffic volume in 11 World regions 2030, 2050 and 2100 for B1 scenario (pkm/capita per year)

	Statistics	B1					
	1999	2030	1999 = 100	2050	1999 = 100	2100	1999 = 100
NAM	**26218**	30808	118	37857	144	44406	169
PAO	**11555**	13000	113	15615	135	17357	150
WEU	**10287**	16395	159	21024	204	25909	252
EEU	**4257**	7365	173	19514	458	26032	611
FSU	**1849**	5481	296	14646	792	19362	1047
CPA	**896**	5235	584	18632	2080	20317	2268
SAS	**2454**	4042	165	9492.1	387	13482	549
PAS	**6522**	11604	178	15046	231	13766	211
LAM	**7054**	19845	281	29488	418	30703	435
MEA	**6134**	10038	164	19754	322	26926	439
AFR	**1905**	3166	166	7504.6	394	10154	533

Table 4: Per capita passenger traffic volume in 11 World regions 2030, 2050 and 2100 for A2 scenario (pkm/capita per year)

	Statistics	A2					
	1999	2030	1999 = 100	2050	1999 = 100	2100	1999 = 100
NAM	**26218**	33545	128	48714	186	60663	231
PAO	**11555**	14258	123	18820	163	21510	186
WEU	**10287**	15510	151	21188	206	25604	249
EEU	**4257**	6795	160	12384	291	16864	396
FSU	**1849**	5405	292	7978	431	16205	876
CPA	**896**	1658	185	8876.1	991	16388	1829
SAS	**2454**	5056	206	8123.4	331	10462	426
PAS	**6522**	7363	113	11054	169	12421	190
LAM	**7054**	13903	197	23694	336	30775	436
MEA	**6134**	9403	153	13707	223	20879	340
AFR	**1905**	3662	192	5310.8	279	6571	345

As discussed, transport demand is treated in an aggregate way in the SRES, so it is not possible to perform a direct comparison with published SRES results (SRES, 2000). In addition, the results presented here are preliminary and based on only two of the key drivers used in the SRES, and future work is necessary to incorporate other more qualitative scenario features.

However, it is possible to compare the results to those from other studies, such as the European Commissions projection to 2030 (EC 2003). Their analysis projected an annual per capita passenger traffic volume for the EU25 of around 18,500 pkm/cap in 2030. Applying the methodology developed in the present study \to the same economic and demographic input data as used in the EC study (EC 2003) results in a traffic demand of 18,600 pkm/cap, providing some validation of the methodology.

Furthermore the total traffic volume of WEU is compared to the result of VLEEM (Chateau et al., 2002), a long-term study carried out for the European Commission, in Table 5. The total for passenger traffic volume generated by the model developed here for the B2 (labeled SG WEU in Table 5) is about 14% higher than the total of VLEEM for 2100. This is can be mainly explained by the fact that WEU consists of a more countries than EU 15 (such as Switzerland, Norway and Turkey). Therefore another comparison has been done for the respective population used in the VLEEM study (SG EU15* in Table 5). With a population of 414 Million people the results vary by less than 4 %.

Table 5: Comparison of the results from VLEEM for the EU15 (Chateau et al., 2002) with 2100 projection for WEU (B2 scenario)

	EU15 - VLEEM 1999	EU15 - VLEEM 2100	WEU B2 2100	EU15* B2 2100
Travel time (bn hours)	137.6	151.2		
Average speed (km/h)	35.3	68		
Total travel (trillion km)	4.9	10.3	11.7	10.6
Difference to VLEEM 2100 (%)			13.7	3.6

Note: WEU B2 refers to the B2 passenger traffic volume scenario developed here for the WEU region. EU15* B2 refers to the results generated using the same methodology but with population based on the EU15, and is hence more directly comparable with the VLEEM results.
Source: VLEEM results from Chateau et al., 2002

In Figure 8 the total traffic volume of passenger transport under the B2 scenario is presented. There is a significant increase of the passenger traffic volume until 2100. In all 11 world regions demand grows, and by 2100 aggregate demand is around five times higher than in 2000 under this scenario.

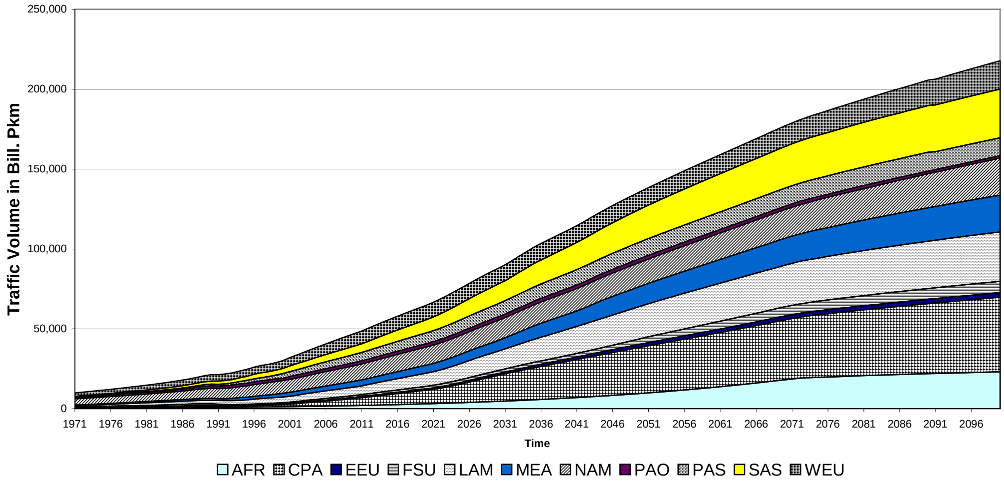


Figure 8: Global passenger traffic volume, 1971-2100 for 11 World Regions, B2 Scenario
Source: calculations based on approaches described in Section 3, with GDP and population data from SRES B2 scenario (SRES 2000).

The traffic volume that is covered by cars in five world regions is presented in Figure 9. For the remaining regions there was insufficient data available, and it was not possible to carry out a modal analysis. For example, the main data source for China, the Chinese statistical yearbook, provides only aggregate data on the traffic volume of cars and buses. Therefore this analysis is limited to WEU, EEU, LAM, NAM and PAO.

The total traffic volume for freight transport is presented in Figure 10. In the presented 6 regions the volume doubles over the next century. The largest increase is projected to occur in the CPA region, where the level in 2100 is three times the base-year level.

Other developing regions were not investigated within this study but are likely to follow a similar path, subject to different GDP and population growth rates.

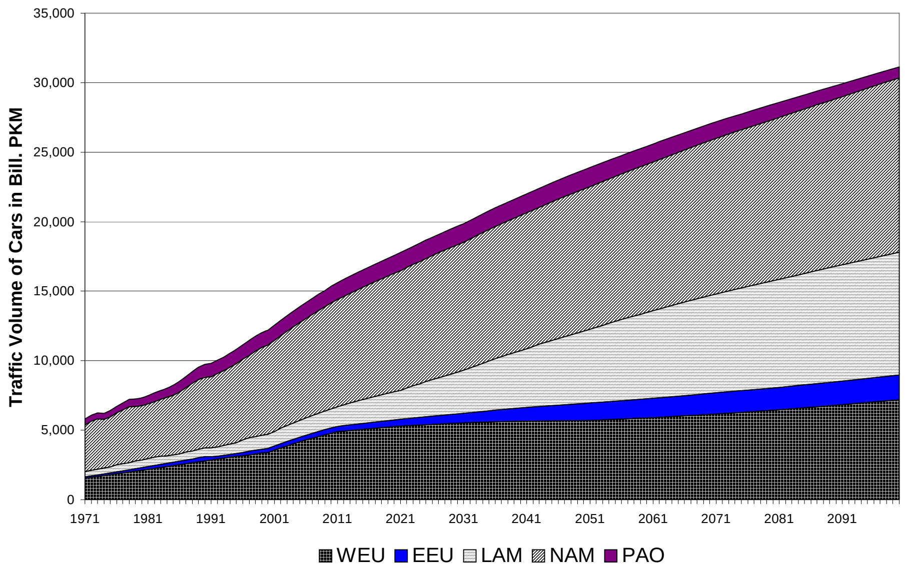


Figure 9: Passenger car traffic volume, 1971-2100 for 5 World Regions, B2 Scenario
Source: calculations based on approaches described in Section 3, with GDP and population data from SRES B2 scenario (SRES 2000).

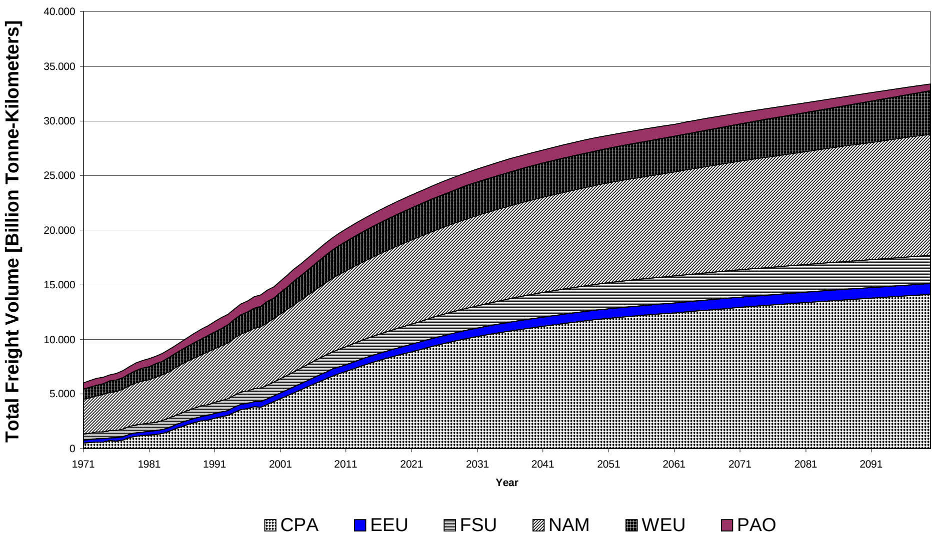


Figure 10: Freight traffic volume, 1971-2100 for 6 World Regions, B2 Scenario
Source: calculations based on approaches described in Section 3, with GDP and population data from SRES B2 scenario (SRES 2000).

The respective freight traffic volume for the B1 scenario is presented in Figure 11. The total demand for freight in the 6 regions in 2100 sums up to 56,000 billion tkm. This is about 50% more than in the B2 scenario. Using the A2 input data gives an even slightly higher result with a cumulative freight demand of almost 58,000 Billion tkm.

Once more, comparing the results to other studies (EC 2003) is only possible by using the respective input data. For the baseline scenario the projected freight transport demand for WEU in 2030 is expected to be 3501 Gtkm (PRIMES) and 3677 Gtkm for WEU, a deviation of approximately 5% from the projection developed in this study.

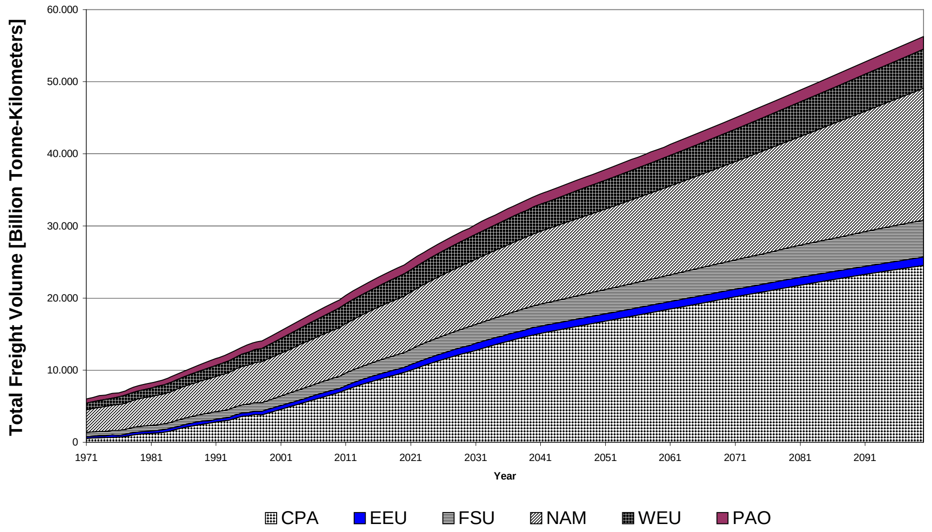


Figure 11: Freight traffic volume, 1971-2100 for 6 World Regions, B1 Scenario
Source: calculations based on approaches described in Section 3, with GDP and population data from SRES B2 scenario (SRES 2000).

5 Outlook

This paper introduces a set of methods for determining future traffic volume and modal split development in the transportation sector on the basis of historic data. These methods have been applied to some of the scenarios of demographic and economic development from the IPCC's Special Report on Emissions Scenarios to develop more detailed projections of transport demand. This represents a significant extension to the aggregated estimates of transport activity in the SRES, although additional work is required to represent other qualitative scenario drivers with the methods presented here.

The focus of this analysis has been passenger transport and, although this paper presents an estimate of future freight transport demand, one further highly recommended future improvement is to better relate freight activity to physical production and trade. For example, the physical output of each industry could be applied as an input parameter into the freight transport demand estimation methodology described in this paper. Applying such an approach would require an analysis of historical relationships between industry output and freight transport volume.

Further development of the transport data analysis and projection framework described herein might also include additional analysis and modeling of occupancy rates and loadings. The ratio of vehicle kilometers to passenger- or ton-kilometers has major implications for the total travel volume and, in particular, final energy consumption. Another important aspect that should not be overlooked is that policy makers can influence occupancy rates and travel behavior by tax policies (e.g. on fuel) or by applying other measures (e.g. high-occupancy vehicle lanes).

The immense growth in traffic volume envisaged in the results presented here, especially in the passenger transport sector, highlights not only the need for new, more efficient travel modes but also new transport technologies producing lower carbon dioxide emissions. Without new transport technologies, a major break from current trends and drivers of transport demand may be necessary to avoid many of the potential impacts related to energy consumption and pollution. Moreover, the growth in transport demand implies and requires drastic changes across almost all world regions merely to cope with future volumes. Larger airports, sufficient air traffic control systems and a good road system will be necessary in order to fulfill that demand, unless government policies to reduce demand are effective and sufficiently politically acceptable.

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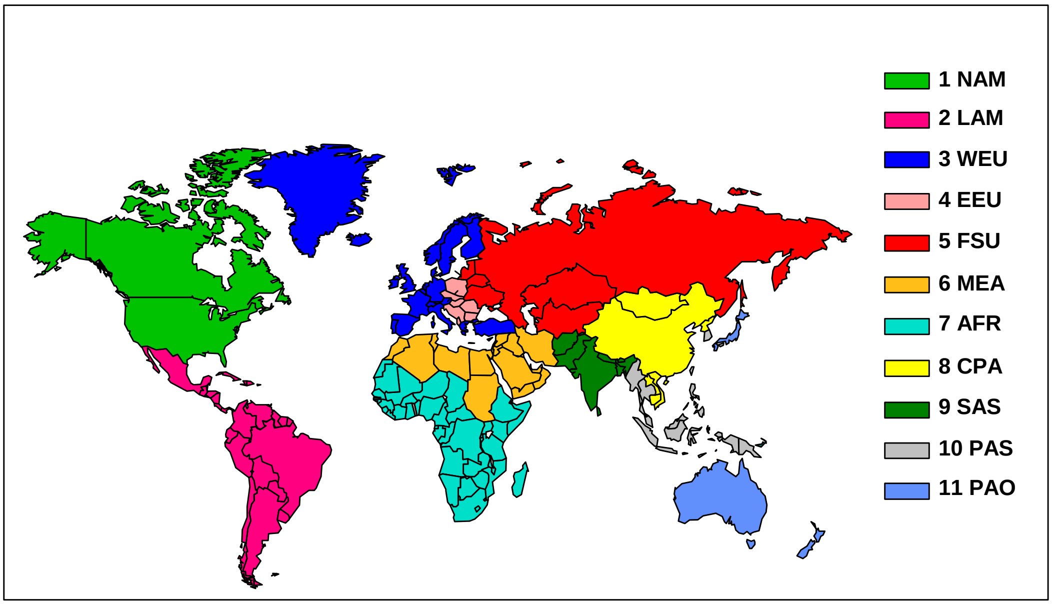
Appendix A



1 NAM North America
2 LAM Latin America & The Caribbean
3 WEU Western Europe
4 EEU Central & 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 A1: Definition of world regions.
Source: SRES, 2000.

Appendix B

An important aspect of the research described in this paper is the collection and collation of data, and the construction of quantitative projections. The following files were generated in the process of developing the methodologies and projections discussed in the main part of this report.

The file **country_specific_data.xls** contains traffic volume data for specific countries, which has been collected, derived or calculated.

In the file **historic data.xls** data for 11 world regions has been aggregated. This was done for the passenger transport and for the freight transport respectively. For freight transportation the regions, for which data could be obtained was limited to North America, Pacific Asia Oceania, Western and Eastern Europe and the former Soviet Union. On the sheet "*person km per Capita BR*" the updated and modified dataset for person kilometers can be found.

The file **Equation.xls** contains the calculation procedure and determination of the respective formulas. Currently the calculation of the travel demand is accomplished within that file. The sheets "GDP-Input" and "Pop_Input" contain the scenario data. In cell **"E1"** the scenario can be chosen.

The sheets "RESULT_PKM_total" and "RESULT_TKM_total" contain the total results. On top of each Region specific slide there is the chosen mathematical relation between time, income and traffic volume.

The transport mode specific projections are carried out in the file **Modal Split.xls**.

It is proposed that the projection models described in these spreadsheets be implemented in visual basic to aid quick formulation of scenarios and for consistency with the other modules if the New Scenario Generator.

Appendix C

Table C1. Economic and demographic assumptions from SRES scenarios

		NAM	PAO	WEU	EEU	FSU	CPA	SAS	PAS	LAM	MEA	AFR
GDP	2000	10441	5249	8629	373	418	1225	627	1320	1975	1143	362
[Bill. US$ (2000)]												
A2	2050	40185	14393	25414	1622	5706	17126	8049	8747	15565	8134	4981
B1	2050	26682	9777	25096	3402	8844	38612	13087	23124	25091	16892	14523
B2	2050	21402	7386	18515	2418	5683	25518	10560	15578	13675	7510	7032
A2	2100	86097	21675	40877	2666	14340	45965	20738	22055	43916	18987	10347
B1	2100	52055	13595	41708	6061	17465	63766	60603	38366	43657	37188	58416
B2	2100	34455	4757	30716	5271	12608	58310	32542	29093	32741	20268	29524
Population	2000	307	150	458	122	293	1383	1363	489	518	341	633
[Mill.]												
A2	2050	463	164	525	125	393	2321	2558	884	1080	1128	1654
B1	2050	463	164	525	125	393	2321	2558	884	1080	1128	1654
B2	2050	389	140	447	115	291	1699	2256	741	805	754	1729
A2	2100	697	183	616	128	578	3331	2872	1136	1700	2000	1858
B1	2100	697	183	616	128	578	3331	2872	1136	1700	2000	1827
B2	2100	407	67	454	111	268	1736	2530	703	885	970	2284
Income	2000	34001	34914	18859	3061	1429	886	460	2697	3815	3352	573
US $ (2000)/capita												
A2	2050	86830	88030	48381	12933	14511	7379	3147	9891	14412	7210	3011
B1	2050	57653	59799	47774	27126	22492	16636	5116	26147	23232	14972	8781
B2	2050	54956	52715	41444	21099	19506	15023	4680	21022	16983	9956	4067
A2	2100	123543	118183	66337	20907	24792	13799	7221	19415	25833	9493	5568
B1	2100	74694	74130	67687	47534	30195	19143	21101	33773	25681	18592	31974
B2	2100	84710	71127	67592	47366	47091	33593	12864	41385	37012	20895	12924

Source: calculated from Miketa, 2004; SRES, 2000